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Cluster2
FGM
Instrument User's Manual

Revisions

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Draft	4	17 Mar. 95	1.5	Table 1.5-1 added
Draft	4		Appendix B	Updated
Draft	4		Appendix C	Updated
Draft	4		Appendix G	Added
Draft	4		Appendix H	Added
Draft	4		Appendix I	Added
Draft	4		Table 6.2-1	Revised in accordance with Appendix I
Draft	4		6.3	Revised in accordance with Appendix I
Draft	4		6.2	Bullet point removed "Cluster2 JSOC informing..."
Draft	4		6.2	Bullet point removed "Cluster2 JSOC, by sending..."
Draft	4		8.1	Table 8.1-2 removed
Draft	4		8.3.1	Added to replace table 8.1-2
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			6	Monitoring parameters added.
2 2	2 2	7th Dec 99	8 Appendix JAppendix J	Contingency procedures updated. Reference to extended mode patch added Appendix J “Software Patches” added
2	2	11th Jan 00	Appendix B	Section 6 Extended Mode Test added Appendix J Patches assigned sequence numbers
3	0	5th July 00	Section 6,7	FGM monitorings revised. FGMOPM1/FGMEXT definition revised. Contingency procedures revised. Figure 6.4 modified

Contents

1. Instrument Description

1.1 Experiment Overview

The principal objective of the Magnetic Field Investigation (FGM) on Cluster2 is to study the 3-D properties of small scale aspects of plasma processes and structures in and around the Earth's magnetosphere. For this purpose, the FGM experiment consists of two tri-axial Fluxgate magnetometers on each of the four Cluster2 spacecraft. The four instruments have an identical design and are inter-calibrated to provide fully compatible data sets consisting of vector samples of the magnetic field along the Cluster2 orbit.

The principal means for achieving this objective, post launch, and assuming the correct operation of all four instruments, is to generate a fully inter-calibrated data set consisting of time series of the magnetic field vectors measured at the four spacecraft, in a unique and physically meaningful co-ordinate system.

Using the data set thus generated, the FGM Science Team will carry out a range of scientific studies related to the mission objectives, many of these in close co-operation with the other Cluster2 investigator teams, also with associated investigators on other related missions (as co-ordinated by the IACG), with ground based observers, and the wider scientific community on topics in Solar-Terrestrial Physics.

The FGM team is engaged in a wide ranging programme of activities with the objective of preparing for the operational phase of the Cluster2 mission. These fall under the following headings:

- FGM primary data processing preparation
- FGM final inter-calibrated data processing preparation
- Definition of interfaces with the CSDS
- Orbit modelling and separation strategy preparation
- FGM science analysis preparation
- Co-ordination of science preparation with other Cluster2 investigators
- Flight ops planning
- Definition of operational interfaces with Cluster2 JSOC and ESOC Cluster2 OCC

1.2 Areas Of Interest

The FGM Science Team is interested in acquiring data from all regions in and out of the magnetosphere, as well as all in physical plasma phenomena, structures and boundaries in and of the magnetosphere.

Full range of regional topics to be addressed by Cluster2 (areas of interest to FGM):

- the interplanetary medium
- fore shock
- bow shock
- magnetosheath
- magnetopause
- boundary layers and cusp
- tail
- ring current regions

Physical topics include:

- properties of shocks and discontinuities
- all instabilities
- waves and turbulence
- magnetic reconnection
- boundary layers

The operation of the FGM will follow the pre-established FGM Flight Operations Plan (FGMFOP) which will be generated following iterations with mission planning and co-ordinated with the other Cluster2 investigations. The FGMFOP will consist of a timelined set of operating mode changes, matched to the mission profile in terms of magnetospheric regions to be traversed, data recording schedule and spacecraft telemetry mode changes.

All nominal science operational modes (see Section 6) can be used at any time during the mission. Optimisation of the modes to be used will be carried out during the preparation of the FGMFOP.

1.3 Instrument Description

The FGM instrument consists of two tri-axial Fluxgate magnetometer sensors mounted on a 5 meter long radial boom (the -Y boom) and of the instrument electronics unit mounted on the spacecraft main equipment platform. The electronics unit contains the magnetometer electronics associated with the two sensors, the analogue-to-digital converters, a dual DC-DC converter power supply unit, dual redundant central processing units, redundant data and command interfaces to the spacecraft, and a microstructure analyser memory unit. The instrumentation is identical on all four Cluster2 spacecraft; this is necessary to ensure that the four-spacecraft measurements form a coherent set and can be combined to generate the derived parameters needed to achieve the scientific objectives of the mission.

The magnetometer boom lies in the spacecraft spin plane, with the outboard sensor mounted at the boom tip, and the inboard sensor mounted at 1.5 m inboard from the boom tip. This configuration minimises the importance of the spacecraft background magnetic field and its variations. The sensors are mounted in such a way that one of the sensor axes (the x axis) is aligned with the spacecraft spin axis, and the other two are in the spin plane of the spacecraft.

A block diagram of the FGM instrument is shown in Figure 1.1. The diagram shows the high level of redundancy within the instrument. This reflects the importance of the magnetic field measurements to the success of the Cluster2 mission. Two magnetometers are used, partly for redundancy, and partly for measuring the spacecraft background field. Most functional blocks in the electronics unit (the DC-DC power converters, the Central Processing Units, the spacecraft Interface Units and the analogue-to-digital converters) are also duplicated, as are the internal control and data buses and the electrical interfaces to the spacecraft. Furthermore, each functional block is protected by a combined current limiter and power switch which can be activated by telecommand or from within the instrument. In the event of failure, individual blocks can be isolated to prevent a fault propagating; this arrangement enables the instrument to survive most single component or single point failures.

The general operation of the instrument is as follows: The two magnetometers continuously generate six voltages at their outputs which are proportional to the components of the magnetic field vector sensed by the magnetometers. These voltages are passed through an analogue switch to a 16-bit analogue-to-digital converter which digitises the voltages representing the components of the magnetic field. A digital processor reads the digitised values of the field components, filters them and then packs the results (with 14-bit precision) into a buffer to be read out over the spacecraft telemetry. In addition, at intervals of 64.4 ms, the instrument sends the most recent measurement of the magnetic field vector to all but one of the other instruments onboard Cluster2.

Magnetic field vector measurements sent over the spacecraft telemetry consist of a 14-bit representation of each of the three components of the vector, and a 3-bit range code. The telemetry allocation limits the normal output of the instrument to about 20 vectors per second. In order to obtain a higher time resolution for short periods of particular scientific interest, data are stored at rates of up to 201.75 vectors per second into a memory block, the micro-structure analyser (MSA). This memory is continually overwritten, until a special event is detected, at which time the memory contents are frozen and held for readout over the spacecraft telemetry, interleaved with the normal, lower resolution data.

Table 1.3-1 : FGM Measurement ranges

RANGE CODE	RANGE
111	- 65,536 nT to + 65,504 nT
110	Not used
101	- 4,096 nT to + 4,094 nT
100	- 1,024 nT to + 1,023.5 nT
011	- 256 nT to + 255.87 nT
010	- 64 nT to + 63.97 nT
001	Not used
000	Not valid field data

The magnetometers have eight possible operating ranges. However, for the Cluster2 mission, only a subset of these ranges is needed, as shown in Table 1.3-1. Even small differences in calibration factors between ranges mean that ground processing is greatly simplified if range changes do not occur too frequently in flight; in view of the high digital resolution (14 bits), a factor 4 between ranges is considered to provide sufficient resolution for the magnetic field measurements. The ranges used in the instrument were selected to give good resolution in interplanetary space (with expected field magnitudes in the range 3 to 30 nT) up to the highest field values expected in the magnetosphere along the Cluster2 orbit (up to about 2,000 nT). The highest range (± 65,500 nT) is used only to facilitate ground testing. Range switching is either automatic, controlled by the instrument DPU in flight, or set by ground command. When in the automatic mode, a range selection algorithm running in the DPU continuously monitors each component of the measured field vector. If any component exceeds a fraction (set at 90%) of the range, an up-range command is generated and transmitted to the sensor at the start of a new telemetry format. (All three components are measured in the same range.) If all three components are smaller than 12.5% of the range for more than a complete spin period, a downrange command is implemented at the start of the next telemetry format. The facility to override the automatic ranging is included partly for test purposes, partly as a capability for failure recovery.

1.4 On-board Data Processing and Software

1.4.1 The Data Processing Unit: hardware description

The DPU controls all the internal functions of the instrument, through its stored software which implements a data acquisition, data processing and interface service. For reliability, essentially all the

DPU functions are duplicated in the instrument, normally in cold redundancy. There are two Central Processing Units, accessing the two Spacecraft Interface Units, the Inter-Experiment Interfaces, the Microstructure Analyser and the two ADCs via redundant Data and Control Buses. The operating configuration of both software and hardware is selected by ground command.

In normal operation, only one CPU is operational, interfacing with one of the Spacecraft Interface Units (but allowing the parallel operation of both Inter-Experiment Link interfaces). In addition, one of the ADCs and the MSA is operational. The CPU used in the FGM instrument is an in-house development, designed to replicate the form, fit and function of the British Aerospace Low Power Processor (LPP) boards which were used in the original Cluster experiments. It is based on the GEC Plessey 31750 microprocessor, implementing the standard MIL-STD-1750A instruction set. An Actel RH1280 gate-array device is used to support the processor functions and to implement a redundant bus structure for interfacing with other functional units in the DPU. Each CPU has 32 kWords of RAM and 8 kWords of ROM for its software. When a processor is first powered, it runs a series of self-checks (including its RAM), and checks other hardware functions of the DPU. It then loads the software from ROM to RAM, and disables the ROM in order to minimise its power consumption. After some further checks (as detailed below in the description of the software), the CPU places the instrument into its normal operational configuration and initiates the main software loop.

The Spacecraft Interface functions are implemented in an ASIC specially designed and built for the FGM instrument. In logical terms, it provides on one side, the functions to service the spacecraft telemetry, telecommand and timing interfaces, as well as the Inter-Experiment Link; on the other side it provides interfaces to the DPU Data and Control Buses, control outputs to the two magnetometers and control signals to the switches in the power distribution system. It also provides the internally generated 60 kHz clock which drives the sensors, the data acquisition sequences in the ADCs and the timing of the software. The ASIC contains four First-In-First-Out stacks for temporary data storage and six data/control registers. Interfaces to the FGM Data and Control buses are via another FGM-specific ASIC, a specially designed bus-buffer in which the input protection circuitry has been modified to prevent units which are unpowered in normal operation being powered through their inputs. This device and the special function it implements is at the heart of the successful hardware operation of the DPU redundancy concept.

The Microstructure Analyser (MSA) hardware consists of a memory block containing 192 Kbytes of RAM. It is used for the storage of magnetic field vectors at the full sampling rate of the instrument (201.75 vectors/s) to record the signature of special magnetic field structures identified by specially stored trigger algorithms. The total capacity of the MSA is 32k vectors, capable of recording at the highest sampling rate 3 minutes of magnetic field data, to be read out over the normal telemetry channel at a slower rate. The MSA can be accessed from either CPU over either of the two redundant Data and Control buses.

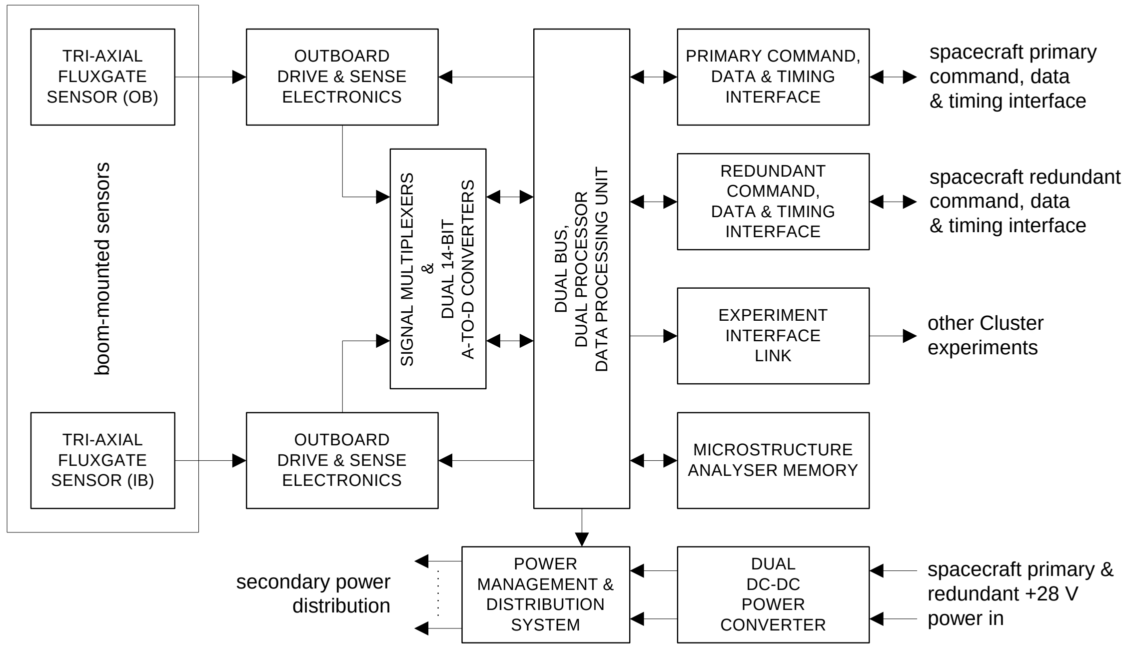

Figure 1-1, FGM Block Diagram

1.4.2 The Data Processing Unit: operation and software description

The functional blocks of the DPU described above provide the hardware environment for the operation of the instrument software which implements the functions to be carried out by the DPU. These functions are described briefly below. The controlling document for the software of the FGM is the 'Cluster FGM Software Requirements Document IC/CLUSTER2/DOC/SRD', attached as Appendix A. This document defines the command, control and monitoring functions of the instrument.

1.4.2.1 Acquisition of magnetic vector data from the magnetometers via the ADCs.

The sampling of vectors from the magnetometer sensor designated as the primary sensor is carried out at the rate of 201.75 vectors/s. This internal sampling rate has been selected to provide an appropriate set of lower rates (after filtering) for the different telemetry modes and to give the highest frequency response for the short periods of interest recorded in the MSA. In order to ensure the high stability of the sampling rate, the clock signal used for it is derived from a 2^{23} Hz crystal oscillator internal to the instrument. The primary requirement is that the sampling of vectors be carried out at equal time intervals. This requirement can be implemented only if the software is strictly sequenced by the sampling clock, and if all software sequences have a deterministic duration.

