W. W. Hansen Experimental Physics Laboratory

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Gravity Probe B Relativity Mission

SQUID Kit / Readout Test Readiness Review

GP-B P0257 Rev -

February 20, 1998

Prepared by: Ken Hooper **Date**
Systems Engineer

Approved by: Bob Schultz **Date**
Chief Systems Engineer

Approved by: Barry Muhlfelder **Date**
Manager, SQUID Development

Approved by: George "Mac" Keiser **Date**
Chief Scientist

Approved by: Jim Lockhart **Date**
SRE IPT Leader

Approved by: B. Taller **Date**
Quality Assurance

Approved by: J. Turneaure **Date**
Hardware Manager

SQUID Kit / Readout Test Readiness Review

Date & Time: December 18, 1997, 2:00 to 4:00 PM
Location: GP-B conference room

Purpose:
To ensure that the test article hardware, test facility, ground support personnel, and test procedures are ready for testing, data acquisition, reduction, evaluation, and control.

Scope:
The SQUID Kit / Readout Test Readiness Review (TRR) will encompass all SQUID Kit / Readout (RO) flight hardware. The RO flight hardware includes the completed SQUID Kits assemblies and their components, including: the SQUID packages, their sensors, cables, connectors, brackets and mounting hardware.

Agenda:
- Requirements Traceability Status
- Procedure Status
- Test Personnel Status
- Test Resources Status
- Test Support Software Status

Review Team:

John Turneaure	Hardware Manager
Barry Muhlfelder	Manager, SQUID Development
George “Mac” Keiser	Chief Scientist
Jim Lockhart	SRE IPT Leader
Ben Taller	Quality Assurance
Bob Schultz	Chief Systems Engineer
Ken Hooper	Review Leader
Ed Ingraham	ONR (ex officio)

Objectives:
- Confirm that in-place test plans and procedures meet verification requirements and specifications.
- Confirm that sufficient and detailed resources (of the right type) are allocated to the test effort.
- Examine detailed test procedures for completeness and safety during test operations. Note who is in charge of the test operations and test article and who is in charge of the facilities.
- Determine the critical test personnel who are authorized to perform test.
- Confirm that test support software is adequate, pertinent, and verified (validated for intended use).
- Confirm that all interfaces with the test article, test equipment, and facilities, especially power, data, instrumentation, etc., are adequate, safe, and in accordance with the test procedure. Ensure the customer, witnessing agents, test personnel, quality assurance, and support personnel understand the objective of the test and the parameters that are critical for successful operation.
- Confirm that the documentation has proper traceability.
- Confirm that test equipment has been appropriately calibrated.

Exit Criteria:

