





SPIRE BSM

Interface Control Document

Issue 3.2

28th September 2004

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RECORD OF ISSUE

Date	Index	Remarks
10 Jan 2002	0.1	Creation of the document (break out from Design description presented art DDR)
10.Jan.02	1.0	Minor updates and first Issue
07.Feb.02	2.0	Changes to structure mass and inertia properties
24 Nov 03	3.0	Major re-write: Re-structured document to include all interfaces, including electronics in one document
26 Nov 03	3.1	Corrected error in wiring table
28 Sep 04	3.2	Replace pseudo-code with block diagrams, add parameter lists for PFM and FSM

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1. Documents

1.1 *Applicable documents*

	Title	Author	Reference	Date
AD1	Not used			
AD2	BSM ICD drawing	T. Paul	SPIRE-BSM-061-002 Rev 1. Sheets 1 to 4 Included in this document for information.	24 th Nov 2003
AD3	ICD drawing: Structure: BSM	MSSL	Drg No A2/5264/907 issue 9	3 rd July 2003
AD4	N/A			
AD5	SPIRE Harness Definition	D.K.Griffin	SPIRE-RAL-PRJ-000608 v1.1	5 th March 2003
AD6	PCAL ICD		SPIRE-BSM-020-001-004 Rev 1 (note ATC drawing is the definitive one: UCL ref is SPIRE-UCF-PRJ-001150, dated 6 th Feb 2002)	June 2001

1.2 *Reference documents*

	Title	Author	Reference	Date
RD 1	Thermal Configuration Control Document	S.Heys	SPIRE-RAL-PRJ-000560	18.Apr.01

1.3 Glossary

AD	Applicable Document	MAC	Multi-Axis Controller
CEA	Commissariat à l' Energie Atomique	MCE	Mechanism Control Electronics
CDR	Critical Design Review	MGSE	Mechanical Ground Support Equipment
CNES	Centre National des Etudes Spatiales	MPIA	Max Planck Institute for Astronomy
CoG	Center of Gravity	MSSL	Mullard Space Science Laboratory
CQM	Cryogenic Qualification Model	NA	Not Applicable
DDR	Detailed Design Review	OGSE	Optical Ground Support Equipment
DESP	Département des Etudes SPAtiales	PFM	ProtoFlight Model
A		RAL	Rutherford Appleton Laboratory
DM	Development Model	RD	Reference Document
DRCU	Digital Read-out and Control Unit	BSM	Beam Steering Mirror
EGSE	Electrical Ground Support Equipment	UK ATC	United Kingdom Astronomy Technology Centre
Herschel	Far InfraRed Space Telescope	BSM	Beam Steering Mirror
FPU	Focal Plane Unit	SPIRE	Spectral and Photometric Imaging REceiver
FS	Flight Spare model	TBC	To Be Confirmed
LAM	Laboratoire d'Astrophysique de Marseille	TBD	To Be Defined
FTS	Fourier Transform Spectrometer	WE	Warm Electronics

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2. ICD Philosophy

The BSMm interfaces with other subsystems in the SPIRE instrument.
This document defines the interface characteristics of the BSMm for the structure and electronics.

The optical interface (controlled by MSSL) is complex and is not easy to represent in a single ICD. In practice this has been done using 3D files (IGES). In order to have a controlled interface:

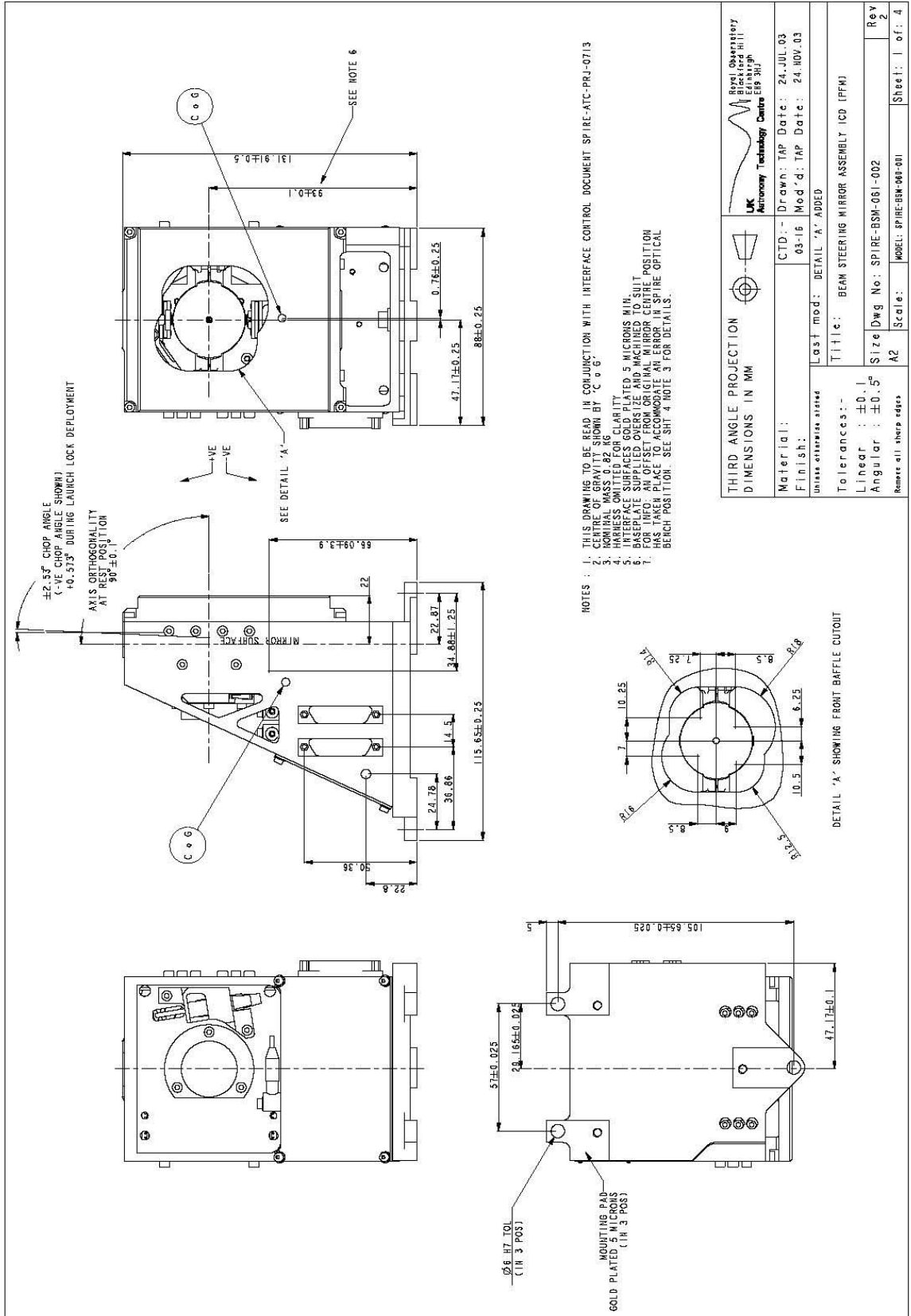
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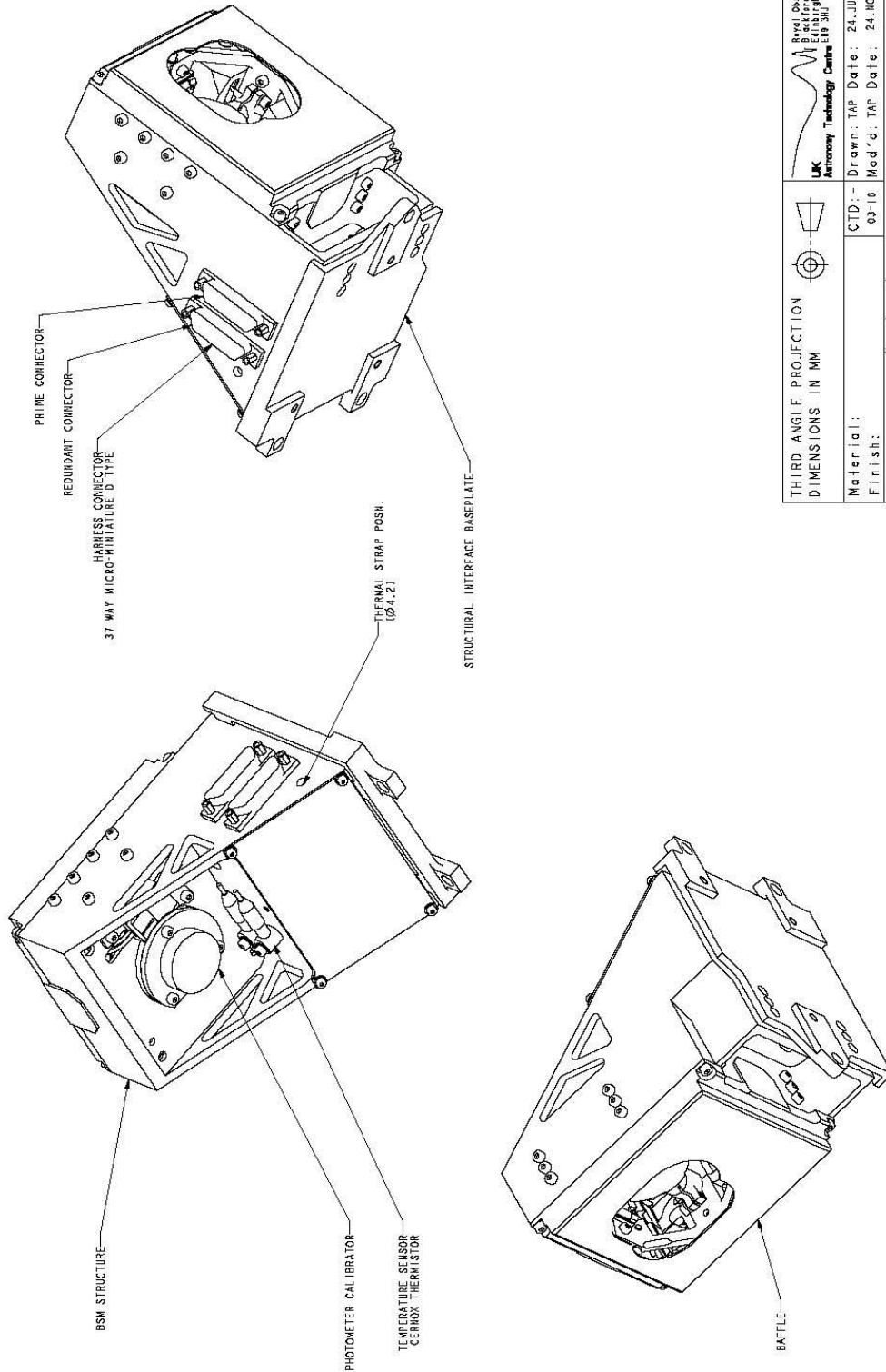
3. Dimensions

These are defined in:

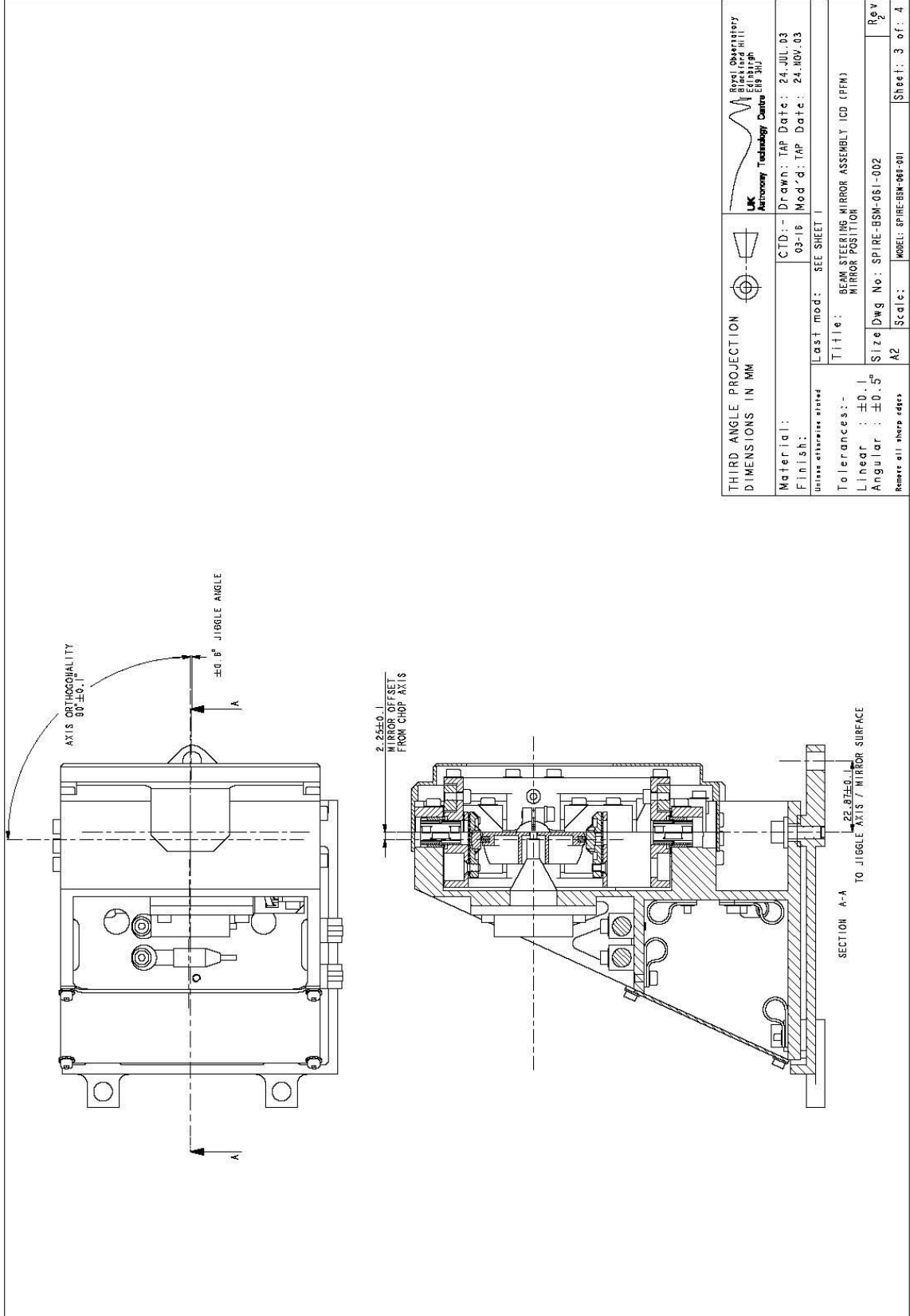
BSMm interface: drawing no SPIRE-BSM-061-002 Rev 2, 24th Nov 2003. Sheets 1 to 4

Shoe interface: drawing no SPIRE-BSM-060-001-002 Rev 1, 28th July 2003

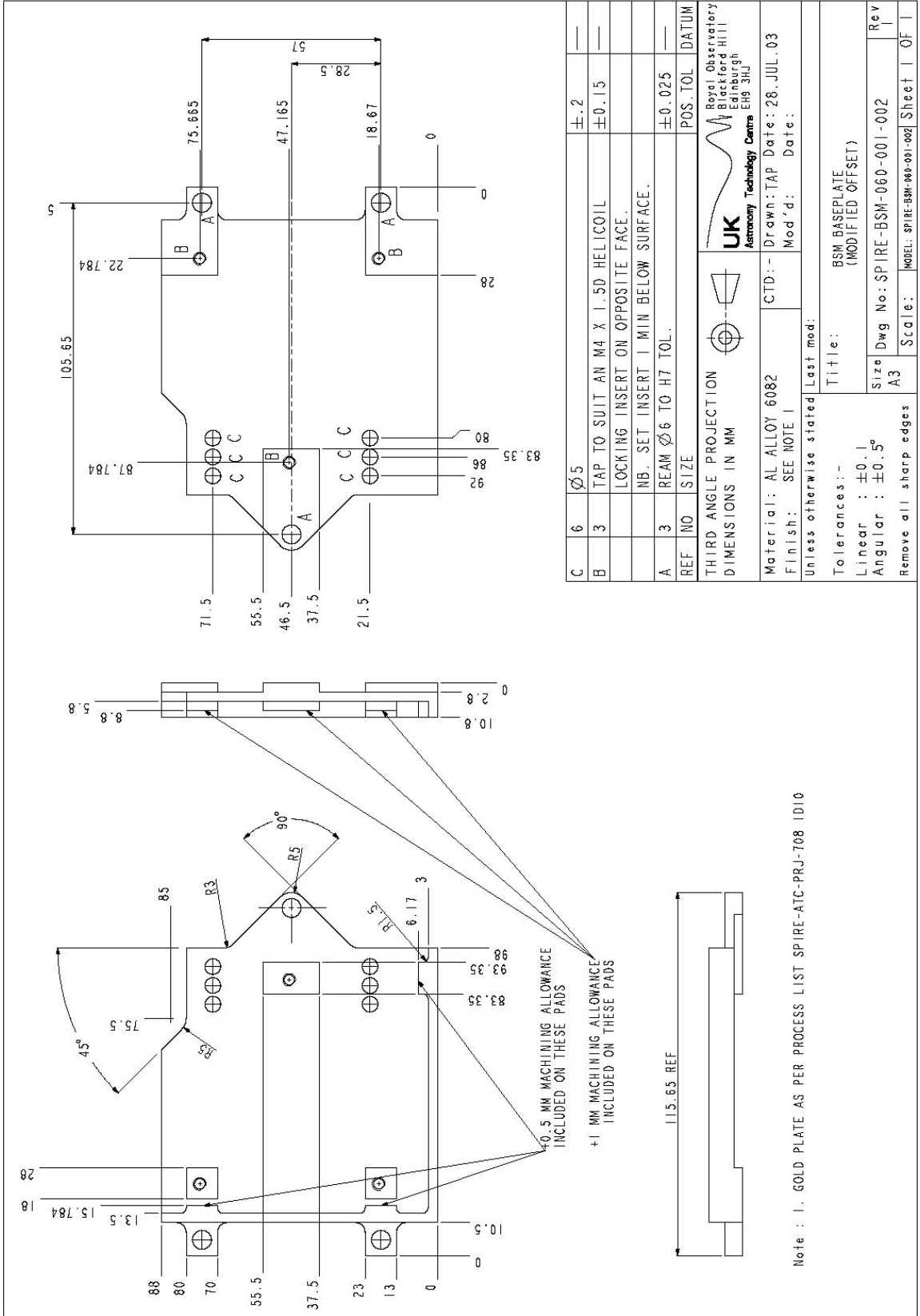




 THIRD ANGLE PROJECTION DIMENSIONS IN MM	CTD: - Drawn: TAP Date: 24.JUL.03 03-18 Mod'd: TAP Date: 24.NOV.03	 UK Astronomy Technology Centre Bristol Observatory Blackford Hill Highfield Bristol, Avon BS10 8XJ
	Last mod: SEE SHEET 1	
Material: Finish: Unless otherwise stated	Title: BEAM STEERING MIRROR ASSEMBLY (CD (PFM)) INFORMATION VIEWS	Size Dwg No: SPIRE-BSM-061-002 Rgv 2
Tolerances:- Linear : ± 0.1 Angular : $\pm 0.5^\circ$	Model: SPIRE-BSM-061-001 Scale: A2 Sheet: 2 of 4	



<p>THIRD ANGLE PROJECTION</p>		<p>UK Astronomy Technology Centre</p> <p>Royal Observatory Blackford Hill Edinburgh EH9 3HJ</p>
<p>DIMENSIONS IN MM</p>	<p>CTD: -</p> <p>03-16</p>	<p>Drawn: TAP Date: 24. JUL. 03</p> <p>Mod'd: TAP Date: 24. NOV. 03</p>
<p>Material:</p> <p>Finish:</p> <p>Unless otherwise stated</p>	<p>LAST MOD: SEE SHEET 1</p>	<p>Title: BEAM STEERING MIRROR ASSEMBLY ICD (PFM)</p> <p>MIRROR POSITION</p>
<p>Tolerances: -</p> <p>Linear : ±0.1</p> <p>Angular : ±0.5°</p> <p>Remove all sharp edges</p>	<p>Size Dwg No: SPIRE-BSM-081-002</p>	<p>Rev</p> <p>AZ Scale: MODEL: SPIRE-BSM-001-001</p> <p>Sheet: 3 of 4</p>



C	6	Ø5	±.2
B	3	TAP TO SUIT AM M4 X 1.5D HELICOIL LOCKING INSERT ON OPPOSITE FACE.	±0.15
		NB. SET INSERT 1 MIN BELOW SURFACE.	
A	3	REAM Ø6 TO H7 TOL.	±0.025
REF	NO	SIZE	POS.TOL
			DATUM

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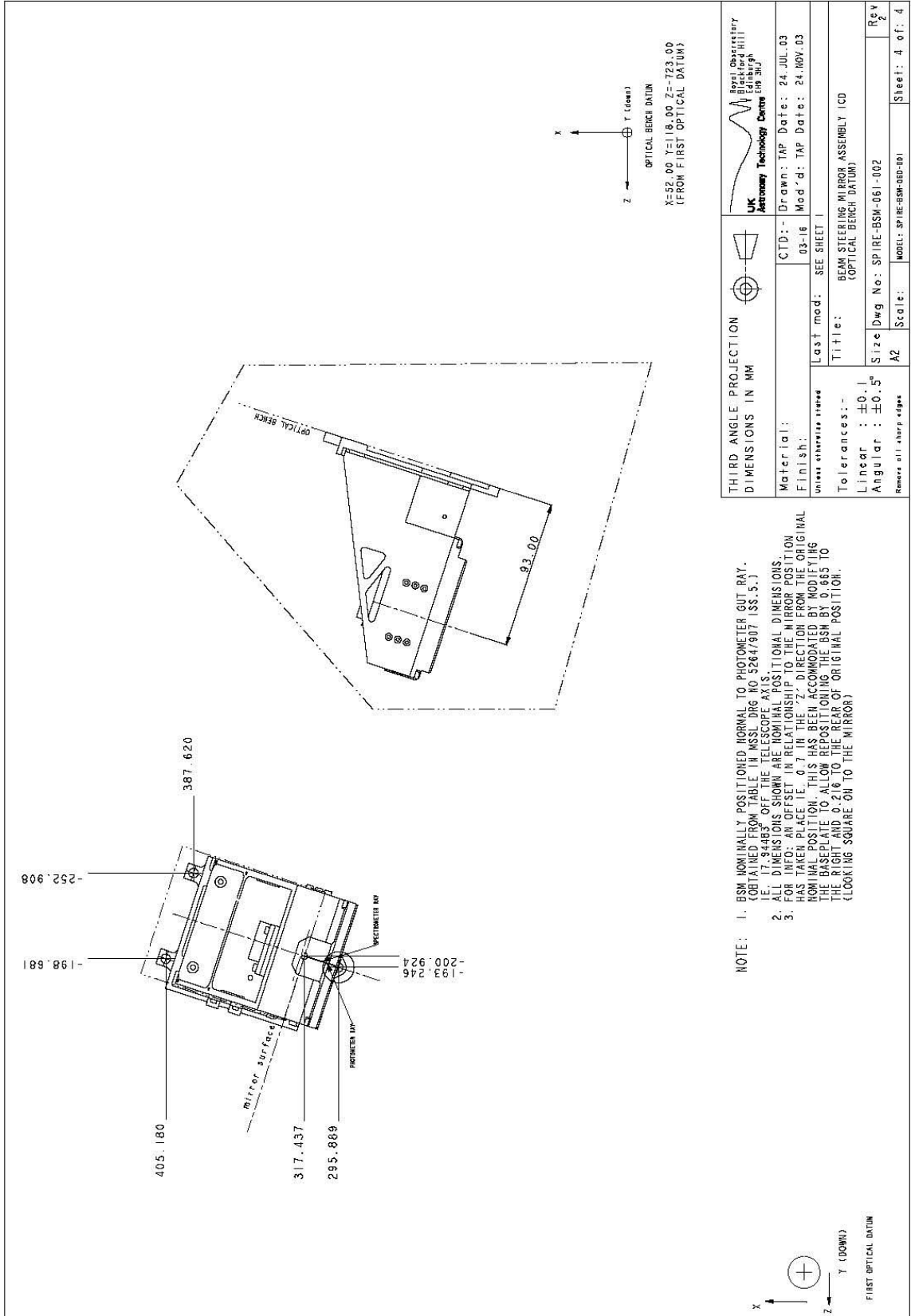
Material: AL ALLOY 6082
Finish: SEE NOTE 1
Unless otherwise stated Last mod: CTD: -
Drawn: TAP Date: 28. JUL. 03
Mod'd: Date:

Title: BSM BASEPLATE
(MODIFIED OFFSET)

Size	Dwg No:	SPIRE-BSM-060-001-002	Rev
A3	Scale:		1

Remove all sharp edges
MODEL: SPIRE-BSM-060-001-002 Sheet 1 OF 1

Note : 1. GOLD PLATE AS PER PROCESS LIST SPIRE-ATC-PRJ-T08 ID10

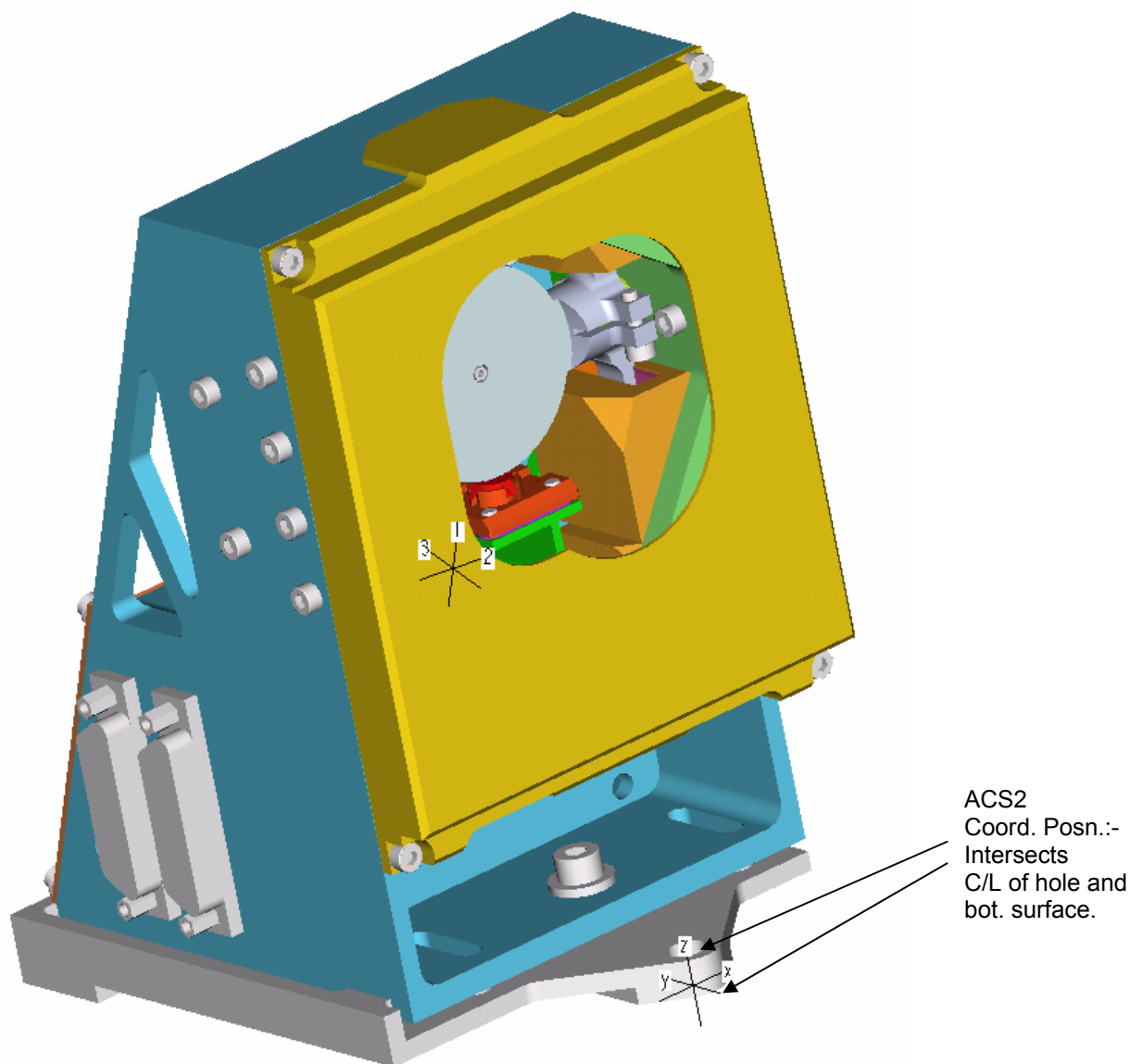


THIRD ANGLE PROJECTION DIMENSIONS IN MM			
Material:	CTD: -	Drawn: TAP	Date: 24 JUL 03
Finish:	03-16	Mod'd: TAP	Date: 24 NOV 03
Unsur: aluminum steered	Last mod: -	SEE SHEET 1	
Tolerances: -	Title: BEAM STEERING MIRROR ASSEMBLY ICD		
Linear: ±0.1	Optical Beam Datum		
Angular: ±0.5°	Size Dwg No: SPIRE-BSM-061-002	Sheet: 4	of: 4
Remove all sharp edges	A2	Scale:	MODEL: SPIRE-BSM-061-001

4. Mass Properties

Mass properties for the assembly are shown below:

NB. ADD ON 50g FOR WIRING TO THE MASS FIGURE SHOWN BELOW



VOLUME = 2.4021643e+05 MM³
SURFACE AREA = 2.3483331e+05 MM²
AVERAGE DENSITY = 3.1293682e-06 KILOGRAM / MM³

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MASS = 7.5172564e-01 KILOGRAM

CENTER OF GRAVITY with respect to ACS2 coordinate frame:

X Y Z 9.3911513e-02 3.9517599e+01 5.8794322e+01 MM

INERTIA with respect to ACS2 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:

lxx lxy lxz 5.3326860e+03 2.4894535e+01 -7.9300866e+01
lyx lyy lyz 2.4894535e+01 4.2932193e+03 -1.4516490e+03
lzx lzy lzz -7.9300866e+01 -1.4516490e+03 2.0907542e+03

INERTIA at CENTER OF GRAVITY with respect to ACS2 coordinate frame: (KILOGRAM * MM^2)

INERTIA TENSOR:

lxx lxy lxz 1.5602162e+03 2.7684307e+01 -7.5150240e+01
lyx lyy lyz 2.7684307e+01 1.6946683e+03 2.9491818e+02
lzx lzy lzz -7.5150240e+01 2.9491818e+02 9.1682229e+02

PRINCIPAL MOMENTS OF INERTIA: (KILOGRAM * MM^2)

I1 I2 I3 8.0911662e+02 1.5687257e+03 1.7938645e+03

ROTATION MATRIX from ACS2 orientation to PRINCIPAL AXES:

0.10598	0.99432	0.01007
-0.31717	0.02420	0.94806
0.94243	-0.10367	0.31794

ROTATION ANGLES from ACS2 orientation to PRINCIPAL AXES (degrees):

angles about x y z -71.461 0.577 -83.916

RADII OF GYRATION with respect to PRINCIPAL AXES:

R1 R2 R3 3.2807707e+01 4.5681865e+01 4.8850063e+01 MM

5. Warm Electronics Interfaces

This section outlines the electrical interface between the Beam Steering Mirror (BSM) assembly and the warm electronics.

The BSM assembly comprises two controllable axes with position sensors and torque motors. It operates at 4 deg. K, remotely (approx. 5m) from the warm electronics, which operates at ~300 deg K.

The BSM electronics has 3 types of analogue sub-circuits per axis :

- a) Position sensor current source
- b) Position sensor output instrumentation amplifier
- c) Motor power amplifier.

The PCAL mechanism and thermometry wiring are also attached to the BSM structure and harness.

All BSM sub-circuits and associated wiring are duplicated to provide full redundancy. In the event of a detected error, the faulty component will be switched out and the backup component used.

5.1 BSM Assembly to Warm Electronics

Each position sensor has 5 connections to a magnetoresistive element designed to form half of a Wheatstone bridge. Two connections supply current and three sense the bridge voltage. The warm electronics has a constant current source and a set of differential receivers for each axis sensor. It also contains voltage-to-current power amplifiers for each axis motor. This ensures that the motor is driven by the correct current independent of its resistance.

To enable back-EMF sensing for the estimation of rate if a position sensor fails, 4-wire connections are used for the motors.

The BSM wiring diagram is shown in Figure 1, and Table 1 lists the wiring requirements for screening and pairing of signals.

Note that the prime and redundant wiring is identical and has separate connectors, so Figure 1 shows the wiring for either the Prime or Redundant circuits. Therefore, the complete BSM wiring will comprise twice the wiring shown in Figure 1.

Dashed lines around an assembly indicate a common assembly to both Prime and Redundant circuits.

The instrument wiring harness wiring for the motor is defined to have a maximum resistance of 20 ohms.

5.2 BSM to Warm Electronics Interface

The position sensor and power amplifier connect to the warm electronics power amplifiers, differential amplifiers and A-D and D-A converters.

5.3 Position Sensor Interface

5.3.1 Current Source

Each position sensor requires a constant current from a suitable precision source, typically Analog Devices AD584.

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Value	1.0 mA per sensor
Tolerance on value	+/- 5%
Variation over 4 hours	< +/- 80 ppm (assumes temperature variation of 1 deg/hr in electronics)
Noise	< 1.0 μ A rms, 0 to 25 Hz (nominal)
Load Voltage capability	> 1V

5.3.2 Position sensor amplifier

The position sensors require a high-impedance differential amplifier, typically Analog Devices AD524.

Noise < 1 μ V rms (input)

5.3.3 Motor Interface

Each axis motor is driven by a voltage-to-current amplifier.

Transfer function gain	5 mA/V +/- 5%
Current sensing resistor	10 Ω
Load impedance	< 500 Ω @20 deg.C
	< 1 Ω @ 4 deg.K
Load Current	50 mA peak
-3 dB bandwidth	>= 5 kHz

5.4 Electronics to SMEC Processor Interface

5.4.1 A-D and D-A Signals

Sample Rate

The sample rate for chop and jiggle position sensor A-D and motor drive D-A interfaces is 360 μ S.

5.4.2 Chop and Jiggle A-D

Resolution	16 bits minimum
Full Scale i/p	+/- 10V
Conversion time	To suit loop sample time

5.4.3 Chop and Jiggle D-A

Resolution	8 bits minimum
Full Scale o/p	+/- 10V
Conversion time	To suit loop sample time

5.5 PCAL TO WARM ELECTRONICS INTERFACE

Refer to the Design Description Document, Annex B for the PCAL INTERFACE.

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To minimise noise coupling, the PCAL wiring is kept physically separate from the BSM wiring, and the connector spare pins are allocated between these groups also.

To minimise BSM internal wire bundle sizes, most of the harness screens terminate (open-circuit) at the 37-way connector, with the exception of the sensor screens.

5.6 ISOLATION

The BSM electronics and wiring will have a minimum resistance to chassis of 10 Mohm at 100V DC.