The FGM Sync Clock Register acts as the master clock for not only the vector sampling, but also for the sequencing of the FGM operating software. The clock also serves as the input to the magnetometer drive electronics to generate the drive waveform to the sensors.

1.4.2.2 Processing of the magnetic field vectors for transmission to the telemetry.

The full bandwidth of the sampled vectors cannot be routinely transmitted via the telemetry because of the limited telemetry rate allocation. The CPU convolves the full bandwidth data with a Gaussian digital filter to match the rate and bandwidth of the transmitted vectors to the available telemetry rate. The filter coefficients are selected from stored sets corresponding to the different telemetry modes.

Following the filtering, completed vector samples are stored in an output queue for the duration of a telemetry frame between reset periods. The recovery of the times at which the vectors were sampled is a very important requirement. The timing chain which enables the conversion (after data recovery on the ground) is indicated schematically in Figure 1.2. While timing of the samples is strictly based on the internal FGM clock, by recording and transmitting a time marker, based on the spacecraft provided

HF clock, which corresponds to the first vector sample in a given telemetry frame, together with the reading of the same clock at the time of the start of the next telemetry frame, the vector sample sequence can be unambiguously recovered.

1.4.2.3 Servicing of the Inter-Experiment Link.

Magnetic field vectors are required and used by most other instruments onboard Cluster2, to co-ordinate measurement sequences and to assist onboard data reduction in real time as a function of the direction and magnitude of the magnetic field. Unfiltered vector data are sent at intervals of 64.35 ms to the plasma ion and electron detectors (CIS and PEACE), to the energetic particle detector (RAPID), and to the Wave Consortium instruments via the Digital Wave Processor (DWP), as well as to the electron gun experiment (EDI). Conflicting requirements on IEL clock speed by the different experiments led to the need to operate the IEL Interfaces in parallel, thus partially removing the redundancy originally built into the FGM instrument. Additionally, if an event is detected in the FGM to trigger the Microstructure Analyser, the occurrence of this trigger is signalled to the other instruments by setting a flag in the IEL data stream.

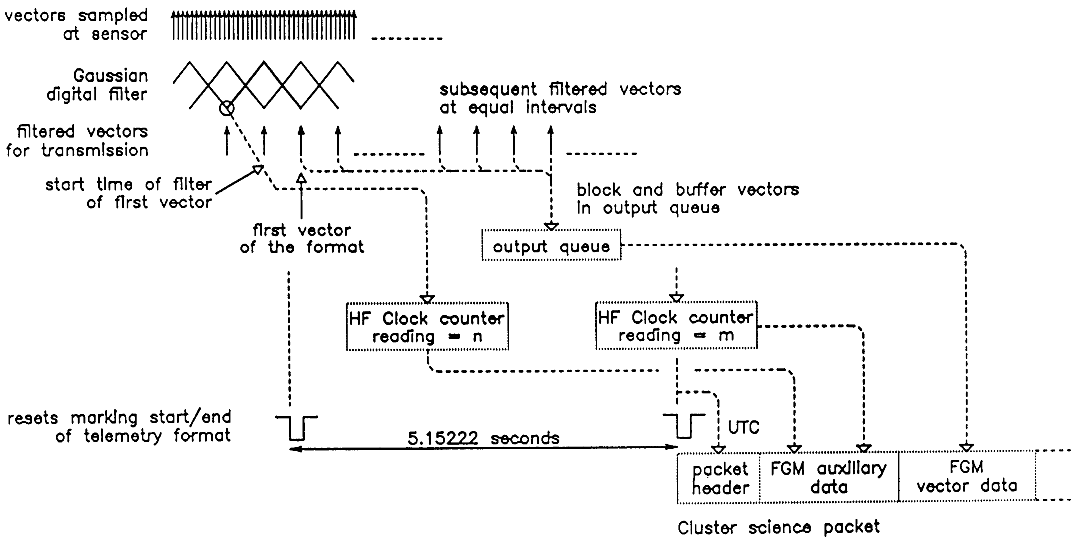

Figure 1-2, FGM Timing

1.4.2.4 Monitoring the data stream for events to trigger the MSA.

The processor has a number of stored algorithms for scanning the acquired vectors for the occurrence of events of particular interest. Events of interest are defined in the form of algorithms such as comparing short term averages of the magnetic field direction and magnitude with longer term averages, either in absolute or relative terms; or the detection of absolute or relative changes in the noise power in certain frequency bands in the spin aligned component of the magnetic field. The objective is to identify the occurrence of such events as boundary crossings or shocks when the high data rate recording capability of the MSA for a short period could capture the detailed signature of the event. The algorithms have been defined at a relatively early stage, but resettable threshold values for the event triggers will enable the operation of this facility to be optimised in flight. Vectors are read continuously, normally at the highest sampling rate, from the primary sensor into the MSA. The configuration of the memory in the MSA is under software control, normally divided into 8 pages which are continuously overwritten until an event to be stored is detected. Following the event trigger, 4 complete pages are filled and the recording stopped. In this way, the triggering event is placed approximately in the middle of the stored data. Readout of the MSA at the allocated telemetry rate will depend on detailed operational considerations which remain to be worked out. A number of different telemetry modes have been defined for the instrument which can accommodate the readout of data stored in the MSA at the most suitable rate.

1.4.2.5 Range and calibration control of the sensors.

As already described above, the auto-ranging facility of the instrument is implemented in software, with the DPU maintaining a command register independently to the two magnetometer sensors containing the three-bit range command word. Up-ranging is implemented immediately when any field component is detected to exceed the threshold of an upper guard band (set at 90% of the current range), while down-ranging is implemented only if all three field components remain below the threshold of the lower guard band (set at 12.5% of the current range) for the duration of a telemetry reset period (5.152 s). This duration of the down-ranging hysteresis was selected to exceed a complete spin period (nominally 4 s) in order to prevent down-ranging due to the spin modulation of the two spin-plane components. The operation of auto-ranging is independent for the two magnetometers. The auto-ranging facility can be overridden by ground command: the two magnetometers can be commanded independently into a fixed range.

The in-flight calibration of the two magnetometers is carried out by introducing a known current step into the feedback loop of the sensors. The standard calibration procedure used with magnetometers has been modified in that the calibration step is applied periodically for a set duration, with a repetition rate corresponding to half the Nyquist frequency. The analysis of the calibration data is carried out in the frequency domain, resulting in a much improved signal to noise ratio of the derived calibration step.

1.4.2.6 Servicing the spacecraft telemetry and telecommand interface.

One of the main roles of the DPU is to support the readout of the science and housekeeping telemetry data from the instrument. The telemetry readout procedure in the Cluster2 spacecraft is controlled by the Command and Data Management Unit which issues telemetry readout gate signals and an associated telemetry readout clock to the instruments. The DPU therefore has the task of holding ready in an interface register the data to be read out each time a telemetry readout gate signal is received. This task is asynchronous with the prime data acquisition task of the DPU. Furthermore, the readout rate is variable, dependent on the spacecraft telemetry mode. In the FGM this potential source of conflict has been removed by acquiring first all the data to be read out during a telemetry cycle (between spacecraft RESET pulses) and holding it to be readout in the next cycle. In this way, the DPU always has data ready to be placed in the readout register. The CPU telemetry service routine detects the readout of words from the spacecraft interface and refills the register with data to taken at the next interrogation.

Two independent 16-bit Memory Load (ML) commands control the instrument operation from the ground. The first, ML1, is a hardware command: this command is read into a hardware register immediately on receipt from the spacecraft; its execution is immediate. It is the primary means to control the configuration and status of the instrument: it controls the power switches to the CPUs, the ADCs and the redundant interface; it also provides the reset, enable, and disable functions of the various units in the instrument.

The second command (ML2) is a software command; on being received from the spacecraft, it is read by the (active) CPU, into a buffer memory capable of storing up to 64 commands. The set of ML2 commands received between spacecraft RESET pulses is executed at the next RESET pulse. The primary role of the ML2 command is to control the configuration and execution of the FGM software. It is used for enabling the execution of start-up configuration commands; it controls the instrument operating mode (i.e. the different telemetry modes, as well as the test and calibration modes); it is also used for the up-linking of different threshold values for the event detection algorithms; the same command also enables the up-linking of (limited) software patches.

The instrument operating modes depend primarily on the spacecraft telemetry mode (see Section 6). Each magnetic field vector from both primary and secondary sensors is transmitted as a block of 45 bits. These represent the three components of the field (14 bits each) and the range of the magnetometer (3 bits), packed to maximise the use of the allocated telemetry bandwidth. In the Normal Modes of spacecraft telemetry and in Burst Mode 2, the FGM can be operated in one of six different telemetry options, depending on the emphasis given, respectively, to data from the primary and secondary sensors and to readout data from the MSA. In Burst Mode 1, the vector sample rate from the primary sensor is increased by between 3 and 4 times to that in the Normal Mode. Burst Mode 3 is used exclusively for readout from the MSA at a rate close to its maximum record rate.

Additional data, also transmitted through the instrument telemetry channels, includes information on the telemetry mode, the times of vector sampling in relation to spacecraft time and information on the times sun pulses. This allows the UTC time and spin phase of each vector to be established.

The health and status monitoring of the instrument is carried out through the housekeeping data, providing information on internal voltages and temperatures, operating and command status, and a single (unfiltered) vector from each sensor to assist in the sequencing of ground testing.

The detailed operation of the FGM in terms of its telemetry modes will depend in the first instance on spacecraft-wide operational strategies and schedules. The relative rates between the primary and secondary sensors will be selected according to the need to monitor the spacecraft background field. The operation and the readout of the MSA will depend heavily on the wider Cluster2 operational context, in particular on the scheduling of Burst Mode operations.

1.4.2.7 The structure of the FGM operating software.

As described previously, the overriding constraint on the onboard software of the instrument is the requirement to carry out magnetic field vector acquisition at regular, hardware determined and unambiguously reproducible intervals. The structure of the software is conditioned primarily by this requirement. Other considerations, such as limited ROM space, the need for testability and speed requirements, also contributed to the definition of the software. The combination of these requirements established the need for the software to be written in assembler. The same considerations led to the elimination of interrupts and the use of polling, strictly driven by the instrument master clock register.

The CPU processors execute the MIL-STD-1750A instruction set, which is a public domain standard defining the operation of an arbitrary 16-bit computer. Both the processor and the assembler used for writing the software have been independently tested to ensure that they conform to the standard. Testing of the software code is implicit: it is functionally tested against the controlled FGM software requirements, based on the functional description of the instrument operations as given above.

When first switched on, a processor carries out a number of self tests and transfers the software from ROM to RAM. It then detects the active spacecraft interface by polling both and configures the instrument automatically. This auto-boot procedure can be overridden by hardware configuration commands. Once configured into a normal operating mode, the software initiates a continuous loop, driven by the contents of the FGM Sync clock register, the master register for the instrument. The highest priority activity of the software, in terms of timing, is the acquisition of data from the primary sensor and the servicing of the telemetry/telecommand interface. The latter has to be serviced at intervals of known maximum duration, but can be accommodated as a repeated set of service calls during the processing of the primary vector. The other subroutines are broken down into activities of known/predictable duration; the software reads at regular intervals the master clock register for initiating these less time-critical or less frequent routines.

1.5 Instrument Physical Characteristics

FGM Experiment Number	S/C Number	Electronics Box			Sensors	
		Label	DPU1 id.	DPU2 id.	OB	IB
F9	FM5	FM5	9	10	FM5	FM5
F6	FM6	FM6	3	4	FM6	FM6
F7	FM7	FM7	5	6	FM7	FM7
F8	FM8	FM8	7	8	FM8	FM8
F1	None	FS	11	12	FM1	FM1

Table 1.5-1 Experiment disposition

1.5.1 Location on spacecraft

The experiment consists of three units. Two magnetometer sensors are mounted on the -Y radial rigid boom. One is mounted at the tip of the boom and is referred to as the outboard (OB) sensor. The other sensor is mounted approximately 1.5m in from the tip of the boom and is known as the inboard (IB) sensor. The electronics required to drive and read the sensors is held in a box mounted on the Main Equipment Platform beside the root of the -Y boom.

1.5.2 Mechanisms

No mechanisms are used within the instrument.

1.5.3 Mass

Sensor bolts	1.1 g	
x 8		9 g
Sensor blanket (test blanket)	56 g	
x 2		112 g
Boot blanket	4 g	
x 2		8 g
Electronics box (FM6)		2005 g
Sensor OB (FM6)		290 g
Sensor IB (FM6)		297 g
Boom harness OB (test harness)		308 g
Boom harness IB (test harness)		211 g
MEP harness (test harness) (FGM harness, from the electronics box to the boom root connector, forms part of the spacecraft MEP harness)		170 g

1.5.4 Flight covers

The experiment as no flight covers.

2. Telemetry

2.1 Monitoring philosophy

2.1.1 Command monitoring

ML1 commands provide a direct control over the hardware of an FGM instrument. Their effect is reported in the housekeeping by allowing the processor to monitor a status register in the interface circuitry which is being commanded by the spacecraft. This information is available only while a processor is running. If the instrument is powered but no processor is running, an ML1 command can be sent to dump the status word directly into the housekeeping telemetry stream.

A processor identifies which interface is being commanded by the spacecraft as part of its boot routine. It designates this as the active interface. The designation of which interface is active can be changed by the use of an ML2 command sent to the inactive interface.

The receipt of ML2 commands is recorded in the telecommand count word of the housekeeping (see SRD, Appendix A). The total number of commands received since switch-on is recorded in an eight bit counter which rolls over on reaching 255. The execution of individual commands is seen by changes to housekeeping parameters associated with particular commands.

2.1.2 Analogue parameter monitoring

A number of analogue parameters are encoded in the housekeeping telemetry: 3 x voltages, 1 temperature and 6 x sensor samples. The voltages represent the levels of the secondary power supplies and have fixed limits. If any of the measured values falls outside the required range corrective action is needed.). The temperature is measured from a thermistor on the DC-DC converter card and represents the temperature of the electronics box. This temperature can be expected to follow the temperature of the Main Equipment Platform; there is no direct means by which this can be controlled. The box temperature needs to be monitored because it is a parameter of the calibration. For the purposes of health checking it becomes important only when it diverges significantly from the temperature of the MEP. The sensor samples are monitored to identify whether a sensor channel has become saturated. This can be seen if any sensor returns a limit value (+ve limit 0x7F or -ve limit 0x80) in successive RESET frames. .