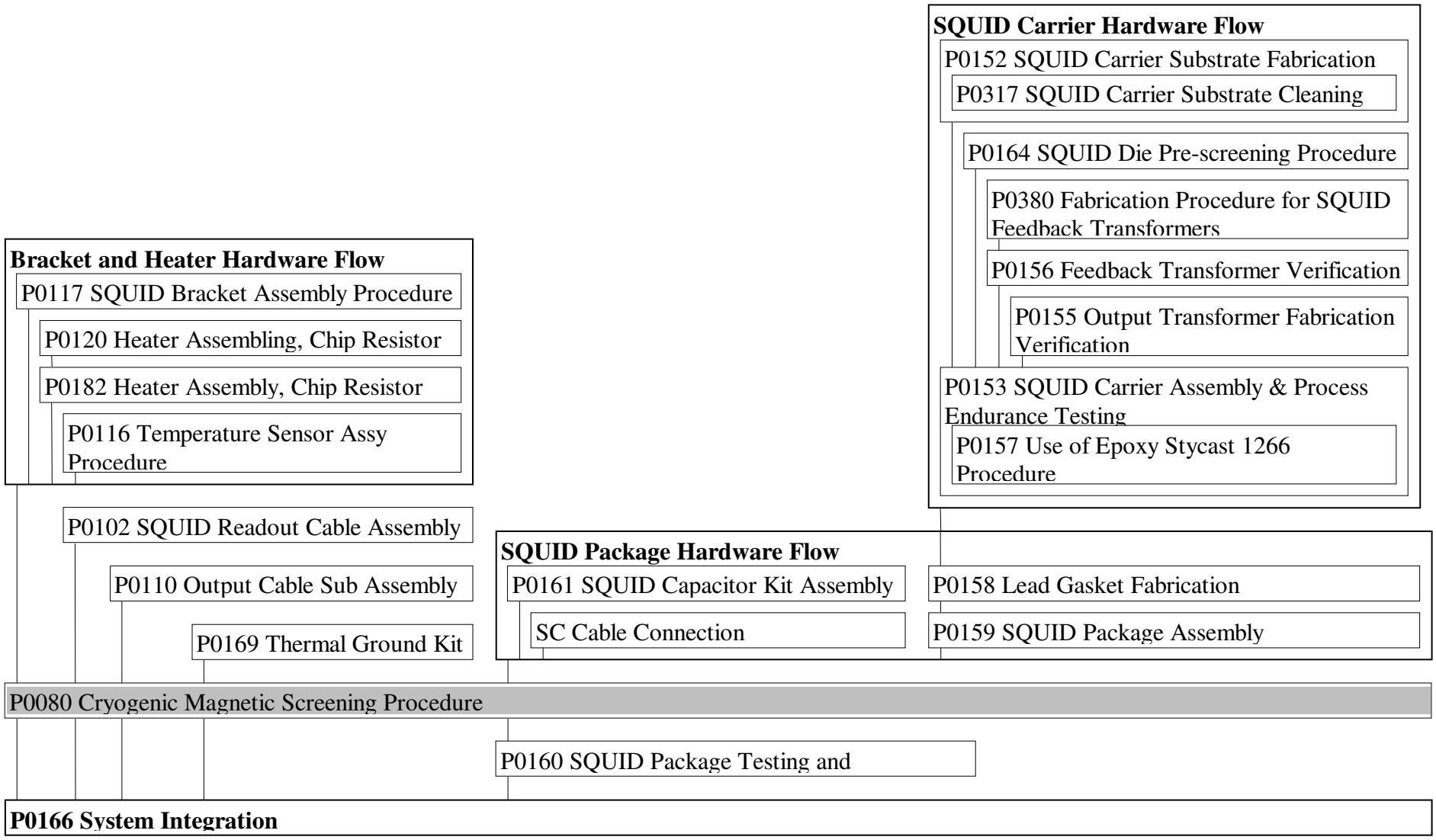
The following items identify the categories of items to be checked; the individual checks are enumerated in the attached checklists:

- Do the test procedures verify all applicable requirements?
- Have test personnel received training in test operations procedures?
- Are resources available to adequately support the planned tests as well as contingencies, including failed hardware replacement?
- Has the test support software been demonstrated to handle test configuration assignments, and data acquisition, reduction, evaluation, control, and archiving?

Attachments:

A. Manufacturing Flow Diagrams
B. Requirements Verification Matrix
C. Document Status Checklist
D. Test Personnel Status Checklist
E. Test Resources Checklists and Test Support Software Checklist
F. Completion Certificate

A. SQUID Kit / Readout Manufacturing Flow



B. SQUID Kit / Readout Verification Matrix

SQUID Kit / Readout Requirements from System Design and Performance Requirements Spec. [T003]