5.7 CONNECTOR TYPE

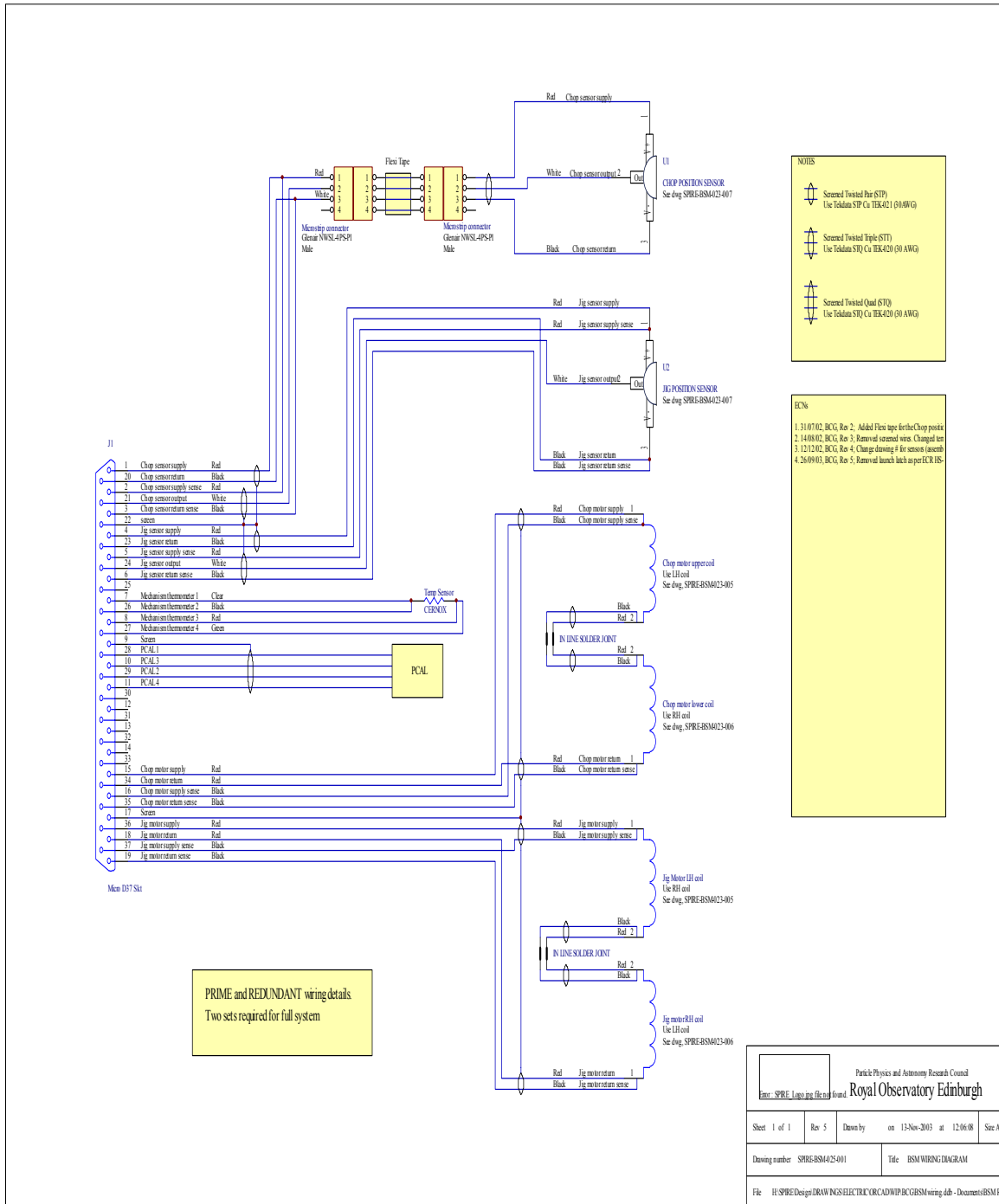
The Connectors used will be 37-way MDM micro-D types with sockets, one connector for prime wiring and one for redundant wiring.

Table 1 BSM Prime and Redundant Wiring

STP = Screened Twisted Pair
STT = Screened Twisted Triple
STQ = Screened Twisted Quad

Pin	Title	Max Voltage	Max Current	Wire Type /Comment
15	Chop motor supply	+/- 15 V	40 mA	STP(15,34)
34	Chop motor return	0V	40 mA	STP(15,34)
16	Chop motor supply sense	+/- 15 V	10 µA	STP(16,35)
35	Chop motor return sense	0V	10 µA	STP(16,35)
36	Jiggle motor supply	+/- 15 V	40 mA	STP(36,18)
18	Jiggle motor return	0V	40 mA	STP(36,18)
37	Jiggle motor supply sense	+/- 15 V	10 µA	STP(36,19)
19	Jiggle motor return sense	0V	10 µA	STP(37,19)
17	Motor Screens			screens (commoned)
1	Chop sensor supply	0.4 V	1 mA	STP(1,20)
20	Chop sensor return	0V	1 mA	STP(1,20)
2	Chop sensor supply sense	0.4 V	10 µA	STT(2,3,21)
21	Chop sensor o/p	0V	10 µA	STT(2,3,21)
3	Chop sensor return sense	0.4V	10 µA	STT(2,3,21)
4	Jiggle sensor supply	0.4 V	1 mA	STP(4,23)
23	Jiggle sensor return	0V	1 mA	STP(4,23)
5	Jiggle sensor supply sense	0.4 V	10 µA	STT(5,6,24)
24	Jiggle sensor o/p	0V	10 µA	STT(5,6,24)
6	Jiggle sensor return sense	0.4V	10 µA	STT(5,6,24)
22	Sensor screens			screens (commoned)
7	Mechanism Thermometer 1	0V	2.5 nA	Single
26	Mechanism Thermometer 2	0V	2.5 nA	Single
8	Mechanism Thermometer 3	0V	2.5 nA	Single
27	Mechanism Thermometer 4	0V	2.5 nA	Single
25	Spare			
13	Spare			
32	Spare			
14	Spare			
33	Spare			
12	Spare			
30	Spare			
31	Spare			
28	PCAL 1	TBD	TBD	STQ(28,29,10,11)
29	PCAL 2	TBD	TBD	STQ(28,29,10,11)
10	PCAL 3	TBD	TBD	STQ(28,29,10,11)
11	PCAL 4	TBD	TBD	STQ(28,29,10,11)
9	PCAL Screen			STQ screen

Figure 1 The BSM Prime (and Redundant) Wiring.



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6. SOFTWARE REQUIREMENTS

CHANGE RECORD (SOFTWARE)

1.0	First Issue
1.1	Remove 'Control Structure Command Requirements' section – include necessary flags, etc in control parameters table. Correct observer coefficients used in code for variable 'cha_h'. Add note to indicate that any suitable code for sinusoidal shaping would be OK (maybe some easier assembler method ?)
1.2	Fix some variable name errors. Correct integral gain term in expression for 'ch_pe'. Include 'Kt' in control parameter list.
1.3	Add the Jiggle code – copy of Chop code with name changes
1.4	Incorporated into the BSM Design Description annex G
2.0	Revise control code to use PID with Feed-forward, replace sinusoidal trajectory with slew-rate limit, add sensor linearisation, change sample time.
2.1	Change sample time. Revise Jiggle cross-coupling to include Chop acceleration.
2.2	Revise cross-coupling
2.3	Replace pseudo-code with block diagrams and add parameter lists

6.1 INTRODUCTION

This document describes the BSM software operation as Matlab Simulink block diagrams – the actual assembly code can be easily derived from these block diagrams.

The BSM is controlled via software running on a DSP. The BSM software controls the position of the two BSM axes in response to external commands from the host software. Each axis can move independently.

The movement with respect to time is profiled via stored parameters to give a minimum energy, minimum noise position change, particularly for step commands.

In general the movements are repetitions of the same position/time profile.

In addition, in the event of measured behaviour resulting in a fault diagnosis, some system backup procedures are available.

Diagnosis of excessive position errors and analysis of recorded transient behaviour during operation can result in modifications to the control system by uploading different parameters into electrically-eraseable memory.

NOTE : As each BSM has specific parameters, the indicated parameters in this document are only nominal values, and the specific values for each BSM are given in the calibration documents in the appendices.

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6.2 WAVEFORM COMMAND REQUIREMENTS

The BSM is slaved to the input demands at all times, so to perform a repetitive chop pattern the host processor has to issue a succession of position demands at the relevant times.

For example, to perform a 2 Hz chop between BSM positions p1 and p2, the following chop axis demand sequence and timing is required.

The command update time (Tu) must always be larger than the loop sample time (Ts). The resultant mirror movements will be limited by the bandwidth of the servo loops.

Time	Demand
0.0 → (0.5-Tu)	p1
0.5 → (1.0-Tu)	p2
1.0 → (1.5-Tu)	p1
1.5 → (2.0-Tu)	p2
2.0 → (2.5-Tu)	p1
etc.	

A step command waveform is assumed. Other waveforms, such as triangular, can be approximated by a succession of incremental step demands, however the resolution will always be dependant on the update rate.

Table 2 Waveform Commands

No.	Parameter	Value or Range
1	Chop Position	+/- 2.53 degrees (BSM axes)
2	Jiggle Position	+/- 0.573 degrees (BSM axes)

6.3 CONTROL SYSTEM DIAGNOSTIC DATA

Some control system data may be used by the host system to determine detected failure correction activities.

Table 3 Control System Diagnostic Data

No.	Parameter	Range
1	Chop position	+/- 10V = +/-2.6deg (CAL)
2	Chop motor current	+/- 10V = +/-50mA
3	Jiggle position	+/- 10V = +/-0.6 deg (CAL)
4	Jiggle motor current	+/- 10V = +/-50mA
5	Chop position error	+/- 10V = +/-2.6deg (CAL)
6	Jiggle position error	+/- 10V = +/-0.6deg (CAL)

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6.4 CONTROL ALGORITHMS

Both axes have position control loops, running at a fixed sample time of 360 μ S, a sample rate of 2.778 kHz.

6.4.1 Description

The algorithm comprises three main parts – the control loop itself, an input slew rate limiter and a sensor linearisation look-up table. On reception of a new position, the transition will be slew-rate limited, and the rate-limited demand applied to the control loop.

The control loop processes the position demand using a digital filter to produce a torque demand to the mirror motor. The algorithm implements a PID servo with position feed-forward.

The slew-rate limiter reduces the rate of change of the Chop demand to a fixed value to reduce power dissipation during step changes.

The control algorithms are illustrated by the Matlab-Simulink block diagram in the following Appendices for the PFM and FSM BSM's. This is based on the simulink model used during dSPACE testing of the BSM.

7. PFM BEAM STEERING MIRROR PARAMETER LIST

This section lists the calibration and control design parameters for the PFM Beam-Steering Mirror.

Refer to Figures 1,2,3 and 4 for the control parameter block diagram functions.

7.1 PFM CHOP CONTROL PARAMETERS

PRIME

Parameter	Description	Value
c_pid_p	PID proportional gain	2.8
c_pid_i	PID integral gain	230
c_intref	integrator reference	6.5
c_pid_ilim	integrator limit	0.006
c_ff_g	feed-forward gain	0.1
c_ff_d	feed-forward diff gain	0
c_rfbkg	rate feedback gain	0.014
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
i/p slew limit		1000deg/s
ffxtalk	cross-coupling	0.0727

REDUNDANT

Parameter	Description	Value
c_pid_p	PID proportional gain	3.082
c_pid_i	PID integral gain	220
c_intref	integrator reference	20
c_pid_ilim	integrator limit	0.006
c_ff_g	feed-forward gain	0.05
c_ff_d	feed-forward diff gain	0
c_rfbkg	rate feedback gain	0.012
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
i/p slew limit		750deg/s
ffxtalk	cross-coupling	0.094

7.2 PFM CHOP DEGRADED MODE

PRIME

Parameter	Description	Value
c_ff_g	feed-forward gain	1.07
c_curr_gain	current gain	0
cmot_r	voltage gain	6
cmot_l	inductive gain	-0.003
c_nps_rsf	bemf gain	0.1
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491

REDUNDANT

Parameter	Description	Value
c_ff_g	feed-forward gain	0.975
c_curr_gain	current gain	0
cmot_r	voltage gain	6
cmot_l	inductive gain	0
c_nps_rsf	bemf gain	0.1
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491

7.3 PFM CHOP SENSOR CALIBRATION

Angles are with respect to axis zero, 'censor' is digitised sensor voltage after preamplification.
Axis zero is defined at normal to PCAL calibration mirror.
The Chop axis demand in degrees is divided by the linear scale factor.