2.1.3 Discrete parameters monitoring

Most of the discrete parameters in the housekeeping have a defined value once a processor has been booted and those values change only in response to a telecommand. There are exceptions. A count of the number of RESET pulses seen increments continuously and the 'keyhole word' changes according to which word in memory is being viewed. Status flags relating to the 'cal' and 'flip' commands change intermittently over a finite period after a command has initiated a calibration sequence.

The instrument performs one autonomous function in normal operation and this relates to the storage of data in the MSA unit. Readings from the primary sensor are processed onboard to identify magnetic events of particular interest. If an event is identified, a block of data with high time resolution is stored and an event flag is set in the house-keeping stream. The instrument has a limited capability to change the allocation of bits in its science telemetry stream after an event, so that the data can be sent to ground. When this switching occurs it is reflected by a change in the 4-bit telemetry option parameter also found in the house-keeping stream.

2.2 Housekeeping

See Appendix A: SRD section 3.2

2.3 Initial settings

2.3.1 Settings after switch-on but prior to DPU boot

After an FGM instrument has been switched on but before commands have been sent to boot a processor the telemetry should be filled with zeros. Confirmation that the spacecraft interface circuitry is working can be obtained by sending the ZEF1DR0S command. The contents of the interface 16 bit status register will be dumped into the housekeeping channel immediately. It will be aligned on a word boundary but its position in a housekeeping block depends on the time at which the command is executed. The value of the status word following power-on should be 0xC510.

2.3.2 Settings after switch-on and standard (Type 2) boot

The default boot sequence for an FGM instrument is give in Appendix C and the configuration on completion of the boot sequence is shown in Table 2-1.

Name	Type	Description	Loc.	Mask	Loc.	Mask	Expected value	AIT dB text message	Expected state, as indicated by value	
									Min.	Max.
EF3ADC01	D	ADC 1 POWER	0x0D	0x40			1	ON		
EF3ADC02	D	ADC 2 POWER	0x0D	0x80			0	OFF		
EF3ADCFB	D	ADC FAIL BUS ACK	0x00	0x02			0	FALSE		
EF3ADCFR	D	ADC FAIL RESET	0x00	0x08			0	FALSE		
EF3ADCFT	D	ADC FAIL TIMEOUT	0x00	0x04			0	FALSE		
EF3AUTST	D	AUTO STARTUP INIT	0x0A	0x10			1	TRUE		
EF3BDDAT	D	BAD DATA WARNING	0x01	0x01			0	FALSE		
EF3BUSBT	D	BOOT BUS	0x0B	0x80			1	PRIMARY		
EF3CALMD	R	CAL SEQUENCE #	0x0F	0xC0			0		Off	
EF3CDPAT	D	CODE PATCH	0x0F	0x10			0	OFF		
EF3CONFG	D	CONFIG TC	0x0E	0xF0			0		None	
EF3DP1RS	D	DPU1 RESET	0x0D	0x01			0	OFF		
EF3DP2RS	D	DPU2 RESET	0x0D	0x02			0	OFF		
EF3DPTMD	R	TEST SEQUENCE #	0x0E	0x0E			0		Off	
EF3DPU01	D	DPU 1 POWER	0x0D	0x04			1	ON		
EF3DPU02	D	DPU 2 POWER	0x0D	0x08			0	OFF		
EF3DPUFL	D	DPU FAULT	0x01	0x20			0	FALSE		
EF3DPUID	D	DPU IDENTITY	0x07	0x0F			-		0x1	0xC
EF3EVENT	D	EVENT REC ENABLE	0x0B	0x40			0	OFF		
EF3FILTR	D	FILTERING ENABLE	0x0A	0x08			1	ENABLED		
EF3I1IEL	D	INT 1 IEL SPEED	0x0B	0x20			0	SLOW		
EF3I2IEL	D	INT 2 IEL SPEED	0x0B	0x10			1	FAST		
EF3IBSNR	D	IB ENABLE	0x0C	0x10			1	ENABLED		
EF3ICALN	D	INBOARD CAL	0x0B	0x04			0	OFF		
EF3IELEN	D	IEL ENABLE	0x0C	0x08			1	ENABLED		
EF3IELFL	D	IEL FAIL STACK	0x01	0x10			0	FALSE		
EF3IFLPN	D	INBOARD FLIP	0x0B	0x01			0	OFF		
EF3INT00	D	OTHER INTERFACE POWER	0x0D	0x10			1	ON		
EF3INT01	D	INTERFACE 1 POWER	0x0C	0x80			1	ON		
EF3INT02	D	INTERFACE 2 POWER	0x0C	0x40			1	ON		
EF3INTFL	D	INTERFACE FAIL	0x00	0x40			0	FALSE		
EF3KEYHO	R	KEYHOLE	0x1A	0xFF	0x1B	0xFF	0xFF74		Hardware status of Int 1	
EF3MDUMP	D	MEMORY DUMP	0x0F	0x20			0	OFF		
EF3MN12V	A	MINUS 12 VOLTS	0x03	0x3F	0x04	0xF0	-		-15.0 V	-12.0 V
EF3MSA00	D	MSA POWER	0x0D	0x20			1	ON		
EF3MSAFL	D	MSA FAULT	0x00	0x10			0	FALSE		
EF3MSAFN	D	MSA_FILTER	0x0E	0x01			0	DISABLED		
EF3NORES	D	ERROR, NO RESET	0x01	0x80			0	FALSE		
EF3NOSTP	D	ERROR, NO STARTUP	0x00	0x01			0	FALSE		
EF3OBSNR	D	OB ENABLE	0x0C	0x20			1	ENABLED		

Continued

Table 2-1 Instrument configuration reported in housekeeping following default (Type 2) boot sequence.

Table 2-1 (continuation)

Name	**Type**	**Description**	**Loc.**	**Mask**	**Loc.**	**Mask**	**Expected value**	**AIT dB text message**	**Expected state, as indicated by value**	
									Min.	Max.
EF3OCALN	D	OUTBOARD CAL	0x0B	0x08			0	OFF		
EF3OFLPN	D	OUTBOARD FLIP	0x0B	0x02			0	OFF		
EF3PARNE	D	PRI AUTORANGE	0x0A	0x04			1	ENABLED		
EF3PATFL	D	CODE PATCH FAIL	0x01	0x40			0	FALSE		
EF3PBREC	R	PARAM BYTES COUNT	0x10	0x7F			0			
EF3PBUPD	D	PARAM BASE UPDATE	0x10	0x80			0	FALSE		
EF3PL05V	A	PLUS 5 VOLTS	0x06	0xFF	0x07	0xC0	-		4.4 V	6.1 V
EF3PL12V	A	PLUS 12 VOLTS	0x02	0xFF	0x03	0xC0	-		12.0 V	15.0 V
EF3PRIMR	R	PRIMARY RANGE	0x15	0x07			-		2	7
EF3PRIMX	A	PRIMARY SENSOR X	0x12	0xFF			-		0x80	0x7F
EF3PRIMY	A	PRIMARY SENSOR Y	0x13	0xFF			-		0x80	0x7F
EF3PRIMZ	A	PRIMARY SENSOR Z	0x14	0xFF			-		0x80	0x7F
EF3PRISR	D	PRIMARY OB/IB	0x0A	0x80			1	OUTBOARD		
EF3PTEMP	A	PSU TEMPERATURE	0x04	0x0F	0x05	0xFC	-		Not defined	Not defined
EF3RAMFL	D	RAM CHECK FAIL	0x00	0x20			0	FALSE		
EF3RESEN	D	DPU RESET ENABLE	0x0C	0x02			1	ENABLED		
EF3RESET	R	COUNT OF RESETS	0x08	0xFF	0x09	0xFF	-		No limit defined	
EF3SARNE	D	SEC AUTORANGE	0x0A	0x01			1	ENABLED		
EF3SECOR	R	SECONDARY RANGE	0x19	0x07			-		2	7
EF3SECOX	A	SECONDARY SENS X	0x16	0xFF			-		0x80	0x7F
EF3SECOY	A	SECONDARY SENS Y	0x17	0xFF			-		0x80	0x7F
EF3SECOZ	A	SECONDARY SENS Z	0x18	0xFF			-		0x80	0x7F
EF3SECSR	D	SECONDARY OB/IB	0x0A	0x40			0	INBOARD		
EF3SEUAD	R	SEU ADDRESS	0x1C	0x01	0x1D	0xFF	0		No SEU	
EF3SEUCT	R	SEU COUNT	0x1C	0xFE			0		No SEU	
EF3SEUEN	D	SEU STATUS	0x0A	0x20			1	ENABLED		
EF3SUMFL	D	SUMCHECK FAIL	0x01	0x08			0	FALSE		
EF3SYN60	D	SYNC 60 ENABLE	0x0C	0x04			1	ENABLED		
EF3TCREC	D	ML2 TC RECEIVED	0x11	0xFF			2		All Type 2 boot commands received	
EF3TMOPT	R	TM OPTION	0x0F	0x0F			0xC		Option C telemetry	
EF3TRIGG	D	EVENT TRIGGERED	0x0A	0x02			0	FALSE		

3. Control

3.1 Control philosophy

All command are executed within one RESET period of being received by the instrument and all commands have an effect which can be seen in the telemetry stream.

3.2 External telecommands

The FGM instrument contains two independent DC-DC converters, which are supplied with power from separate spacecraft latching current limiters (LCL).
Note : Switching on both primary power supplies to the FGM should be avoided.
In addition to the primary power supplies, the instrument receives a separate power supply for the FGM sensors heaters. This can be switched on and off by the spacecraft independent of the state of the FGM primary power supplies (see section 4.1).

As described in section 1.4.2.6, the instrument is controlled from the ground by two 16-bit memory load command channels, ML1 and ML2. These are duplicated so that commands can be sent independently to either the main or redundant spacecraft interface of the instrument. The ML1 channel provides a set of direct hardware controls. Commands received via this channel are decoded in hardware and executed immediately. They are used for functions such as controlling internal power switches and enabling hardware signals. Commands sent on the ML2 channel are used as software controls. They are read into a hardware buffer and held until they can be read by a processor. Once a processor is powered it reads the buffer at frequent intervals and transfers the information to a software buffer capable of holding up to 64 command words. The set of ML2 commands received between spacecraft RESET pulses is executed at the next RESET pulse. The primary role of these commands is to control the configuration and execution of the FGM software. They are used for enabling the execution of start-up configuration commands; they control the instrument operating mode (i.e. the different telemetry modes, as well as the test and calibration modes); also, they are used for the up-linking of different threshold values for the event detection algorithms and for up-linking patches of replacement software.

A full list of FGM ML commands is given in the FGM Software Requirements Document (SRD) which is included as Appendix A. The list of ML2 commands in this document is necessary for the definition of the flight software. ML1 commands are not needed in this context but are included for completeness.

3.3 Reflection of telecommands on telemetry

All details relating to the Housekeeping-Telecommand cross checks are given in the FGM SRD (see Appendix A).

3.4 On-board calibration table modification

No calibration corrections are performed onboard for any transmitted data. The only use made of calibration factors, by the flight software, is in the processing of data for event detection. An area of processor memory has been designated a parameter block. Particular address in the block have been allocated to particular functions. For example, location 0 in the table holds the pointer to the word which appears as the 'keyhole' word in the housekeeping telemetry. Other words in the block contain approximate sensor offset figure, scale factors, MSA trigger thresholds and a variety of other information.

The parameter table is modified by a command which defines a base offset within the table, followed a series of command which write bytes of data in successive locations up from the base address. No data in the parameter block is critical to the operation of the experiment so it is excluded from the continuous code sum-check.

Table Address	Name	Verbose	Default Value
0	KEYHOL	Key Hole	0xFE70
1	MDADDR	Memory Dump Base Address	0x1625
2	MDLEN	Memory Dump Length	0x00FF
3	SHRTNO	Short Averaging Length	0xFFFA
4	LONGNO	Long Averaging Length	0xFFFB
5	VXTF	Var. X Threshold: Rn. 0	0x0020
6		Rn. 1	0x0020
7		Rn. 2	0x0020
8		Rn. 3	0x0020
9		Rn. 4	0x0020
10		Rn. 5	0x0020
11		Rn. 6	0x0020
12		Rn. 7	0x0020
13	VXOSET	Variance X Offset MS word	0x0000
14		LS word	0x0008
15	BXTF	Mag X Threshold	0x0020
16	BXOSET	Mag X Offset MS word	0x0000
17		LS word	0x0008
18	B2TF	Field Mag Threshold	0x0020
19	B20SET	Field Mag Offset MS word	0x0000
20		LS word	0x0008
21	BL2TF	Field Rotation Threshold	0x0020
22	BL2OST	Field Rotation Offset MS word	0x0000
23		LS word	0x0008
24	ZY2TF	Spin Plane Threshold	0x0020
25	ZY2OST	Spin Plane Offset MS word	0x0000
26		LS word	0x0008
27	MSADEC	MSA Data Decimation	0x0001
28	EDAND	Event Param AND Word	0x00FF
29	EDOR	Event Param OR Word	0x0000
30	TMSMAX	Telem. Mode Switch Time	0x0010
31	IBOFFS	Inboard Sensor Offsets Rn. 0 X	0x0000
32		Y	0x0000
33		Z	0x0000
34		Rn. 1 X	0x0000
35		Y	0x0000
36		Z	0x0000
37		Rn. 2 X	0x0000
38		Y	0x0000
39		Z	0x0000
40		Rn. 3 X	0x0000
41		Y	0x0000
42		Z	0x0000
43		Rn. 4 X	0x0000
44		Y	0x0000
45		Z	0x0000
46		Rn. 5 X	0x0000
47		Y	0x0000
48		Z	0x0000
49		Rn. 6 X	0x0000
50		Y	0x0000
51		Z	0x0000
52		Rn. 7 X	0x0000
53		Y	0x0000
54		Z	0x0000
55	OBOFFS	Outboard Sensor Offsets Rn. 0 X	0x0000
56		Y	0x0000
57		Z	0x0000
58		Rn. 1 X	0x0000
59		Y	0x0000
60		Z	0x0000

61		Rn. 2 X	0x0000
62		Y	0x0000
63		Z	0x0000
64		Rn. 3 X	0x0000
65		Y	0x0000
66		Z	0x0000
67		Rn. 4 X	0x0000
68		Y	0x0000
69		Z	0x0000
70		Rn. 5 X	0x0000
71		Y	0x0000
72		Z	0x0000
73		Rn. 6 X	0x0000
74		Y	0x0000
75		Z	0x0000
76		Rn. 7 X	0x0000
77		Y	0x0000
78		Z	0x0000

Table 3.4-1 Map of parameter table in FGM flight software

Parameter name	Location Bit 15 = LSB	Parameter
ZYTEC	11	$B_y^2 + B_z^2$
BL2TEC	12	$\delta B_y^2 + \delta B_z^2$
B2ETEC	13	$B_x^2 + B_y^2 + B_z^2$
BXETEC	14	B_x
VXETEC	15	σB_x

Table 3.4-2 EDAND and EDOR bit assignments

3.5 On-board software modification

See Section 7.5

3.6 Internal control and commands

Autonomous functions incorporated in the FGM are as follows:

- Auto-boot, see Section 5.1
- Monitoring the occurrence of "events" defined by the operational configuration of the MSA, and subsequent freezing of the MSA memory, to await readout.
- The operation of science operational modes FGMOPM4, FGMOPM5 and FGMOPM6, whereby, on the detection of an 'event' and subsequent freezing of the MSA memory, automatic switching will occur from FGMOPM4 or FGMOPM5 (whichever is activated at the time) to FGMOPM6, to allow the readout of the MSA memory. Following the readout, the instrument switches automatically back to its previous operating mode, i.e. FGMOPM4 or FGMOPM5 (see Section 6).