Section	Title	Text *& Comments*	Method	Verification Plan	RE	ECD	✓
3.2	Accuracy						
3.2.1	Linearity	The readout system meets the following linearity requirements in the presence of trapped flux levels as specified in requirement 1.5:					
3.2.1.1	High Frequency	In the frequency range 100-1000 Hz the harmonic distortion of each of harmonics 2-6 of sinusoids with amplitude corresponding to the trapped flux levels of section 1.5 shall be less than 1e-4.	T(D)	Preliminary test in P0160 SQUID Package Testing and Verification Will be verified during SRE testing	B Muhlfelder	4/98	
3.2.1.2	Low Frequency	For frequencies less than 1 Hz, the harmonic distortion of each harmonic 2-6 of sinusoids with amplitude up to 80 arcsec London moment equivalent shall be less than 1e-4.	T(A)	Preliminary test in P0160 SQUID Package Testing and Verification Will be verified during SRE testing	B Muhlfelder	4/98	

SQUID Kit / Readout Requirements from SIA Specification [PLSE-12 F277277 §3.7.1.7]

Section	Title	Text *& Comments*	Method	Verification Plan	RE	ECD	✓
3.7.1.7	SQUID Kit						
3.7.1.7.1	Prime Item Definition	A SQUID kit consists of two SQUID Packages, each containing one SQUID Sensor, the cables connecting the above components to the cold end Probe connectors, and the SQUID bracket (providing the components for thermal control) and other mounting hardware required to hold the above components in place. There are two SQUID kits in the SIA.					
3.7.1.7.1.1	Prime Item Diagrams						
3.7.1.7.1.1.2	SQUID Package						
3.7.1.7.1.2	Interface Definition						
3.7.1.7.1.2.1	Functional Interfaces	The SQUID kit shall interface through the probe cables to the SQUID forward Electronics for power and operational control (Section 3.7.1.7.1.2.2), for thermal control (Section 3.7.1.7.1.2.4), and to deliver Science Signals (Section 3.7.1.7.1.2.2). It shall interface to each Science Gyroscope through its Superconductive Cable. It shall interface to the structure of the Probe through the SQUID Mounting Bracket.	I	Inspect to drawings 25132-101 (NEG X), and 25132-102 (POS X)	B Muhlfelder	4/98	✓

3.7.1.7.1.2.2	Signal Interfaces	Each SQUID kit shall have the following electrical inputs and outputs. 1. Bracket instrumentation inputs and outputs a. Input drive currents to two GRTs. b. Output signal voltages from two GRTs. c. Two SQUID bracket heater current inputs (one prime & one spare). 2. The following inputs and output to/from each of the two SQUID packages contained in a SQUID kit for connection to the SQUID forward electronics. a. Bias current input. b. Modulation signal input. c. Feedback signal input. d. Voltage signal output. 3. The following input to each of the two SQUID packages contained in a SQUID kit for connection to the gyroscope pickup loop. a. Gyroscope pickup loop flux signal.	I	Inspect to drawings 25132-101 (NEG X), and 25132-102 (POS X)	B Muhlfelder	4/98	✓
3.7.1.7.1.2.3	Electrical Interfaces	The SQUID hardware shall interface to the cold end connectors as shown in LMSC drawing 1C34103	I	Inspect to drawings 25132-101 (NEG X), and 25132-102 (POS X)	D Bardas	5/98	✓
3.7.1.7.1.2.4	Thermal Interfaces	The operating temperature of each SQUID Package shall be maintained as specified in Sections 3.7.1.7.2.1.6.4 and 3.7.1.7.2.1.6.5 by an active thermal control system that uses a GRT and a heater mounted on each SQUID Bracket. The Probe maintains a temperature at the mounting as specified in Section 3.7.2.5. The total power delivered to the SQUID Bracket shall not exceed that specified in 3.7.2.5.7	I	To be verified at payload testing	B Muhlfelder	5/98	
3.7.1.7.1.2.5	Mechanical Interfaces	Each SQUID Bracket shall interface to the Probe Quartz Block Support structure as shown in LMMS drawing 1C34103 .	I	Inspect to drawings 25132-101 (NEG X), and 25132-102 (POS X)	D Bardas	5/98	✓
3.7.1.7.2	Characteristics						
3.7.1.7.2.1	Performance	In the specifications below, the conversion from flux signal in the SQUID input loop to angle equivalent signal assumes a four turn pickup loop, a 130 Hz spin speed, and a 3 minute roll period.					
3.7.1.7.2.1.1	Noise at 5.5 milliHertz	The SQUID sensor noise shall have a magnitude less than 140 marcsec/Hz^0.5 equivalent at 5.5 mHz (single-sided).	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.2	Noise at 130 Hertz	The SQUID sensor noise shall have a magnitude less than 60 marcsec/Hz^0.5 at 130 Hz, where the flux to angle scale factor assumes a rotating trapped dipole flux level equal to the London dipole moment at 130 Hz (this trapped flux level is an assumption only, and does not occur in fact).	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.3	DC Linearity	The V-flux characteristic of the SQUID sensor shall have a linearity better than 1% over a +/- 100 arcsec range of uncompensated error.	S	A qualification unti will be tested in P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓

3.7.1.7.2.1.3.1	Harmonic Distortion	The harmonic distortion of the SQUID operating with flux-locked-loop electronics having a disturbance rejection in the range of 100-200 for signals as specified in 3.7.1.5.2.1.1 shall be less than 10^-4	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.4	SQUID Thermal Characteristics						

3.7.1.7.2.1.4.1	Operating Temperature Range	(a) The nominal operating temperature range is defined in 3.4 of T003, and it is the range over which all other performance requirements must be met. (b) The functional operating temperature range is 2.5 K to 4.2 K, and it is the range over which the only requirement is that the SQUID shall be able to be flux locked.	a) N/A (b) T	Test during acceptance testing of SQUID package. P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.4.2	SQUID Bias Temperature Coefficient	The SQUID shall have a bias temperature coefficient of less than 0.01 flux quanta/K over the temperature range 2.7 K - 3K	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.4.3	SQUID Scale Factor Temperature Coefficient	The SQUID shall have an input current-to-SQUID flux transfer coefficient whose temperature coefficient is less than 3.0x10^-4 in the range 2.7-3K	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	4/98	✓
3.7.1.7.2.1.4.4	Temperature Stability	Deleted. *Requirement intent moved to 3.7.1.7.2.1.16 SQUID Bracket Thermal Characteristics.*					
3.7.1.7.2.1.4.5	Temperature Drift	Deleted. *Requirement intent moved to 3.7.1.7.2.1.16 SQUID Bracket Thermal Characteristics.*					
3.7.1.7.2.1.5	Flux Jumps	There shall be no more than 1 flux jump per day with an amplitude in the range of 1 to 20 arcsec. There shall be no flux jumps with an amplitude exceeding 20 arcsec.	A	Analysis: S0295 On-Orbit Proton Induced Flux Jump Rate, P0160 SQUID Package Testing and Verification	B Muhlfelder	6/98	✓
3.7.1.7.2.1.6	Input Coil Impedance	The SQUID sensor input coil shall have an inductance less than 2.0 microhenry and shall be stable to 5 parts per million per year.	I,A	Inspection of manufacturer data - in hardware folder. Analysis: S0296 Input Coil Feedback Transformer and Input Circuit Stability	B Muhlfelder	6/98	✓
3.7.1.7.2.1.7	Damping of Cable to Package Joint	The decay time of the SQUID Package Input circuit and Cable to package joint shall be less than 1% in 10 min.	T	P0160 SQUID Package Testing and Verification Re-verified at payload test	B Muhlfelder	8/98	▨
3.7.1.7.2.1.8	Feedback Transformer Coupling	The SQUID Feedback Transformer shall have mutual inductance of 0.35 microhenry to 0.45 microhenry and shall be stable to 5 parts per million per year.	A,S	Analysis: S0296 Input Coil Feedback Transformer and Input Circuit Stability Similarity: Qual. unit tested in P0156 Feedback Transformer Verification	B Muhlfelder	5/98	✓
3.7.1.7.2.1.9	Electrical Isolation	The resistance between any two of the following shall be greater than 20 megaohms: bias, modulation, feedback, and signal.	T	P0160 SQUID Package Testing and Verification (Will be re-verified after integration with probe.)	B Muhlfelder	4/98	✓
3.7.1.7.2.1.10	Pickup Loop to SQUID Coupling	The Pickup Loop shall have a coupling to the SQUID better than 40 fA/marcsec. The coupling shall have as a goal a stability of one part in 100,000 per year.	A	S0296 Input Coil Feedback Transformer and Input Circuit Stability. A functional test will be performed at Payload level to verify input configuration	B Muhlfelder	8/98	✓

