FGM Extended Mode Description

Revision List

Issue	Rev.	Date	Section	Change
Draft		28/06/01		Document created

Scope

The current release of the FGM DP software does not process MSA data. The primary reason for this was the lack of an obvious method for constructing a timeline for data whose sample time bears no simple relation to its download time. This document describes how the main component of the MSA download, namely extended mode data is encoded and proposes a method of how an absolute timeline may be constructed with a view to the development of an additional DP module. It should be emphasised at this stage that this document aims to represent a reflection of some of the ideas that came up during a discussion during the February FGM team meeting at IC. It should not be regarded as definitive and is open for modification and revision.

Current Status on in-fight use of FGMEXT

Routine use of extended mode through JSOC began on March 20^{th} 2001 and since this date all periods outside of AI (Acquisition Interval) have seen instrument switches into extended mode (FGMEXT). However it was soon noticed that there was a problem with the mode whereby the instrument while in FGMEXT would drop out into FGMOPM1 ie FGM normal mode and remain in this mode until the next scheduled commanding. These dropouts occurred at random occasions with no perceivable pattern but the end result was not insignificant periods of lost data. The problem was believed to be due to noise from the spacecraft resulting in a anomalous reading of an incoming ML2 command over the spacecraft interface. A software patch was developed to address this problem and tested in June 2001 on S/C 3 over a two week period when there were significant periods of FGMEXT. The test was a success with the FGM operating in FGMEXT for > 150 hours with no dropout while many dropouts were observed on the other three spacecraft. The patch was uplinked to all four spacecraft on 27^{th} of June 2001 and all subsequent extended mode periods after this date should be complete and match intervals of no coverage given in the Master Science Plan up to a maximum of 23 hours.

1. Introduction

The purpose of this document is to provide a specification in order to maximize the return of FGM BM3 science packets (ie MSA data) containing data sampled while the instrument was in extended mode. This is a specially designed mode that is used during periods when there is no available telemetry coverage. It is clear from the Master Science Plan that there are significant periods when there is no telemetry acquisition, total data coverage being approximately 50%. It is possible for the FGM instrument to take data during these data gaps and store it within the instrument for later transmission to ground. To significantly extend the data coverage period it is necessary to reduce the data storage rate to less than that of the normally available FGM modes. A convenient rate is spin synchronised with one averaged vector per spin being stored to memory. In this way an additional 27 hours of data can be recovered from periods when there is no telemetry coverage.

This mode was included in the Cluster 1 on-board software as a patch when the large size of the data gaps became known after the instruments had been integrated to the spacecraft. For Cluster 2 the algorithms were incorporated into the main body of the code. The main feature of this mode is that it writes spin averaged data to the FGM MSA (Micro Structure Analyzer) only, i.e. it does not write data to the spacecraft HK channel. However for Cluster 2 it became apparent that HK would be taken at all times during the orbit and hence at the insistence of ESA it became necessary to provide a patch that caused the FGM to provide HK data during FGMEXT. Due to the special nature of this mode and its detachment from the main body of the code this patch was as a consequence very complicated indeed (in fact 17 individual patches). This fact is mentioned in relation to a later discussion in this document.

2.0 Implementation

Each FGM contains 192Kbytes (96K words) of memory, the MSA which is normally used for capturing short periods of high resolution data. At the beginning of LOS (Loss of Signal) the FGM is commanded into FGMEXT which utilises the MSA to store long periods of spin averaged data. Naturally, this data must be read out as soon as telemetry is restored so that the memory can revert to its normal purpose. This is achieved through the use of the BM3 dump (FGMOPM8) which normally occurs soon after the next acquisition of signal (AOS) occurs. FGMEXT was tested during the early phase commissioning of the FGM but did not become fully operational until after the BM3 dumps at AOS were routinely implemented in the Master Science Plan, thus FGMEXT became operational on orbit 113. Data is taken only by the primary sensor (Outboard sensor by default) so the secondary sensor is switched to a safe range when the switch to FGMEXT occurs. The primary sensor remains in the autoranging mode.