The status of the instrument remains uniquely defined in the HK channel.

3.7 Control of redundant hardware

As described by section 1.4.1, a number of the hardware modules in an FGM instrument are duplicated. These redundant elements can be used, in the event of a hardware fault, to allow the functionality of the instrument to be recovered. The redundancy scheme begins with the supply of power and service signals to an instrument by the spacecraft. With the exception of the FGM sensor heater power supply, all such signals are provided by the spacecraft on 'main' and 'redundant' lines (see EID A Section 3.1.2.2 & 3.3.4.5).

The 'main' and 'redundant' primary power supplies are routed to two separate DC-DC converters within the instrument. These converters are wired together at their output. Power can be supplied to an instrument by the spacecraft on either the 'main' or 'redundant' branch but the spacecraft must not switch on both supplies at the same time. When a primary power supply is switched on, power is delivered to the FGM sensor electronics and to the two blocks of spacecraft interface electronics but all other modules in the instrument remain switched off.

The 'main' and 'redundant' sets of service signals are routed to two separate blocks of spacecraft interface electronics. Each block can pass data over the service signal lines connected to it but cannot access the other set. A spacecraft interface executes the ML1 commands and buffers ML2 commands. As described in Section 3.2, ML1 command are used to provide direct hardware controls. An interface can be commanded to switch on the power to any of the remaining hardware modules; DPU1, DPU2, ADC1, ADC2 & MSA. In addition, it can be commanded to switch off the other interface. An interface must drive a continuous square-wave signal to hold the power supply to another unit on, except in the case of the other interface where it must drive the signal if it needs to keep the module switched off. Naturally, it cannot drive any signal when it is not powered itself. This scheme ensures that faulty modules can be switched off and once off, they will not interfere with the remainder of the instrument.

In a normal boot sequence, power to an instrument is switched on, then four ML2 commands are sent to the instrument via the set of service signals with which the spacecraft wishes to exchange data with the instrument. Next, an ML1 command is sent instructing the instrument to switch on a DPU. Under normal conditions the command to select DPU1 is sent, however the command to power DPU2 could be used if DPU1 were known to be faulty. When a DPU is powered it boots from the code held in ROM and reads the buffers in the two spacecraft interfaces, looking for data words which will tell it how to proceed. It attempts to read two words from an interface over one of two internal data busses, if that fails it tries again using the other bus. If words it reads request an automatic boot. the DPU will switch on ADC1 and the MSA, then begin gathering magnetic field measurements. It will send the data it gathers to the interface from which it read a valid pair of start-up words. Alternatively, a manual boot can be requested. In this case no hardware will be switched on by the DPU and it will go directly to its data gathering cycle. If a manual boot is selected, all choices over which hardware should be used must be made on the ground and appropriate commands sent to the instrument.

The mechanisms outlined here allow the hardware of the instrument to be switched on in stages even when faults exist. Using the steps of the commissioning procedure it is possible to systematically locate a fault, then have a high probability of being able to reconfigure the instrument to avoid it.

4. Environment

4.1 Thermal

4.1.1.1 Electronics box thermistor - Conditions

The temperature of the FGM Electronics Box is monitored by one thermistor located on the DC-DC converter card. The resistance is measured by the instrument and encoded in the housekeeping telemetry stream.

The power consumption of the instrument is not affected by its mode of operation (except at the level of whether or not it is switched on). Therefore, provided that the instrument is functioning correctly, there is no means of controlling the temperature of the electronics box. The temperature is required as a parameter of the instrument calibration but there is no requirement for it to be controlled.

Operating temperature limits set in the EID-B are :

- 10 ^{o}C	minimum
+ 40 ^{o}C	maximum

The electronics box can be expected to function correctly in the temperature range of -55 to +90 ^{o}C although it has not been acceptance tested over this range.

4.1.2.1 Electronics box thermistor - Monitoring

The temperature of the electronics box is measured using a potential divider made up from a 182 kΩ resistor at the 'top' and a 182 kΩ resistor with a thermistor in parallel at the bottom. V_{in} , applied to the top of the potential divider, is taken from the +5V nominal internal supply. The actual level of this supply is provided in the house-keeping. V_{out} is measured at the centre of the potential divider and digitised by the active ADC card. The ADC returns a 16 bit value such that MAX = 4.5V and MIN = -4.5V. The value obtained from the ADC is converted to a 2's compliment number and shifted right by 2 places. The resulting value is truncated, losing the least significant bits, and placed in the house-keeping.

The decoding of this parameter is described also in the AIT database.

Temperature (°C)	PS Thermistor Resistance Rt (K Ohm)	Vout / Vin
-60	845.9	0.4514
-55	607.8	0.4349
-50	441.3	0.4145
-45	323.7	0.3903
-40	239.8	0.3625
-35	179.2	0.3316
-30	135.2	0.2989
-25	102.9	0.2653
-20	78.91	0.2322
-15	61.02	0.2007
-10	47.54	0.1716
-5	37.31	0.1454
0	29.49	0.1224
5	23.46	0.1025
10	18.79	0.0856
15	15.13	0.0713
20	12.26	0.0594
25	10	0.0495
30	8.194	0.0413
35	6.752	0.0345
40	5.592	0.0289
45	4.655	0.0243
50	3.893	0.0205
55	3.27	0.0173
60	2.76	0.0147
65	2.339	0.0125
70	1.99	0.0107
75	1.7	0.0092
80	1.458	0.0079
85	1.255	0.0068
90	1.084	0.0059
95	0.9393	0.0051
100	0.8168	0.0044
105	0.7126	0.0039
110	0.6235	0.0034
115	0.5473	0.0030
120	0.4818	0.0026
125	0.4253	0.0023
130	0.3764	0.0021
135	0.334	0.0018
140	0.2972	0.0016
145	0.2651	0.0015
150	0.237	0.0013

Table 4.1-1 Thermistor characteristics for Electronics Box (resistances given +/- 1%)

4.1.3.1 Electronics box thermistor - Control

The temperature of the electronics box can be controlled by:

1. Switching the instrument on or off
2. Changing the temperature of the Main Equipment Platform

4.1.1.2 Sensor thermistors - Conditions

The FGM sensors each contain a thermistor, which is independent of the FGM electronics and which is monitored by the spacecraft. Similarly, each sensor contains a heater which can be operated independently from the remainder of the s/c electronics. Both heaters are powered through a single switch which is controlled by the spacecraft.

When a sensor is in sunlight the surface finish on the thermal blanket should control the temperature to ensure that it remains within its required limits. This should be true whether or not the sensors are powered. When a sensor is in shadow its temperature will drop and the heaters may be needed maintain the temperature above the minimum limit.

In the event that one sensor is in sunlight and the other is in shadow, it is more important that the hot sensor should remain below its maximum temperature, than that the cold sensor should remain above its minimum.

4.1.2.2 Sensor thermistors - Monitoring

The sensors have very good thermal insulation and their temperature can be expected to change at a maximum of 20 ^{0}C per/hour (TBC). Therefore the sensors need to be monitored at intervals of the order of 30 minutes.

Derivation of FGM OB & IB Sensor Temperatures from Spacecraft Housekeeping.

Sensor thermistors are conditioned by spacecraft powered and read conditioning circuits. Voltage outputs are digitised (nominally 20mV. per count) and provided in the housekeeping transfer frame VC0 at location 576, specifically packet EX_TH_BM, the APID of which is 0x0081. Conversion to temperature is by a calibration curve.

OB Thermistor:

Packet Name:	EX_TH_BM
Location:	12
Mask:	0xFF
Calibration Curve:	KFGM1OBT

Curve KFGM1OBT is as follows:

Raw Value	Engineering Value (^{0}C)
0	716
188	90
194	70
196	60
199	50
201	40
204	30
206	20
209	10
212	0
214	-10
216	-20
219	-30
222	-40
224	-50
226	-60
234	-70

237	-80
239	-110
255	-163

IB Thermistor:

Packet Name: EX_TH_BM
Location: 4
Mask: 0xFF
Calibration Curve: KFGM2IBT

Curve KFGM2IBT is as follows:

Raw Value	Engineering Value (^{0}C)
0	400
27	95
29	70
31	40
33	20
35	0
37	-20
39	-40
41	-60
42	-70
44	-110
61	-280*
255	-280*

* Values taken from Dornier database

4.1.3.2 Sensor thermistors - Control

Boom stowed
The most severe thermal conditions will be seen in the period before boom deployment. It is predicted that, when the +X surface of the spacecraft is in shadow, the interface of the boom to the FGM IB sensor will fall to a temperature around -110 ^{0}C. The OB sensor will receive some sunlight and consequently will remain warmer. With the heater on the sensor temperature can be raised to roughly 60 ^{0}C above the temperature of the boom interface.

Boom deployed
Once the -Y radial boom has been deployed temperature control should be needed only during eclipses. It is expected that the heaters will be turned on at the start of an eclipse an turned off at the end. During the mission it may be possible to optimise the use of heater power to conserve spacecraft power based on the measured operating temperature of the sensors and their measured rate of cooling.

Automated heater control
It would be unreasonably difficult to control the temperature of the sensors solely by commands from ground. Therefore, a small assembler code programme has been written which is to be up-linked to the spacecraft before launch and scheduled by ESOC. Execution of this code module at regular intervals will provide the necessary control for the sensor heaters.

The algorithm which is to be executed by the code module is written here as a piece of C code:

```
#define OB_sensor 1
#define IB_sensor 2
#define On 1
#define Off 0

float get_temp(int sensor) ;          /* read the temperature of a thermistor */
void heater(int state) ;              /* set the state of the FGM heater */

void FGM_sensor_control(int automatic)
{
  if (automatic) {
    if ((get_temp(OB_sensor) > 60.0) || (get_temp(IB_sensor) > 60.0)) heater(Off) ;
    else if ((get_temp(OB_sensor) < -60.0) || (get_temp(IB_sensor) < -60.0)) heater(On) ;
    else if ((get_temp(OB_sensor) > 40.0) && (get_temp(IB_sensor) > 40.0)) heater(Off) ;
    else if ((get_temp(OB_sensor) < -40.0) && (get_temp(IB_sensor) < -40.0)) heater(On) ;
  }
}
```

This algorithm was the subject of ECR 2007.

Temperature ^{o}C	IB Thermistor K Ohms	OB Thermistor K Ohms
-60	12.9018	8.6339
-55	12.7079	8.5466
-50	12.517	8.4598
-45	12.3289	8.3735
-40	12.1437	8.2877
-35	11.9612	8.2022
-30	11.7822	8.1177
-25	11.6064	8.0338
-20	11.4333	7.9505
-15	11.2626	7.8676
-10	11.0947	7.7853
-5	10.9297	7.7037
0	10.7673	7.6227
5	10.6083	7.5426
10	10.4518	7.4632
15	10.2982	7.3845
20	10.1474	7.3067
25	10	7.2299
30	9.8556	7.1541
35	9.7142	7.0793
40	9.5754	7.0053
45	9.439	6.9320
50	9.3044	6.8592
55	9.1704	6.7861
60	9.037	6.7127
65	8.9036	6.6389
70	8.7701	6.5644
75	8.6369	6.4894
80	8.5033	6.4137
85	8.3697	6.3374
90	8.2367	6.2609
95	8.104	6.1839
100	7.9716	6.1065
105	7.84	6.0290
110	7.7103	5.9520
115	7.5837	5.8763
120	7.4592	5.8012
125	7.3416	5.7299
130	7.2318	5.6628
135	7.1311	5.6008
140	7.0374	5.5429
145	6.946	5.4860
150	6.8582	5.4311

Table 4.1-2 Thermistor characteristics for OB & IB sensors (resistances given +/- 1%)

Experiment unit	Operating ^{o}C	Non-operating ^{o}C
OB sensor	-80 to +70	-130 to +85
IB sensor	-80 to +70	-130 to +85
Electronics box	-20 to +50	-30 to +60

Table 4.1-3 FGM acceptance test temperature ranges

4.2 Power

4.2.1 Electronics box - Power profile

With an input voltage of 27.8 V the electronics box draws 67mA when first switched on. After a processor is booted (bringing the FGM into normal operational mode FGMOPM1) the current rises to 75mA and remains at that level.
(All figure are given +/- 5%)

4.2.2 High voltages

The experiment uses no high voltages

4.2.3 Conditions

Once the instrument boot routine is complete, the power drawn is independent of the operating mode. The current can be expected to rise slowly during the mission due to the effects of radiation on electronic components but there should be no short term changes.

4.2.4 Monitoring

4.2.4.1 Monitoring total current drawn

A direct measure can be provided only by the s/c house-keeping.

Redundant blocks within the FGM are protected by current limiting power switches. If a block draws excessive current it is switched off and the failure is seen as a change in the instrument house-keeping. The failure of the MSA or an ADC is signalled by an explicit flag but the failure of a DPU or an INT block is seen only as a complete loss of instrument telemetry.

4.2.4.1 +12V

The actual voltage on the nominal +12V internal supply is measured using a potential divider made up from a 300 K Ohm resistor at the 'top' and a 23.8 K Ohm resistor at the 'bottom'. V_{in} , applied to the top of the potential divider, is taken from the +12V nominal internal supply. V_{out} is measured at the centre of the potential divider and digitised by the active ADC card. The ADC returns a 16 bit value such that MAX = 4.5V and MIN = -4.5V. The value obtained from the ADC is converted to a 2's compliment number and placed in the housekeeping.