3.7.1.7.2.1.11	Input Circuit Mutual Inductance Stability	The mutual inductance of input coil to SQUID loop shall be stable to better than 5 parts in 1.0e6 per year.	A	S0296 Input Coil Feedback Transformer and Input Circuit Stability	B Muhlfelder	5/98	✓
3.7.1.7.2.1.12	SQUID Bias Current	The SQUID sensor shall have a bias current between 20 microampere and 60 microampere.	T	P0160 SQUID Package Testing and Verification	B Muhlfelder	8/98	✓
3.7.1.7.2.1.13	Modulation Coil to SQUID Mutual Inductance	The mutual inductance shall be between 1.3 nH and 1.5 nH.	I	Inspection of vendor acceptance data package - in hardware folder	B Muhlfelder		✓
3.7.1.7.2.1.14	Input Filter Capacitance	The capacitance from each contact block to ground shall be between 8 nF and 13 nF.	T	P0161 SQUID Capacitor Kit Assembly	B Muhlfelder		✓
3.7.1.7.2.1.15	SQUID Package AC Magnetic Shielding	The SQUID package shall provide ac shielding such that flux coupling from an applied external magnetic field shall be <= 1.0e-7 flux-quanta/pT (flux is referred to flux in SQUID loop). The applied external field is the free magnetic field applied to the exterior of the SQUID package.	S ~~T~~	P0160 SQUID Package Testing and Verification	B Muhlfelder		✓
3.7.1.7.2.1.16	SQUID Bracket Thermal Characteristics	The thermal design of the SQUID bracket (including GRTs & heaters), SQUID packages, and related electrical cables shall have the capability to meet the requirement in 3.4 of T003.	A	Analysis of thermal design to verify capability to meet requirements (stability requires temperature control electronics). S0297 SQUID Bracket Thermal Characteristics	B Muhlfelder	6/98	✓
3.7.1.7.2.1.16.1	Germanium Resistance Thermometer Characteristics	The GRTs shall have a nominal resistance of 1500 Ω to 2500 Ω at 4.2 K and be calibrated over the temperature range 2.5 K to 20 K with an accuracy of 5 mK over the temperature range from 2.5 K to 10 K.	I	Inspection of calibration data provided by vendor - in hardware folder.	B Muhlfelder	4/99	✓
3.7.1.7.2.1.16.2	Heater Resistance	The heaters shall have a resistance of 1320 ohm +/- 100 ohm at 4.2 K.	T	P0120 Heater Assembling, Chip Resistor	B Muhlfelder	4/98	✓
3.7.1.7.2.1.16.3	Heater Dipole Moment due to Current	The heaters shall have a current induced magnetic dipole moment < 2.0e-9 A-m^2/mA (2.0e-6 emu/mA).	S	Similarity to qual unit test	B Muhlfelder	2/98	✓
3.7.1.7.2.1.16.4	Thermal Delay Time	The time delay from heat applied to the SQUID bracket to the response at the GRT on the bracket shall be less than 1 s. Will be tested in component-level tests for the Science Mission. Will be tested in GTU-2 integrated test.	A	Using design & data from GTU-2	J Lockhart	2/99	✓
3.7.1.7.2.1.17	Flux Slipping	It shall be possible to slip a flux quantum in the SQUID loop with a measurement error of less than 1 part in 10^5.	T	P0160 SQUID Package Testing and Verification.	B Muhlfelder	4/98	✓