3.0 Data Acquisition and Filtering

In this mode the instrument synchronises acquisitions to spin sectors by measuring the Sun Reset Pulse (SRP) period and dividing by 512. These are then despun, averaged and stored to the MSA. Data timing is by the HF clock (4096 Hz) at points derived from a measure of the spin period. For example with a 4 second spin period each data point will be 32 ticks separated from its neighbours on either side. Data acquisition is performed by calls to the routine normally used to read the secondary vectors and housekeeping voltages. Vectors are acquired with a delay of no more than 100 µs after the allotted clock transition.

Despinning is achieved in a similar way to that of the Ulysses instrument i.e. by implementing Walsh transforms with Haar coefficients, where the Haar coefficients are given by,

$$C_H(t) = \frac{Cos(\omega t)}{|Cos(\omega t)|}$$

$$S_H(t) = \frac{Sin(\omega t)}{|Sin(\omega t)|}$$

These functions are simply +1 where the corresponding trigonometric function is positive and -1 where the corresponding function is negative. They are, unfortunately, undefined at the zero crossing points of the functions. As the number of points per spin is a power of 4, this means that data points are taken where the functions are undefined. For this reason the Haar functions are given a phase delay so that the transition lies between vectors. This is achieved onboard by establishing what quadrant a particular vector is being calculated in and stating explicitly what the Haar coefficients are for all vectors in that quadrant. i.e. the coefficients are not calculated for each new angle.

The despun components are calculated from the spinning measurements as,

$$B_Z = \frac{\sum_{i=0}^{N-1} \frac{\pi}{4}\left[B_{ZS_i} C_{H_i} + B_{YS_i} S_{H_i}\right]}{N}$$

$$B_Y = \frac{\sum_{i=0}^{N-1} \frac{\pi}{4}\left[-B_{ZS_i} S_{H_i} + B_{YS_i} C_{H_i}\right]}{N}$$

where:

$B_Z =$ Despun Z component
$B_Y =$ Despun Y component
$N =$ Number of points per spin = 512

$B_{ZS} =$ Sampled Z component
$B_{YS} =$ Sampled Y component
$C_H, S_H =$ Haar functions

Each vector is the arithmetic mean of 512 despun vectors over a single spacecraft spin. Assuming that the spin period is 4 seconds and the code acquires a vector on the required HF clock tick (ν = 4096 Hz) then each component will be consistent with a resolution of 0.022 degrees.

4.0 Data Encoding and Transmission

The MSA storage option implemented is:

X component - 16 bits
Y component - 16 bits
Z component - 16 bits
1bit sensor ID, 3 - bit range, 12 - bit reset count.

where:

X component is twos complement encoded and has 15 + sign valid data bits
Y component is twos complement encoded and has 15 + sign valid data bits.
Z component is twos complement encoded and has 15 + sign valid data bits.
Reset count will increment by one every 16 reset periods (82.4 Seconds).
Sensor ID indicates the sensor from which the data was acquired.
Range is FGM sensor range 0-7.