4.2.4.2 -12V

Processed as +12V nominal (see 4.2.4.1)

4.2.4.3 +5V

The actual voltage on the nominal +5V internal supply is measured using a potential divider made up from a 66.4 K Ohm resistor at the 'top' and a 45.5 K Ohm resistor at the 'bottom'. V_{in} , applied to the top of the potential divider, is taken from the +5V nominal internal supply. V_{out} is measured at the centre of the potential divider and digitised by the active ADC card. The ADC returns a 16 bit value such that MAX = 4.5V and MIN = -4.5V. The value obtained from the ADC is converted to a 2's compliment number and placed in the house-keeping.

4.2.5 Control

There is no means of varying the power consumed by the instrument.

4.3 Communications

FGM Telemetry Option Number (hex)	Available in OBDH Mode	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset	Comment / Requirement
2	NM1, NM2, NM3 or BM2	81 (13)	6 (185)	128	Auto-switching mode
3	NM1, NM2, NM3 or BM2	95 (11)	37 (29)	0	Auto-switching mode
4	NM1, NM2, NM3 or BM2	116 (9)	16 (67)	0	Auto-switching mode
A	NM1, NM2, NM3 or BM2	81 (13)	6 (185)	128	Normal Data
B	NM1, NM2, NM3 or BM2	95 (11)	37 (29)	0	Normal Data
C	NM1, NM2, NM3 or BM2	116 (9)	16 (67)	0	Normal Data
D	BM1	348 (3)	41 (26)	0	Burst Data
F	BM3	0	0	1781	MSA Dump

(n) n is the data reduction factor needed to produce the output data rate.

4.4 Timing

Each spacecraft interface in the instrument contains a 2^{23} Hz crystal oscillator. This is divided by 140 to produce a signal of 60 kHz. As soon as a processor is booted, one of the two clocks is disabled. The active clock is used to control all timing within the instrument.

The processor repeatedly counts 297 cycles of the 60 kHz signal and uses this period as the time between vector acquisitions from the sensors. Circuitry in the ADC units synchronises a software request for data to a hardware clock edge. This scheme has been chosen because the HF clock signal from the spacecraft has too large a jitter. The consequence is that all timing within the instrument runs asynchronously with respect to the spacecraft. Time in the experiment is fixed against time on the spacecraft by recording when RESET pulses are seen.

4.5 Interface to other experiments

4.5.1 Conditions

Magnetic field vectors are distributed by the FGM, over the IEL, to 5 other instruments (EDI, CIS, PEACE, RAPID & DWP). When the instrument is in its normal configuration, data for EDI is sent from redundant spacecraft interface (INT 2) of the FGM with a clock speed of 16 kHz (approx.). Data for the other experiments is sent from the primary spacecraft interface (INT 1) with a clock speed of 1 kHz (approx.). The transmission of data to all experiments except EDI can be halted by sending a command to disable the IEL output drivers.

4.5.2 Monitoring

The housekeeping telemetry provides a record of whether the IEL outputs are enabled on the active spacecraft interface and gives the clock speed of the transmission from each interface. These parameters will be monitored with the remainder of the housekeeping and require no special provisions.

4.5.3 Control

The IEL requires no explicit control, although commands affecting data transmitted over the IEL may appear in boot or calibration sequences.

5. Commissioning

5.1 Initialisation of the instrument

5.1.1 Introduction to commissioning procedure

The commissioning of the four FGM instruments is comprised of a set of functional checks to be performed on each unit followed by a perigee pass. The functional checks should be performed on one, or possibly two, instruments at a time. For the perigee pass the four instruments should be operated simultaneously. The perigee pass is requested because it provides the best environment for checking the co-alignment of the sensors and allows the instruments to exercise all of their flight operation ranges.

A detailed commissioning procedure is provided in Appendix B. The appendix contains a command sequence with the associated time line and a description of the checks which are needed to verify the correct execution. The remainder of this section gives a summary of the tests which are to be performed.

5.1.2 Instrument functional check procedure.

The outline of the commissioning sequence appears as section 1.1 of the commissioning procedure in appendix B.

5.2 Mechanisms

The FGM experiment has no mechanisms.

5.3 High voltages

This experiment does not use high voltages.

6. Nominal Operations

6.1 Operational modes

6.1.0 General Introduction to the FGM Operational Philosophy

The objective of FGM Flight Ops activities is to maximise the science return from the four instruments on the four Cluster2 spacecraft. For this purpose, the FGM team will establish the FGM Flight Ops Plan (FGMFOP), in close co-operation with the other Cluster2 science investigations. The FGMFOP will be, when integrated into the overall Cluster2 operations plan, the baseline for nominal operations of the FGM instruments.

The iterative process for establishing the FGMFOP is illustrated in Figure 6.1. It is expected that the methodology will be consistent with the following principles:

- Science operations guidelines for the FGM will be established by the FGM Science Team, under the leadership of the PI.

- Iteration of the FGM science operations will be co-ordinated with the other Cluster2 investigator teams via the Cluster2 JSOC. Mission constraints will also be taken into account following iteration with JSOC.

- Instrument status and constraints affecting the FGM science operations will be taken into account based on information derived from the monitoring activities of the FGM Flight Operations Team.

- The fully iterated FGM science operations plan will be incorporated into the FGMFOP, established by the FGM Flight Operations Team, and approved by the PI. The command sequences implementing the FGMFOP will be established and verified also by the FGM Flight Operations Team who will transmit it to JSOC for integration into the overall command sequences for Cluster2 and further transmission to the Cluster2 OCC at ESOC.

- Monitoring of the execution of the FGMFOP will be carried out by the FGM Flight Operations Team via access to quick look data from the Cluster2 Data Disposition System at ESOC. Parallel monitoring by JSOC is also expected to be carried out at the level of status (HK) data only. The output of JSOC monitoring will be made available to the FGM Flight Operations Team.

- Monitoring of the instrument science performance will be carried out by the FGM Science and Flight Operations Teams, via access to quick look data from the Cluster2 Data Disposition System at ESOC.

- The FGMFOP, after approval by the PI, will be under configuration control and will be subject to TBD change procedures. Changes can be initiated by the FGM Science Team, the FGM Flight Operations Team, JSOC (representing also the Project Scientist), and the Cluster2 OCC at ESOC.

- Instrument malfunctions detected by the FGM Flight Operations Team, JSOC or the OCC, and mission constraints/emergencies, requiring unscheduled commanding of the instrument, will be normally treated using the change procedure to the FGMFOP. [Note: the FGMFOP may contain contingent command sequences which can be sent in response to specific conditions of the instrument or to mission-related events.] The only exception to this principle is the authority delegated to the Cluster2 OCC to switch off the FGM in any emergency.

The FGM has

- eight science operational modes, designated FGMOPM1 to FGMOPM8
- one in-flight calibration mode, designated FGMCAL
- One mode whereby the FGM stores data to the internal memory only (no science data to the OBDH), designated FGMEXT
- a range of engineering modes, designated FGMENGn, where n = 1 to TBD.

Nominal science operations are carried out in the science operational modes (with occasional, scheduled operation of the calibration mode, FGMCAL). The science modes are set uniquely by the TM format option command (an ML2 command), but can correspond to different configurations of the instrument by the selection or configuration of the different subsystems of the FGM. For nominal operations, the instrument configuration is selected during switch on and boot, followed by selecting the appropriate science operational mode. While maintaining nominal operations, the only commanding required is that needed to switch the FGM from one science mode into another, following a pre-determined science operational plan, implemented in the FGMFOP. The configuration of the instrument is uniquely set by the hardware/software configuration commands and sequences (ML1 and ML2 commands) during the boot, and can be determined at any time from the FGM housekeeping packet. Figure 6.2 illustrates the top level structure of the nominal operation modes of the FGM.

The FGM instrument is normally switched on, booted and configured for nominal science operations only in spacecraft telemetry modes NM1, NM2 or NM3. For nominal science operations, the following default settings apply after switch on:

FUNCTION	DEFAULT SETTING
Operating mode	FGMOPM1
Telemetry Option	C
Telemetry Format	1
Vector Filtering	Enabled
Auto-ranging	Enabled
Primary sensor	Outboard sensor
Secondary sensor	Inboard sensor
Event recognition	Disabled
Data acquisition	Through ADC 1

For other default settings, including all hardware functions and parameters, see Section 5.

The science operational modes are dependent on the spacecraft telemetry mode. In nominal operations, FGMOPM1 to FGMOPM6 are used only in spacecraft telemetry modes NM1, NM2, NM3 and BM2, FGMOPM7 is used only in spacecraft telemetry mode BM1 and FGMOPM8 is used only in spacecraft telemetry mode BM3. For more details, see Sections 6.1.1 to 6.1.8.

The FGM also has a mode which can be used whilst the FGM is powered but no science data is being collected by the OBDH. In this mode, designated FGMEXT, spin-averaged magnetic field vectors are stored to an internal memory device, the MSA with reduced house keeping data delivered to the OBDH. This mode is intended to be used to increase the orbit-coverage by taking data at times when the payload is not normally scheduled for operations, therefore the mode is known as 'extended-coverage mode'. The data stored in the MSA may be transmitted to ground during the next scheduled BM3 period (FGMOPM8).The ability to supply house keeping while operating in FGMEXT requires the uplinking of a software patch to the FGM. This uplink has been included as part of the default boot sequence (Boot Type 2). This boots the FGM into FGMOPM1 i.e. the FGM is not in FGMOPM1 unless the patches have been uplinked. The housekeeping parameters that are delivered during FGMEXT are given in Appendix G. The instrument patches are listed in Appendix J.

The FGMFOP may contain, other than science mode commanding, commands/sequences which change the underlying configuration of the FGM. The need for, and the role of such reconfigurations will be established later, but conceptually there is provision for their incorporation into the FGMFOP.

