XMM Optical Monitor

MULLARD SPACE SCIENCE LABORATORY
UNIVERSITY COLLEGE LONDON

Author: Mark Cropper

USER REQUIREMENTS SPECIFICATION

DOCUMENT: XMM-OM/MSSL/SP/0030.02 22-Mar-95

CHANGE RECORD

ISSUE	DATE	PAGES CHANGED	COMMENTS
1	24-May-94	all	comments from **HEH** and **SH** included
2	22-Mar-95	Table 1	changes to telemetry types supported and to permit activation of the filter wheels in idle state
		all	removal of references to red beam-steering mechanism
		2	Idle state redefined slightly
		reqt 20000/34	quantisation changed from 8 to 16 pixels
		Figure 2	changed to restrict to synchronous blue/red exposures only
		reqt 20000/48	deleted as no longer required because synchronous blue/red exposures
		5	text modified so as not to restrict data format in FAST MODE
		reqt 20000/54	requirement modified so as not to restrict data format in FAST MODE
		reqt 20000/60	requirement modified so as not to restrict data format in FAST MODE
		reqt 20000/72	item 11 deleted as no longer required because synchronous blue/red exposures
		reqt 20000/79	corrected so as ICU not DPU holds telemetry information
		reqt 20000/90	added
		all	clarifications in response to e-mail from C Ho 30 Mar 95 and response from M Cropper on 2 Apr 95

Contents

1 Introduction **1**

2 Reference Documents **1**

3 Overview **1**

4 Initial Status **2**

5 Safe **2**

6 Idle **2**

7 Science **2**

7.1 Overview 2

7.2 Windows and Binning 3

7.3 The Observing Sequence 3

7.4 Field Acquisition 3

7.5 Tracking 4

7.6 Science Modes 4

7.6.1 Blue Image Mode 5

7.6.2 Blue Fast Mode 5

7.6.3 Red Image Mode 5

7.6.4 Red Fast Mode 5

7.7 Submodes 6

7.8 Mode Combinations 6

7.9 Exposure control 6

7.10 Data file structures 6

8 Engineering and Calibration **7**

9 Telemetry **8**

10 Telecommand **9**

11 Deleted Requirements **9**

1 Introduction

The ^{XMM}OM is a UV/optical telescope which forms part of the instrument package for the XMM observatory, an ESA Cornerstone mission due for launch in 1999. The instrument consists of a Telescope Module, which contains all the optics, mechanisms and detectors, and an external redundant pair of Digital Electronics Modules, which are responsible for the control of the instrument and the data processing.

In order to meet the scientific requirements in XMM-OM/MSSL/SP/0001, the ^{XMM}OM is required to function appropriately and ensure its own safety and that of the XMM observatory. The technical requirements for the instrument are set out in the Technical Requirements Specification (XMM-OM/MSSL/SP/0009) and the documents called up thereunder. This User Requirements Specification provides the functional requirements for the ^{XMM}OM . It is based on and supercedes entirely the discussion in the Observing and Telemetry Modes document (XMM-OM/MSSL/TC/0007.02).

2 Reference Documents

XMM-OM/MSSL/SP/0001 – ^{XMM}OM Science Requirements Specification
XMM-OM/MSSL/SP/0009 – ^{XMM}OM Technical Requirements Specfication
XMM-OM/MSSL/TC/0007 – ^{XMM}OM Operating and Telemetry Modes Document
XMM-OM/MSSL/TC/0028 – XMM Drift Characteristics

3 Overview

In order to function appropriately and insure its own safety, the ^{XMM}OM will always be in one of five states (in the sense that states are mutually exclusive) which apply to the instument as a whole.

20000/23: The ^{XMM}OM will support the following states:-

1. *Initial Status;*
2. *Safe;*
3. *Idle;*
4. *Engineering and Calibration;*
5. *Science.*

20000/24: The condition of the instrument in each of these stages shall be as specified in Table 1.

The State Transition Diagram is shown in Figure 1. Transitions between modes are shown as either normal (under command) or emergency (self- triggered).