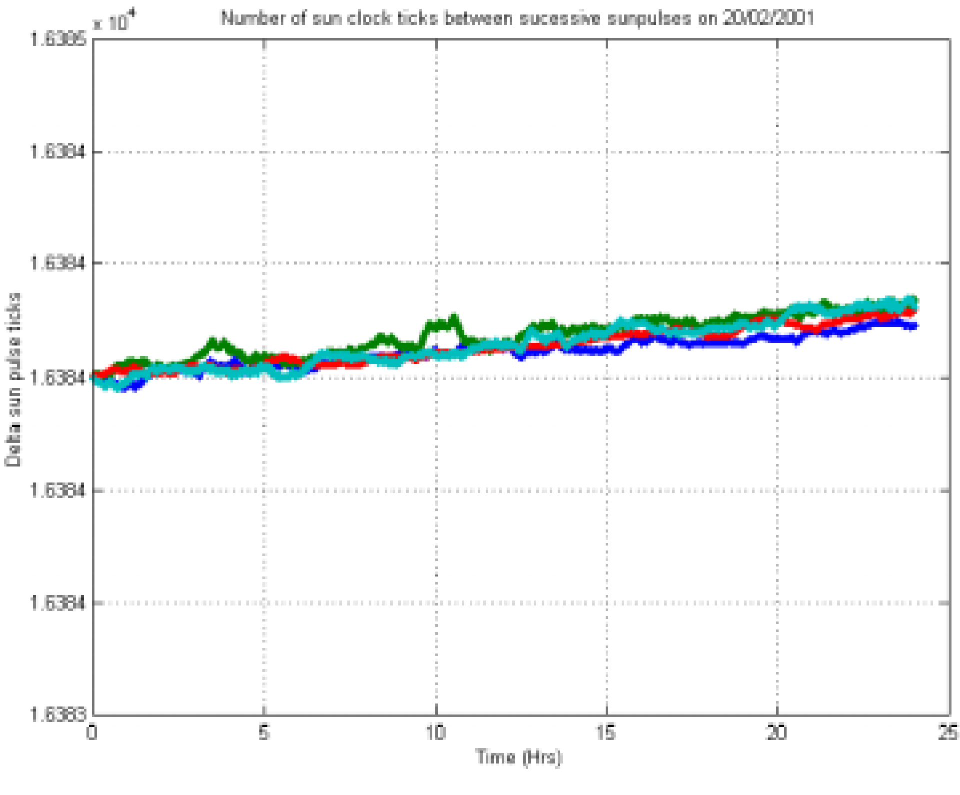
Data sampled in FGMEXT is also written to the On-Board Data Handling System (OBDH). Although there is no science telemetry there is continuous house keeping monitoring. For this reason the FGM provides a reduced set of safety critical house keeping parameters (power supply temperature, voltages, and reset count) for the purposes of on-board monitoring. Data is also written to the science telemetry channel but this is of no value except during ground testing.

Once the FGM is switched into FGMEXT it remains in this mode until the instrument has filled up the MSA (23 hours initially but this may be ramped up to 28 hours depending on in-flight performance) or switched back to FGMOPM1 due to AOS occurring. In both cases the contents of the MSA are automatically frozen until transmission to ground has been completed. It is possible to download the MSA contents in other telemetry modes (eg. FGMOPM3) but the BM3 option is the most efficient. The $\pi/4$ term is included during ground processing.

5. Reconstructing the Vector Timeline

Recovery of the vector timeline must be significantly different to that of the usual normal and burst (NM1, NM2, BM1, etc) mode packets encountered during routine data processing. For these modes types the UTC time in the packet header (supplied by the spacecraft) has a clearly defined relationship with the time of the first vector of each packet (recorded by the FGM internally in HF clock ticks and written to the science packet with a resolution of < 250µs) essentially because vectors sampled over a reset are always packetised the very next reset. In this way the time stamp of every vector in the packet can be unambiguously recovered. However for extended mode data (and any other kind of BM3 data) there is no relationship between the UTC header time and the time of any vector in the extended mode data, the time difference between them is completely arbitrary determined in part by the length of the extended mode period and also the timing of the BM3 dumps. Currently there is no timing information written to the extended mode data, the reason being that the purpose of the mode is to maximise the time over which data can be taken. Increasing the number of words written to the MSA each spin by one word would reduce the maximum acquisition period by 20%! Furthermore it can be demonstrated that regardless of what available timing information could be included inside the extended mode data structure there would still be no way of matching the time of any vector to the UTC time in the transmitted packet header. It is clear therefore that whatever timing scheme is introduced will not be able to rely on the use of the BM3 packet alone.

Given that there exists a method of isolating the extended mode data from the rest of the BM3 packet any feasible timing scheme must have the ability to relate UTC time to the time of at least one vector from the extended mode data and ideally the first vector. Assuming this it will be possible to extrapolate the timeline for all subsequent vectors inside the extended mode data in a manner similar to that employed when time stamping data processed using the standard DP pipeline. Of course the important issue here is whether the spin rate changes over the course of data acquisition while in extended mode The normal DP chain calculates the UTC time of the first vector of **every** packet i.e. approximately every 5.15222s, the proposal applied to extended mode would involve extrapolating the timeline by up to a maximum of 28 hours from a single timestamp. Because the extended mode sampling period is triggered by the sun pulse (the actual timestamping is still made using the HF clock) the important question is whether there is non zero drift in the sun pulse times. Figure (i) shows the drift in the sun pulse period for a typical day from February 2001. The plot graphs the change in running average of the number of ticks of the HF clock between successive sun pulses over the course of 24 hours. For all four spacecraft the change is significantly less than 1 sun pulse tick which is within the accepted resolution used for processing normal and high resolution vectors. We can thus see that the spin period of all four spacecraft is extremely stable and that the extrapolation method proposed is reasonable.