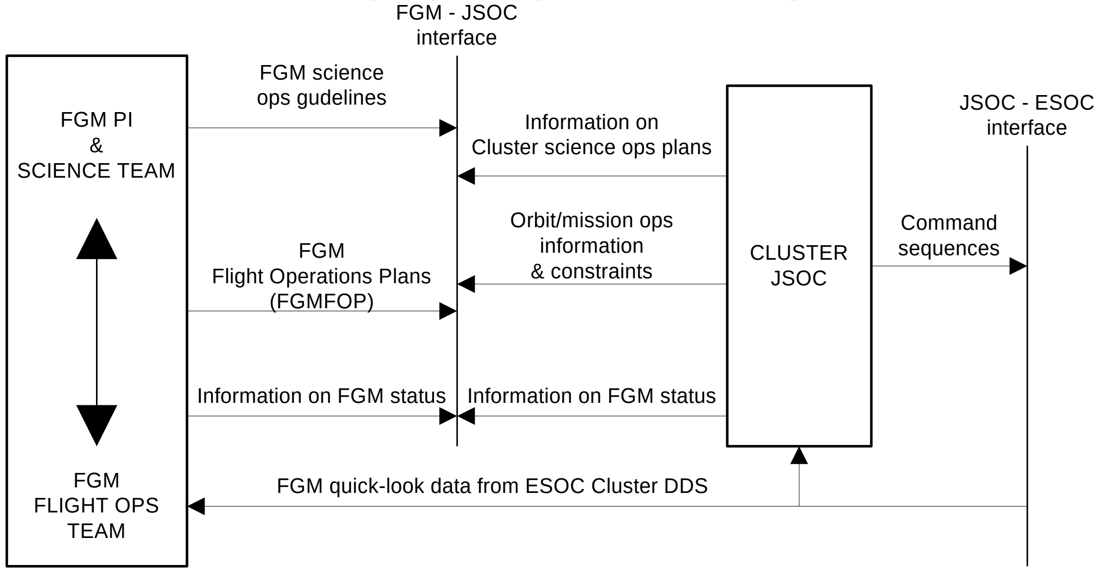

Figure 6-1, Methodology for Establishing FGMFOP

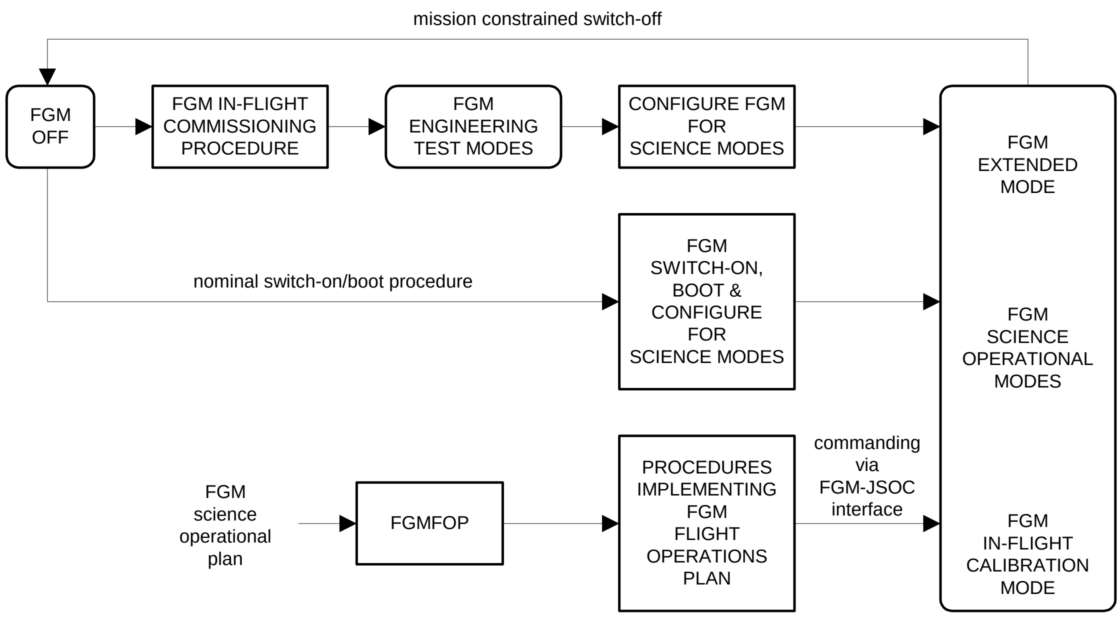

Figure 6-2, FGM Nominal Operational Modes, Top-level Structure

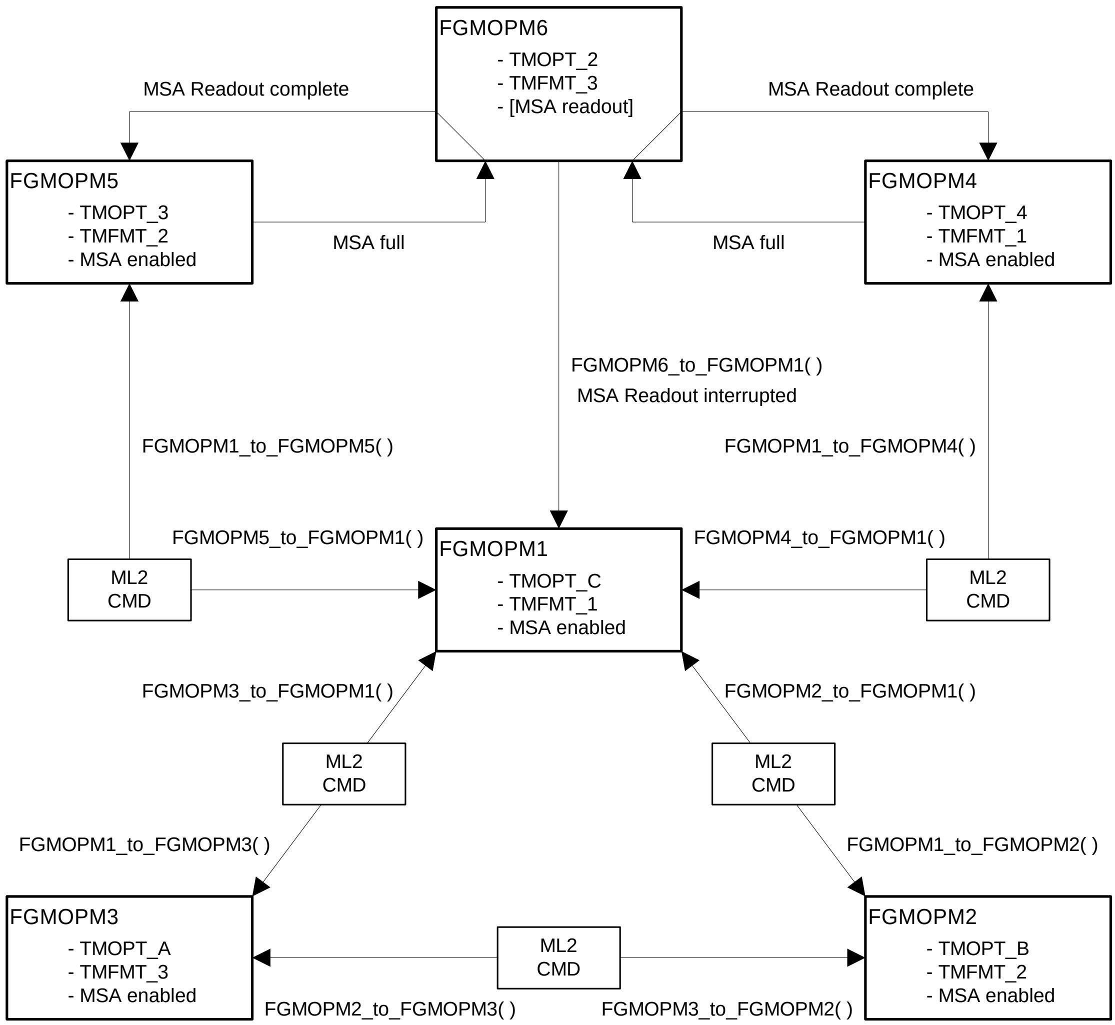

Figure 6-3, FGM Operating Modes in S/C Telemetry Modes NM1, NM2, NM3 and BM2

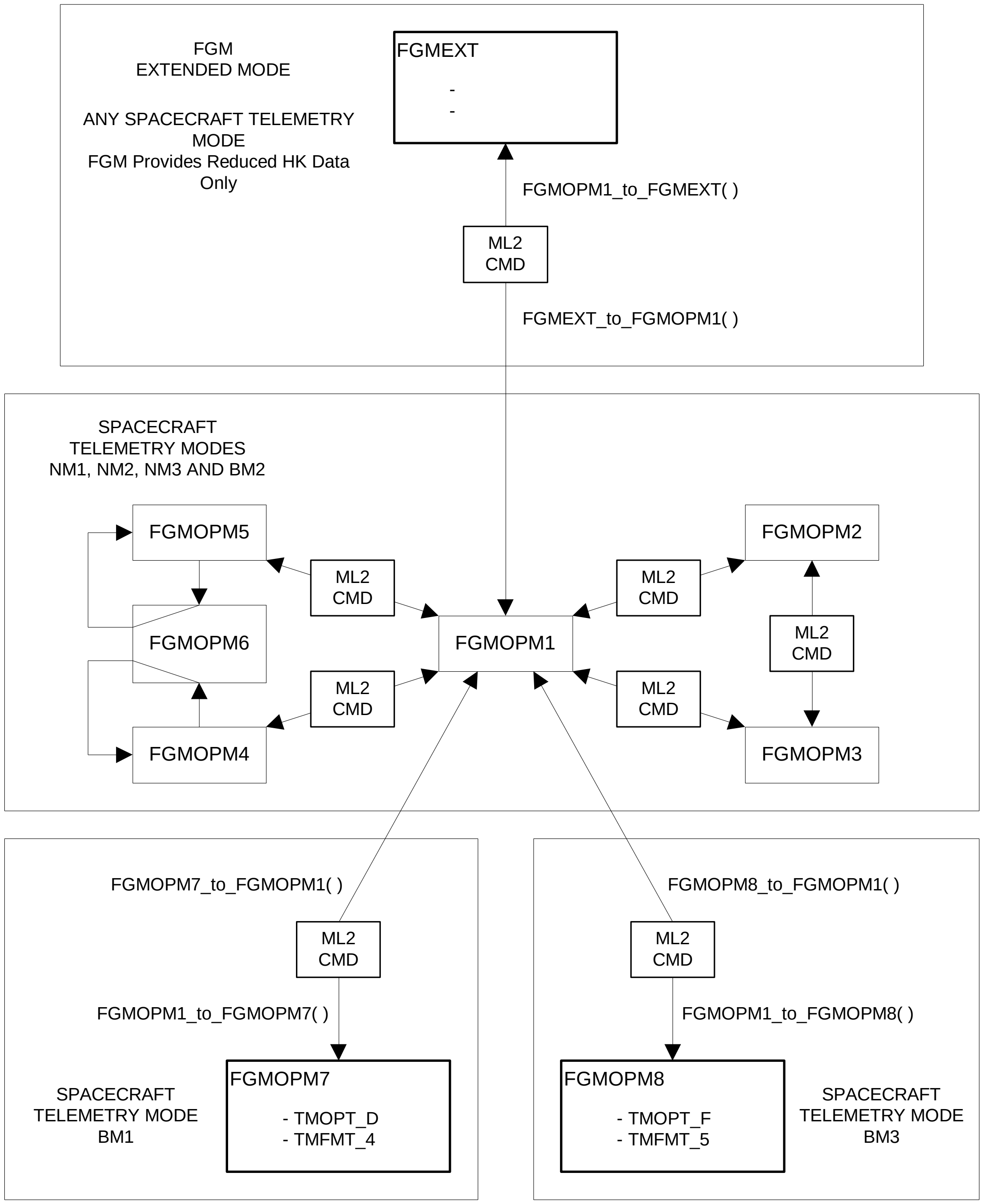

Figure 6-4, FGM Operating Modes in S/C Telemetry Modes BM1, BM3 and Extended Mode

FGM Engineering Modes will only be used as part of the in-flight commissioning procedure, software patches and during failure recovery or troubleshooting operations. For more details, see Sections 5 and 7.

The two flowcharts in Figures 6.3 and 6.4 show the allowed transitions between the different science operating modes.

6.1.1 Mode FGMOPM1

6.1.1.1 Description of mode FGMOPM1

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	C	1	116	16	0

In this mode, science data are transmitted only from the primary and secondary sensors. While the MSA may be enabled, and may be operated, no data from the MSA are transmitted. The objective of this mode is to maximise the acquisition rate of magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration command sent during the instrument boot). The instrument remains in this mode until a new Telemetry Option Command is sent to the FGM.

FGMOPM1 is the FGM default operating mode. The instrument is left in this mode at the completion of the boot sequence. If the telemetry mode of the spacecraft is not one of the set defined above, the instrument will function correctly but it will not make optimum use of the available telemetry.

Science packet format (TMFMT_1) corresponding to mode FGMOPM1 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	5491	5220
Unused	5492	5503	12
Secondary Vectors	5504	6223	720
Unused	6224	6239	16

Commanding frequency and use of this mode will depend on the FGMFOP.

6.1.1.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.1.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.2 Mode FGMOPM2

6.1.2.1 Description of mode FGMOPM2

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	B	2	95	37	0

In this mode, science data are transmitted only from the primary and secondary sensors. While the MSA may be enabled, and may be operated, no data from the MSA are transmitted. The objective of this mode is to acquire magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration commands sent after boot) and also, simultaneously, a significant number of vectors from the secondary sensor. It is only to be used in the indicated telemetry modes.

Until a new Telemetry Option Command is sent to the FGM, the instrument remains in this mode.

Science packet format (TMFMT_2) corresponding to mode FGMOPM2 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	4546	4275
Unused	4547	4559	13
Secondary Vectors	4560	6224	1665
Unused	6225	6239	15

Commanding frequency and use of this mode will depend on the FGMFOP (but is not expected to be used routinely).

6.1.2.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.2.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.3 Mode FGMOPM3

6.1.3.1 Description of mode FGMOPM3

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	A	3	81	6	128

In this mode, science data are transmitted from the primary and secondary sensors and also read out from the MSA. The objective of this mode is to acquire magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration commands sent after boot) and also, simultaneously, a small number of vectors from the secondary sensor. Its role is to allow the readout of the MSA at a slow rate, while acquiring normal science data. It is only to be used in the indicated telemetry modes.

Until a new Telemetry Option Command is sent to the FGM, the instrument remains in this mode.

Science packet format (TMFMT_3) corresponding to mode FGMOPM3 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	3916	3645
Unused	3917	3919	3
Secondary Vectors	3920	4189	270
Unused	4190	4191	2
MSA data	4192	6239	2048

Commanding frequency and use of this mode will depend on the FGMFOP.

6.1.3.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.3.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.4 Mode FGMOPM4

6.1.4.1 Description of mode FGMOPM4

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	4	1	116	16	0

In this mode, science data are transmitted only from the primary and secondary sensors. The MSA is enabled and operated, but no data from the MSA are transmitted. However, if an appropriate event is detected, resulting in the recording of the event, and the MSA is frozen, the FGM automatically exits from this mode into FGMOPM6 for the readout of the MSA data. The objective of this mode is to maximise the acquisition rate of magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration command sent after boot), while allowing the MSA to operate. It is only to be used in the indicated telemetry modes.

The instrument remains in this mode until either a new Telemetry Option Command is sent to the FGM or the MSA is frozen, having detected an event. When the MSA readout is complete, mode FGMOPM4 is re-entered from FGMOPM6.

Science packet format (TMFMT_1) corresponding to mode FGMOPM4 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	5491	5220
Unused	5492	5503	12
Secondary Vectors	5504	6223	720
Unused	6224	6239	16

Commanding frequency and use of this mode will depend on the FGMFOP.

6.1.4.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.4.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.5 Mode FGMOPM5

6.1.5.1 Description of mode FGMOPM5

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	3	2	95	37	0

In this mode, science data are transmitted only from the primary and secondary sensors. The MSA is enabled and operated, but no data from the MSA are transmitted. However, if an appropriate event is detected, resulting in the recording of the event, and the MSA is frozen, the FGM automatically exits from this mode into FGMOPM6 for the readout of the MSA data. The objective of this mode is to acquire magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration commands sent after boot) and also, simultaneously, a significant number of vectors from the secondary sensor, while allowing the operation of the MSA. It is only to be used in the indicated telemetry modes.

The instrument remains in this mode until either a new Telemetry Option Command is sent to the FGM or the MSA is frozen, having detected an event. When the MSA readout is complete, mode FGMOPM5 is re-entered from FGMOPM6. Commanding the FGM can overwrite this mode, but such commanding is not expected in normal operation.

Science packet format (TMFMT_2) corresponding to mode FGMOPM5 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	4546	4275
Unused	4547	4559	13
Secondary Vectors	4560	6224	1665
Unused	6225	6239	15

Commanding frequency and use of this mode will depend on the FGMFOP (but is not expected to be used routinely).

6.1.5.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.5.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.6 Mode FGMOPM6

6.1.6.1 Description of mode FGMOPM6

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
NM1, NM2, NM3 or BM2	2	3	81	6	128

In this mode, science data are transmitted from the primary and secondary sensors and read out from the MSA acquired previously in modes FGMOPM4 or FGMOPM5. The objective of this mode is to acquire magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration commands sent after boot) and also, simultaneously, a small number of vectors from the secondary sensor. Its role is to allow the readout of the MSA at a slow rate, while acquiring normal science data. It is only to be used in the indicated spacecraft telemetry modes.

FGMOPM6 is entered from either FGMOPM4 or FGMOPM5, when the contents of the MSA as been frozen by an event detection algorithm. When the contents of the MSA as been read out the instrument returns to the mode from which it came, either FGMOPM4 or FGMOPM5. The automatic switching can be interrupted by commanding the instrument into FGMOPM1.

Science packet format (TMFMT_3) corresponding to mode FGMOPM6 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	3916	3645
Unused	3917	3919	3
Secondary Vectors	3920	4189	270
Unused	4190	4191	2
MSA data	4192	6239	2048

Use of this mode in nominal operations will depend on the FGMFOP.

6.1.6.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.6.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.7 Mode FGMOPM7

6.1.7.1 Description of FGMOPM7

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
BM1	D	4	348	41	0

In this mode, science data are transmitted only from the primary and secondary sensors. The objective of this mode is to maximise the acquisition rate of magnetic field vectors from the primary sensor (which can be either the outboard or the inboard sensor, depending on the configuration command sent after boot). It is only to be used in spacecraft telemetry mode BM1.

The instrument remains in this mode until a new FGM Telemetry Option Command is sent. If the telemetry mode of the spacecraft is not set to BM1 the instrument will function correctly but telemetry data will be lost.

Science packet format (TMFMT_4) corresponding to mode FGMOPM7 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
Primary Vectors	272	15931	15660
Unused	15932	15935	4
Secondary Vectors	15936	17780	1845
Unused	17781	17855	17

Commanding frequency and use of this mode depends only on the use of Burst Mode 1 operations by the spacecraft.