20000/25: The ^{XMM}OM will support the both Normal transitions under command, and Emergency transitions originated autonomously by the instrument.

Each state may contain activities to configure it on entry and exit. These activities shall be as specified in Figure 1.

20000/26: The transitions between states and the activities to be performed on entry and exit from the state shall be as specified in Figure 1.

It is imperative that the safety of the instrument be assured at all times.

20000/27: Any condition endangering the safety of the instrument shall trigger an emergency transition to the safe state.

20000/28: Transitions between states shall be possible either under direct or under deferred telecommand.

4 Initial Status

The aim of the Initial Status state is to support the option of direct memory access from the spacecraft, along the lines indicated in the OBDH Users Guide issue 1.1 (RS-PX-0015). XMM Instruments are required by ESA to support a minimal level of self-check, testablility and responsiveness without dependence on the keep-alive power supply. Initial Status will therefore support telecommand from and housekeeping telemetry to the spacecraft interface as specified in Table 1. It will also support the provision of dummy science data packets to the spacecraft interface.

20000/29: On application of power to at least one of the redundant 28V power lines, the configuring for the Initial Status state will be supported without the need to download code from memory dependent on the Keep- Alive Line.

On exiting from the Initial Status state, the remainder of the code for the ICU and DPU will be loaded and the thermal control system will switch to closed loop operation.

5 Safe

On entry to the safe state the blue detector EHT will always be switched off and the filter wheels rotated to their reference blocked position. In the Safe State, the instrument will be configured as for data acquisition, except that the blue detector high voltage supplies will be off, no data will be acquired and the filter wheels will be in the blocked position. It will be possible to command the Peltier cooler on or off, with the default being off. Any backlog science data may be transmitted.

6 Idle

On entry into the Idle state, the blue detector EHT will be activated, and the Peltier cooler switched on if it is not on already. The ICU will command the DPU to enter its standby mode.

In the Idle State the instrument will be configured as for the Science state, so that the selected blue detector high voltage will be active and the Peltier cooler will be on. The filter wheels will now be commandable. Idle state differs from the Science state only in that data is not actively being taken.

7 Science

7.1 Overview

It is recognised that the planned long operational life of the XMM observatory requires the maximum flexibility to be maintained for the observer. This has to be traded against the extra complexity this entails, which should be minimised.

^{XMM}OM has two types of detector, a photon counting device in the blue beam, and an integrating device in the red beam. These detectors differ in that the red beam detector will never be read out sufficiently fast for a high time resolution to be achieved, and it is therefore not feasible or possible to incorporate a very high time resolution mode. In addition, the red detector traps cosmic rays, and these have to be removed by processing. Otherwise the aim is to maintain as much symmetry between the modes for the two detectors as possible, in order to simplify and maximise the choices for the observer.

It is important to note the the manner in which the astronomical data are transferred to the DPU is different in the case of the blue and red detectors. In the case of the blue detector the data are transferred event by event: since these can occur randomly over the full area of the detector, positional information must be supplied for each event, but no intensity information is required. In the case of the red detector, integration occurs on the detector and the information passed to the CCD is a series of intensities corresponding to adjacent pixels, so no positional information is required, only the intensity information. In the case of the blue detector, the events have to be processed in real-time. The amount of processing required places constraints on the way this is managed. On the other hand, because the integration is taking place in the DPU memory, more flexible operation (in particular, more than one observing mode) is possible. The red detector exposure integration takes place on the CCD, so only one observing mode is possible.

7.2 Windows and Binning

Given the large format of the detectors, it will neither be possible to store information from the entire active area, nor would it be possible to transmit it to the ground in a reasonable time. It will therefore be required to provide the capability for the observer to select of areas of interest over the X-ray field of view (windows). In order to supply sufficient flexibility and to provide a tracking capability (see below), support for up to 15 separate windows will be required.

