GYRO READOUT

CRITICAL DESIGN REVIEW

JANUARY 18, 1996

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

9:30	1.	Overview and Requirements	J. Lockhart
9:50	2.	PDR Action Item Status	J. Lockhart
9:55	3.	Baseline Design	B. Muhlfelder
10:20	4.	Science Data Requirements / Loop Sym.	M. Keiser
10:40	5.	Specification Documents	M. Tapley
10:50	6.	Design Status	J. Anastas
11:00	7.	Manufacturing Plan	M. Luo
		Test and Verification	
11:15	8.	Overview; Pickup Loop & Cables	B. Muhlfelder
11:30		SQUID Bracket	B. Muhlfelder
11:35	9.	SQUID Die, Carrier and Package	G. Gutt
11:50	10.	SQUID System	J. Lockhart
12:00		LUNCH BREAK	
		Development Testing	
1:00	11.	System Performance/GTU-1	J. Lockhart
1:10	12.	SQUID Temperature Control	B. Muhlfelder
1:25	13.	Outstanding Issues	B. Muhlfelder
		Systems Issues	
1:30	14.	Magnetics and Trapped Flux	J. Mester
1:45	15.	Electronics Interfaces; Constraints	J. Lockhart
1:50	16.	EMI, Grounding, Shielding	J. Lockhart
2:00	17.	Vibration Compatibility	L. Sokolsky
2:05	18.	Thermal & Proton Compatibility	B. Muhlfelder
2:15	19.	Reliability / Quality	F. Berkowitz
2:20	20.	Schedule & Resources	J. Burns
2:25	21.	Wrap Up & Action Items	J. Lockhart

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**

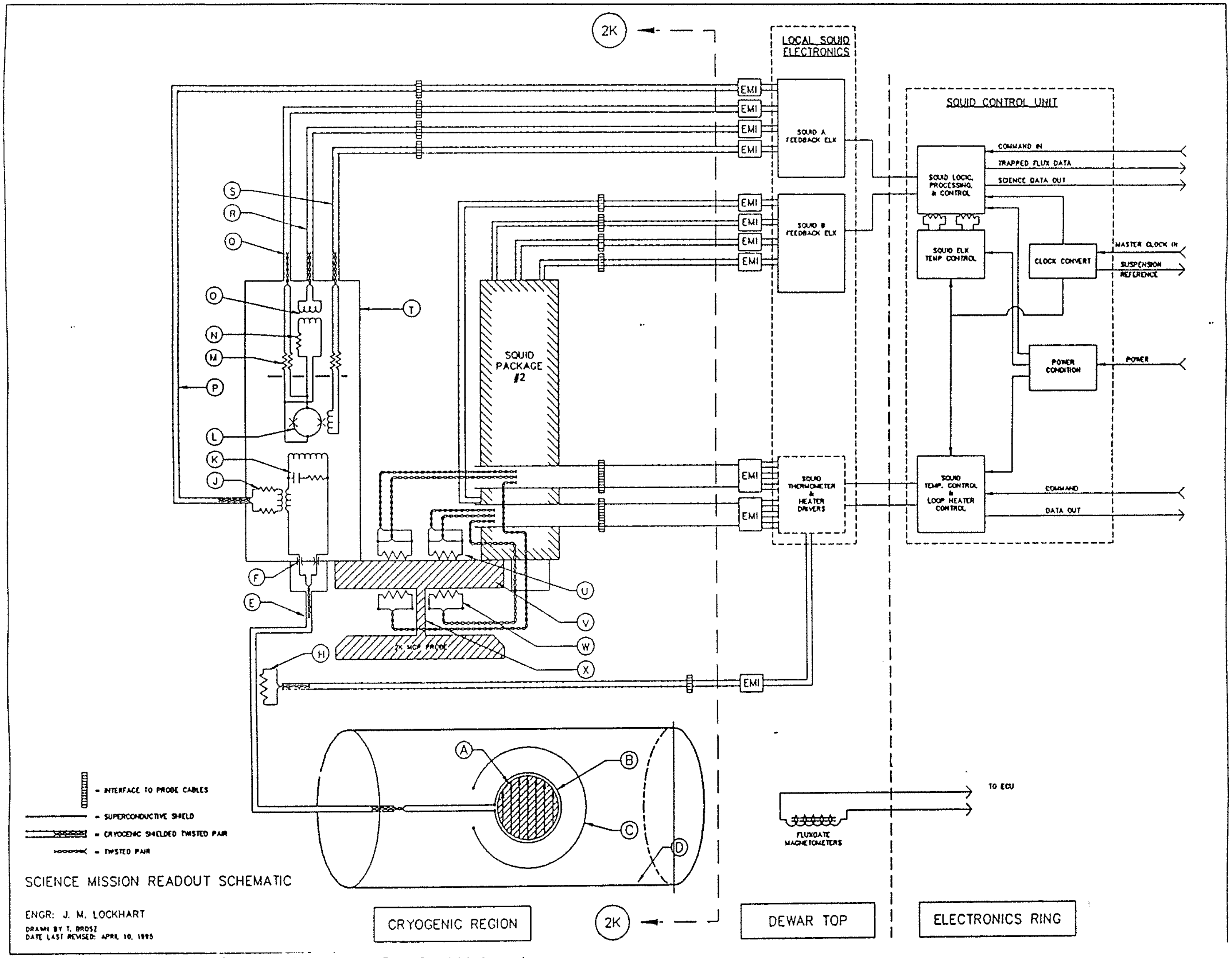
- **Rotor covered in Gyro PDR/CDR**

- **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**


2K
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SQUID CONTROL UNIT
EMI
SQUID A FEEDBACK ELX
SQUID B FEEDBACK ELX
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TRAPPED FLUX DATA
SCIENCE DATA OUT
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CLOCK CONVERT
MASTER CLOCK IN
SUSPENSION REFERENCE
POWER CONDITION
POWER
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COMMAND
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D
TO ECU
FLUXGATE MAGNETOMETERS
= INTERFACE TO PROBE CABLES
= SUPERCONDUCTIVE SHIELD
= CRYOGENIC SHIELDED TWISTED PAIR
= TWISTED PAIR
SCIENCE MISSION READOUT SCHEMATIC
ENGR: J. M. LOCKHART
DRAWN BY T. BROSZ
DATE LAST REVISED: APRIL 10, 1995
CRYOGENIC REGION
DEWAR TOP
ELECTRONICS RING

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

Gyro Readout Operating Modes and Parameters
(Signal Amplitudes at SQUID)

Mode	London Moment Ampl. (Φ_0)	Trapped Flux Ampl. (Φ_0 Specs.)	Trapped Flux Ampl. (Φ_0 Goal)	FLL Range (Φ_0)	FLL Output (μV/marcs)
Ground Test (360°; 150 Hz spin)	61	0.57	0.11	100	0.03
Spin Align (2°)	2.1	0.57	0.11	5	0.6
Science - Low Sens. (100 arcs)	0.03	0.57	0.11	1	3.0
Science - High Sens. (100 arcs)	0.03	0.57	0.11	0.2	15

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

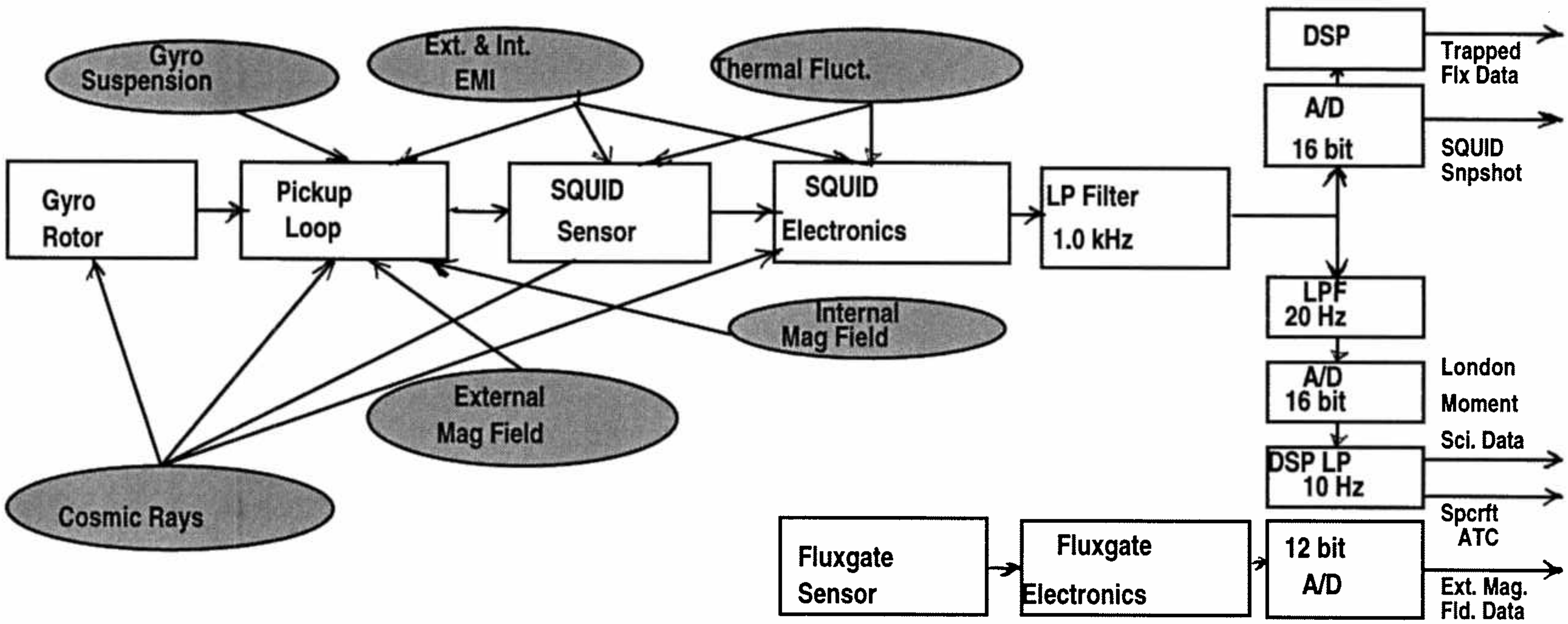
* Fluxgate Magnetometer Requirements

→ 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

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

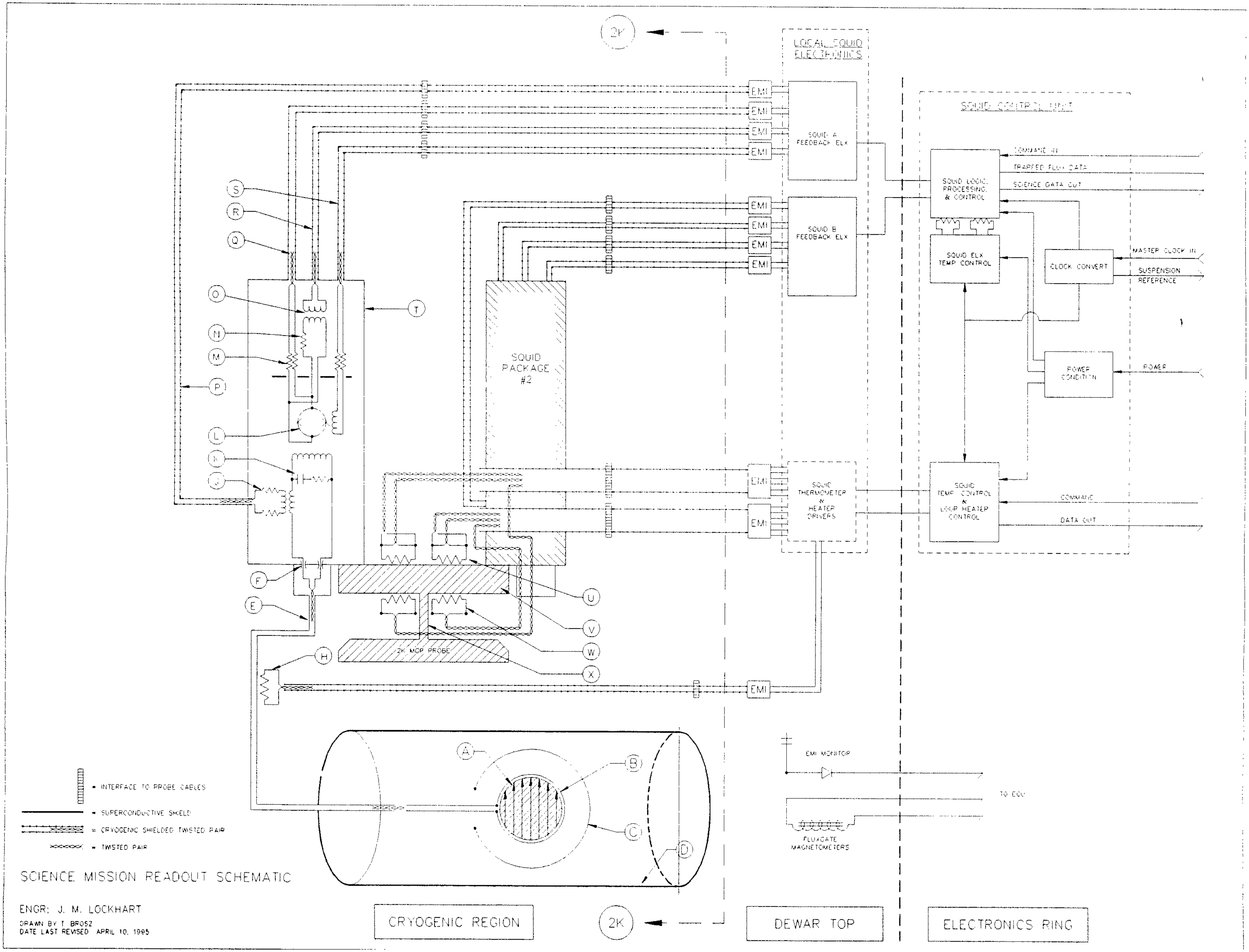
- ***The following items are to be re-assigned to the SRE PDR Action Item List***