Given the above conclusion the next question concerns the determination of the time of the first vector in the extended mode data packet. Since the only available link to a UTC time stamp is in packet headers provided by the spacecraft and given that there is no science packets at this time the most realistic option involves the use of the FGM HK packet to record the precise moment the first vector of the averaging cycle is sampled. This of course is governed by the sun pulse. By recording the UTC times of the sun pulse it is possible to place a time stamp on the despun vector. It has been determined during ground testing that the extended mode averaging cycle begins on the last sun pulse to appear in the FGM science telemetry. By time stamping this to the UTC header time (it is measured by the same clock that measures the time of the first vector) and adding a suitable phase delay (derived from the current spin period) we can calculate an accurate time stamp for the first vector of the extended mode data. It should be immediately apparent that this represents a significant departure from the functionality of the main DP chain which does not deal with HK packets although the FGM mission monitoring software may be of some use here.

The processing module must be able to track exactly at what point the instrument switches into extended mode and to be able to pick up the extended mode data in the appropriate BM3 packet. Given that the sun pulse controls the sampling in extended mode one idea might be to track the latest sun pulse time from the auxillary header in the science packet prior to a switch into extended mode and wait for the value of the sun pulse to go to zero. However this method is not foolproof because there will be cases when the science telemetry disappears even though the instrument is not in extended mode i.e. the detection criterion is not unique. However a unique trigger is available through the use of the HK packet based on the fact that when the FGM is in extended mode the first five words of the HK packet are supplied to the spacecraft OBDH. Thus the switch to extended mode occurs uniquely when the following logical expression is TRUE

IF ((WORD1 **OR** WORD2 **OR** WORD3 **OR** WORD4) $\neq$ 0) **AND** ((WORD5 **AND** WORD6 **AND** WORD7 **AND** WORD8 **AND** WORD9 **AND** WORD10 **AND** WORD11 **AND** WORD12 **AND** WORD13 **AND** WORD14) = **1**) THEN FGM is in FGMEXT

This is algorithm used by ESOC to detect when the FGM has switched to extended mode for monitoring purposes. The possibility of a a TRUE occurring on occasions when the FGM is not in FGMEXT is extremely remote and has not been seen in-flight. Given the proposal to use the HK data it would be useful if some timing information could be supplied. One proposal which has been recently been implemented (it has become part of the instrument power on procedure since 21/06/01) is to change the keyhole word of the HK packet so that it points to the most recent sun-pulse count. This is held in word 13 (counting from 0) of the HK packet. Of course this word will disappear once the instrument switches into FGMEXT but it will be possible to detect that the instrument has made the switch **and** record the sun-pulse time of that switch in HF ticks with only one packet. At this stage it will still be necessary to open the normal science packet corresponding to the last complete HK packet. This is necessary in order to read the time of the reset in HF clock ticks. This links the HF clock reading to the UTC time in the packet header. The UTC time of the sun pulse and hence the UTC time of the switch to FGMEXT is easily calculated thereafter.