To further increase the accessibility of the field of view, and to reduce the resources required to process and transmit the data, it shall be possible to bin pixels at the detectors (by a factor of 2×2) and within the DPU (by factors of $2^n \times 2^m$, $1 \leq (n, m) \leq 3$ and n, m integer). It shall be possible to provide different binning factors for each window.

20000/30: It shall be possible to acquire data from up to 15 areas (windows) within the field of view of both red and blue detectors in the Science state.

20000/31: It shall be permitted for two windows to overlap if one is fully superimposed, but not if it is partially superimposed.

20000/32: It shall be possible to pre-bin pixels at the detectors (by a factor of 2×2*).*

20000/33: Each exposure shall utilise no more than the available memory.

20000/34: Window sizes will be quantised in units of 16 unbinned detector pixels.

20000/35: It shall be possible to bin pixels within the DPU by factors of $2^n \times 2^m$*,* $0 \leq (n, m) \leq 2$ *and* n, m *integer and different for each window.*

20000/36: The binning factor within any window will be constant.

7.3 The Observing Sequence

The observing sequence is given in Figure 2. This considers a typical orbit to start at perigee, and while the spacecraft is below operational altitude, no scientific observations can take place. Above the operational altitude, orbit will be broken up into several *pointings*, each separated by a spacecraft slew. Each pointing will generally (but not necessarily) consist initially of an acquisition phase followed by several exposures in both red and blue detectors, each commencing with by an opportunity to select different windows or filters,(see Figure 2). The blue and red exposures will start and stop in phase to within electronic commanding latency. Some exposures in either red or blue detectors might be appropriated for survey images. Sometimes the red or blue exposures will complete before the end of the pointing.

Within the Science State, the operational sequence will be carried out either manually by commands in pseudo-real-time, or by pre-stored commands.

20000/37: It must be possible to support the synchronous sequencing of the observations with red and blue detectors in the Science state by either manual commands in pseudo-real-time or by pre-stored commands on the instrument.

7.4 Field Acquisition

In order to ensure that the target objects fall within small windows, the position of the targets in the field of view must be known with some accuracy. It will therefore be required to provide an acquistion procedure. which can be run using either the blue (default) or red detector. It will generally be run at the beginning of each pointing, but can be activated at any time an exposure is not active.

20000/38: It shall be possible to locate the pointing direction of the XMM OM within 1 arcsec of a nominal axis which can be updated.

20000/39: The acquisition module shall support the use of both blue (default) and red detectors.

Calibration and storage on the instrument of the image shifts between the three detectors and in each filter relative to the filter used for the acquisition will allow the offsets to be applied to the window positions for subsequent exposures.

20000/40: The image shifts between the three detectors and in each filter relative to an updateable nominal position will be stored on the instrument.

7.5 Tracking

In order not to permit the blurring of the data from spacecraft drift, it will be particularly important to maintain knowledge of the pointing direction throughout the pointing. This activity is called Tracking. Tracking is a task in the DPU active only when data acquisition is enabled from the detector used for tracking. It involves a calculation of the movement of the images as a result of spacecraft drift and roll, recorded in successive time slices of data every t_t sec.

Either the blue or red detector can be used for tracking. The default configuration requires that up to 10 windows are reserved for the tracking, but it must be possible to reconfigure the DPU to reduce the number of windows reserved for guide stars to a minimum of 6. Those windows reserved for guide stars but not used because of a lack of suitable candidates will not be released for science use.

20000/41: It shall be possible to perform tracking using a maximum of 10 windows reserved for guide stars, and it shall be possible to reduce this number to a minimum of 6 under command should the maximum not prove necessary.

20000/42: Each exposure will commence with an initial binned scan of the full field of view in the detector used for tracking (the 'reference frame'). In the case of the red detector this scan will be done in two halves in order to remove cosmic rays.

20000/43: DPU will locate suitable tracking sources and assign tracking windows appropriately.

20000/44: The DPU will combine the tracking window selection with that requested for the science data to calculate the active area of the detector for the observation. The ICU will set up the detectors accordingly. Thereafter the DPU will integrate a reference frame at full detector resolution in the tracking windows for subsequent image registration.