4 , 7, 18

GYRO READOUT CRITICAL DESIGN REVIEW

Baseline Design

Barry Muhlfelder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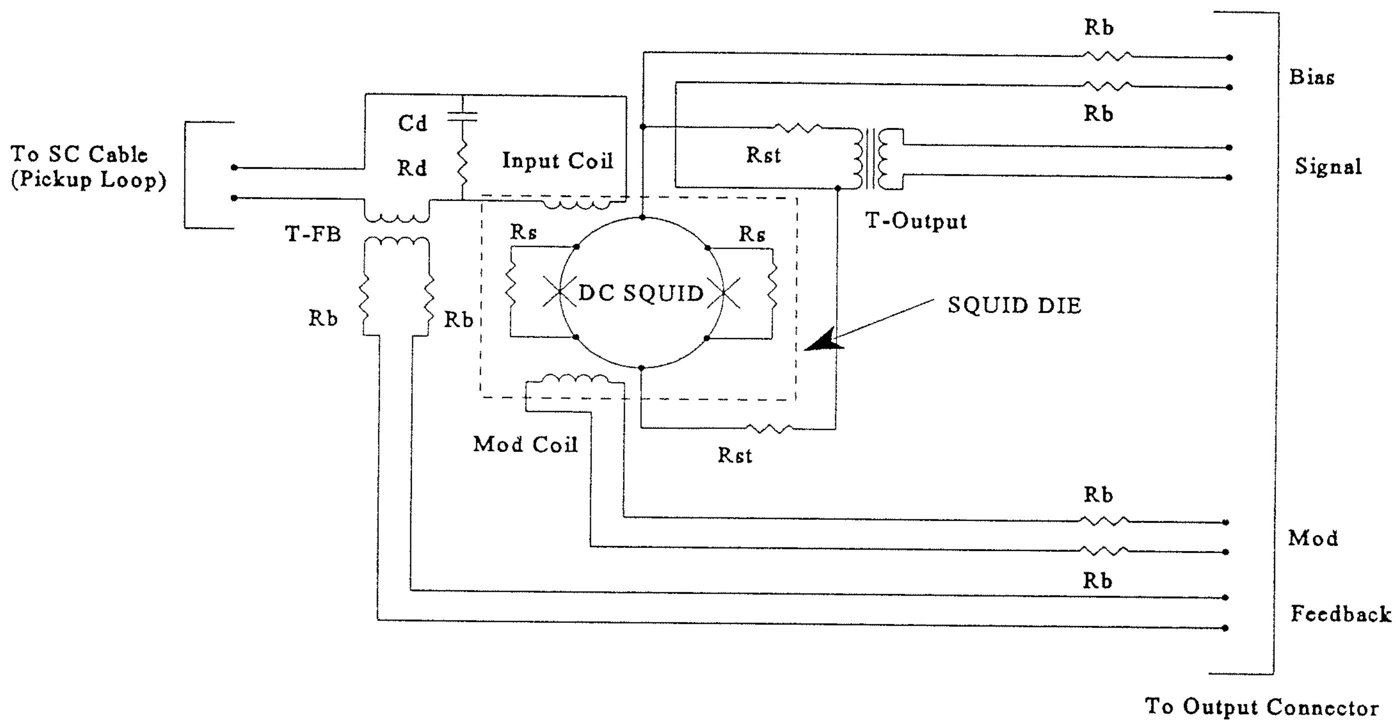
SQUID Carrier Design

Carrier Schematic



BASELINE HARDWARE DESIGN

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

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 Ω 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

$$z = C_g\left[\left(NS + R_G t + A_{NS}\right)\cos(\phi_R + \delta\phi) + \left(EW + R_F t + A_{EW}\right)\sin(\phi_R + \delta\phi) + b + \nu\right]$$

where

- C_g is the SQUID and gyroscope scale factor
- ϕ_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
- ν 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

A. S. Silbergleit and G. M. Keiser, " Pickup Loop Symmetry and Centering", Gravity Probe B Document S0243, October 1995.

REQUIREMENTS ON SQUID BIAS VARIATION (T003 - SYSTEM DESIGN AND PERFORMANCE REQUIREMENTS)

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 2×10^{-5}.

(2) Over any 15 day period, the linear drift in scale factor shall be less than 2×10^{-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.

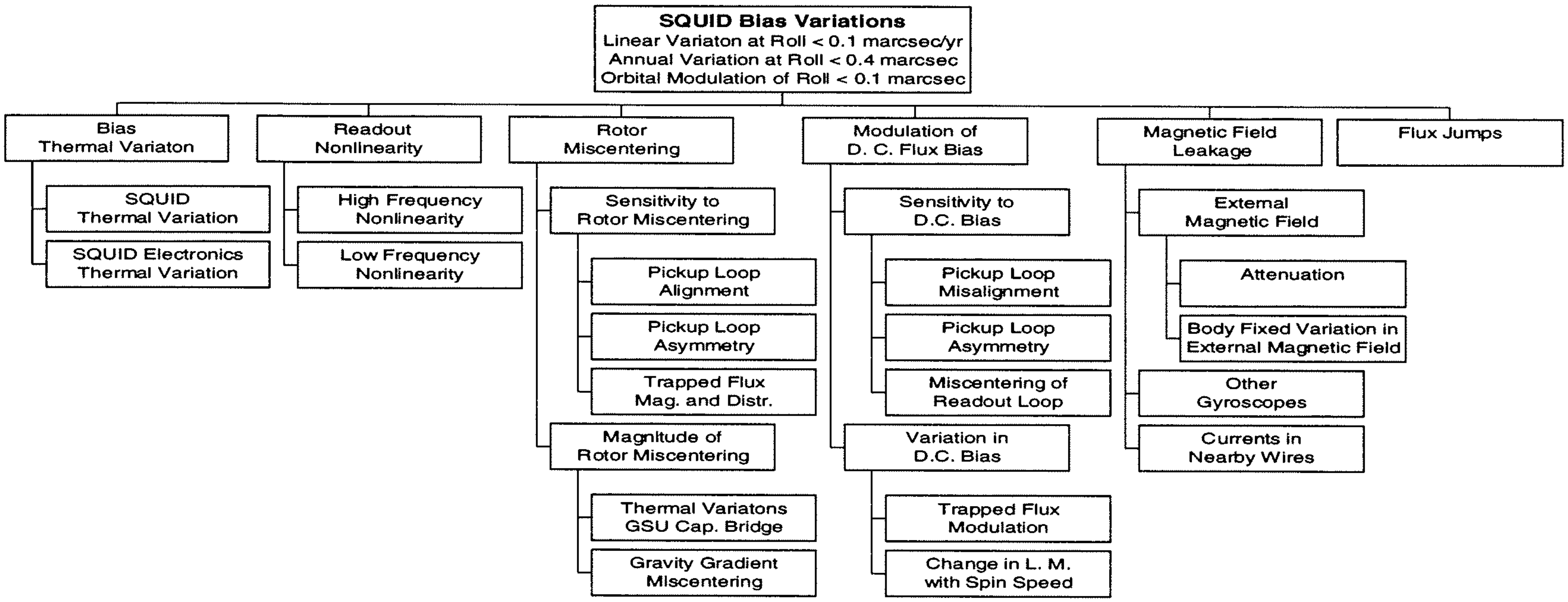
3.5.5 Phase Shift Variation

a) Over any 15 day period, the variation in the phase shift at orbital frequency shall be less than 2×10^{-5} radians.

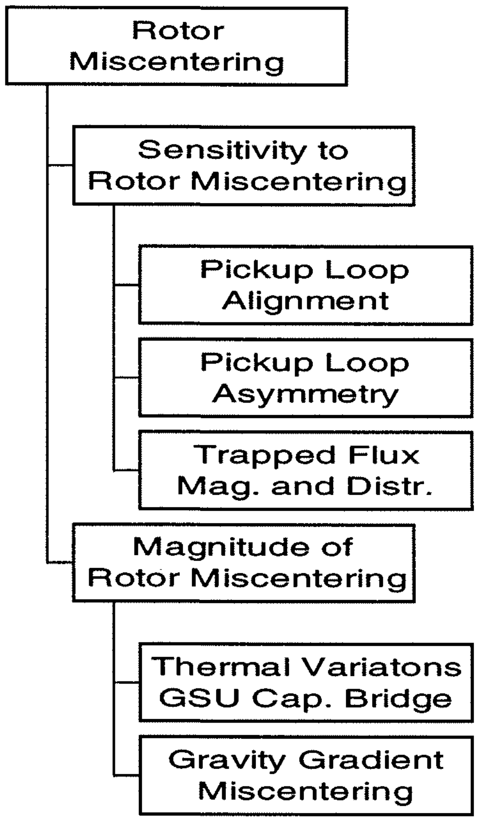
b) Over any 15 day period, the linear drift in phase shift shall be less than 2×10^{-5} radians.

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



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 **70^0** 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

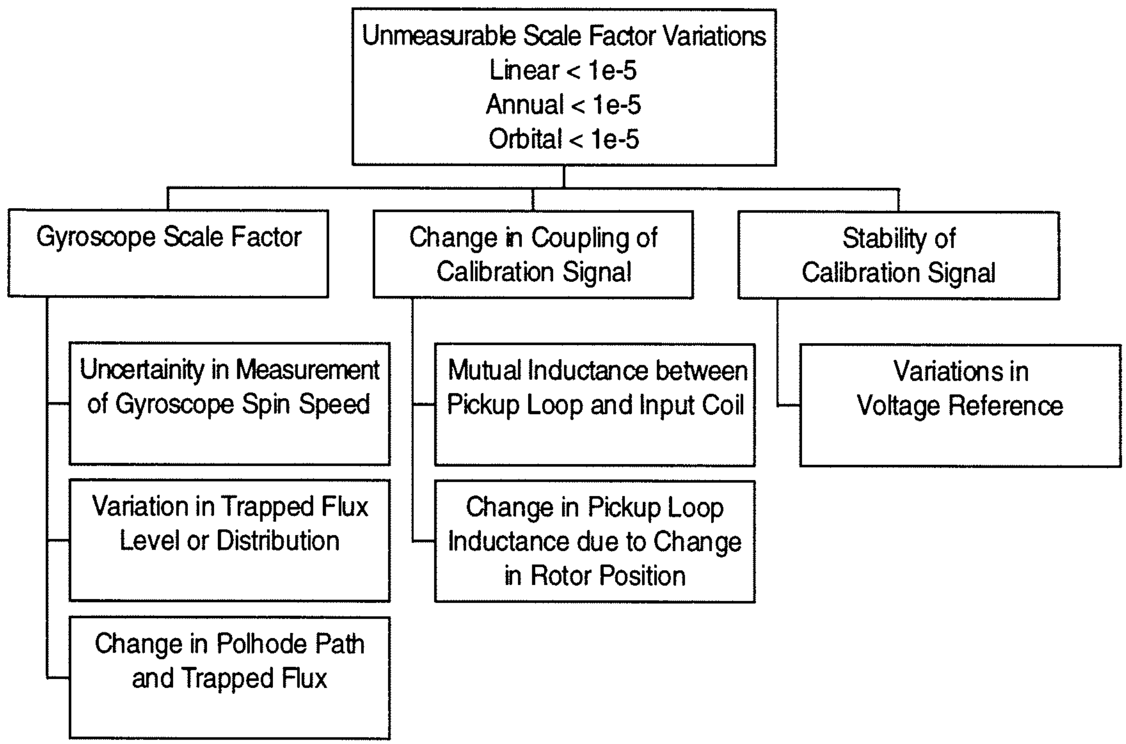
Roll Frequency Miscentering due to thermal (or other) variations in GSU capacitance bridge < 0.3 nm

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

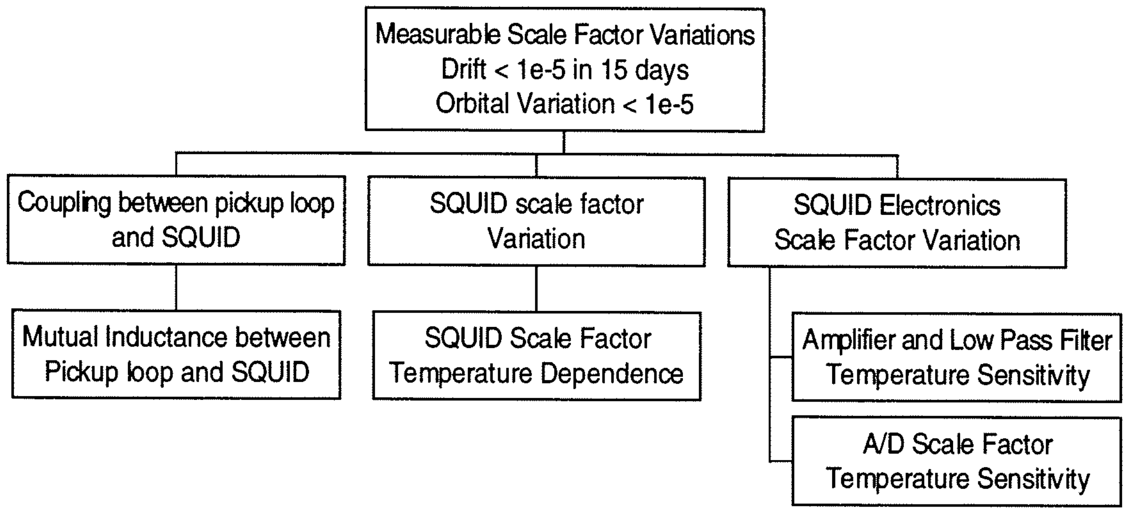
UNMODELED ERRORS DUE TO SCALE FACTOR VARIATION

A. SCALE FACTOR VARIATIONS NOT MEASURABLE WITH CALIBRATIONS SIGNAL



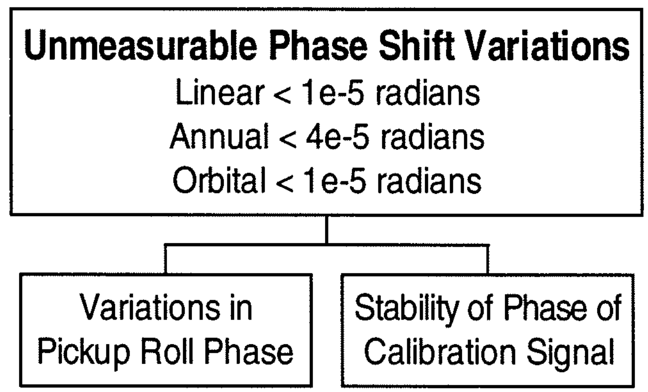
UNMODELED ERRORS DUE TO SCALE FACTOR VARIATION (cont.)