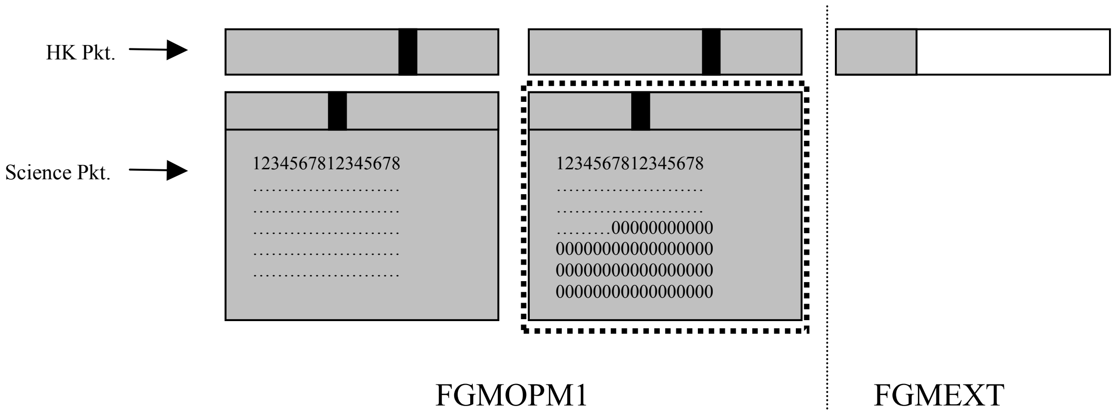


Figure (ii) Use of SRP in HK packet

Figure (ii) above shows the last two HK and Science packets of a normal data taking mode and the first packet of the extended mode data (HK only of course as no science is transmitted). The black square indicates the presence of the latest sun-pulse time in the keyhole position of the HK packet as well as the auxillary header in the Science packet (which goes to zero during extended mode). The zeroes in the second science packet are there to indicate that the exact time when the extended mode begins is indeterminate from the structure of the final science packet. Assuming one detects using the HK packet the time of the extended mode transition the UTC time of the first extended mode vector will be given by

$$T^{1}_{\mathrm{extr}} = T_{\mathrm{UTC}} - \frac{(m_{r} - n_{\mathrm{SRP}})}{f_{c}} + \frac{T_{spin}}{2}$$

Where T^{1}_{extv} is the UTC time of the first vector of the extended mode packet
T_{UTC} the UTC time of the packet header (boxed)
m_{r} is the number of ticks of the HF clock on receipt of the S/C reset
n_{SRP} is the number of ticks of the HF clock for the latest sun pulse reading
f_{c} is the count rate of the 16bit HF counter (4096Hz)
T_{spin} the spin period

All subsequent extended mode vectors after this will have times

$$T^{j}_{\mathrm{extr}} = T^{1}_{\mathrm{extr}} + j\left(\frac{T_{\mathrm{spin}}}{2}\right)$$

One might well ask the question 'why use the sun pulse in the HK packet when you still have to read a science packet (which also contains the sun pulse) to UTC stamp the sun pulse time?' The answer to this question lies in the fact that only the FGM HK packet provides a unique signal of the instrument switch into extended mode. The fact that no science data is transmitted during extended mode means you cannot check the science packet to see if the sun pulse has disappeared or read its last non zero value! In other words we only find out we have switched into FGMEXT after the event has happened through the change in the HK packet and can then retrospectively check the previous science packet(s) to calculate the first vector time. A further advantage of using the sun pulse in the HK keyhole word is that a software patch is not required.

6. The BM3 Packet Structure

Once the UTC time of the extended mode switch has been recorded it will be possible to extrapolate the timeline for subsequent vectors based on the current spin period calculated from the HK sun pulse times or for greater accuracy from the attitude files. Then the software has to pick up the next BM3 packet and extract the data corresponding to the time interval in question. Mission planning should ensure that there a one to one correspondence between intervals of extended mode data taking and BM3 packets. If this turns out not to be the case it may be necessary for FGM operations to simply not avail of BM3 dumps which occur during AI but this touches on the wider issue of MSA use for event detection etc. which will not be discussed in this document.

We can identify three main data structures in BM3 packets

(i) MSA not frozen, FGM switches to FGMOPM8 → downloaded data is the most recent 160s of high resolution data sampled by the fgm.

(ii) MSA frozen by event detection triggering, FGM switches to FGMOPM8 → downloaded data 1/3 pre-trigger event and 2/3 post-trigger event. MSA remains frozen until its contents have been downloaded.

(iii) MSA frozen by extended mode, FGM switches to FGMOPM8 →Extended mode data starts at the beginning of the MSA; the extended mode data will end before the end of the MSA, the rest of the data being of type (i).