20000/45: The offsets between the images in the three detectors and in the filter elements of each detector relative to an updateable nominal pointing direction will be applied by the DPU to the tracking information before distribution within the instrument.

20000/46: It shall be possible to provide the drift and roll values to within 0.2 arcsec in pitch and yaw, and 0.02 radians in roll, relative to the pointing direction obtained from the reference frame, to the spacecraft OBDH bus within 5 sec of the end of the tracking frame.

20000/47: If the red detector is being used for the tracking, the red detector integration time must be set to t_t.

In view of the expected characteristics of the XMM AOCS (XMM-OM/MSSL/TC/0028.01), it is not envisaged that the windows will need to be updated in the course of an exposure.

20000/48: DELETED.

7.6 Science Modes

There are only two types of observing modes: IMAGE MODE and FAST MODE. The principle difference is that IMAGE MODE produces time integrated images whereas FAST MODE produces compact time-resolved image data. The drift history is telemetered with the data package.

There are two reasons for this arrangement:-

1. In order to produce the single integrated image in IMAGE MODE the DPU has to perform several tasks, for example to correct for spacecraft drift or for cosmic rays. As the selected exposure time is reduced, it is not possible to carry out these tasks in the time available, so they have to be done subsequently on the ground. If a shorter integration time is selected, therefore, the images have to be produced in a compact time-resolved data package so that the information required to do this processing is retained. This carries penalties in the telemetry bandwidth required.
2. Generally if the selected exposure time is short, this is to detect variability, thus more than a single exposure is required. It is inefficient to produce a separate request for each short exposure but much more efficient if each call results in a sequence of short exposures.

There are also two embedded modes: BRIGHT STAR and TRANSIENT. Either of these could be selected in the detector being used for tracking.

In addition to the two image operational modes, there will also be an engineering mode for each detector.

7.6.1 Blue Image Mode

20000/49: The photon events from the blue detector shall be integrated for the blue exposure time of $T_b = k_b \times t_t$ *sec (integer* $2 \leq k_b, T_b \leq 10^4$*) where* t_t *is the tracking frame duration,* $t_t \leq 20$ *sec. Data taken within each tracking frame shall be shifted with respect to the reference frame and summed to form the final image 24 bits deep.*

20000/50: All the blue IMAGE MODE *windows in use during any exposure will have the same* T_b *exposure time.*

7.6.2 Blue Fast Mode

20000/51: The photon events from the blue detector shall be integrated in time slices τ_b *of duration between 10 msec and* t_t *sec long and where* $t_t \tau_b$ *is a power of 2.*

20000/52: subsumed into 20000/51, thus deleted here.

20000/53: The tracking correction will be telemetered with the blue FAST MODE *data but not applied to it.*

20000/54: The blue FAST MODE *data shall be packaged in a compact form by the DPU for transmission: this will be compressed further if possible using the normal ICU compression algorithm.*

20000/55: All blue FAST MODE *windows in use during any exposure will have the same* τ_b *integration time.*

7.6.3 Red Image Mode

20000/56: The photon events from the red detector shall be integrated for the red exposure time of $T_r = k_r \times t_c$ *sec (integer* $2 \leq k_r, T_r \leq 3.6 \times 10^3$ *sec), where* $T_r \leq T_b$ *and where* $t_c = 200$ *sec is the duration of individual integrations on the CCD.*

Cosmic ray events limit the duration of exposures on the red detector.

20000/57: The individual integrations shall be intercompared to screen for cosmic ray events, which shall be removed, and the frames then summed to form a final image 24 bits deep.

20000/58: All red IMAGE MODE *windows in use during any exposure shall have the same* T_r *exposure time.*

7.6.4 Red Fast Mode

20000/59: The photon events from the red detector shall be integrated in time slices τ_r *of duration between 1 sec and* t_c *sec long. The total number of slices* j_r *will be the integer number fitting within the red exposure time* T_r *(i.e.* $(T_r/\tau_r - 1) < j_r \leq T_r/\tau_r$*). Not data will be taken to fill the non-integer remainder.*

The cosmic ray comparison is not carried out.