C. SQUID Kit / Readout Requirements Verification Documents Checklist

Readout Fabrication & Assembly

Document	Revision Date	Author	Title	Written	In Database	Approval Status	Dwg Ref	Flow Ref	Verif Ref
P0102	2/1/93	M Luo	SQUID Readout Cable Assembly	✓	✓	Approved		✓	
P0110	ECD 2/5/98	M Luo	Output Cable Sub Assembly				✓	✓	
P0116	ECD 4/30/98	D Bardas	Temperature Sensor Assy Procedure				✓	✓	
P0117	ECD 3/25/98	B Muhlfelder	SQUID Bracket Assy Procedure				✓	✓	
P0119	ECD 3/11/98	B Muhlfelder	Clip Kit						
P0120	1/16/98	M Luo	Heater Assembling, Chip Resistor	✓	✓	Approved	✓	✓	
P0152 A	7/15/97	R Shile	SQUID Carrier Substrate Fabrication	✓	✓	Approved	✓	✓	
P0153 A	7/15/97	R Shile	SQUID Carrier Assembly & Process Endurance Testing	✓	✓	Approved	✓	✓	
P0155	11/21/95	M Luo	Output Transformer Fabrication Verification	✓	✓	Approved	✓	✓	
P0157	11/27/95	M Luo	Use of Epoxy Stycast 1266 Procedure	✓	✓	Approved			
P0158	12/13/95	M Luo	Lead Gasket Fabrication	✓	✓	Approved	✓		
P0159	8/8/97	M Luo	SQUID Package Assembly	✓	✓	Approved	✓	✓	
P0161	ECD 3/4/98	M Luo	SQUID Capacitor Kit Assembly			Draft		✓	
P0166	12/13/95	B Muhlfelder	System Integration	✓	✓	Approved		✓	
P0169	ECD 3/11/98	D Hipkins	Thermal Ground Kit			Draft	✓		
P0182	ECD 4/15/98	D Bardas	Heater Assembly, Chip Resistor			Draft	✓		
P0380	ECD 2/18/98	R Shile	Fabrication Procedure for SQUID Feedback Transformers					✓	

Readout Test

Document	Revision Date	Author	Title	Written	In Database	Approval Status	Dwg Ref	Flow Ref	Verif Ref
P0156	11/21/95	R Shile	Feedback Transformer Verification	✓	✓	Approved	✓	✓	✓
P0160 A	1/8/98	B Muhlfelder	SQUID Package Testing and Verification	✓	✓	Approved			✓
P0164	12/13/95	V Chiang/ M Luo	SQUID Die Pre-screening Procedure	✓	✓	Approved		✓	
P0170	1/29/96	B Muhlfelder	Readout Shake Test	✓	✓	Approved		✓	
P0387 A		B Muhlfelder	Pickup Loop Resistance Measurement	✓	✓	Approved		(SG)	

Additional Documents

Document	Date	Author	Title	Written	In Database	Approval Status	Dwg Ref	Flow Ref	Verif Ref
P0057 A	9/29/94	J Lockhart	GP-B Magnetic Control Plan - Science Mission	✓		Approved	✓		
P0059 C	6/19/94	M Keiser	Probe C Contamination Control Plan	✓	✓	Approved	✓		
P0080	9/5/97	J Lockhart	Cryogenic Magnetic Screening Procedure	✓	✓	Approved	✓		
23200-107 E	10/20/94 ECO 1/30/98	B Taller	DRAWING TREE, SQUID KIT, NEG X, SM	✓		Released	✓		
23200-117 C	8/3/96 ECO 1/30/98	B Taller	DRAWING TREE, SQUID KIT, POS X, SM	✓		Released	✓		
25132-101			SQUID KIT, NEG X				✓		✓
25132-102			SQUID KIT, POS X				✓		✓
S0295	ECD 4/30/98	B Muhlfelder	On-Orbit Proton Induced Flux Jump Rate						✓
S0296	ECD 4/30/98	B Muhlfelder	Input Coil Feedback Transformer and Input Circuit Stability						✓
S0297	ECD 4/30/98	B Muhlfelder	SQUID Bracket Thermal Characteristics						✓
S0302	ECD 3/20/98	B Muhlfelder	Results of SQUID Qualification Tests						