7.3.1 PRIME

ELECTRICAL OFFSET ADDED TO 'censor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.1635

LINEAR SCALE FACTOR = 3.082

SENSOR_OP = 50*(V(21,2)-V(3,21))+10Voffset, where

V(21,2) = voltage at BSM pin 21 with respect to voltage at BSM pin 2.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following Matlab file creates the lookup table for use in the Simulink model, where the lookup table input vector is 'chop_in', and the table output is 'chop_out'.

```
% SPIRE PFM PRIME Sensor scaling vectors      B.Stobie UKATC 27/04/04
% -----
%
% NOTE 'raw' vectors are by cut-and-paste from spreadsheets
% 'pfm_sensor_scaling_PRIME_230404' and
% 'pfm_sensor_scaling_REDUNDANT_230404'
%
chop_outx = [1.01968 1.00031 0.96637 0.92559 0.87984 0.82990 0.77789 0.72383 0.66906
0.61409 0.55997 0.50751 0.45413 0.40124 0.34725 0.29248 0.23660 0.17969 0.12113 0.06132
0.00000 -0.05824 -0.11415 -0.16817
-0.22028 -0.27136 -0.31999 -0.36766 -0.41393 -0.45913 -0.50323 -0.54651 -0.58914 -0.63055 -
0.67172 -0.71144 -0.74917 -0.78441 -0.81598 -0.84038 -0.85420];
%
% Simulink Lookup Table expects vectors in the form [-1:1]
% instead of [1:-1];
chop_out = fliplr(chop_outx);
%
chop_inx = [0.83063 0.82134 0.80436 0.78237 0.75634 0.72680 0.69414 0.65864 0.62049
0.57989 0.53696 0.49182 0.44459 0.39534 0.34416 0.29112 0.23628 0.17970 0.12143 0.06151
0.00000 -0.05839 -0.11526 -0.17057
-0.22428 -0.27634 -0.32668 -0.37526 -0.42201 -0.46685 -0.50969 -0.55044 -0.58899 -0.62519 -
0.65889 -0.68989 -0.71793 -0.74264 -0.76352 -0.77963 -0.78845];
chop_in = fliplr(chop_inx);
%
```

7.3.2 REDUNDANT

ELECTRICAL OFFSET ADDED TO 'censor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.2315

LINEAR SCALE FACTOR = 3.082

SENSOR_OP = 50*(V(21,2)-V(3,21))+10Voffset, where

V(21,2) = voltage at BSM pin 21 with respect to voltage at BSM pin 2.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following table is used to scale any demands into the BSM, and the inverse table needs to be used to translate amplified sensor voltages into actual angles (see block diagram in Appendix 1)

```
% SPIRE PFM REDUNDANT Sensor scaling vectors      B.Stobie UKATC 26/03/04
% -----
% for matlab-simulink Lookup-Table block.
% NOTE 'raw' vectors are by cut-and-paste from spreadsheets
% 'pfm_sensor_scaling_PRIME_230404' and
% 'pfm_sensor_scaling_REDUNDANT_230404'
%
% REDUNDANT
chop_outx = [1.01064 0.98361 0.94100 0.89337 0.84279 0.78993 0.73532 0.67925 0.62289
0.56712 0.51260 0.45949 0.40789 0.35715 0.30702 0.25702 0.20685 0.15617 0.10503 0.05302
0.00000 -0.06412 -0.12480 -0.18346
-0.23995 -0.29466 -0.34732 -0.39846 -0.44781 -0.49544 -0.54158 -0.58577 -0.62935 -0.67137 -
0.71193 -0.75099 -0.78798 -0.82215 -0.85213 -0.87608 -0.88961];
%
% Simulink Lookup Table expects vectors in the form [-1:1]
% instead of [1:-1];
chop_out = fliplr(chop_outx);
%
chop_inx = [0.77872 0.77001 0.75409 0.73348 0.70906 0.68138 0.65076 0.61747 0.58171
0.54365 0.50340 0.46108 0.41680 0.37063 0.32265 0.27292 0.22151 0.16847 0.11384 0.05767
0.00000 -0.06968 -0.13755 -0.20356
-0.26766 -0.32978 -0.38987 -0.44785 -0.50363 -0.55714 -0.60827 -0.65690 -0.70290 -0.74611 -
0.78633 -0.82333 -0.85679 -0.88628 -0.91119 -0.93043 -0.94095];
chop_in = fliplr(chop_inx);
%
```

7.4 PFM CHOP MOTOR RESISTANCE

PRIME R_{motor} = 0.822 ohm

REDUNDANT R_{motor} = 0.835 ohm

7.5 PFM CHOP POWER DISSIPATION

Average Power Dissipation = Chop transient power + I²*R + Sensor Power

From PFM test data, Chop transient power can be estimated at 5mW average for 25mS. Therefore at 2 Hz the average transient power is 5.0*25/250 = 0.5mW.

Chop sensor power = 0.46mW.

I²*R can be obtained from data in spreadsheet "pfm_power.xls" (Appendix A), where I = 21 mA/deg

e.g. if the PRIME Chop axis continuously moves between -1.25 and 1.25 deg., the average power is

$$\begin{aligned}
& 0.0005 + (1.25 \cdot 0.021)^2 \cdot 0.822 + 0.00046 \text{ W} \\
& = 0.0005 + 0.00057 + 0.00046 \text{ W} \\
& = 1.53 \text{ mW}.
\end{aligned}$$

For more complex sets of movements, a spreadsheet can be used to calculate the average dissipation based the time sequence of movements, and assuming a linear relationship between transient power and chopped angle.

7.6 JIGGLE CONTROL PARAMETERS

PRIME

Parameter	Description	Value
j_pid_p	PID proportional gain	1.1
j_pid_i	PID integral gain	100
j_intref	integrator reference	2.8
j_pid_ilim	integrator limit	0.01
j_ff_g	feed-forward gain	1.7
j_ff_d	feed-forward diff gain	0
j_rfbkg	rate feedback gain	0.047
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
jsign	invert motor drive	-1

REDUNDANT

Parameter	Description	Value
j_pid_p	PID proportional gain	1.1
j_pid_i	PID integral gain	100
j_intref	integrator reference	2.8
j_pid_ilim	integrator limit	0.01
j_ff_g	feed-forward gain	1.5
j_ff_d	feed-forward diff gain	0
j_rfbkg	rate feedback gain	0.044
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
jsign	invert motor drive	1

7.7 PFM JIGGLE DEGRADED MODE

PRIME

Parameter	Description	Value
j_ff_g	feed-forward gain	3.63
j_curr_gain	current gain	0
jmot_r	voltage gain	15
jmot_l	inductive gain	-0.014
j_nps_rsf	bemf gain	-0.28
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491
jsign	invert motor drive	-1

REDUNDANT

Parameter	Description	Value
j_ff_g	feed-forward gain	3.41
j_curr_gain	current gain	0
jmot_r	voltage gain	15
jmot_l	inductive gain	-0.014
j_nps_rsf	bemf gain	0.28
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491
jsign	invert motor drive	1

7.8 PFM JIGGLE SENSOR CALIBRATION

Angles are with respect to axis zero, 'jsensor' is digitised sensor voltage after preamplification. Axis zero is defined at normal to PCAL calibration mirror. The Jiggle axis demand in degrees is divided by the linear scale factor.

7.8.1 PRIME

ELECTRICAL OFFSET ADDED TO 'jsensor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.1187

LINEAR SCALE FACTOR = 1.954

SENSOR_OP = 50(V(5,24)-V(24,6))+10Voffset, where

V(5,24) = voltage at BSM pin 5 with respect to voltage at BSM pin 24.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following table is used to scale any demands into the BSM, and the inverse table needs to be used to translate amplified sensor voltages into actual angles (see block diagram in Appendix 1)

% SPIRE PFM PRIME Sensor scaling vectors B.Stobie UKATC 27/04/04

% -----

% NOTE 'raw' vectors are by cut-and-paste from spreadsheets

% 'pfm_sensor_scaling_PRIME_230404' and

% 'pfm_sensor_scaling_REDUNDANT_230404'

% Jiggle sensor feedback is inverted between prime and redundant, so

% inversion is used in prime, and

% 'fliplr' is used in redundant.

%

% PRIME

jig_outx = [0.36869 0.35062 0.31864 0.27815 0.23158 0.18020 0.12446 0.06433 0.00000 -
0.04780 -0.09330 -0.13501 -0.17309 -0.20748 -0.23721

-0.26024 -0.27324];

jig_out = -jig_outx;

%

jig_inx = [0.37359 0.35708 0.32689 0.28780 0.24151 0.18900 0.13094 0.06781 0.00000 -
0.05016 -0.09686 -0.13981 -0.17865 -0.21289 -0.24181

-0.26414 -0.27636];

jig_in = -jig_inx;

%

7.8.2 REDUNDANT

ELECTRICAL OFFSET ADDED TO 'jensor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = 0.1023

LINEAR SCALE FACTOR = 1.954

SENSOR_OP = 50(V(5,24)-V(24,6))+10Voffset, where

V(5,24) = voltage at BSM pin 5 with respect to voltage at BSM pin 24.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

% SPIRE PFM REDUNDANT Sensor scaling vectors B.Stobie UKATC 26/03/04

% -----

% for matlab-simulink Lookup-Table block.

% NOTE 'raw' vectors are by cut-and-paste from spreadsheets

% 'pfm_sensor_scaling_PRIME_230404' and

% 'pfm_sensor_scaling_REDUNDANT_230404'

% - however Jiggle sensor feedback is inverted between prime and

% redundant, so inversion is used in prime, and

% 'fliplr' is used in redundant.

%

%

% REDUNDANT

```
jig_outx = [0.36516 0.34837 0.31818 0.27959 0.23440 0.18327 0.12733 0.06638 0.00000 -
0.04596 -0.08828 -0.12856 -0.16613 -0.20052 -0.23046
-0.25461 -0.26802];
```

```
jig_out = fliplr(jig_outx);
```

```
jig_inx = [0.40942 0.39132 0.35824 0.31540 0.26467 0.20712 0.14349 0.07431 0.00000 -
0.04923 -0.09506 -0.13722 -0.17534 -0.20895 -0.23733
-0.25925 -0.27124];
```

```
jig_in = fliplr(jig_inx);
```

%

7.9 PFM JIGGLE MOTOR RESISTANCE

PRIME $R_{\text{motor}} = 0.799 \text{ ohm}$

REDUNDANT $R_{\text{motor}} = 0.828 \text{ ohm}$

7.10 PFM JIGGLE POWER DISSIPATION

Average Power Dissipation = Jiggle transient power + I^2R + Sensor Power

From PFM test data, Jiggle transient power can be estimated as 2.0mW for 100mS. Therefore at 0.5Hz the average transient power is $2.0 \times (0.1/1) = 0.2\text{mW}$
Jiggle sensor power = 0.46mW.