B. SCALE FACTOR VARIATIONS MEASURABLE WITH CALIBRATIONS SIGNAL



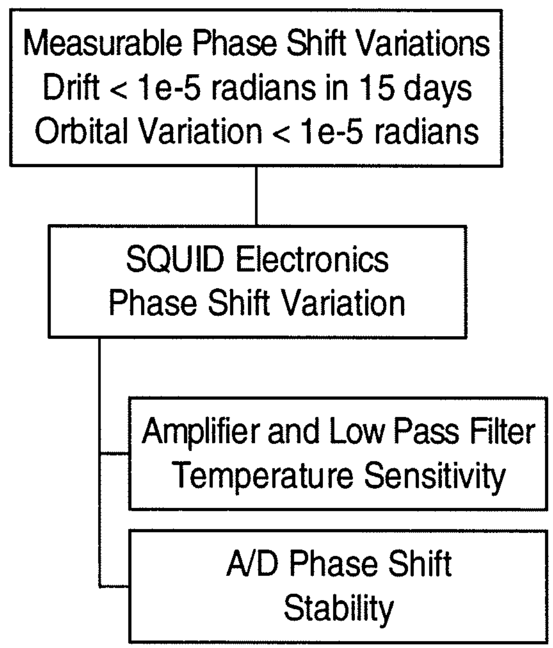
UNMODELED ERRORS DUE TO PHASE SHIFT VARIATION

A. PHASE SHIFT VARIATIONS NOT MEASURABLE WITH CALIBRATIONS SIGNAL

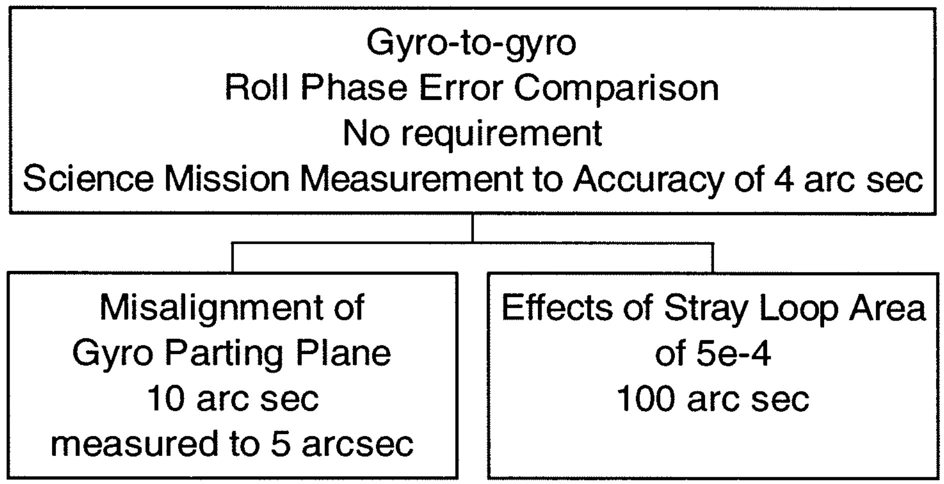


UNMODELED ERRORS DUE TO PHASE SHIFT VARIATION

B. PHASE SHIFT VARIATIONS MEASURABLE WITH CALIBRATIONS SIGNAL



CONTRIBUTIONS TO DIFFERENCES IN GYRO-TO-GYRO ROLL PHASE ERRORS



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Specification Documents

Mark Tapley

Science Instrument Assembly Specification

- **Contains Complete Performance Specifications for Readout Cryogenic Hardware**
  Perfomance 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**

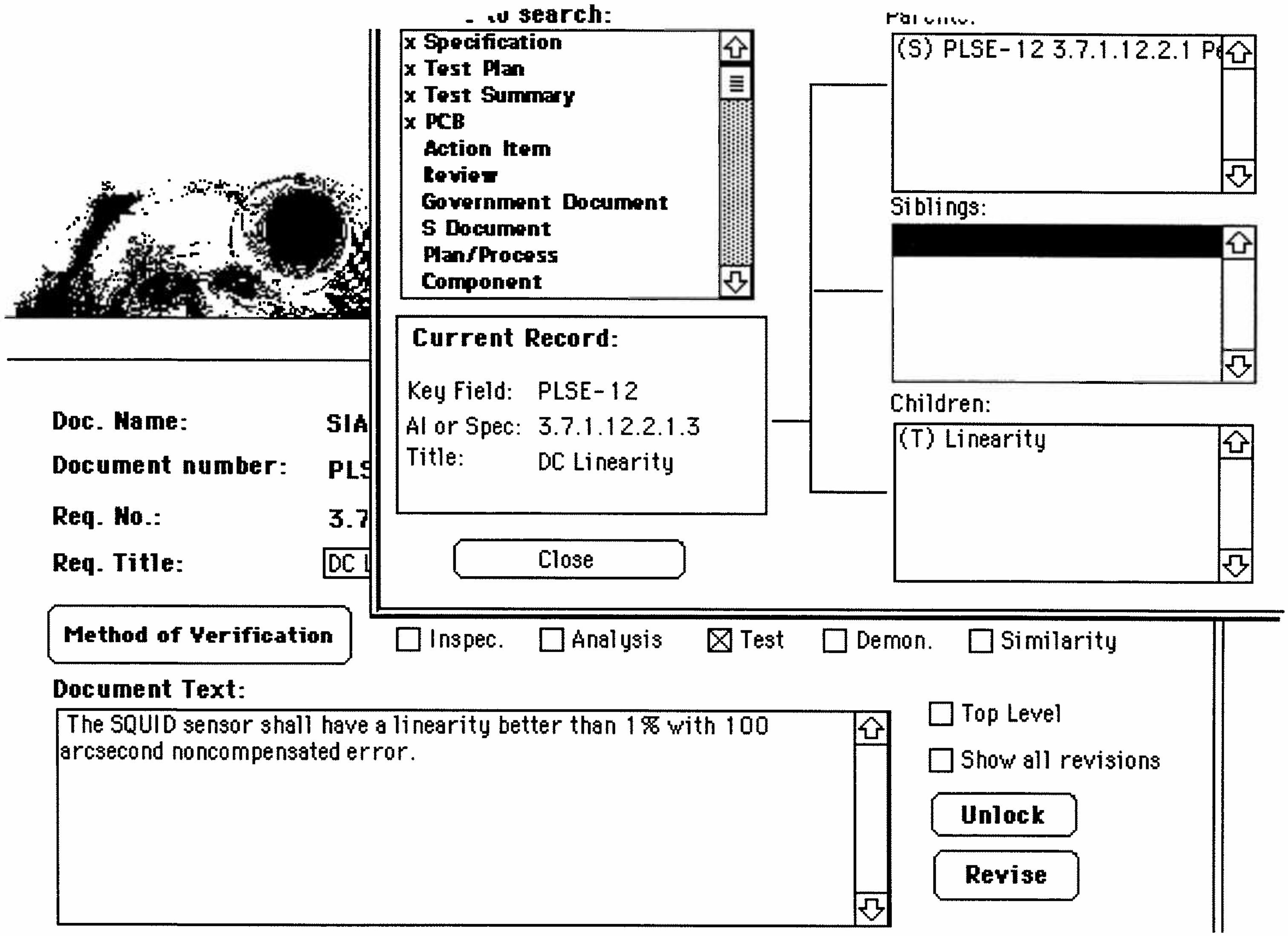
- **Readout System Section Specs Which Have been Met in Tests: 25**

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

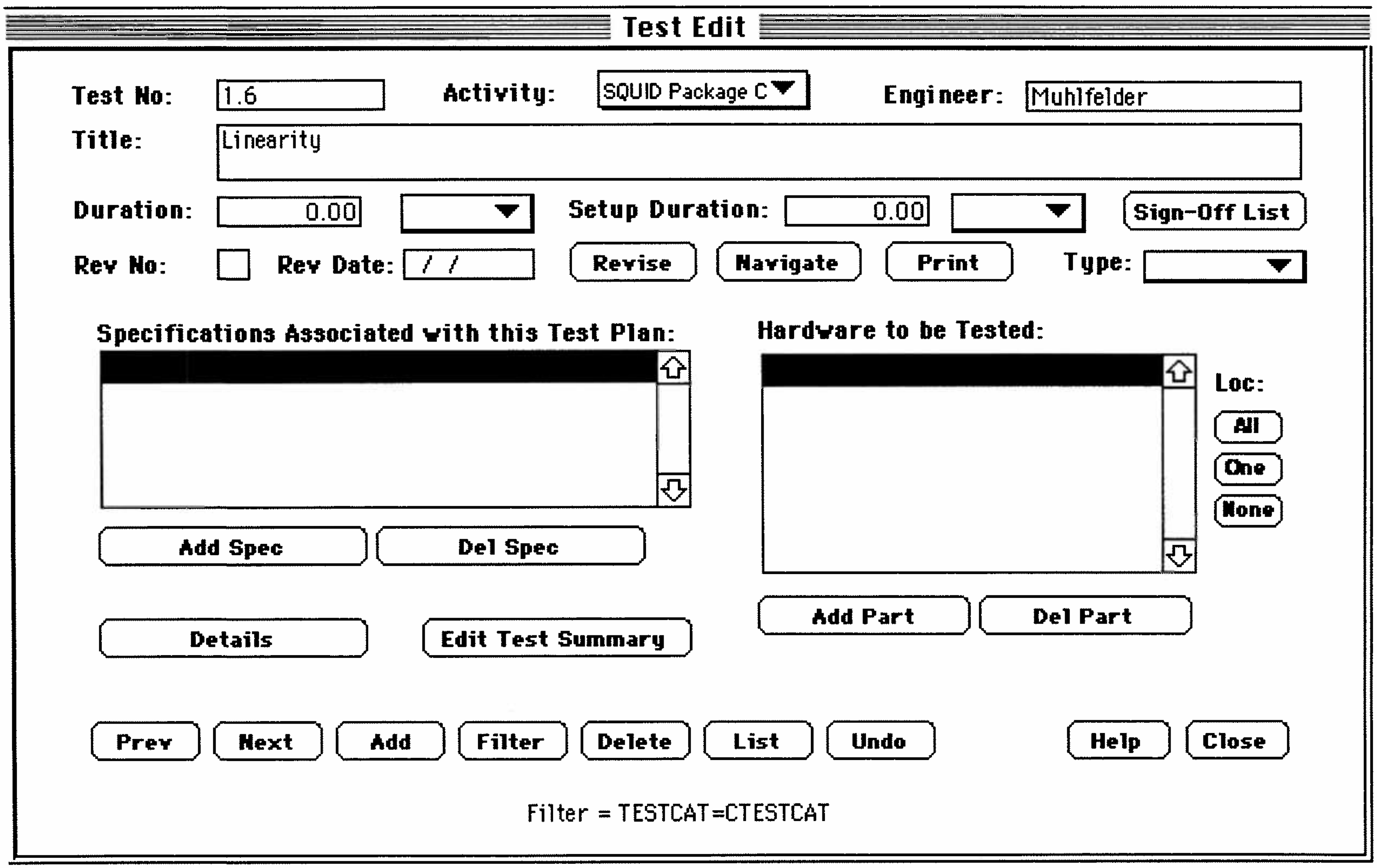
- **Readout System Section Specs Which Have Not Been Tested in System Tests: 6**

- **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**

Database Tracking of Verification Methods:



Test Plan Screen in Database



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**

Deliverables

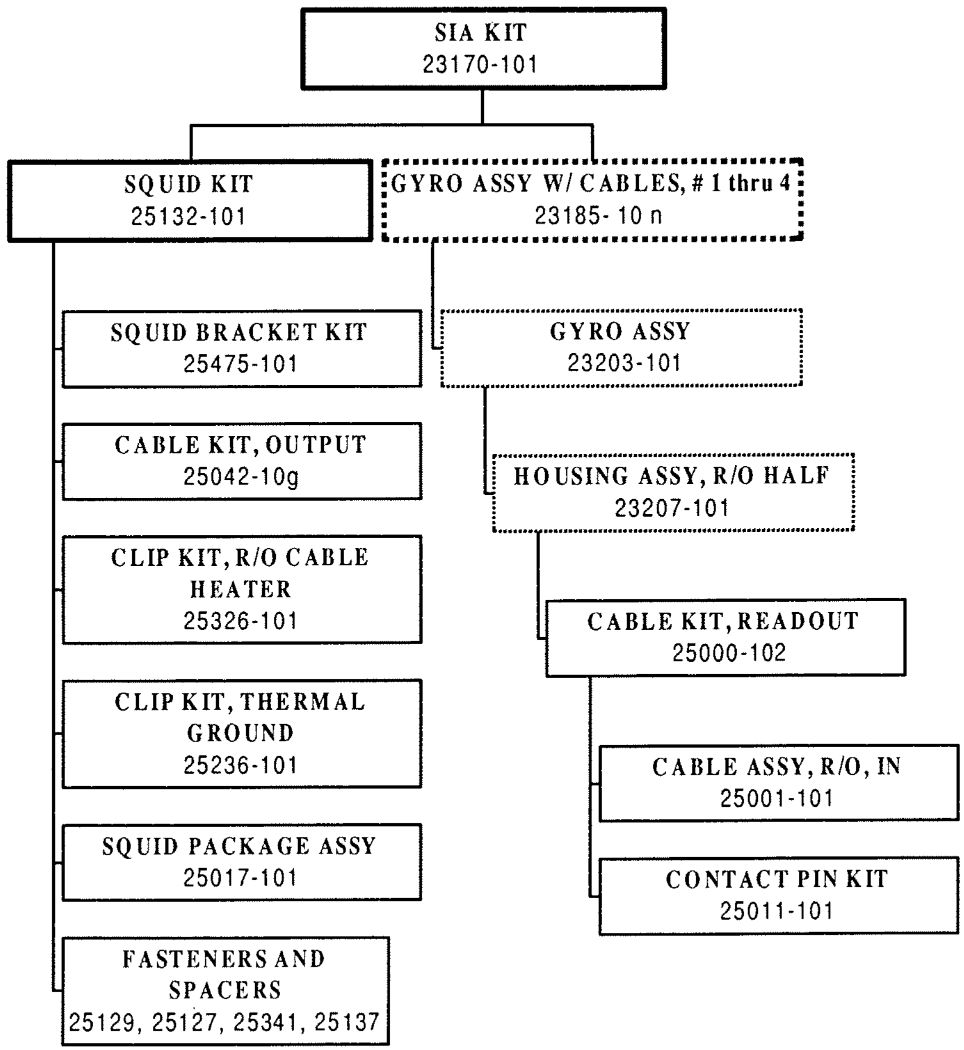
- FMECA
- SIA Specification
- Test Plan Matrix
- Drawing Tree

GYRO READOUT CRITICAL DESIGN REVIEW

Design Status

Jay Anastas

Top Level Drawing Tree
Readout Hardware



Design Status

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

Completed			# of parts
100%	FASTENERS AND SPACERS		5
90%	SQUID BRACKET KIT	25475-101	12
80%	CABLE KIT, OUTPUT	25042-10g	11
90%	CLIP KIT, R/O CABLE HEATER	25326-101	8
90%	CLIP KIT, THERMAL GROUND	25236-101	3
80%	SQUID PACKAGE ASSY	25017-101	36
100%	CABLE KIT, READOUT	25000-102	14

⇒Total of 99 drawings

⇒2 Drawing trees (SM and GTU2) released

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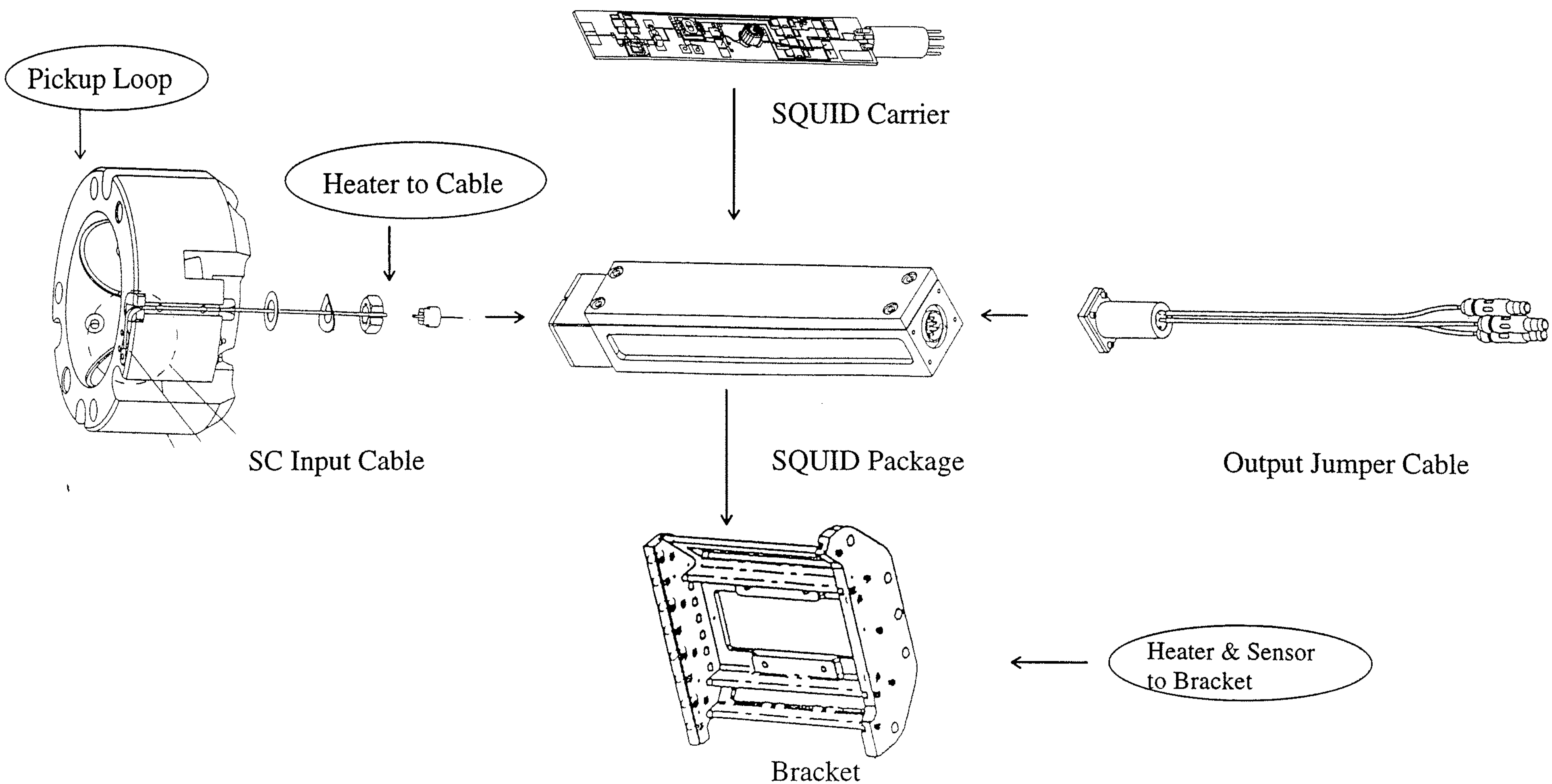
Manufacturing Plan