6.1.7.2 Operational constraints

The requirements for entering this mode are that the instrument be configured for science operations and that the spacecraft is operated in Burst Mode 1.

6.1.7.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.8 Mode FGMOPM8

6.1.8.1 Description of FGMOPM8

Used in spacecraft telemetry modes	FGM Telemetry Option	FGM Telemetry Format	Primary Vectors per Reset	Secondary Vectors per Reset	MSA Words per Reset
BM3	F	5	0	0	1781

In this mode, no direct science data are transmitted, only the contents of the MSA are dumped. It is only to be used in spacecraft telemetry mode BM3.

The instrument remains in this mode until a new FGM Telemetry Option Command is sent. If the telemetry mode of the spacecraft is not set to BM3 the instrument will function correctly but telemetry data will be lost.

Science packet format (TMFMT_5) corresponding to mode FGMOPM8 is as follows:

Data Type	Start Bit	End Bit	Duration
Auxiliary	0	271	272
MSA data	272	28767	28496

Commanding frequency and use of this mode depends only on the use of Burst Mode 3 operations by the spacecraft.

6.1.8.2 Operational constraints

The requirements for entering this mode are that the instrument be configured for science operations and that the spacecraft is operated in Burst Mode 3.

Note : The spacecraft telemetry mode must beset to BM3 **before** the instrument is set to FGMOPM8. If this is not done some of the stored data will be lost.

6.1.8.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.9 Mode FGMCAL

6.1.9.1 Description of mode FGMCAL

This mode is initiated nominally once per orbit (or at a slower rate, TBD) to check on the performance of the FGM instrument. In this mode, an internally generated calibration signal is applied to the primary sensor, following a pre-set sequence. The full sequence consists of 512 cycles of CAL ON and CAL OFF steps, with a 50% duty cycle. The frequency of the steps is one half of the Nyquist frequency of the current primary science output. The sequence is always terminated with a CAL OFF.

As an optional part of mode FGMCAL (to be used infrequently), the FLIP command is used instead of the CAL steps, acting on the primary sensor. In this option, 512 cycles of FLIP are executed at a fixed rate of one half Hertz, i.e. FLIP once per second. This sequence is always terminated by FLIP OFF.

6.1.9.2 Operational constraints

While maintaining nominal science output formats, data acquired during this time are not valid in a simple sense. Data acquired during FGMCAL will be reduced and analysed off-line by the FGM Flight Ops team, using the ESOC Cluster2 DDS quick-look facility.

During the operation of FGMCAL, data on the FGM IEL would not be valid, therefore the IEL outputs are inhibited for the duration of the mode. This constitutes an operational constraint on the instruments using the FGM IEL. The operation of mode FGMCAL will be co-ordinated with the IEL users, and scheduled accordingly in the FGMFOP.

6.1.9.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.1.10 Mode FGMEXT

6.1.10.1 Description of mode FGMEXT

In this mode, no science and only the first five words of housekeeping data are transmitted to the OBDH. The objective of this mode is to allow the FGM to take data during periods of no telemetry acquisition and store them for later transmission to ground. The coverage is extended by reducing the data storage rate to one averaged spin synchronised vector per spin.

FGMEXT is entered from FGMOPM1. Data is taken from the primary sensor only (which can be either the outboard or inboard sensor, depending on the configuration before entering this mode). Unlike other telemetry mode changes, to switch to this mode it is necessary to update an address in the parameter block. Upon termination of FGMEXT, the FGM returns to FGMOPM1.

During normal operations, extended data may be read out from the MSA as convenient using either FGMOPM3 or FGMOPM8.

Commanding frequency and use of this mode will depend on the FGMFOP.

6.1.10.2 Operational constraints

The only requirement for entering this mode is that the instrument is configured for science operations, and that the spacecraft is operated in the appropriate modes.

6.1.10.3 Resources required

This mode requires the nominal resources allocated to the FGM.

6.2 Operational Procedures

6.2.1 Nominal Operational Procedures

As described in Section 6.1.0, the FGM will be operated following a pre-established Flight Operations Plan (FGMFOP). In nominal operations, the FGMFOP will consist of a timelined series of ML commands, normally to change science operational modes as described above.

The FGMFOP needs to be matched to the spacecraft operational plan in terms of spacecraft telemetry mode changes:

- Change from (NM1 or NM2 or NM3 or BM2) to BM1: Initiate FGMOPM7
- Change from (NM1 or NM2 or NM3 or BM2) to BM3: Initiate FGMOPM8
- Change from (BM1 or BM3) to (NM1 or NM2 or NM3 or BM2): Initiate FGMOPM1

The timing of the changes is not critical. However, at any time when the instrument is generating more data than the spacecraft can accept, the FGM science telemetry will be corrupted.

The FGMFOP will also contain a full description of the timelined HK status and configuration data corresponding to the expected operational sequence.

On-line operations, with ground contact, are required only during instrument commissioning and instrument troubleshooting.

FGM power off/power on commands are executed by the instrument immediately. All FGM ML commands are executed on receipt of the next RESET pulse (max. delay 5.15222 s). FGM contains no stored command sequences.

All commands/sequences for transmission to FGM are generated exclusively by the FGM Flight Ops team, under the (delegated) responsibility of the FGM PI. Certified commands/sequences are stored at ESOC Cluster2 OCC and JSOC, together with the associated instrument condition/constraints for the specified commands/sequences. All stored commands/sequences and the associated instrument conditions/constraints for use at ESOC Cluster2 OCC and Cluster2 JSOC remain under configuration control, and changes can only be introduced after review and certification by the FGM Flight Ops team, under the (delegated) responsibility of the FGM PI.

Commands/sequences for instrument operation can be sent

- by ESOC Cluster2 OCC; pre-set FGM commands/sequences stored at ESOC Cluster2 OCC for transmission to FGM in response to pre-set instrument conditions/constraints (including instrument malfunctioning) or in response to pre-set spacecraft/mission conditions/constraints; FGM power off can be sent by ESOC Cluster2 OCC at any time;

- by ESOC Cluster2 OCC; commands/sequences constituting the FGM in-flight commissioning procedures and other commands/sequences as determined by the FGM Flight Operations team in response to instrument malfunction during troubleshooting

- by Cluster2 JSOC, via ESOC Cluster2 OCC; time-tagged combination of commands/sequences generated by the FGM Flight Operations team as part of an integrated and pre-determined FGM nominal science operations plan, defined by the FGM Science Team after iteration with other Cluster2 Science teams through the Cluster2 JSOC

6.2.2 Monitoring Requirements

The scientific performance of the instrument will be monitored by the FGM team on a continuous basis, using science data packets retrieved daily from the DDS (and in the longer term, the full data set on CDROM).

For day-to-day operations, it is necessary to monitor the instrument for both health/safety, and correct execution of the command timeline. For health and safety, this is performed:

- in real-time, on-board the spacecraft, for detection of 'safety-critical' faults;

- off-line at ESOC Cluster2 OCC, for detection of anomalies (i.e. events of operational significance which are not safety-critical).

- off-line, using data acquired over the network from the Cluster2 Data Disposition System by the FGM Flight Operations Team.

For verification of the timeline, this is the sole responsibility of the FGM team, and this will be performed on a daily basis using housekeeping data packets retrieved from the DDS.

The set of parameters which it is required to be monitored is described in Tables 6.2-1 and 6.2-2. For the purposes of monitoring these parameters, two levels of criticality are defined

1. Identification of safety-critical faults.
   This involves on board monitoring of HK packets. The action required is always to power-off the FGM. Monitoring consists of out of limit tests on the FGM voltages and temperature as well as providing for ADC latch-up detection (See Section 6.2.3).
2. Identification of anomalous events.
   This involves ground monitoring of HK and Science packets. This is off-line and will be performed by both ESOC and Imperial College. For ESOC, the action shall always be to alert the FGM team. Monitoring consists of both out of limit tests and status checks/consistency tests. The out of limit tests are identical to those of the onboard monitoring except that the limits are softer.

On-board monitoring shall identify faults liable to cause damage to the FGM instrument. This shall be a limited set of parameters to be monitored. When the FGM has been powered off, this shall be flagged to the FGM team as early as possible (see also section 8.1). Anomalies are events of operational significance, but which pose no immediate threat to the FGM hardware. These shall be checked for off-line at ESOC, and anomalies shall be reported to the FGM team.. The mode validity for each parameter is displayed in the right hand column of Tables 6.2-1 and 6.2-2. A logical test has been designed to indicate whether the FGM is in FGMEXT or not. This test is valid

(i) only if the FGM is powered on
(ii) only for purposes of off line monitoring

WORD 2 Valid

The FGM house keeping packet is made up of 15 words (16 bits each) which are numbered 0 to 14. When the FGM is in FGMEXT the packet validity is as follows

WORD 0	Not valid
WORD 1	Valid
WORD 3	Valid
WORD 4	Valid
WORD 5	Not Valid
WORD 6	Not Valid
WORD 7	Not Valid
WORD 8	Not Valid
WORD 9	Not Valid
WORD 10	Not Valid
WORD 11	Not Valid
WORD 12	Not Valid
WORD 13	Not Valid
WORD 14	Not Valid

The test to see if the FGM is in FGMEXT is

IF ((WORD1 **OR** WORD2 **OR** WORD3 **OR** WORD4) ≠ 0) **AND** ((WORD5 **AND** WORD6 **AND** WORD7 **AND** WORD8 **AND** WORD9 **AND** WORD10 **AND** WORD11 **AND** WORD12 **AND** WORD13 **AND** WORD14)= 0) THEN

Set 'derived parameter' = 0 → FGM is in FGMEXT **ELSE**

Set 'derived parameter' = 1 → FGM is not in FGMEXT

6.2.3 Note on ADC latch-up

The ADC device used on the FGM ADC cards can be prone to latch up in the space environment. Measures have been taken to detect a latch up state and protect the device from permanent damage. These measures are as follows.

1. During latch up, the ADC device will draw between 10 and 100 times the nominal operational current. The nominal current consumption of the Crystal ADC device is 12mA which will increase to at least 120mA during latch up. The current trip on the ADC card power switch is set at approximately 100mA, which would then switch off the ADC card if the device goes into a latched up state. The current trip on the power switch is also set to trip after 10mS, giving good protection of the device.

2. In a latched up state the ADC device will cease to convert analogue inputs to digital outputs. This will be seen by the FGM software as a convert timeout error and will cause the software to switch off the ADC card.

3. If the ADC device is in a latched up state but continues to convert values, the output of the ADC device and therefore the ADC card will have a high noise content. Since the PSU voltages (+12v, -12v and +5v) are sampled by the ADC card, stringent monitoring of these values with tight upper and lower limits will give warning that latch up has occurred and the ADC card can be switched off. These voltages are also monitored on board the spacecraft so will protect the ADC during periods of orbit with no ground contact

4. The state of latch up which does not draw enough current to trip the ADC card power switch, does not cease conversion and also does not introduce enough noise on all three housekeeping voltage values to signal an alarm has been deemed to be very unlikely indeed.

We can therefore conclude that latch up of the ADC device is well protected against in all likely scenarios.

FGM Parameter Monitoring

Table 6.2-1On board (safety critical) monitoring parameters

Monitoring item	AIT Parameter	Action limits		Monitoring frequency	Action	Validity
		Upper limit	Lower limit			
+5V	EF3PL05V	6.6V	4.4V	Once every **3** resets	Action level exceeded for 2 successive samples ⇒ power FGM off	Nominal & Extended modes
+12V	EF3PL12V	15.0V	12.0V	Once every **3** resets	Action level exceeded for 2 successive samples ⇒ power FGM off	Nominal & Extended modes
–12V	EF3MN12V	-11.6V	-15.5V	Once every **3** resets	Action level exceeded for 2 successive samples ⇒ power FGM off	Nominal & Extended modes
Temperature	EF3PTEMP	60ºC	-25ºC	Once every **12** resets	Action level exceeded for 2 successive samples ⇒ power FGM off	Nominal & Extended modes

Table 6.2-2A Off line (anomalous events) monitoring parameters: Out of limit checks.

Monitoring item	**AIT Parameter**	**Action limits**		**Monitoring frequency**	**Action**	**Validity**
		Upper limit	**Lower limit**			
+5V	EF3PL05V	6.05V	4.95V	Every reset	Action level exceeded for 4 successive samples ⇒ inform FGM team	Nominal & Extended modes
+12V	EF3PL12V	13.75	12.25V	Every reset	Action level exceeded for 4 successive samples ⇒ inform FGM team	Nominal & Extended modes
Temperature	EF3PTEM P	40ºC	-10ºC	Every reset	Action level exceeded for 2 successive samples ⇒ inform FGM team	Nominal & Extended modes

Table 6.2-2B Off line (anomalous events) monitoring parameters: Status checks.

Monitoring item	AIT Parameter	Action condition	Monitoring frequency	Action	Validity
Primary X channel saturation	EF3PRIMX	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
Primary Y channel saturation	EF3PRIMY	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
Primary Z channel saturation	EF3PRIMZ	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
Secondary X channel saturation	EF3SECOX	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
Secondary X channel saturation	EF3SECOY	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
Secondary X channel saturation	EF3SECOZ	0x7F **OR** 0x80	Every reset	Action condition detected for 4 successive samples ⇒ inform FGM team	Nominal mode
SEU count	EF3SEUCT	≠ 0x0	Every resets	Action level exceeded for 2 successive samples ⇒ inform FGM team	Nominal mode
Interface fault	EF3INTFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
RAM check fail	EF3RAMFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
MSA fault	EF3MSAFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
ADC fault (reset)	EF3ADCFR	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
ADC fault (timeout)	EF3ADCFT	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
ADC fault (busack)	EF3ADCFB	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
Monitoring item	**AIT Parameter**	**Action condition**	**Monitoring frequency**	**Action**	**Validity**
No reset pulse	EF3NORES	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode

No start up words	EF3NOSTP	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
DPU fault	EF3DPUFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
IEL fault	EF3IELFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
Sumcheck error	EF3SUMFL	TRUE	Every reset	Status check fail ⇒ inform FGM team	Nominal mode
Reset count	EF3RESET	Not incrementing with s/c reset pulse	Every reset	Status check fail ⇒ inform FGM team	Nominal and Extended modes

		From								
		FGMOPM1	FGMOPM2	FGMOPM3	FGMOPM4	FGMOPM5	FGMOPM6	FGMOPM7	FGMOPM8	FGMEXT
To	FGMOPM1	-	FGMOPM2_to_FGMOPM1()	FGMOPM3_to_FGMOPM1()	FGMOPM4_to_FGMOPM1()	FGMOPM5_to_FGMOPM1()	FGMOPM6_to_FGMOPM1()	FGMOPM7_to_FGMOPM1()	FGMOPM1_to_FGMOPM8()	FGMEXT_to_FGMOPM1()
	FGMOPM2	FGMOPM1_to_FGMOPM2()	-	FGMOPM3_to_FGMOPM2()	-	-	-	-	-	-
	FGMOPM3	FGMOPM1_to_FGMOPM3()	FGMOPM2_to_FGMOPM3()	-	-	-	-	-	-	-
	FGMOPM4	FGMOPM1_to_FGMOPM4()	-	-	-	-	Automatic	-	-	-
	FGMOPM5	FGMOPM1_to_FGMOPM5()	-	-	-	-	Automatic	-	-	-
	FGMOPM6	-	-	-	Automatic	Automatic	-	-	-	-
	FGMOPM7	FGMOPM1_to_FGMOPM7()	-	-	-	-	-	-	-	-
	FGMOPM8	FGMOPM1_to_FGMOPM8()	-	-	-	-	-	-	-	-
	FGMEXT	FGMOPM1_to_FGMEXT()	-	-	-	-	-	-	-	-

Table 6.2-3 FGM mode changes

6.3 Planning sequences

Routine commanding of an FGM instrument is to be carried out in terms of a set of 'parameterised command sequences'. These are set out in document ref. IC\CLUSTER2\A95-0002.DOC, which is attached as Appendix G. In addition, two further command sequences are provided; they are the 'commissioning procedure' (see Appendix B) and the 'default boot sequence' (see Appendix C). These command sequences provide all the necessary controls for the normal operation of an instrument.