20000/60: The red FAST MODE *data shall be packaged in a compact form by the DPU for transmission: this will be compressed further if possible using the normal ICU compression algorithm.*

20000/61: The tracking correction will be telemetered with the red FAST MODE *data but not applied to it.*

20000/62: All red FAST MODE *windows in use during any exposure will have the same τ_r integration time.*

7.7 Submodes

Embedded in the above modes are two submodes: BRIGHT STAR and TRANSIENT. These operate on the detector used for tracking, and a choice must be made between them.

20000/63: The Science state shall support the TRANSIENT *submode in which the active windows are scanned to identify and determine the brightness and position of the 10 brightest objects during the last t_t sec frame.*

20000/64: The Science state shall support the BRIGHT STAR *submode in which the brightness and position of the tracking stars for each tracking frame will be telemetered.*

7.8 Mode Combinations

In the case of the blue detector both IMAGE MODE and FAST MODE can be available simultaneously, while in the case of the red detector only one mode is possible at a time. Modes can be mixed according to the capabilities of the detector and the memory and telemetry budgets.

20000/65: It shall be possible to support the simultaneous running of blue IMAGE MODE*, blue* FAST MODE *and either red* IMAGE MODE *or red* FAST MODE*.*

7.9 Exposure control

20000/66: An exposure will commence in the science state within 1 sec of its receipt from the spacecraft interface.

20000/67: Exposure durations shall be accurate to 10 msec.

It is important to realise that any exposure is telemetered down during the next exposure, or during the spacecraft slew if a particular pointing is complete. It is conceivable that in order to telemeter a large image, some dead time may ensue before the next exposure can begin. Data will be transferred to the ICU from the DPU at the request of the ICU. The DPU will need to ensure that no data are overwritten unless by request from the ICU.

20000/68: At the start of a science state integration, the DPU shall inform the ICU whether sufficient memory is available to start another integration. If an integration is time critical and insufficient DPU memory is available, the ICU shall force a start to the exposure. The DPU shall minimize the loss of stored data.

20000/69: It shall be possible to terminate exposures either by halting them early, in which case the data shall be telementered as usual, or by aborting them, in which case the data shall be lost.

20000/70: The ICU shall compress the science data with a reversible data compression algorithm before transmission.

It will be necessary to use a software simulator to establish whether the observing sequence was restricted in any way by the telemetry bandwidth.

7.10 Data file structures

20000/71: Each window in each exposure shall result in a data file.

20000/72: The data files produced by each exposure shall contain the following information:

1. *a unique exposure reference number;*
2. *the start time of each exposure accurate to within 1 msec;*
3. *the stop time of each exposure accurate to within 1 msec;*
4. *if a* FAST MODE *window, the* FAST MODE *integration time;*
5. *the filter used for the exposure;*
6. *the binning factor on the detector;*
7. *the binning factor applied by the DPU;*
8. *the address in unbinned pixel coordinates of the* $(-Y, -Z)$ *corner of the window;*
9. *the size of the window in binned pixels;*
10. *the tracking frame time;*
11. *if a blue window, the tracking frame time* t_t*; frames;*
12. *if a red window, the cosmic ray subtraction time* t_c*.*

20000/90: Each exposure shall also result in a drift history file.

8 Engineering and Calibration

In the Engineering and Calibration state, functions will be carried out which will permit the optimisation of the instrument performance. It may prove to be possible that these functions can be carried out when the spacecraft is below the nominal operational altitiude.

20000/73: The following Engineering and Calibration functions shall be supported (but not necessarily simultaneously):

1. *integration and transmission of a full frame of the blue detector at full resolution, without the need for drift correction;*
2. *integration and transmission of a full frame of the red detector at full resolution, without the need for cosmic ray subtraction;*
3. *storage and transmission of up to* 10^6 *raw data events from the blue detector as an event list;*
4. *modulo 8 binning of the full blue detector frame in both spatial coordinates to obtain the modulation pattern;*
5. *the pulse height distribution of blue detector photon events;*
6. *the pulse width distribution of blue detector photon events.*

20000/74: It shall be possible to provide flat-field illumination of the detectors under software command to enable their calibration.