Ming Luo

Readout Hardware Structure



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:
20×4=60

Spare Parts:
20×8= 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:
21×4=84

Spare Parts
21×4=84

SU Man Hrs: 40

Bracket and Heater

Req Assem.: 2
Spare: 1
Man Hour: 20

- Package Bracket
- Should Washer
- Insulation Shim
- Heater
- Thermometer
- Fastening Clips
- Screws

Req Parts: 20×2=40
Spare: 20×1=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: 14×4 = 56
Spare Parts: 14×8 = 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: 37×4 =148
Spare Parts: 37×2 = 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

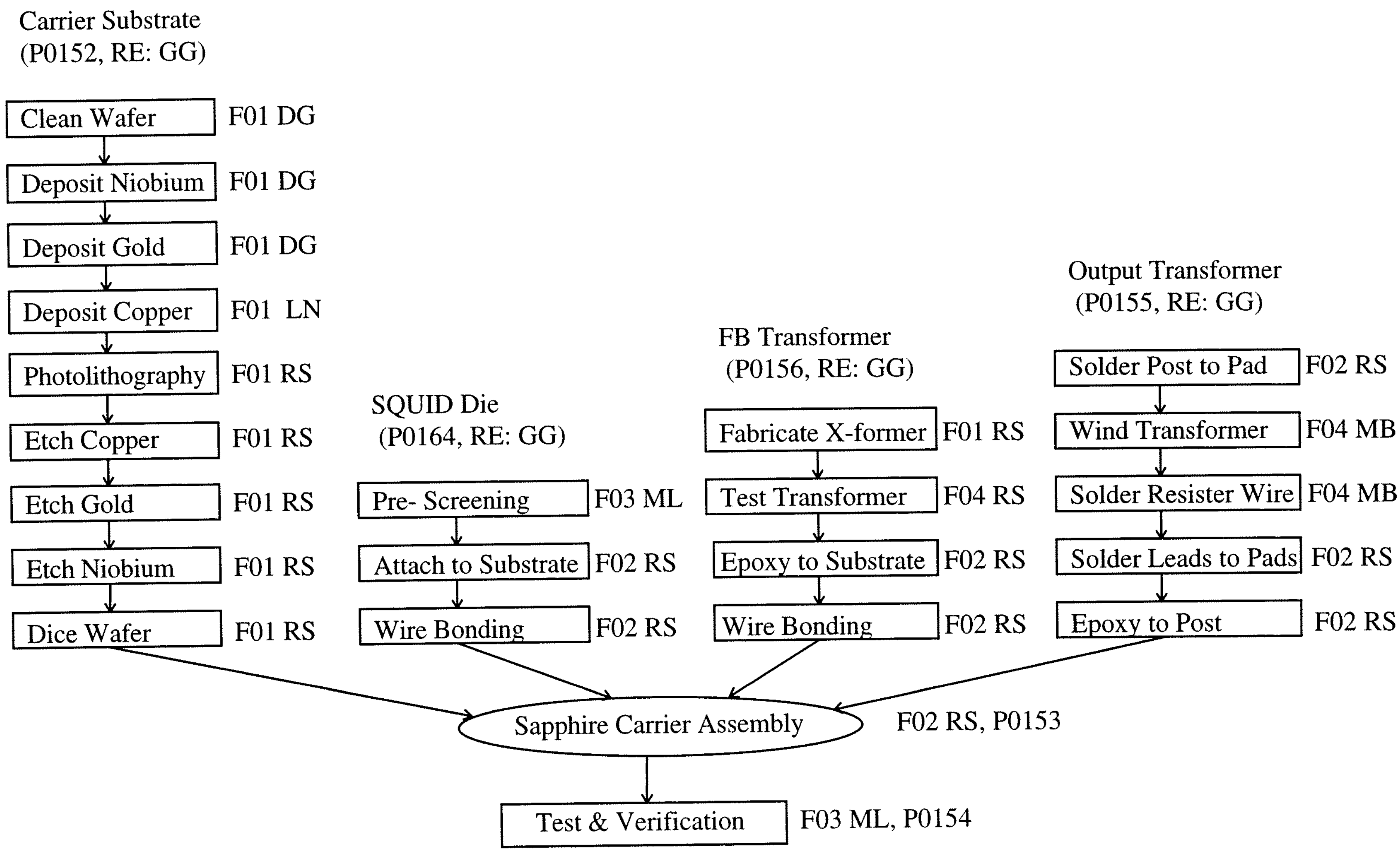
F03= Readout EMI Screen Room

F04= Readout General Assembly Area

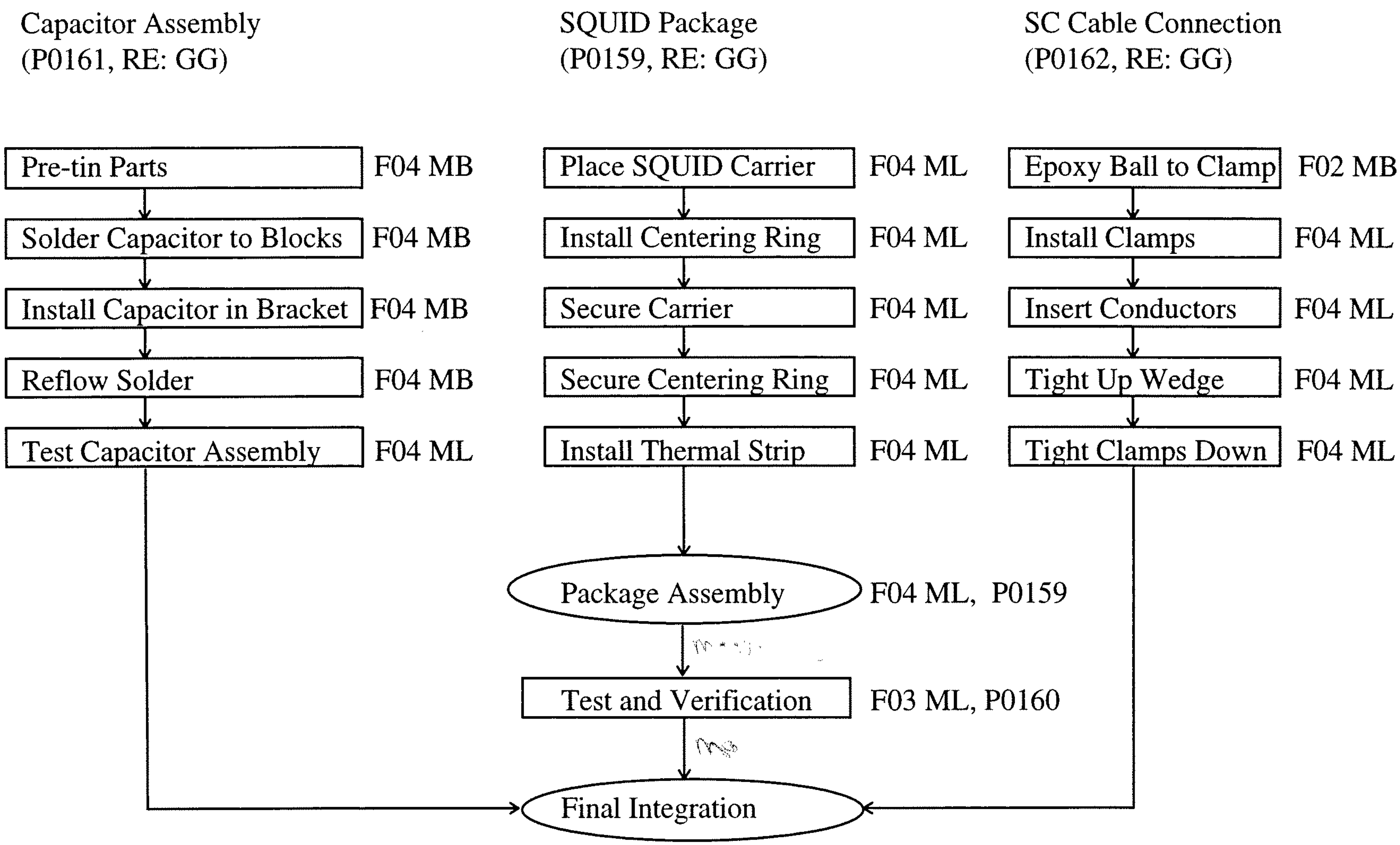
F05= Other GP-B Area

* Not a member of readout group.

SQUID Carrier Hardware Flow Chart

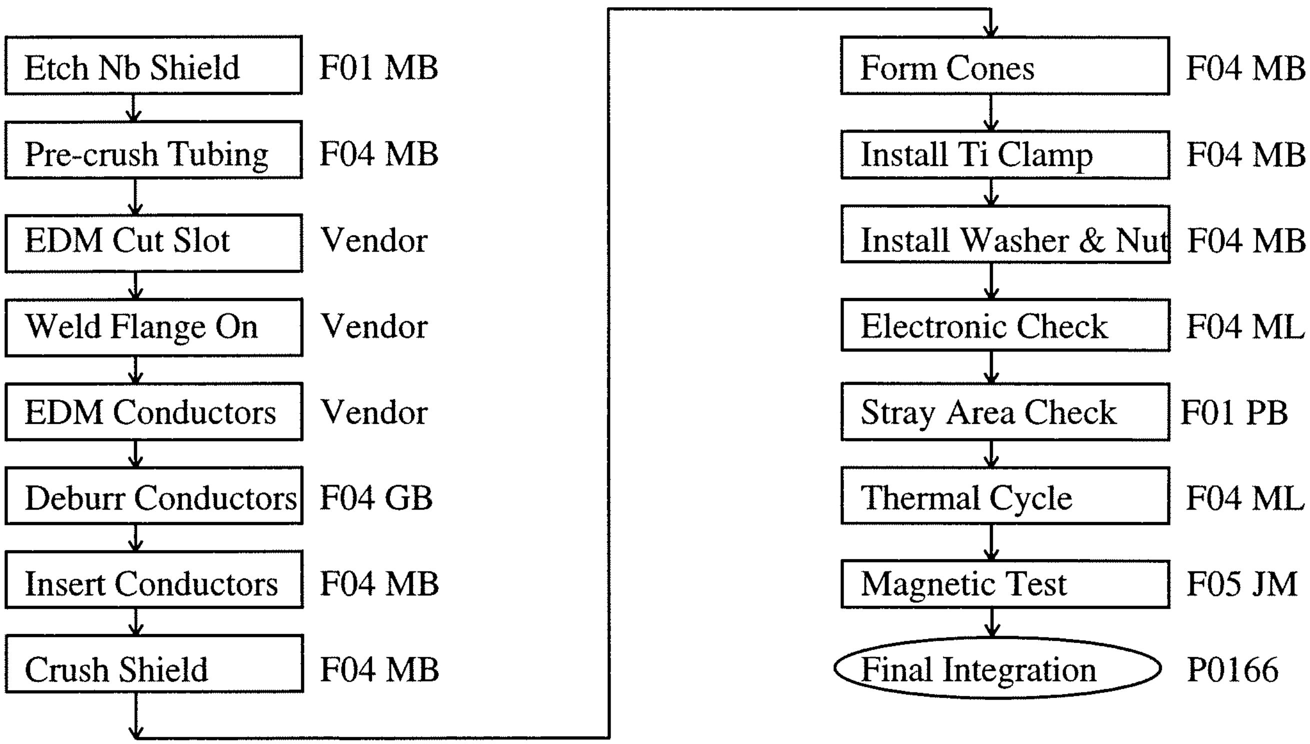


SQUID Package Hardware Flow Chart



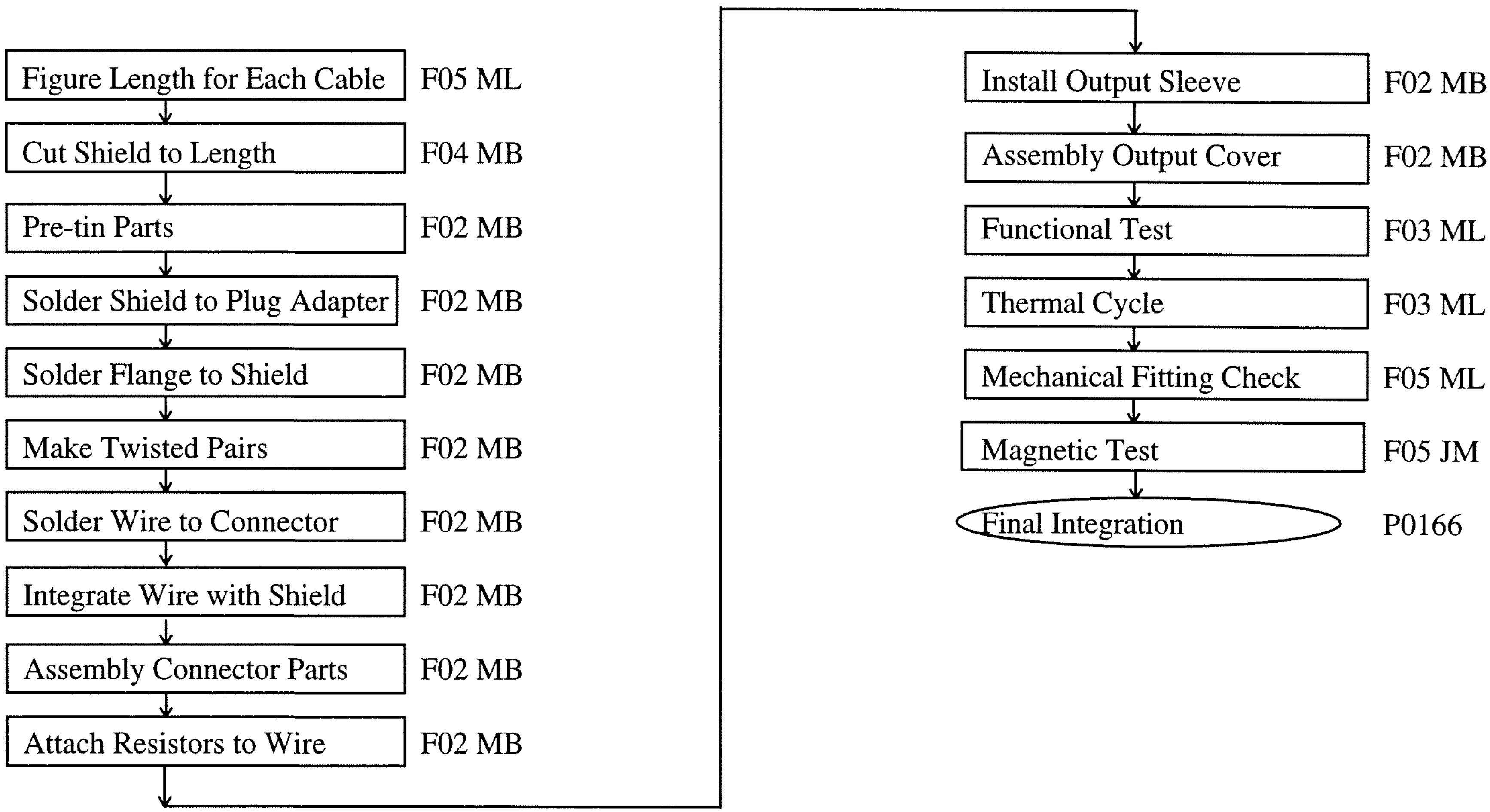
SC Cable Hardware Flow Chart

(P0102, RE: BM)