I^2R can be obtained from data in spreadsheet "pfm_power.xls" (Appendix A), where $I = 97 \text{ mA/deg}$

e.g. if the PRIME Jiggle axis continuously moves between -0.28 and 0.28 deg., the average power is

$$0.0002 + (0.28 \times 0.097)^2 \times 0.822 + 0.00046 \text{ W}$$

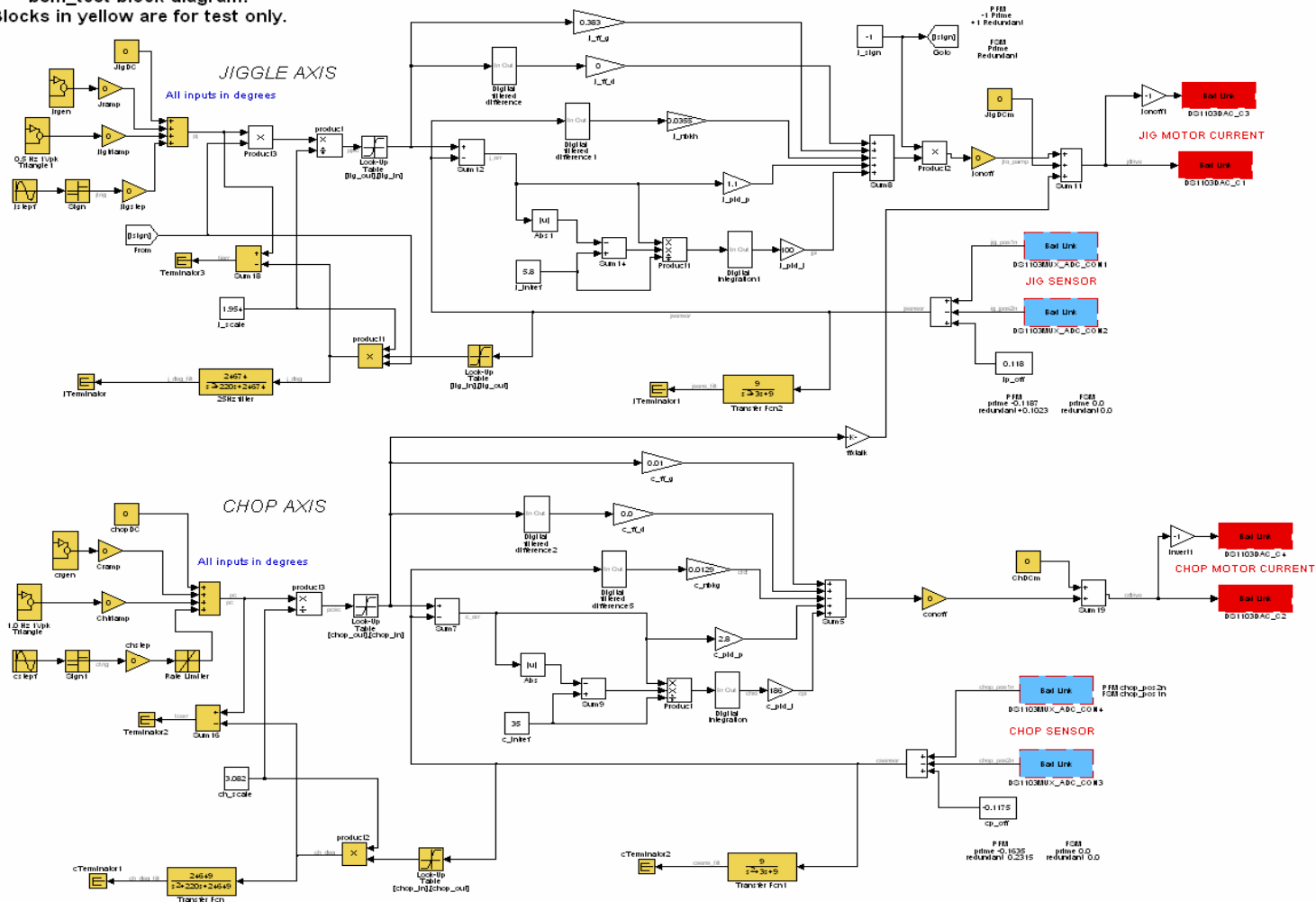
$$= 0.0002 + 0.00061 + 0.00046 \text{ W}$$

$$= 1.27\text{mW.}$$

For more complex sets of movements, a spreadsheet can be used to calculate the average dissipation based the time sequence of movements, and assuming a linear relationship between transient power and Jiggled angle

Figure 2 **Parameter Block Diagram**

bsm_test block diagram:
Blocks in yellow are for test only.



bsm_test_degraded

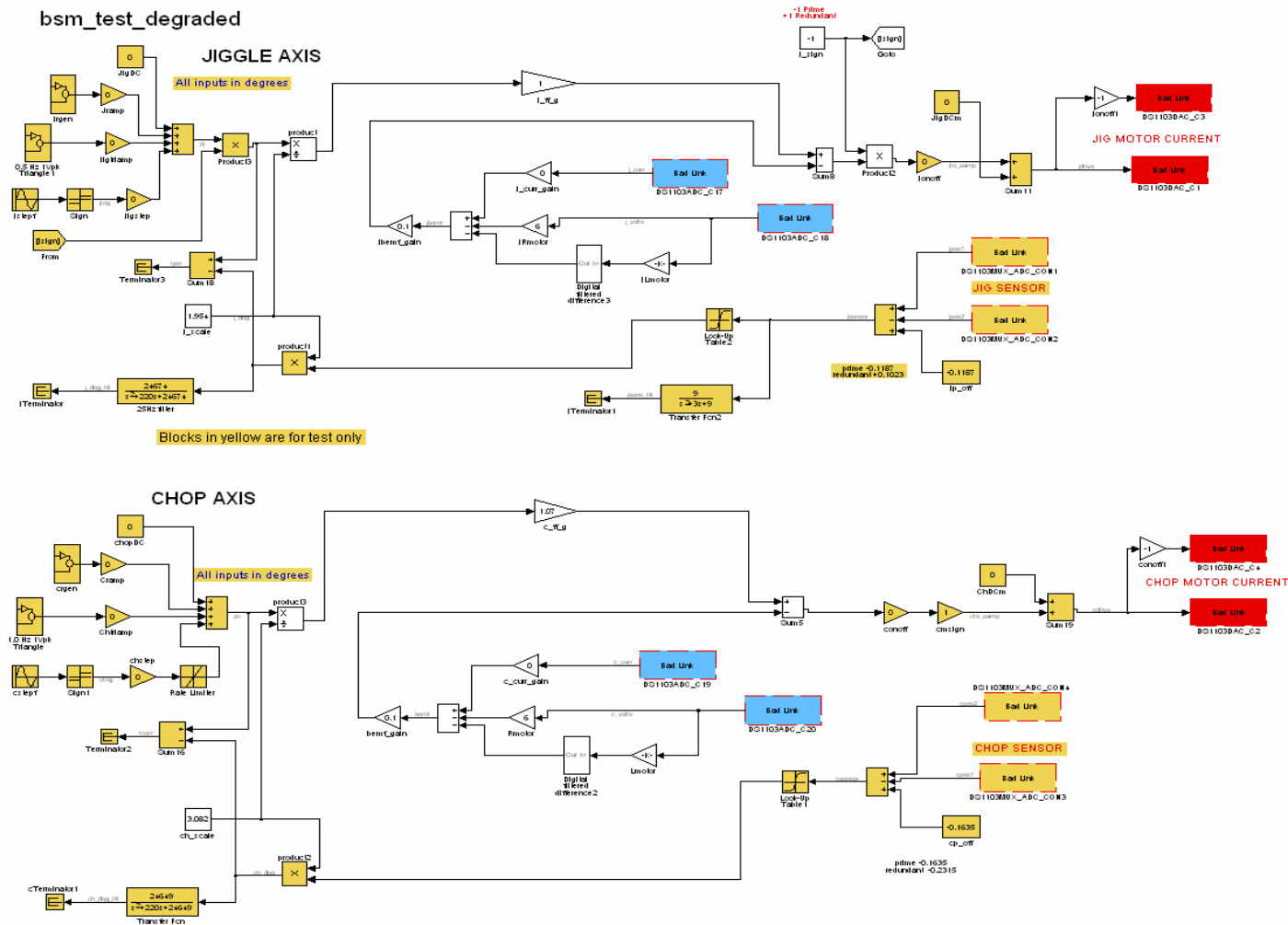


Figure 3 Block Diagram for Degraded Mode

Figure 4 Digital Filtered Difference Block

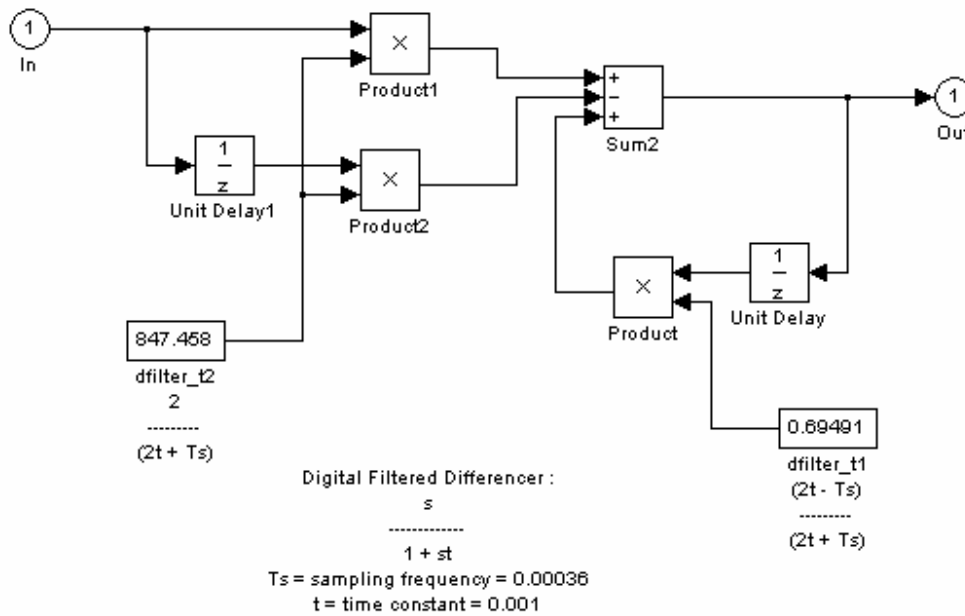
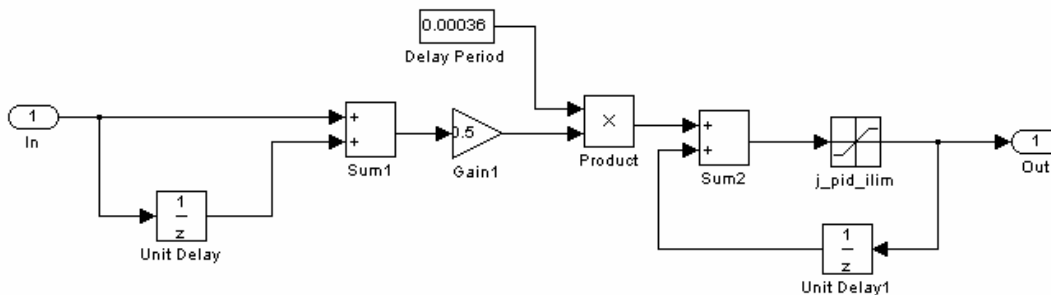


Figure 5 Digital Integration Block



FSM BEAM STEERING MIRROR PARAMETER LIST

This section lists the calibration and control design parameters for the FSM Beam-Steering Mirror.

Refer to Figures 1 and 2 for the control parameter block diagram functions.

7.11 FSM CHOP CONTROL PARAMETERS

PRIME

Parameter	Description	Value
c_pid_p	PID proportional gain	2.8
c_pid_i	PID integral gain	168
c_intref	integrator reference	50
c_pid_ilim	integrator limit	0.006
c_ff_g	feed-forward gain	0.0
c_ff_g_L	large demand F-F gain	0.059
c_ff_ul	F-F gain upper limit	0.5106
c_ff_ll	F-F gain lower limit	-0.6329
c_ff_d	feed-forward diff gain	0
cp_rfbkg	pos rate feedback gain	0.0143
cn_rfbkg	neg rate feedback gain	0.0139
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
i/p slew limit		1000deg/s
ffxtalk	cross-coupling	0.042

REDUNDANT

Parameter	Description	Value
c_pid_p	PID proportional gain	3.0
c_pid_i	PID integral gain	176
c_intref	integrator reference	45
c_pid_ilim	integrator limit	0.006
c_ff_g	feed-forward gain	0.0
c_ff_g_L	large demand F-F gain	0.06
c_ff_ul	F-F gain upper limit	0.5154
c_ff_ll	F-F gain lower limit	-0.6794
c_ff_d	feed-forward diff gain	0

cp_rfbkg	pos rate feedback gain	0.0147
cn_rfbkg	neg rate feedback gain	0.0145
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
i/p slew limit		750deg/s
ffxtalk	cross-coupling	0.042

7.12 FSM CHOP DEGRADED MODE

PRIME

Parameter	Description	Value
c_ff_g	feed-forward gain	0.66
c_curr_gain	current gain	0
cmot_r	voltage gain	6
cmot_l	inductive gain	-0.003
c_nps_rsf	bemf gain	0.1
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491

REDUNDANT

Parameter	Description	Value
c_ff_g	feed-forward gain	0.698
c_curr_gain	current gain	0
cmot_r	voltage gain	6
cmot_l	inductive gain	0
c_nps_rsf	bemf gain	0.1
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491

7.13 FSM CHOP SENSOR CALIBRATION

Angles are with respect to axis zero, 'censor' is digitised sensor voltage after preamplification. Axis zero is defined at normal to PCAL calibration mirror. The Chop axis demand in degrees is divided by the linear scale factor.