Modifications or additions to these defined command sequence should be necessary only in the event of a hardware failure.

7. Critical operations

7.1 Short eclipses

Power sensor heaters during eclipse

Provided that the magnetometer is powered it can record data, therefore operational mode FGMEXT may be requested during eclipses.

7.2 Long eclipses

As 7.1 Short eclipses.

If the instrument is primary power is switched off during a long eclipse, it should be switched on, following the eclipse, using the default boot sequence (Type 2).

7.3 Perigee passes

No special requirements

7.4 Manoeuvres

No special requirements

7.5 Patching software

7.5.1 Loading the code patch

See Appendix A:- SRD section 2.6

7.5.2 Verification of code patch loading

A code patch block contains a sum-check which verifies that the data to be patched has been received correctly. In addition, it contains an update of the value of the sum-check for all of the code held in the RAM of the processor. The processor runs a continuous sum check on its code space and reports the result in the housekeeping telemetry stream.

7.5.3 Validation of code patch sequences

Code patch sequences will be generated and tested in the same way as all other command strings sent to the instrument. See section 6.

7.5.4 Reload of software at power on

This instrument has no 'keep alive line', therefore, all code patches will be lost when the instrument is powered off.

7.5.5 Constraints

The maximum length of the block to be patched is 64 words, excluding the header. A code patch block must be loaded into the instrument within 16 RESET periods. A maximum of 255 ML2 commands can be loaded into the instrument in a single RESET period.

8. Contingency operations

8.1 Failure analysis

The FGM as been built with a high level of redundancy so it is possible to overcome a wide variety of failures. The telemetry provides a means of monitoring the instrument to identify when a fault has occurred but it does not immediately identify where the fault is. That can be achieved only by repeatedly sending commands and checking their effect in the housekeeping, until the fault as been isolated. Clearly, it is not practical to produce a trouble shooting chart, the combinations of faults, commands and parameters quickly become unmanageable. It is for this reason that the Fig 6.2 specifies an 'Engineering Mode' in which faults can be traced under the direct control of the FGM hardware team.

Table 8-1 describes the effect of a small number major failures which might occur. However, the instrument development programme has shown that the majority of faults are more subtle and more localised. In many cases a failure will not require an entire functional block be switched off. Although, it might be decided that this is the most efficient solution.

Functional block	**Type of fault**	**Recovery action**	**Loss of functionality following recovery**
INT1	Total failure	Route all digital signals via the redundant path. Reconfigure or reboot instrument to use redundant interface.	IEL data must be driven from INT2 and all users must accept the same clock speed.
INT2	Total failure	Route all digital signals via the main path. Reconfigure or reboot instrument to use redundant interface.	IEL link to EDI is lost.
DPU1	Total failure	Switch off DPU1 via ZEF1 command. Boot DPU2.	None
DPU2	Total failure	Switch off DPU2 via ZEF1 command. Boot DPU1.	None
ADC1	Total failure	Switch off ADC1 via ZEF1 command and configure instrument to gather data on ADC2.	None
ADC2	Total failure	Switch off ADC2 via ZEF1 command and configure instrument to gather data on ADC1.	None
MSA	Total failure	Switch off MSA via ZEF1 and disable event detection software.	Loss of MSA data.
Bus 1	Total failure	Switch off ADC1 via ZEF1 command, and configure instrument to use Bus 2 and ADC2.	None

Bus 2	Total failure	Switch off ADC2 via ZEF1 command, and configure instrument to use Bus 1 and ADC1.	None
OB sensor	Total failure	Set IB sensor to primary.	Loss of secondary sensor data.
IB sensor	Total failure	Set OB sensor to primary.	Loss of secondary sensor data.
PS 1	Total failure	S/c to switch off primary power 1 and converter Sync. 1, then turn on primary power 2 and converter Sync. 2. Reboot instrument.	None
PS 2	Total failure	S/c to switch off primary power 2 and converter Sync. 2, then turn on primary power 1 and converter Sync. 1. Reboot instrument.	None
Sensor heater	Total failure	The sensor heater is not redundant. However, powering the instrument causes some power to be dissipated in the sensors.	Extremely low tempera-tures (-100^{o}C) may disturb the calibration of the instrument.
OB thermistor	Total failure	In the deployed condition, the temperature of the sensors should be similar, so data from the other sensor could be used. In the stowed condition, will have to be estimated based degree of solar illumination.	Excessively high tempera-tures can soften the sensor mountings and disturb the alignment. Extremely low tempera-tures (-100^{o}C) may disturb the calibration of the instrument.
IB thermistor	Total failure	In the deployed condition, the temperature of the sensors should be similar, so data from the other sensor could be used. In the stowed condition, will have to be estimated based degree of solar illumination.	Excessively high tempera-tures can soften the sensor mountings and disturb the alignment. Extremely low tempera-tures (-100^{o}C) may disturb the calibration of the instrument.

Table 8.1-1 Failure types and recovery actions

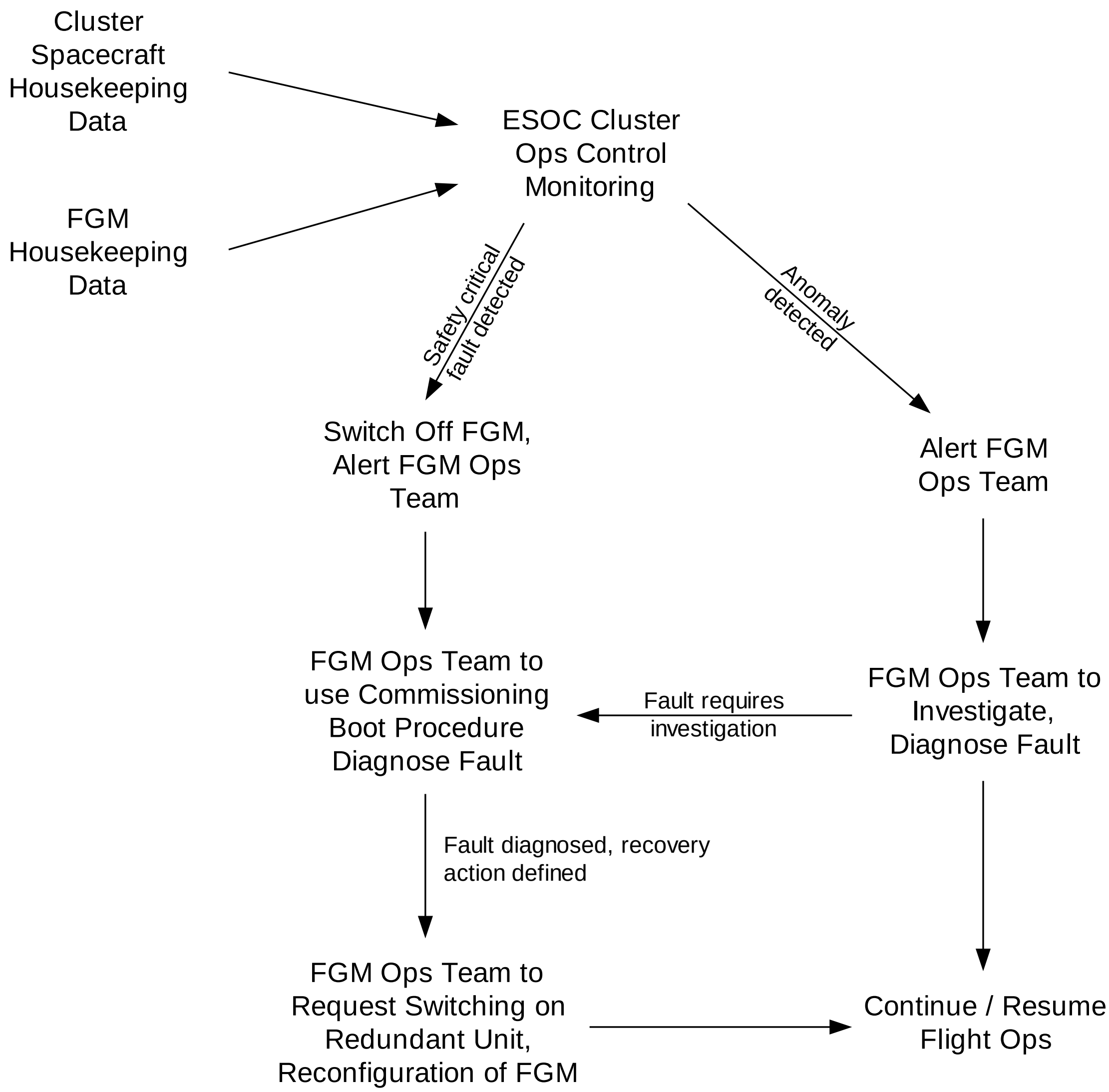

Figure 8-1, FGM Flight Operations Contingency Handling

8.2 Instrument failure recovery

The high level of redundancy, within each FGM instrument, provides many combinations of settings to enable failure recovery. Despite the size of the problem the initial path taken is the same in all cases. The general approach is to find as much information as possible about the nature of the problem and then to select a means of recovering from it. In many instances the solution will be to switch off the functional block in which a problem has occurred. However, in the event of a second failure, it may be necessary to use some remaining functions in the block where the original failure was found. The initial fault must be characterised as soon as it is found in-case a second failure makes analysis impossible.

Assuming that an instrument has been switched off, following the discovery of a fault, the recovery procedure is very similar to the commissioning procedure. The same steps will need to be executed up to the point at which an incorrect response is seen. The only difference is that 'wait' is needed after each step so the response of the instrument can be checked. From that point at which an abnormal response is seen it is the responsibility of the FGM team to identify extra commands which should be sent to further isolate the problem and to remove commands from the remainder of the commissioning procedure which it would be inappropriate to send. The baseline is that as much of the commissioning procedure should be executed as is permitted by the fault observed.

While the above process is being performed, the FGM may be described as being in 'Engineering Mode'. Once the hardware fault has been located, a new hardware configuration which isolates the fault will be defined. This becomes the new default operating mode (FGMOPM1). The sequence of commands required to power FGM on into FGMOPM1 will be re-defined. Since all the other Op Modes are independent of this hardware configuration, the command sequences required to move from one Op Mode to another are unchanged.

8.2.1 Autonomous Failure Recovery

The only automatic failure recovery sequence built into the instrument relates to the ADC unit. If a DPU reads an ADC which it expects to be active and fails to receive the correct response, it turns the ADC off and waits for the next spacecraft RESET signal. Following the RESET it waits a further 2.5 Sec. before turning on the ADC power and initialising the unit. This function was included to protect the ADC against particle induced latch-up, to which the one component in the converter is susceptible.

8.3 Contingency procedures

The procedure for handling contingencies is given in figure 8.1. The set of parameters which require to be monitored is given in section 6. For contingency procedures, two levels of criticality are defined:

1. Identification of safety-critical faults.
   Monitoring on-board is required; the action required is always to power-off the FGM.
2. Identification of anomalous operation of the FGM.
   For off-line monitoring at ESOC and Imperial College. For ESOC, the action shall always be to alert the FGM team.

On-board monitoring shall identify faults liable to cause damage to the FGM instrument. This shall be a limited set of parameters to be monitored. When the FGM has been powered off, this shall be flagged to the FGM team as early as possible. Anomalies are events of operational significance, but which pose no immediate threat to the FGM hardware. These shall be checked for off-line at ESOC, and anomalies shall be reported to the FGM team.

Section 6 defines the monitoring required to be performed on-board the spacecraft and off-line at ESOC. The only contingency procedure as a result of monitoring to be applied by ESOC shall be to power-off the FGM. There is one other contingency procedure which has been defined at this stage. It is called by the ESOC Boot Type 2 sequence if the FGM patches have not uplinked correctly and is outlined below.

Contingency Procedure 2

This procedure can be called during the sequence 1SFGMSPAT as part of the Boot Type 2 sequence 1SFGMM000. It should be executed if an error has occurred during the uplink of the IPCH files. This can be triggered in two ways, either the assertion of the code patch fail flag, AIT <EF3PATFL>, or the assertion of a sumcheck error flag during step 24 of 1SFGMSPAT. The procedure basically consists of powering the FGM off and repeating the boot up sequence.

Step	Action
1	Power off FGM using dedicated OBDH macro
2	Check LCL FGM A STATUS A= OFF

	Check LCL FGM B STATUS B = OFF
3	Wait 10 seconds
4	Run sequence 1SFGMM000
5	Inform FGM team

Appendix A - Software Requirements Document

Appendix B - Commissioning Procedure

Appendix C - Instrument boot sequences

Appendix D - Paper : On the analysis...

Appendix E - Paper : The Cluster2 configuration...

Appendix F - FGM Input to AIT Database - Telecommands

Appendix G - FGM Input to AIT Database - HK Parameters

Appendix H - FGM Input to AIT Database - Use of HK analogue parameters.

Appendix I - Parameterised Command Sequences

Appendix J Instrument Patches