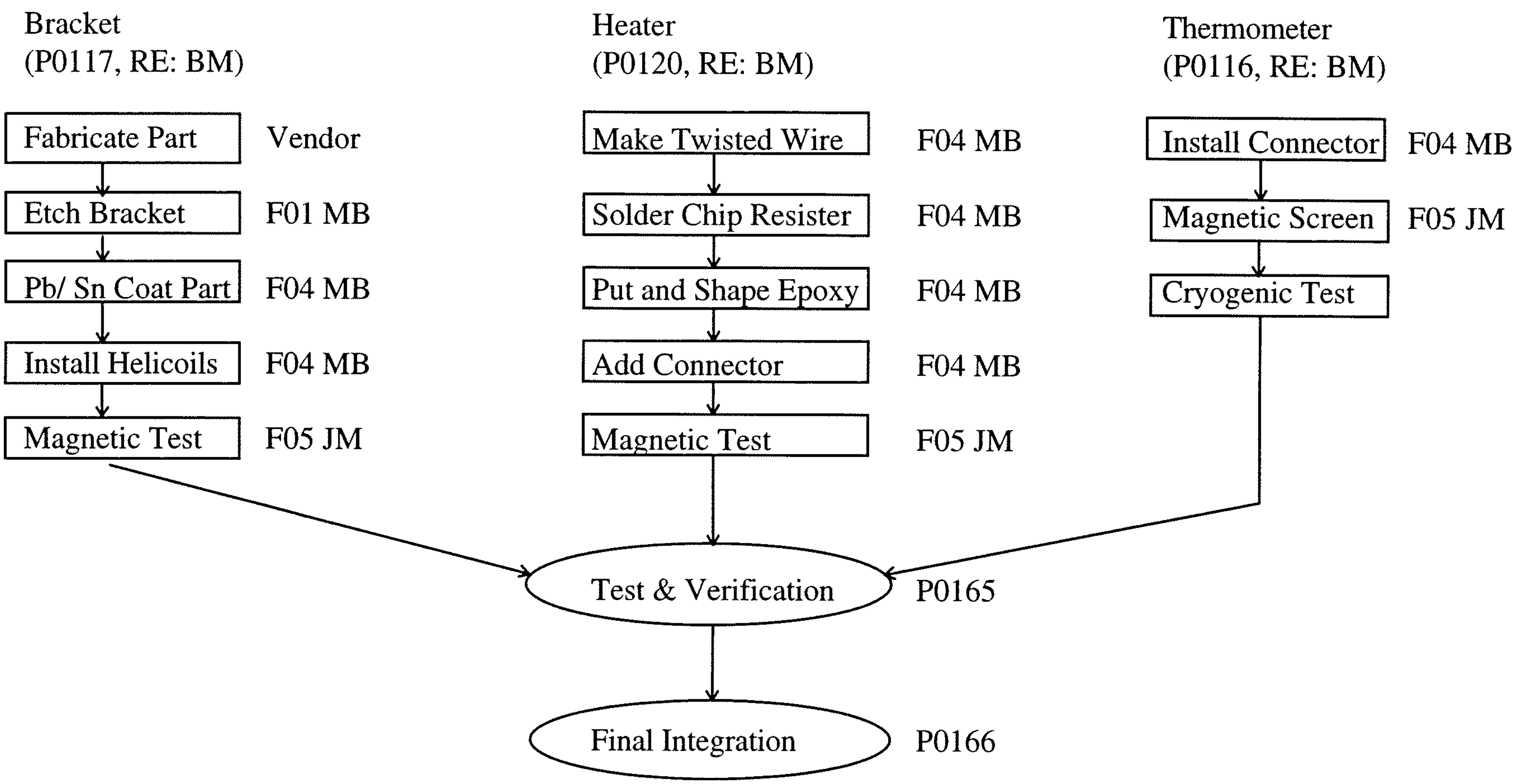


Jumper Cable Hardware Flow Chart

(P0163, RE: BM)

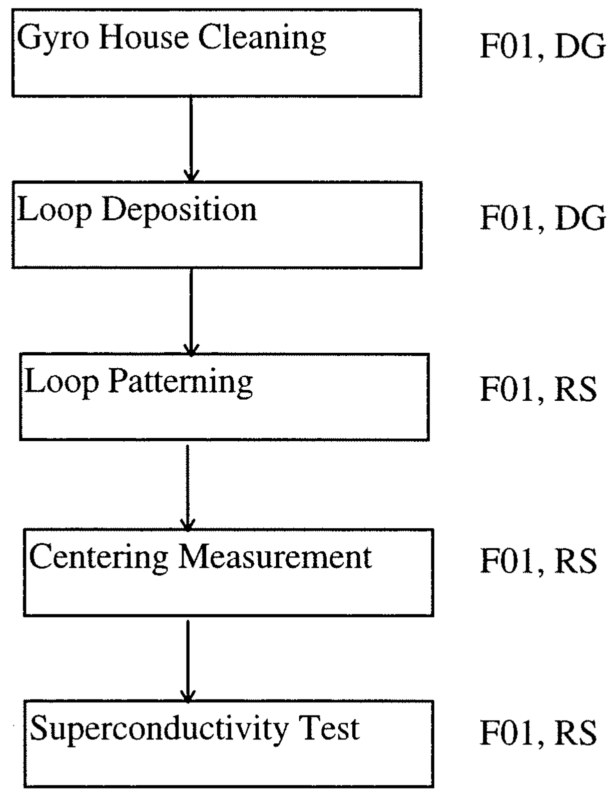


Bracket and Heater Hardware Flow Chart



Pickup loop Fabrication

(P0114, RE: BM)



* See Gyro CDR for Housing Fabrication Procedure

Hardware Storage and Documentation

Hardware	Intermediate Storage	Trace Method
SQUID Carrier	Readout Clean Area	Serial Number
SQUID Package	Readout Clean Area	Serial Number
SC Cable	Readout Cabinet #3	Serial Number
Jumper Cable	Readout Cabinet #3	Serial Number
Bracket	Readout Cabinet #3	Serial Number
Parts	Readout Cabinet #4	Lot Number
Raw Material	John Stamets	Lot/ Heat Number

Document	Storage
Raw Materials Request	Cabinet #7
Conformance Certificate	Cabinet #7
Travelers	Cabinet #7
Procedures	Cabinet #7
Test Reports	Cabinet #7

* Final parts go to John Stamets /Bonded Storage.

Readout Procedures

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

Readout Procedures (Continued)

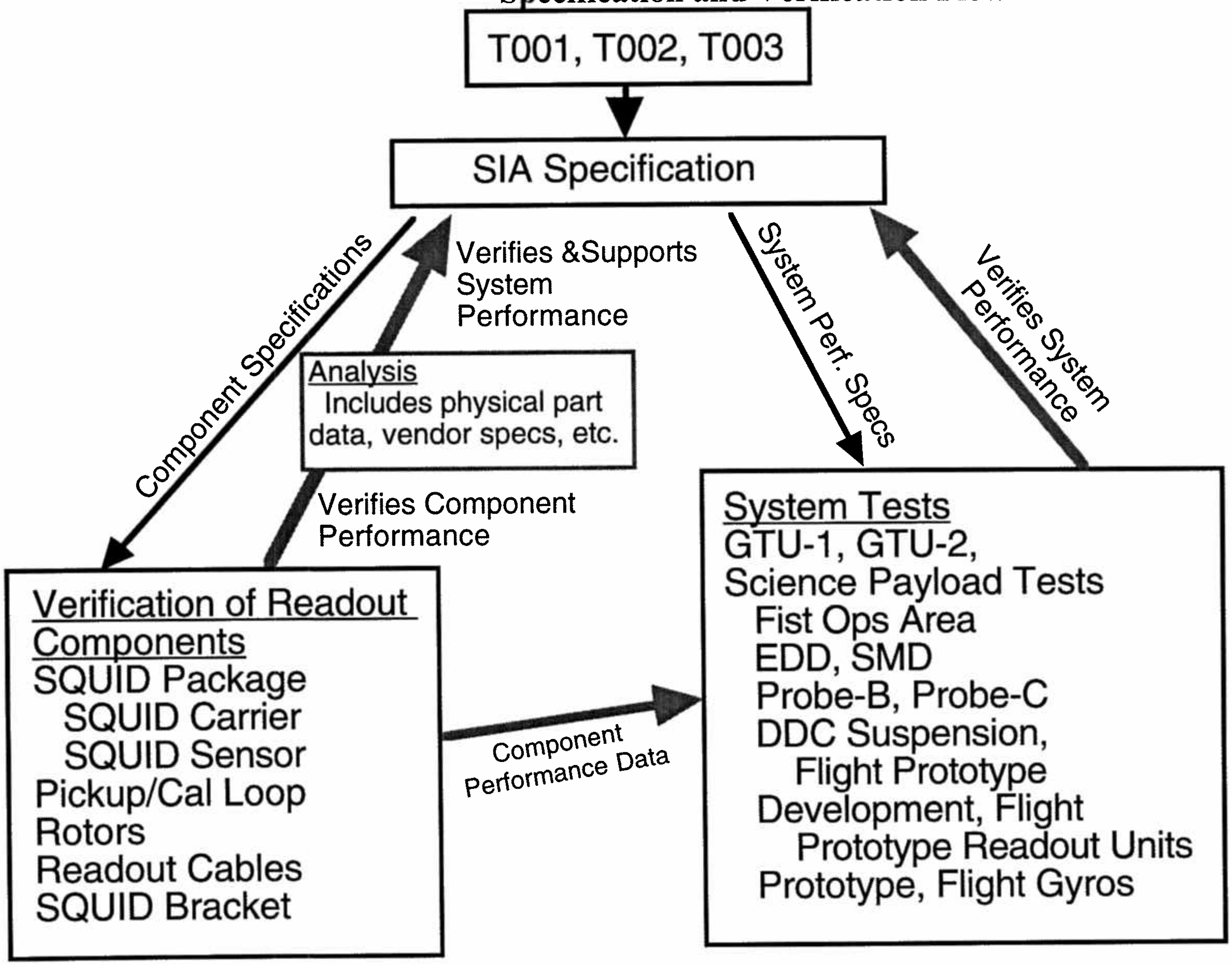
Procedure Number & Name		Percentage Completed
<u>Test & verification (Total 7):</u>		<u>20%</u>
P0154	SQUID Carrier Testing and Verification	0%
P0156	FB Transformer Verification	0%
P0160	SQUID Package Testing and Verification	0%
P0164	SQUID Die Pre-screening Procedure	75%
P0165	Bracket and Heater Verification	0%
P0167	Loop and SC Cable Verification	0%
P0168	FB Transformer Specification	90%
<u>Other Related Procedures (Total 4):</u>		<u>100%</u>
P0057	GP-B Magnetic Control Plan	100%
P0080	Cryogenic Magnetic Screening	100%
P0147	Relativity Mission Contamination Control Plan	100%
P0145	Stanford Material Process Control Plan	100%

GYRO READOUT CRITICAL DESIGN REVIEW

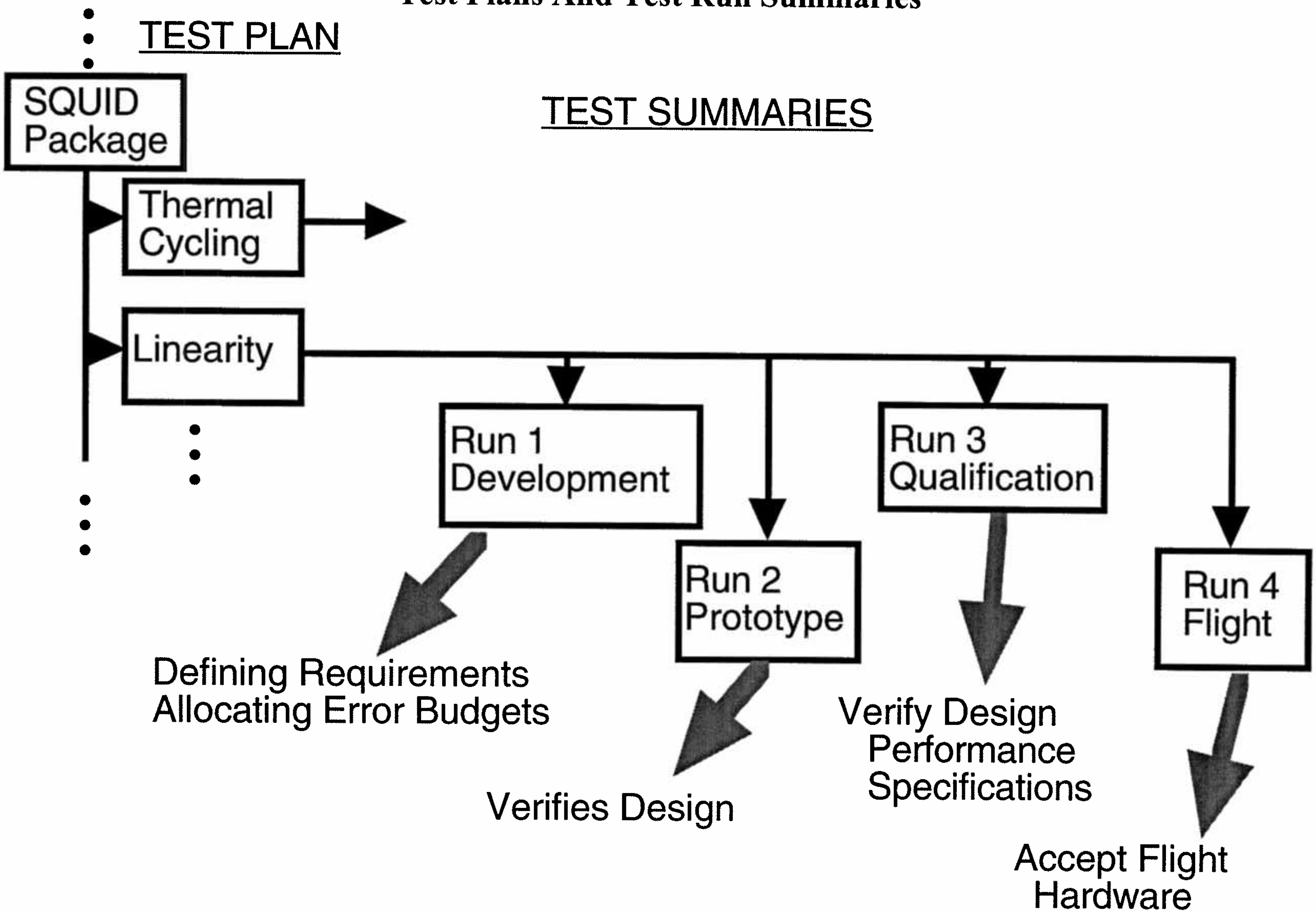
Test and Verification

Barry Muhlfelder

Specification and Verification Flow



Test Plans And Test Run Summaries



TEST PLAN MATRIX FOR READOUT COMPONENTS (1ST PAGE ONLY)