7.13.1 PRIME

ELECTRICAL OFFSET ADDED TO 'censor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.1175

LINEAR SCALE FACTOR = 3.082

SENSOR_OP = 50*(V(21,2)-V(3,21))+10Voffset, where

V(21,2) = voltage at BSM pin 21 with respect to voltage at BSM pin 2.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following Matlab file creates the lookup table for use in the Simulink model, where the lookup table input vector is 'chop_in', and the table output is 'chop_out'.

```
% SPIRE FSM PRIME Sensor scaling vectors      B.Stobie UKATC 01/07/04
% -----
% for matlab-simulink Lookup-Table block.
% NOTE 'raw' vectors are by cut-and-paste from spreadsheets
% 'fsm_sensor_scaling_PRIME_010704' and 'fsm_sensor_scaling_REDUNDANT_xxxxxxx'
% - however Jiggle sensor feedback is inverted between prime and redundant, so inversion is
% used in prime, and
% 'fliplr' is used in redundant.
%
% PRIME
%
chop_outx = [0.86479 0.85028 0.82459 0.79191 0.75479 0.71456 0.67179 0.62753 0.58185
0.53499 0.48752 0.43956 0.39128 0.34290 0.29446 0.24595 0.19734 0.14835 0.09935 0.05010
0.00000 -0.06275 -0.12333 -0.18171 -0.23826 -0.29287 -0.34570 -0.39644 -0.44579 -0.49314 -
0.53859 -0.58227 -0.62393 -0.66423 -0.70232 -0.73860 -0.77196 -0.80259 -0.82942 -0.85009 -
0.86167];
chop_out = fliplr(chop_outx);
%
chop_inx = [0.58404 0.57751 0.56557 0.55011 0.53180 0.51103 0.48807 0.46310 0.43629
0.40773 0.37755 0.34581 0.31260 0.27797 0.24199 0.20469 0.16613 0.12635 0.08538 0.04325
0.00000 -0.05526 -0.10909 -0.16145 -0.21228 -0.26155 -0.30921 -0.35519 -0.39943 -0.44187 -
0.48242 -0.52099 -0.55748 -0.59174 -0.62364 -0.65299 -0.67952 -0.70291 -0.72267 -0.73793 -
0.74627];
chop_in = fliplr(chop_inx);
```

7.13.2 REDUNDANT

ELECTRICAL OFFSET ADDED TO 'censor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.2355

LINEAR SCALE FACTOR = 3.082

SENSOR_OP = $50 \cdot (V(21,2) - V(3,21)) + 10V_{\text{offset}}$, where

$V(21,2)$ = voltage at BSM pin 21 with respect to voltage at BSM pin 2.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following table is used to scale any demands into the BSM, and the inverse table needs to be used to translate amplified sensor voltages into actual angles (see block diagram in Appendix 1)

```
% SPIRE FSM REDUNDANT Sensor scaling vectors      B.Stobie UKATC 02/07/04
% -----
% for matlab-simulink Lookup-Table block.
% NOTE 'raw' vectors are by cut-and-paste from spreadsheets
% 'fsm_sensor_scaling_PRIME_010704' and 'fsm_sensor_scaling_REDUNDANT_020704'
% - however Jiggle sensor feedback is inverted between prime and redundant, so inversion is
% used in prime, and
% 'fliplr' is used in redundant.
%
% REDUNDANT
%
chop_outx = [0.87171 0.85470 0.82504 0.78864 0.74797 0.70460 0.65924 0.61266 0.56549
0.51788 0.47033 0.42303 0.37585 0.32878 0.28244 0.23567 0.18886 0.14201 0.09496 0.04761
0.00000 -0.06518 -0.12750 -0.18752 -0.24531 -0.30076 -0.35399 -0.40540 -0.45509 -0.50297 -
0.54886 -0.59273 -0.63483 -0.67459 -0.71217 -0.74768 -0.77998 -0.80956 -0.83469 -0.85478 -
0.86595];
chop_out = fliplr(chop_outx);
%
chop_inx = [0.58404 0.57751 0.56557 0.55011 0.53180 0.51103 0.48807 0.46310 0.43629
0.40773 0.37755 0.34581 0.31260 0.27797 0.24199 0.20469 0.16613 0.12635 0.08538 0.04325
0.00000 -0.06007 -0.11858 -0.17549 -0.23074 -0.28430 -0.33610 -0.38607 -0.43417 -0.48030 -
0.52437 -0.56630 -0.60595 -0.64320 -0.67787 -0.70977 -0.73861 -0.76404 -0.78551 -0.80209 -
0.81116];
chop_in = fliplr(chop_inx);
%
```

7.14 FSM CHOP MOTOR RESISTANCE

PRIME Rmotor = 0.80 ohm

REDUNDANT Rmotor = 0.78 ohm

7.15 FSM CHOP POWER DISSIPATION

Average Power Dissipation = Chop transient power + I*I*R + Sensor Power

From FSM test data, Chop transient power can be estimated at 2mW average for 25mS. Therefore at 2 Hz the average transient power is $2.0 \times 25 / 250 = 0.2\text{mW}$.

Chop sensor power = 0.48mW.

I*I*R can be obtained from data in spreadsheet "pfm_power.xls" (Appendix A), where I = 14 mA/deg

e.g. if the PRIME Chop axis continuously moves between -1.25 and 1.25 deg., the average power is

$$\begin{aligned} &0.0002 + (1.25 \times 0.014)^2 \times 0.8 + 0.00048 \text{ W} \\ &= 0.0002 + 0.00024 + 0.00046 \text{ W} \\ &= 0.9\text{mW}. \end{aligned}$$

For more complex sets of movements, a spreadsheet can be used to calculate the average dissipation based the time sequence of movements, and assuming a linear relationship between transient power and chopped angle.

7.16 JIGGLE CONTROL PARAMETERS

PRIME

Parameter	Description	Value
j_pid_p	PID proportional gain	1.1
j_pid_i	PID integral gain	90
j_intref	integrator reference	5.8
j_pid_ilim	integrator limit	0.01
j_ff_g	feed-forward gain	0.795
j_ff_d	feed-forward diff gain	0
j_rfbkg	rate feedback gain	0.0355
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
jsign	invert motor drive	-1

REDUNDANT

Parameter	Description	Value
j_pid_p	PID proportional gain	1.1
j_pid_i	PID integral gain	90
j_intref	integrator reference	5.8
j_pid_ilim	integrator limit	0.01
j_ff_g	feed-forward gain	1.08
j_ff_d	feed-forward diff gain	0
j_rfbkg	rate feedback gain	0.0355
dfilter_t1	differential filter t.c. 1	847.458
dfilter_t2	differential filter t.c. 2	0.69491
jsign	invert motor drive	1

7.17 FSM JIGGLE DEGRADED MODE

PRIME

Parameter	Description	Value
j_ff_g	feed-forward gain	2.61
j_curr_gain	current gain	0
jmot_r	voltage gain	15
jmot_l	inductive gain	-0.014
j_nps_rsf	bemf gain	0.23
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491
jsign	invert motor drive	-1

REDUNDANT

Parameter	Description	Value
j_ff_g	feed-forward gain	2.7
j_curr_gain	current gain	0
jmot_r	voltage gain	15
jmot_l	inductive gain	-0.014
j_nps_rsf	bemf gain	0.28
nps_t1	BEMF rate filter t.c. 1	847.458
nps_t2	BEMF rate filter t.c. 2	0.69491
jsign	invert motor drive	1

7.18 FSM JIGGLE SENSOR CALIBRATION

Angles are with respect to axis zero, 'jsensor' is digitised sensor voltage after preamplification. Axis zero is defined at normal to PCAL calibration mirror. The Jiggle axis demand in degrees is divided by the linear scale factor.

7.18.1 PRIME

ELECTRICAL OFFSET ADDED TO 'jsensor' TO GIVE ZERO DEGREES
AT MECHANICAL ZERO = 0.118
LINEAR SCALE FACTOR = 1.954

SENSOR_OP = $50(V(5,24)-V(24,6))+10V_{offset}$, where

V(5,24) = voltage at BSM pin 5 with respect to voltage at BSM pin 24.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

The following table is used to scale any demands into the BSM, and the inverse table needs to be used to translate amplified sensor voltages into actual angles (see block diagram in Appendix 1)

% SPIRE FSM PRIME Sensor scaling vectors B.Stobie UKATC 01/07/04

% -----

% for matlab-simulink Lookup-Table block.

% NOTE 'raw' vectors are by cut-and-paste from spreadsheets

% 'fsm_sensor_scaling_PRIME_010704' and 'fsm_sensor_scaling_REDUNDANT_xxxxxxx'

% - however Jiggle sensor feedback is inverted between prime and redundant, so inversion is used in prime, and

% 'fliplr' is used in redundant.

%

% PRIME

jig_outx = [0.33757 0.31950 0.28741 0.24801 0.20374 0.15619 0.10630 0.05420 0.00000 -
0.05998 -0.11485 -0.16469 -0.20963 -0.24914 -0.28271 -0.30892 -0.32350];

jig_out = -jig_outx;

%

jig_inx = [0.35824 0.34241 0.31346 0.27597 0.23158 0.18123 0.12556 0.06502 0.00000 -
0.07431 -0.14349 -0.20712 -0.26467 -0.31540 -0.35824 -0.39132 -0.40942];

jig_in = -jig_inx;

%

7.18.2 REDUNDANT

ELECTRICAL OFFSET ADDED TO 'jensor' TO GIVE ZERO DEGREES

AT MECHANICAL ZERO = -0.181

LINEAR SCALE FACTOR = 1.954

SENSOR_OP = 50(V(5,24)-V(24,6))+10Voffset, where

V(5,24) = voltage at BSM pin 5 with respect to voltage at BSM pin 24.

(NOTE: The polarity of this should be checked with the final LAM preamplifier board. If necessary, a software inversion should be added before applying the following table).

```
% SPIRE FSM REDUNDANT Sensor scaling vectors      B.Stobie UKATC 02/07/04
% -----
% for matlab-simulink Lookup-Table block.
% NOTE 'raw' vectors are by cut-and-paste from spreadsheets
% 'fsm_sensor_scaling_PRIME_010704' and 'fsm_sensor_scaling_REDUNDANT_020704'
% - however Jiggle sensor feedback is inverted between prime and redundant, so inversion is
% used in prime, and
% 'fliplr' is used in redundant.
%
% REDUNDANT
%
jig_outx = [0.30987 0.29489 0.26764 0.23322 0.19354 0.15001 0.10266 0.05266 0.00000 -
0.05618 -0.10803 -0.15643 -0.20013 -0.23955 -0.27371 -0.29964 -0.31452];
jig_out = fliplr(jig_outx);
%
jig_inx = [0.33265 0.31795 0.29107 0.25626 0.21504 0.16829 0.11659 0.06038 0.00000 -
0.06502 -0.12556 -0.18123 -0.23158 -0.27597 -0.31346 -0.34241 -0.35824];
jig_in = fliplr(jig_inx);
%
```

7.19 FSM JIGGLE MOTOR RESISTANCE

PRIME Rmotor = 0.69 ohm

REDUNDANT Rmotor = 0.66 ohm

7.20 FSM JIGGLE POWER DISSIPATION

Average Power Dissipation = Jiggle transient power + I*I*R + Sensor Power

From PFM test data, Jiggle transient power can be estimated as 2.0mW for 100mS. Therefore at 0.5Hz the average transient power is $2.0 \times (0.1/1) = 0.2\text{mW}$

Jiggle sensor power = 0.49mW.