Movement of the dichroic mechanism will be permitted only in the engineering and calibration state to ensure that proof can be obtained via the blue detector full frame integration above that the mechanism has operated successfully.

20000/75: The dichroic mechanism shall be activated only when the instrument is in the Engineering and Calibration state.

20000/76: At the start of a Engineering & Calibration state integration, the DPU shall inform the ICU whether sufficient memory is available to start another integration. If an integration is time critical *and insufficient DPU memory is available, the ICU shall force a start to the exposure. The DPU shall minimize the loss of stored data.*

20000/77: It shall be possible to terminate exposures either by halting them early, with a latency of the tracking time t_t for blue exposures and t_c for the red exposures in which case the data shall be telementered as usual, or by aborting them, in which case the data shall be lost.

20000/78: Data from any Engineering and Calibration exposure which is terminated as the result of an emergency transition shall be lost.

9 Telemetry

20000/79: Science and Engineering & Calibration data shall be held in the DPU memory until requested for transmission by the ICU.

20000/80: It shall be possible to transmit science data and Engineering & Calibration data in any of the ^{XMM}OM instrument states except the Initial Status state.

^{XMM}OM will generally be allocated either 4 or 8 kbit/sec of telemetry; however, there will be occasions when a higher telemetry bandwidth will be allocated, either for testing, or if the instrument is used to take a snapshot of the field of view for operational reasons.

20000/81: It shall be possible to support a telemetry rate of 40kbit/sec.

20000/82: The ^{XMM}OM shall support the DBI interface to the XMM spacecraft, using the RBI protocol defined in the EID-B.

Downlink data will be in source packets.

20000/83: The following telemetry types will be supported:

1. *Housekeeping – basic instrument health and status to be polled at fixed rates;*
2. *Tracking – attitude control information at a fixed rate;*
3. *Periodic engineering – supplemental instrument status and performance parameters, fixed rate;*
4. *Aperiodic engineering – reports of events (mechanical configuration, heater changes etc., not at fixed rate;*
5. *Aspect information – no fixed rate;*
6. *Science – windowed, processed and compressed data from the detectors;*
7. *Calibration – processed data from the Engineering and Calibration state;*
8. *Feedback – from direct commands.*

20000/84: The housekeeping data shall contain the following parameters:

1. *instrument derived time;*
2. *currents;*
3. *voltages;*
4. *temperatures;*
5. *heater status;*
6. *mechanism positions;*
7. *switching configuration (relays, high voltage enables etc.);*
8. *high voltage sensors (health, voltage and/or current);*

9. *packet counts (each uplink and downlink);*
10. *errors (count and last error code); confirmations (last direct command packet ID and return code);*
11. *instrument state (safe, science etc.);*
12. *subsystem status (indicating health and activity for each subsystem);*
13. *tracking status (terse report on lock condition and drift vector status);*
14. *science parameters (minimal).*

20000/85: Housekeeping telementry points shall be sampled sufficiently frequently to ensure the safety of the instrument.

10 Telecommand

20000/86: The XMM OM shall support the telecommand packets, formatted according to the XMM Packet Structure Definition document RS-PX-0032, in a queue structure in the ICU memory, as required in the EID-B.

20000/87: It shall be possible to support a telecommand rate of 2 kbit/sec.

20000/88: It shall be possible to support up to 8 high-level on/off commands.

20000/89: The XMM OM shall support the DBI interface to the XMM spacecraft, using the RBI protocol defined in the EID-B.

11 Deleted Requirements

20000/52: The total number of blue FAST MODE *slices* j_b *will be the integer number fitting within the blue exposure time* T_b *(i.e.* $(T_b/\tau_b - 1) < j_b \leq T_b/\tau_b$*). Data taken during the non-integer remainder will be discarded.*