TEST PLAN #	TEST NAME	REQUIREMENT	REQ. FLOW DOWN (TOO3)	SPEC	VERIFICATION METHOD & FACILITY	STATUS (does not refer to flight hardware)	DESIGN OR COMP.	P Doc Number
	SQUID PACKAGE							
1.1	Thermal Cycling	20 Cycles Between 77K and Room Temp.	28		T, SQUID Package Accept. Facility	DONE	C	
1.2	Vibration	Sin Sweep 0-100 Hz, 10g's	22.1		T, Ames	NOT DONE	D	
1.3	EMI	TBD	14,8, 12.5		T, A, SQUID Package Acceptance Fac.	PARTIAL	C	
1.4	Thermal Cycling	300-4 K quant:3x	28		T,SQUID Package Accept. Facility	DONE, Achieved in GTU-1 testing	C	
1.5	Magnetic Shielding	$<2x10^{-23}$ Webers	8		T,SQUID Package Accept. Facility	DONE, Achieved $1x10^{-23}$ Wb (margin of 2)	C	
1.6	Linearity	0.01% for science level signals/ 1% for 100 arcsec error	3.2		T,SQUID Package Accept. Facility	PARTIAL	C	

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)

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 µK 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 (magneticstest 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)

Test Plan Number	Reference Specification	Test Name	Requirement	Verification Method
1.3	14, 8, 12.5	EMI	TBD	Expose package to EMI Source & measure FLL output
1.4	28	Thermal Cycle (Package)	300-4 K 3 times	Dip test in liquid Helium bath
1.5	8	Magnetic Shielding	$< 2 \times 10^{-23}$ Webers	Expose package to varying external magnetic field, measure FLL output
1.6	3.2	Linearity	1% for 100 arc-sec error	Calibrate V-Φ curve using dither signal and open loop FLL output
1.8	8.2, 12.3	Magnetics	Zone 2A	Measure piece parts and final assembly using appropriate magnetic test facility (RT Gradiometer, Susceptometer, LFF)
1.10	3.2, 3.3, 3.5	Output Transformer Coupling	k>0.85, Lp=8μH, Ls=285μH	Measure at room temperature using LCR meter
1.11	3.2, 3.5	Electrical Isolation	> 20 Mohms	Measure at room temperature using Ohm meter
1.13	3.2	SQUID Package Noise	<140marc-sec/rt Hz @ 5.5 mHz	Measure flux locked output of SQUID, @4.2K, in liquid Helium, input shorted
1.15	12.8, 3.4	SQUID Bias Temp Coef	< 40 arcsec/K	Measure flux locked output while varying temperature between 2.5 and 4.2 K

1.16		SQUID Scale Factor Temp Co.	< 3x10^{-4} @ f=.1 Hz	Inject sinusoidal signal into SQUID while varying the temperature between 2.5 and 4.2K, measure FLL output
1.19		SQUID Carrier Critical Current	10μA - 30μA	Tune up SQUID, measure bias current using calibrated SQUID electronics
1.21		Input Filter Capacitance	1 to 10nF	Measure at RT using LCR meter
1.22		SQUID Package White Noise	< 60 marc-sec/ rt Hz @ f=130Hz	Measure FLL output of SQUID package @ 4.2K, input shorted
1.25		Decay Time of Input (SC test)	Less than 1% change in 10min	Measure FLL output with a dc test field coupled to the input circuit, calculate worst case decay time.
1.27		Electrical Isolation to SM Probe	> 20 Mohms	Measure at RT using Ohm meter
2.1		SQUID Sensor White Noise	60 marc-sec/ rt Hz @ 130Hz	Pre-test in quick dip probe, before integration. Measure FLL output of SQUID @4.2K in liquid Helium.
2.2		SQUID Sensor Low Freq Noise	< 200marc-sec/rt Hz @ 5.5mHz	See 2.1
2.6		Input Coil Inductance	< 2.0μH	Tested at QD
2.8		Modulation Coil Coupling		Tested at QD
2.9		Input Coil Inductance		Tested at QD

2.10		Input Coil Coupling		Tested at QD
2.11		Input Coil Critical Current		Tested at QD
2.12		Bias Current		Tested at QD
7.1	28	SQUID Carrier Electrical Cont.	Internal Spec	Measured at RT using Ohm Meter
7.2	28	SQUID Carrier Therm Cycle	300K-77K 20 Times	Dip test in liquid Nitrogen
7.4	28	SQUID Carrier Bake	300-360K for 1 week	Bake at 60 C for one week
7.5	TBD	Visual Check	Internal Spec	Inspect at 30X-100X per MIL-STD 883 Method 207

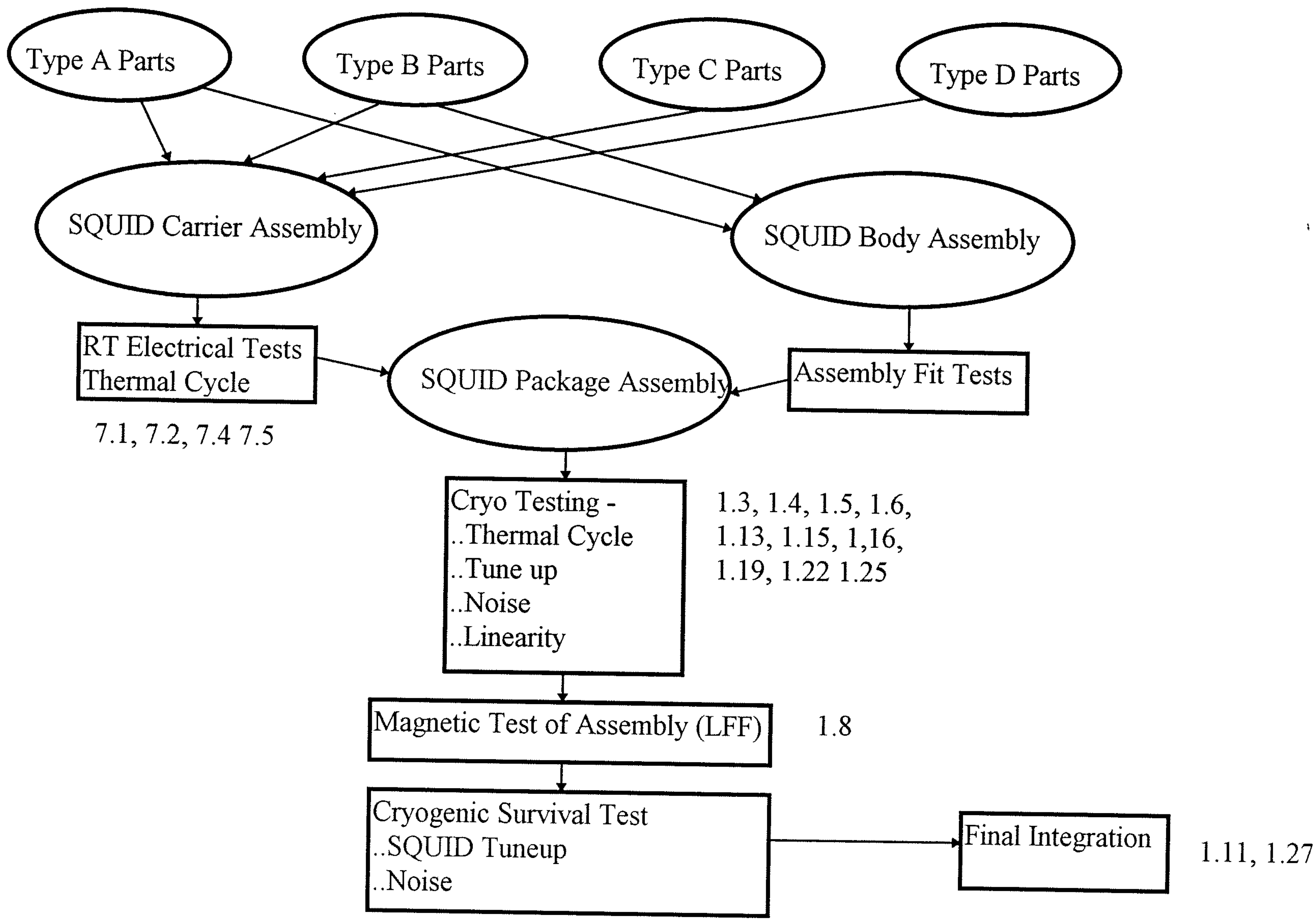
Comparison of Testing Between GTU-1 and Science Mission

	Number of Tests	Number of Cryogenic Tests at Stanford
GTU-1	14	5
GTU-2 / SM	27	13
Percent Increase in Testing	92%	160%

SQUID Package Verification Flow Diagram

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

SQUID Package Assembly Verification Flow



SQUID Chip/Carrier/Package Tests (One Time Verifications)

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

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:**

Quantity	Requirement	Observed Value
→Readout System Noise	<190 marcs/√Hz	188 marcs/√Hz
→ac magnetic shielding factor	$<10^{-12}$	$<10^{-13}$
→Science Data Validation (Nb Bird)	Consistent with noise	Consistent with noise
→SQUID Input Circuit Coupling (multi-turn pickup loop)	>40 fA/marcs	>40 fA/marcs

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

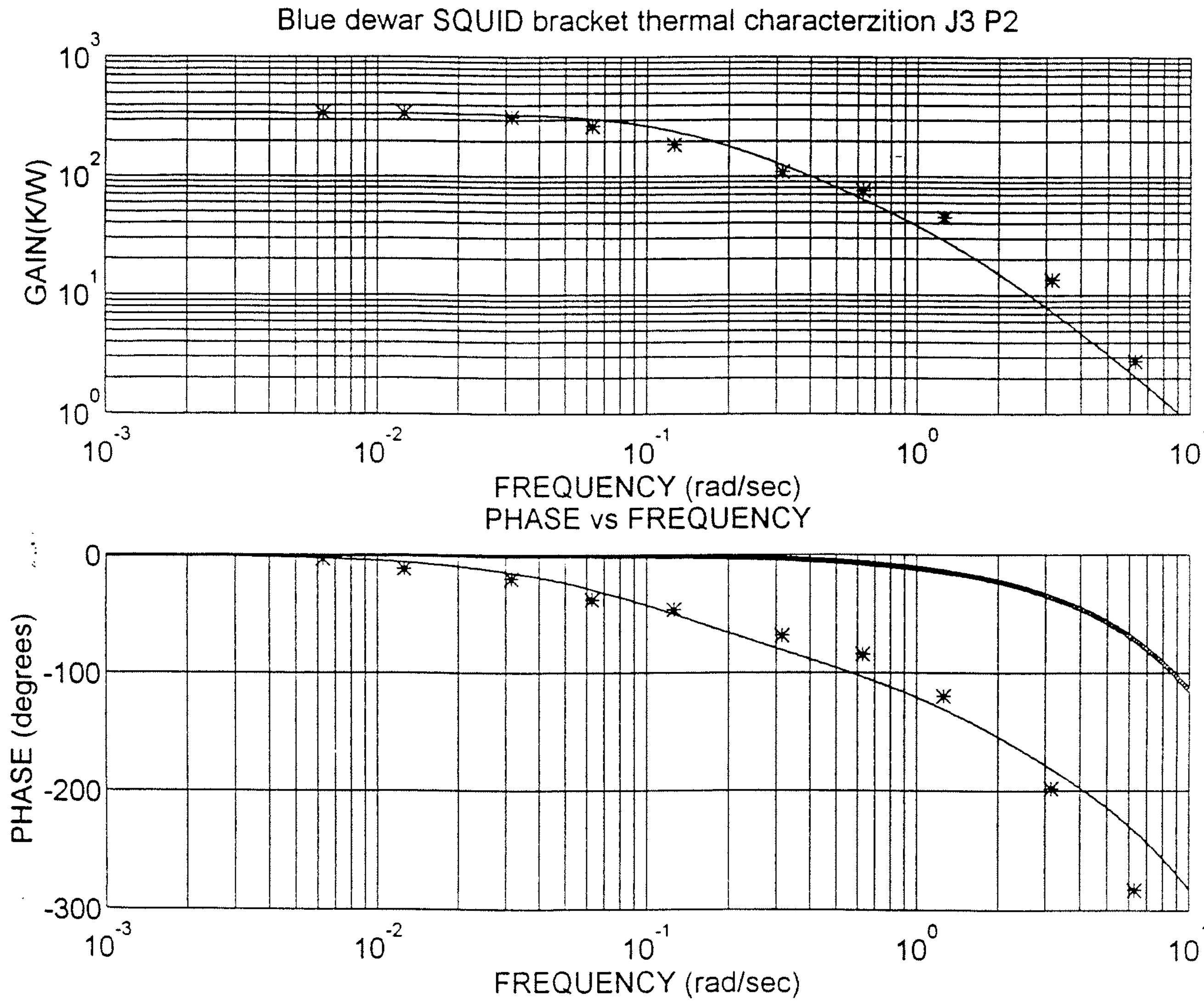
- GTU-1 Vintage Readout (Cryogenic Hardware)
  - Bracket with heaters and thermometers on SQUID mounting plate
  - 2 SQUID Packages with jumper cables (thermometer on 1 SQUID carrier)
  - Heater and thermometer on simulated spider
  - Thermal impedance from simulated spider to ground not representative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