I*I*R can be obtained from data in spreadsheet "pfm_power.xls" (Appendix A), where I = 68 mA/deg

e.g. if the PRIME Jiggle axis continuously moves between -0.28 and 0.28 deg., the average power is

$$0.0002 + (0.28 \times 0.068)^2 \times 0.69 + 0.00046 \text{ W}$$

$$= 0.0002 + 0.00025 + 0.00046 \text{ W}$$

$$= 0.91\text{mW}.$$

For more complex sets of movements, a spreadsheet can be used to calculate the average dissipation based the time sequence of movements, and assuming a linear relationship between transient power and Jiggled angle

bsm_test block diagram:
Blocks in yellow are for test only.

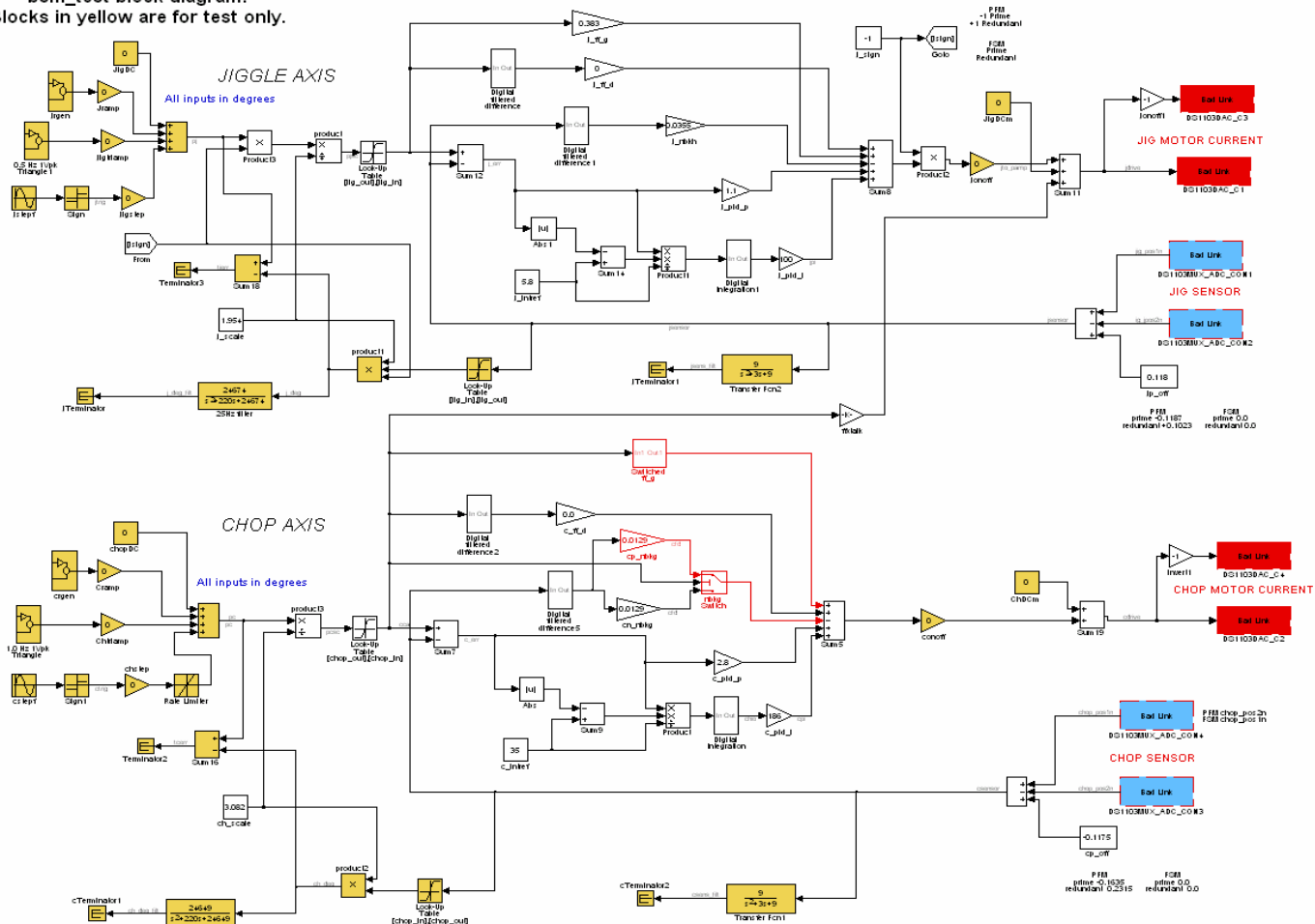


Figure 6 Parameter Block Diagram

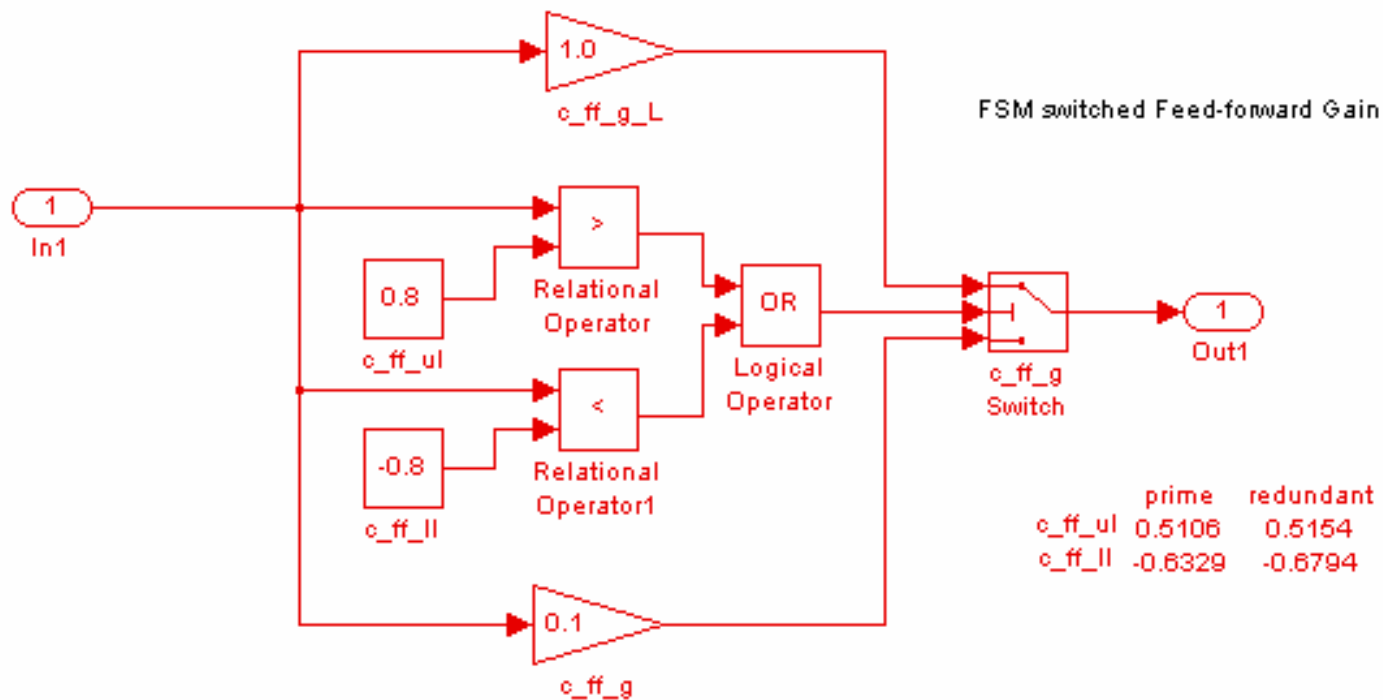


Figure 7 Switched Feed-forward Block

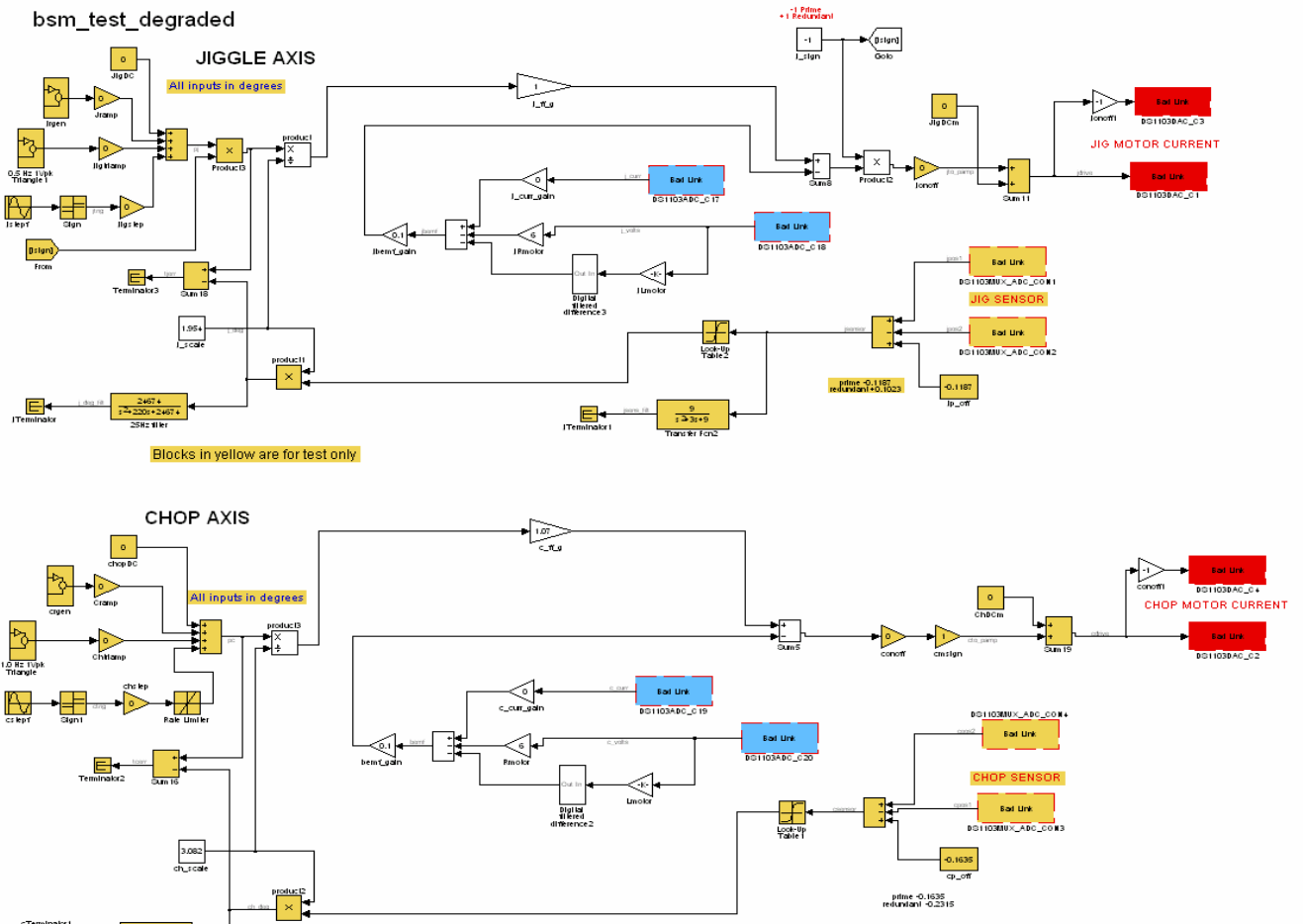


Figure 8 Block Diagram for Degraded Mode