D. SQUID Kit / Readout Test Personnel Status Checklist

Test Conductors / Inspectors for the SQUID Kit / Readout Test Facilities

Name	Received Training in Test Operations
Barry Muhlfelder	
Dale Gill	
M Luo	
R Shile	
Marge Bogan	

Qualified Test Directors for SQUID Kit / Readout

Name
Barry Muhlfelder

Procedures Requiring Director Approval

#	Title
P0153 A	SQUID Carrier Assembly & Process Endurance Testing
P0160	SQUID Package Testing and Verification
P0170	Readout Shake Test

E. SQUID Kit / Readout Test Resources Checklists

Instruments requiring standard calibration

Item Description	Seq.#	ID / Serial #	Next Cal. Date	Available
HP 4277A LCZ meter with 16047A test fixture		00008646231	2/9/99	✓
Keithley 580 Micro-ohmmeter		00001289091	10/98	✓
HP 54601A Oscilloscope	29	3227A06648	5/7/98	✓
SR 345 Function Generator	28	26434	2/4/99	✓
BTI model CCS Current Source	31	262490-04	5/22/98	✓
HP8620C Oscillator	33	1604A00504	3/7/98	✓
Fluke 77 Hand Meter		66970626	7/98	✓
Quantum Design 5000 electronics	55	000012259669	7/1/98	✓
SR 560 preamplifier	27	00204	5/22/98	✓
Network Analyzer SR770	30	24185	2/5/99	✓
Keithley 196 Multimeter	34	0575473	5/7/98	✓

Instruments requiring non-standard calibration

Item Description	Seq.#	ID / Serial #	Next Cal. Date	Available
Rev B SQUID electronics	54	0001	7/1/98	✓
Strawberry Tree Data Acquisition System				✓

Facilities

SQUID Acceptance Probe
SQUID Acceptance Dewar
Clean Room 130, 132
Readout Clean Area
Readout EMI Screen Room
Readout General Assembly Area

Test Support Software

Software Product	Environment	Version	Controlled
Strawberry Tree WORKBENCH	PC DOS	V2.1.0	N/A
log1.wbw	WORKBENCH	-	✓
log1.smpump.wbw	WORKBENCH	-	✓
Matlab	Windows 3.1	4.2c.1	N/A
bkcrunch.m	Matlab	-	✓

SQUID Kit / Readout TRR Action Items

#	Action	Assignee	ECD	Status as of 2/27/98
1	Have procedures P0317, P0157, P0160 and P0080 approved	B Muhlfelder & J Lockhart	1/9/98	done
2	Provide ECD dates for procedures & additional doc's not yet approved	B Muhlfelder	1/9/98	done
4	PCB for all proposed spec. changes & corresponding change to Science Gyro Assembly to include deflux heaters	K Hooper	Jan. PCB	done
5	Reword & modify verification of SIA rqmt. 3.7.1.7.2.1.3.1 & 3.7.1.7.2.1.4	B Muhlfelder & J Lockhart	Jan. PCB	done
6	Include pickup loop to SQUID coupling functional test	D Pickett		done
7	Review SQUID bias critical current rqmt.	J Lockhart & B Muhlfelder	Jan. PCB	done
8	Review modulator coil to SQUID mutual inductance verification data generated by Quantum Design	B Muhlfelder	acceptance review	
9	QA & SE to define how to capture verification data	QA (B Taller) & SE (B Schultz/K Hooper)	acceptance review	
10	Release SQUID Kit drawing tree	B Muhlfelder	acceptance review	