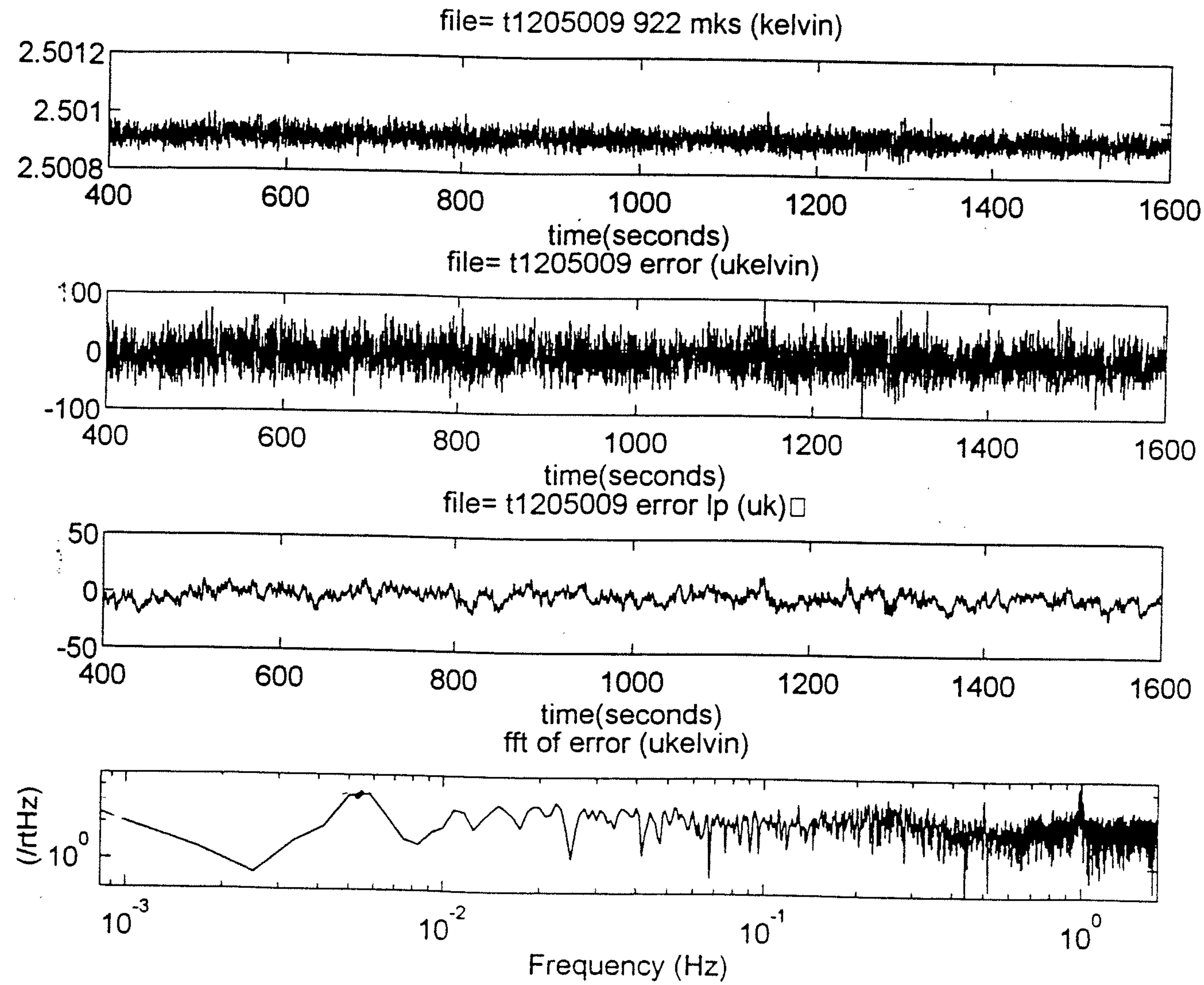


Temperature

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 < 2×10^{-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

Design	Material Selection	Fabrication	Assembly
GPB Document *Drawing Notes For Magnetic Control of Parts*	GPB Document *GPB Candidate Materials List*	GPB Document *Guidelines for Non-magnetic Fabrication Practices*	GPB Document *GPB Procedure for Magnetic Control of Tools, Fixtures, and Support Equipment*
Magnetics zones specified in drawing notes	Material Coupons submitted for mag approval as outlined in Control Plan	Fabed Parts submitted for mag approval as outlined in Control Plan	Nonmagnetic tool sets maintained by magnetics group
Dimension Specs should account for Chem Etch Cleaning	Inventory control of approved materials	Inventory control of approved parts	Critical Assemblies submitted for magnetics approval

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 $\Rightarrow$ DC field at gyro. Minimize.

B. Susceptibility $\Rightarrow$ Allows sensitive test for magnetic contamination. Minimize.

C. Superconductivity $\Rightarrow$ Can flux trap or distort fields. Use only as required.

D. Electrical Resistivity $\Rightarrow$ Low resistivity materials generate Johnson noise currents which can interfere with readout. Minimize use of high conductivity materials.

Material Magnetics Standards By Zone

Magnetic Zone	Rem. Moment	Susceptibility	Superconductivity	Resistivity
1	<1 x10^{-7} d^3 emu	<5 x10^{-6} emu/G/g	Only as required	>1.0 μΩ-cm @ 2K
2A	< 2 x10^{-6} emu	<5 x10^{-6} emu/G/g	Only as required	>0.2 μΩ-cm @ 2K
2B	< 4 x10^{-6} emu	<1 x10^{-5} emu/G/g	Only as required	>0.1 μΩ-cm @ 2K

d = distance from rotor surface in cm

Finished Part Magnetics Standards By Zone

Magnetic Zone	Rem. Moment	Verification Method
1	$<1 \times 10^{-7} d^3$ emu	Cryogenic
2A	$< 2 \times 10^{-6}$ emu	Cryogenic
2B	$< 4 \times 10^{-6}$ emu	Cryogenic or Gradiometer

d = 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 Cryosceening 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

$\Rightarrow$ Magnetic Field Noise Requirement $< 5 \times 10^{-11}$ Gauss/$\sqrt{\text{Hz}}$ at 5.5 mHz

$< 1 \times 10^{-11}$ Gauss/$\sqrt{\text{Hz}}$ 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: $\sqrt{\sigma}$ (σ = 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 cm^3 Metallic Source 2 cm From Gyro

Material	Resistivity at 2K	Calculated Field Noise
Ti	11.3 $\mu\Omega$-cm	4.7×10^{-13} Gauss/$\sqrt{Hz}$
Cu	0.002 $\mu\Omega$-cm	3.4×10^{-11} Gauss/$\sqrt{Hz}$

$\Rightarrow$ Minimize Use Of High Conductivity Metals Near Gyro

For Sources Outside Magnetic Zone 1, The Local Nb Shield Provides AC Shielding Factor Of 7×10^{-3} Axial, 4×10^{-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 7×10^{-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)

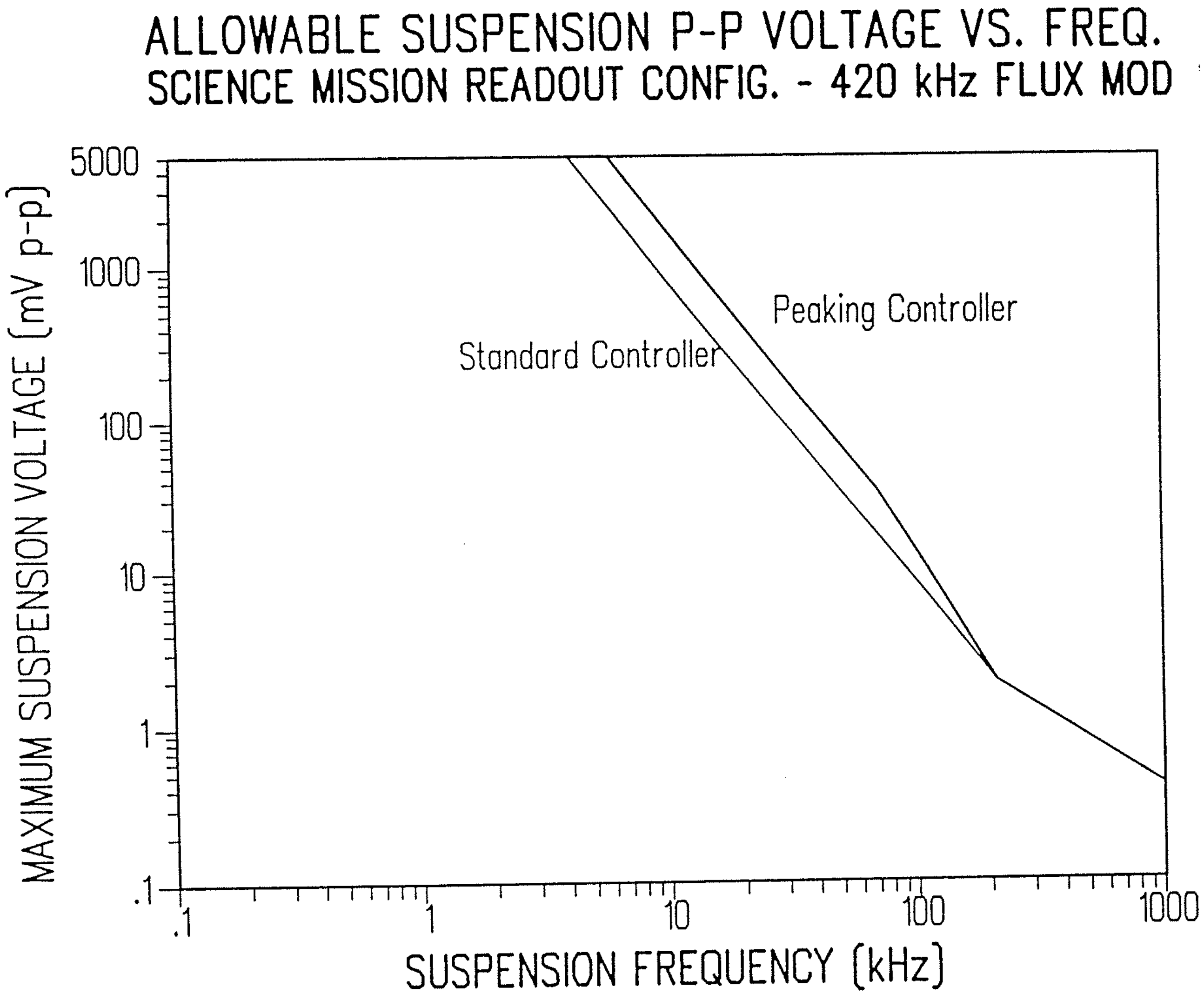
- **SQUID System Power: 0.2 μW per SQUID plus 0.25 mW per SQUID Bracket**

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



GYRO READOUT CRITICAL DESIGN REVIEW

EMI Compatibility
Grounding & Shielding

J.M. Lockhart

Design EMI Environment

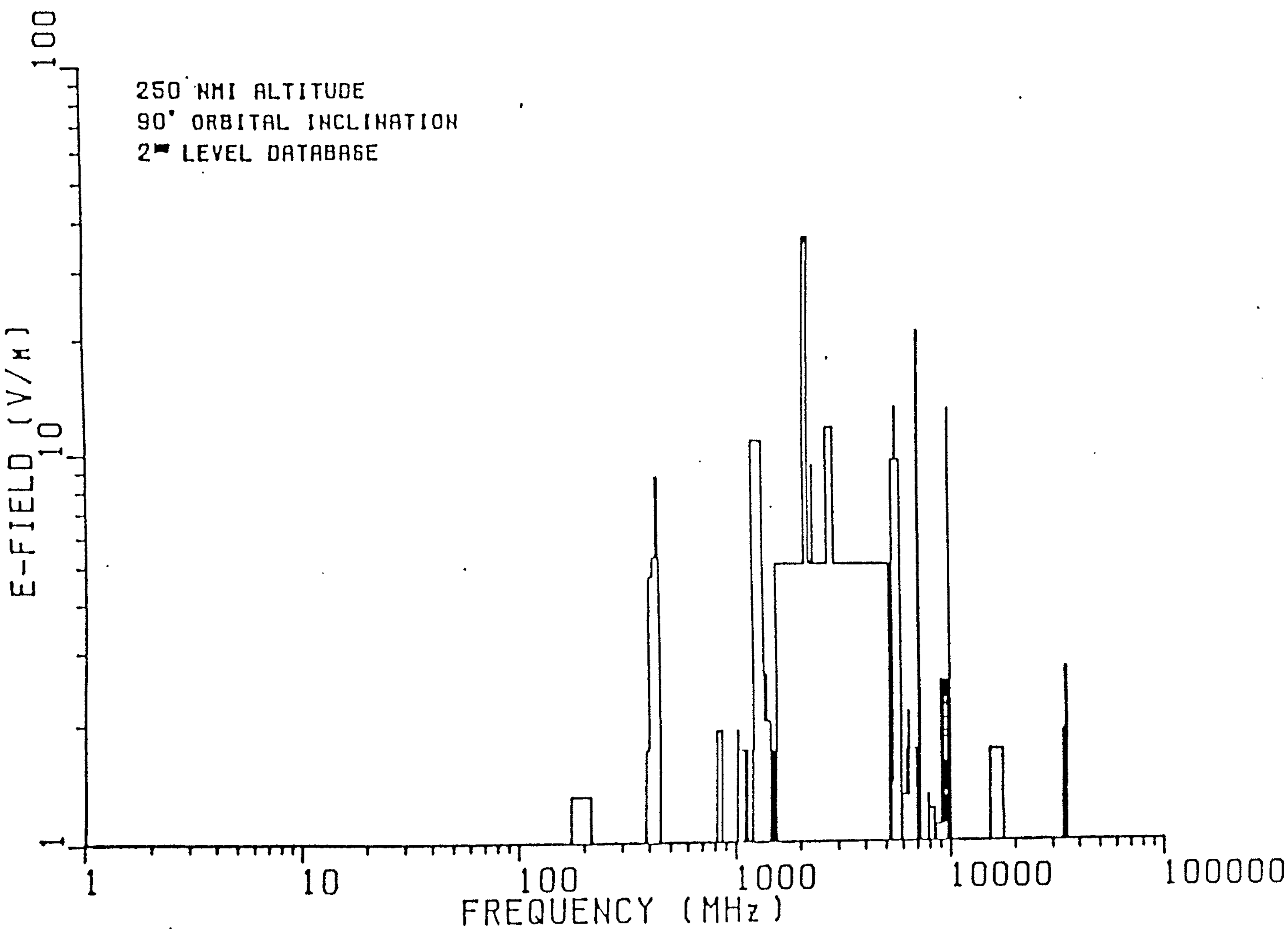


Figure F-18. Electric field intensity versus frequency for orbital parameters of 250 nmi @ 90° inclination. (Logarithmic Ordinate Scale)

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 instrumenation connections and emi filters in place; evaluate emi resistance

- System level tests

  →GTU-1 tests completed; showed need for improvement in

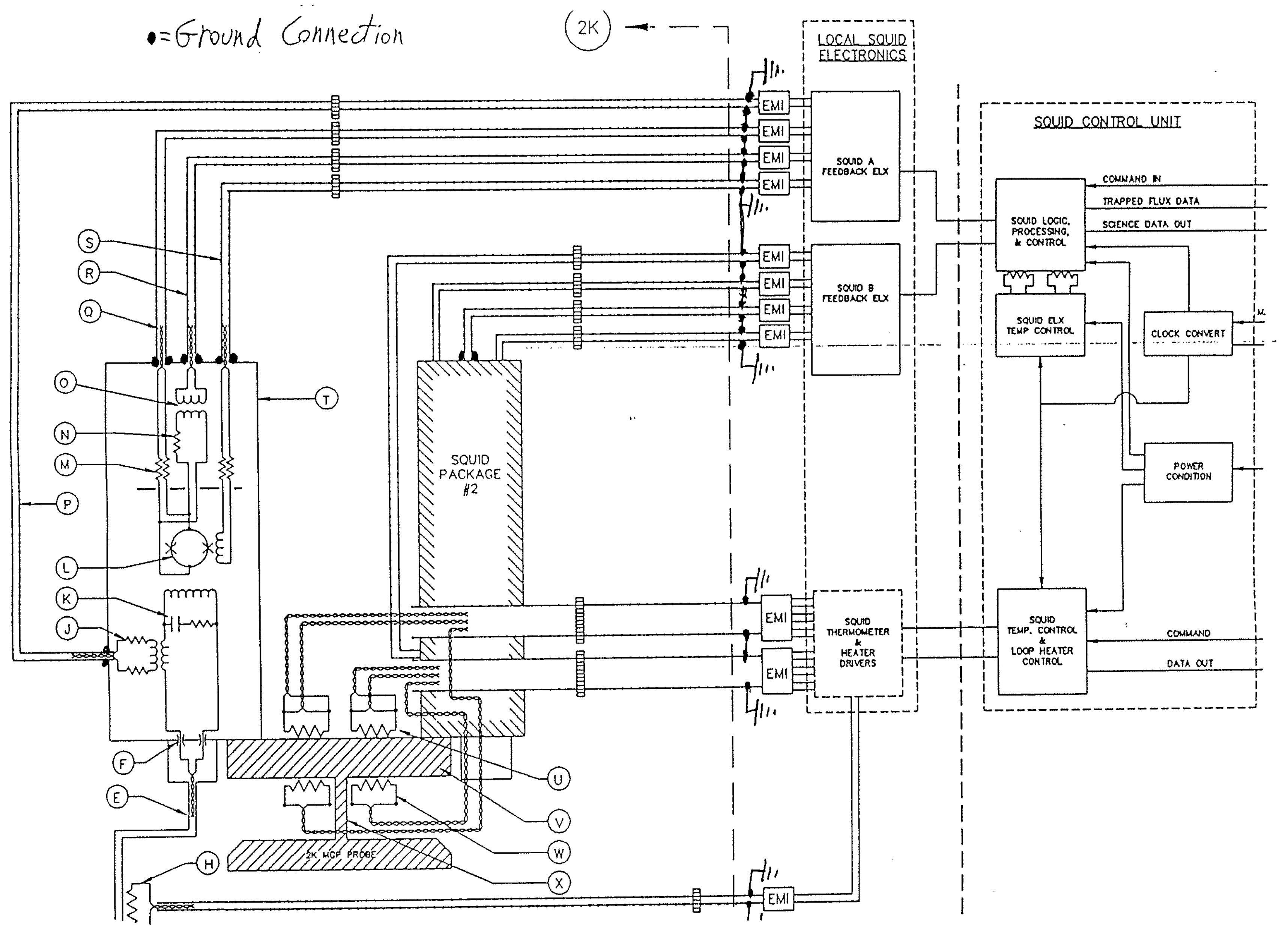
  * Tophat-to-electronics cables

  * emi filters (suspension and instrumentation)

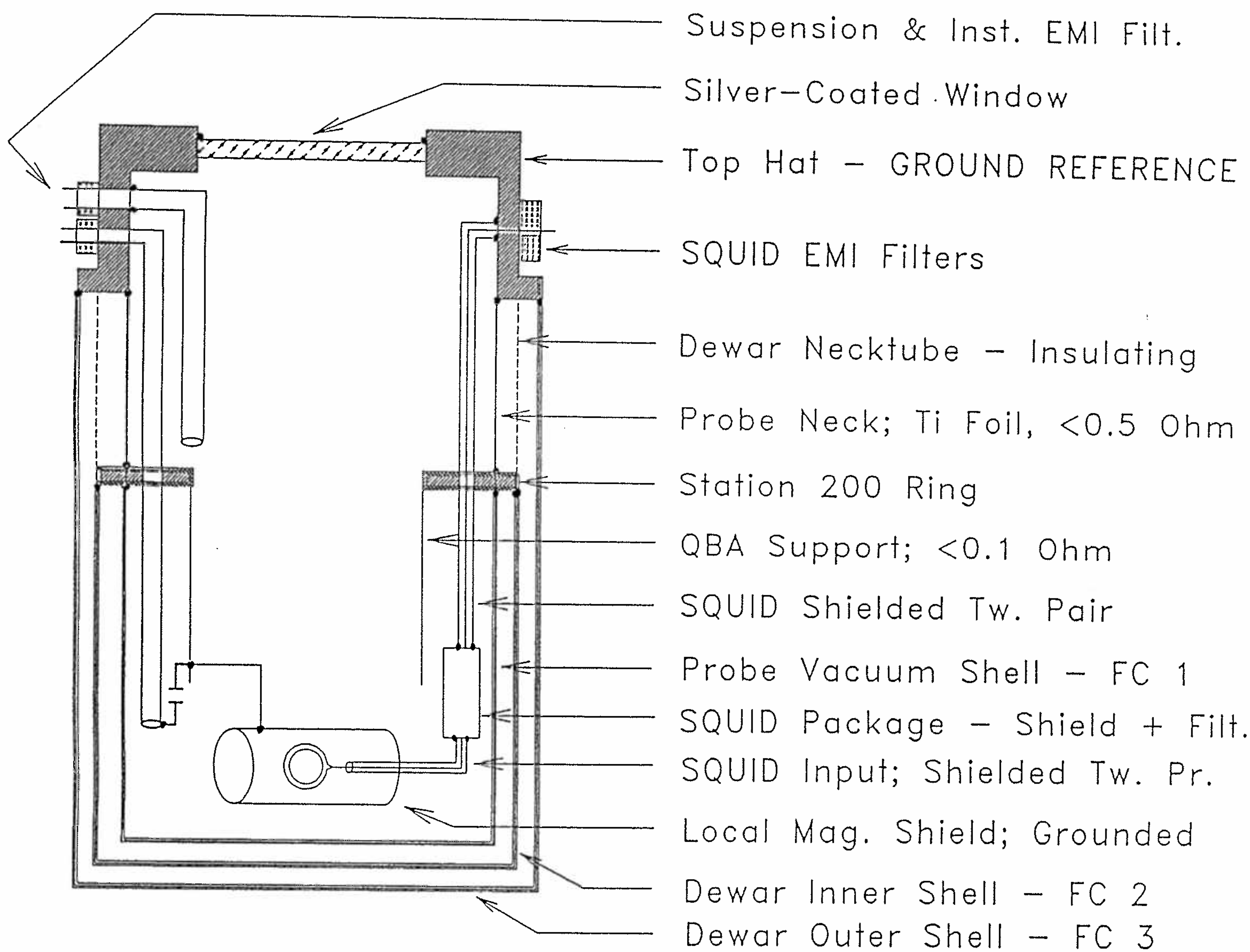
  * Reduction of emi entering telescope aperature (window 4 & sunshade)

  →GTU -2 full system tests scheduled

SQUID Package Grounding Scheme



Probe Shielding Scheme with Faraday Cage Around Pickup Loops & SQUIDs



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)

Frequency (hz)	Protoqual level (g^2/hz)	Qual Level (g^2/hz)
10	0.005	0.010
20	0.005	0.010
50	0.05	0.10
300	0.05	0.10
2000	0.001	0.002
Composite (grms)	5.05	7.14

- 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

- 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: Survivablility 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)

- **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

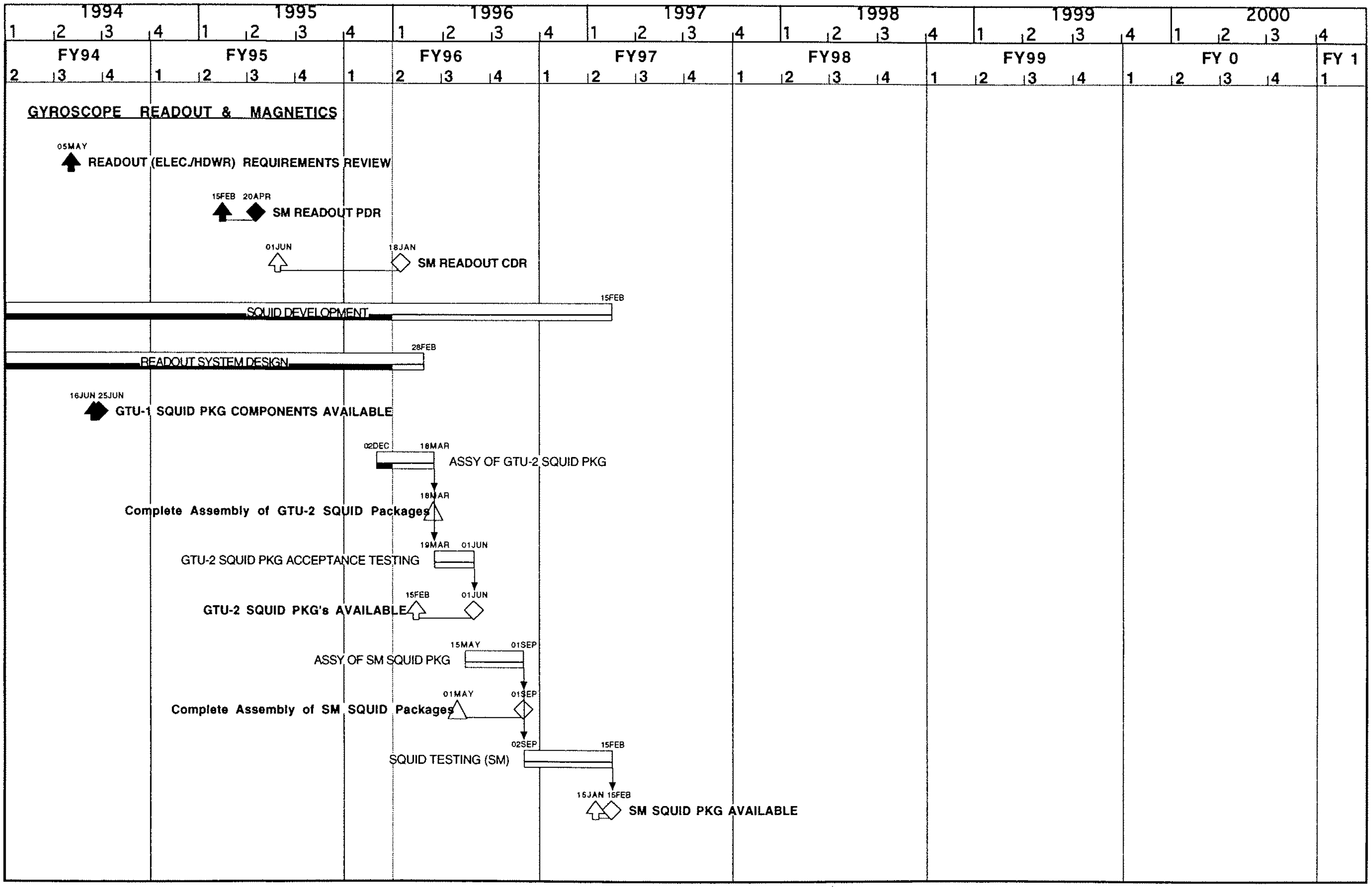
Schedule and Resources

Jim Burns

Stanford University

GYROSCOPE READOUT
OVERVIEW SCHEDULE

RELATIVITY MISSION



LEGEND

CRITICAL MILESTONE
MAJOR MILESTONE
TECHNICAL MILESTONE

PROGRAM ACTIVITY (BASELINE)
PROGRESS ON ACTIVITY

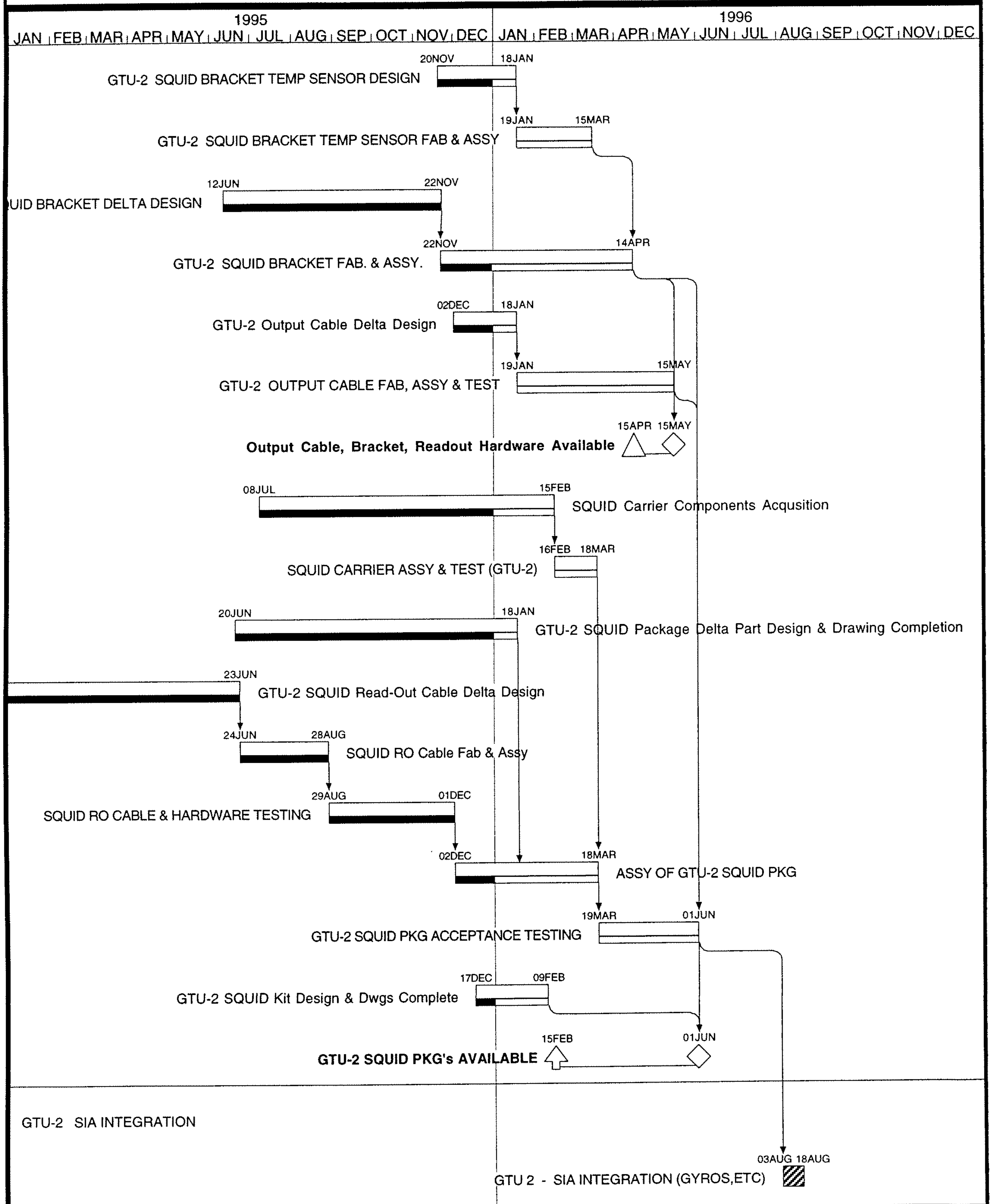
CURRENT CHANGES TO START OR COMPLETE DATES

Rev. Number: R-6

Data Date: 01JAN96

FRM File SKD122F.FMT SCH File: GP-B DATA:34:1:GPB MASTER NET (R-8)

GTU-2 READOUT HARDWARE



Readout Critical Design Review

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 ..**