This document is only concerned with type (iii) data therefore data of types (i) and (ii) are ignored. The FGM option F data is contained within the spacecraft BM packets ie BM1 packets and BM3 packets are mixed together. The BM3 packets are 3611 bytes long and are made up of the following.

15 byte DDS header

34 byte FGM auxillary science
3562 bytes of raw data ie 1781 data words

Extraction of BM3 packets from the BM binary file can be achieved by reading the second byte of the FGM auxillary science header, for valid BM3 packets it has the value 0F, corresponding to the FGM telemetry option for FGMOPM8 ie MSA dump. If extended mode data is present inside the BM3 packets it will begin on the first word after the auxillary header ie beginning byte 50 and the first word of an extended mode data period always appears in the first BM3 packet ie extended mode data is written from the start MSA address. The extended mode four word vector structure (bx, by, bz and the range and reset count) appears consecutively until the end of the extended mode data after which the internal packet structure reverts to the normal MSA data type (i). It is worth noting here that the last three words of each extended mode BM3 packet are not valid ie for a given BM3 packet containing only extended mode data there will not be more than 1778 words. Also as 1778 is not divisible by four vector triples will straddle across BM3 packet boundaries. One way to detect the length of the extended mode data set is to extract the reset count from every fourth word of the extended mode data until it is no longer the same value as the previous value **or** has incremented by one. Once this point is reached the rest of the BM3 packer can be thrown away.

7. Calibration

At present there is no calibration applied to the sampled data on-board before despinning. It is not clear what process if any can be used to feed in the magnetometer calibration to the transmitted data. Initial analysis of data suggest that the effect of the sensor offsets may be averaged out over a complete spin but further analysis is necessary to determine if any meaningful calibration can be applied. There will also be errors in the data due to the fact that the Walsh transform despin is only an approximation to the correct sinusoidal despin vector although an estimate of the quantity of information lost during the on-board processing may be possible on ground. It may also be possible at a later stage to include a sensor offset correction to the sampled data through patching of the flight software although as mentioned in the introduction even simple patching of the extended mode code requires considerable effort and it would be unfeasible to incorporate the sensitivity and orthogonality factors of the calibration matrix. However given that extended mode data is designed for use in global studies ie to provide context for normal and high resolution data this should not be regarded as a major issue, ie poorly calibrated data is better that no data. The magnetic data is transmitted in a despun non-orthogonal sensor coordinate system.

8. Example of Decoded FGMEXT data

As an demonstrative example Figure (iii) shows a plot of data taken during the early commissioning phase. The plot compares uncalibrated extended mode data from spacecraft 1 with calibrated normal mode data from spacecraft 3 (the spikes are in the normal mode data and are caused by a now corrected software bug). The normal mode data has been processed using the standard DP chain output in the SCS system. The extended mode data has been rotated from a non-orthogonal despun sensor coordinate system to the SCS system as shown below. The spacecraft phase of both spacecraft taken from the attitude files were within 1^o and not included.

$$\begin{aligned}
X_{Sensor} &\rightarrow Z_{SCS} \\
Y_{Sensor} &\rightarrow Y_{BB} + 6.5^o + \angle\, Y_{BB,\ Sun\ Sensor}\ (\equiv X_{SCS}) \\
Z_{Sensor} &\rightarrow Z_{BB} + 6.5^o + \angle\, Y_{BB,\ Sun\ Sensor}\ (\equiv Y_{SCS})
\end{aligned}$$

where for the sake of simplicity the extended mode spin plane data is assumed to be along the body build axes minus the boom angle (taken to be 6.5^o) and $\angle Y_{BB,\ Sun\ Sensor}$ is the angle between Y_{BB} and the Sun sensor, defined to be 26^o.

The time stamping of the data has been performed manually using the spacecraft 3 sun pulse times and extrapolating. The first vector was stamped with a time of the first extended mode sun pulse time in UTC + (3.9624)/2 seconds, where 3.9624 is the spin period derived from normal sun pulse time differences prior to the transition into extended mode. An offset of 2nT was added to the spin axis extended mode data in order to align the traces and this is similar to the difference between the two spin axes in the cal files. One can see that there is good agreement between the two data sets and illustrates that the extended mode processing module is definitely something worth pursuing!

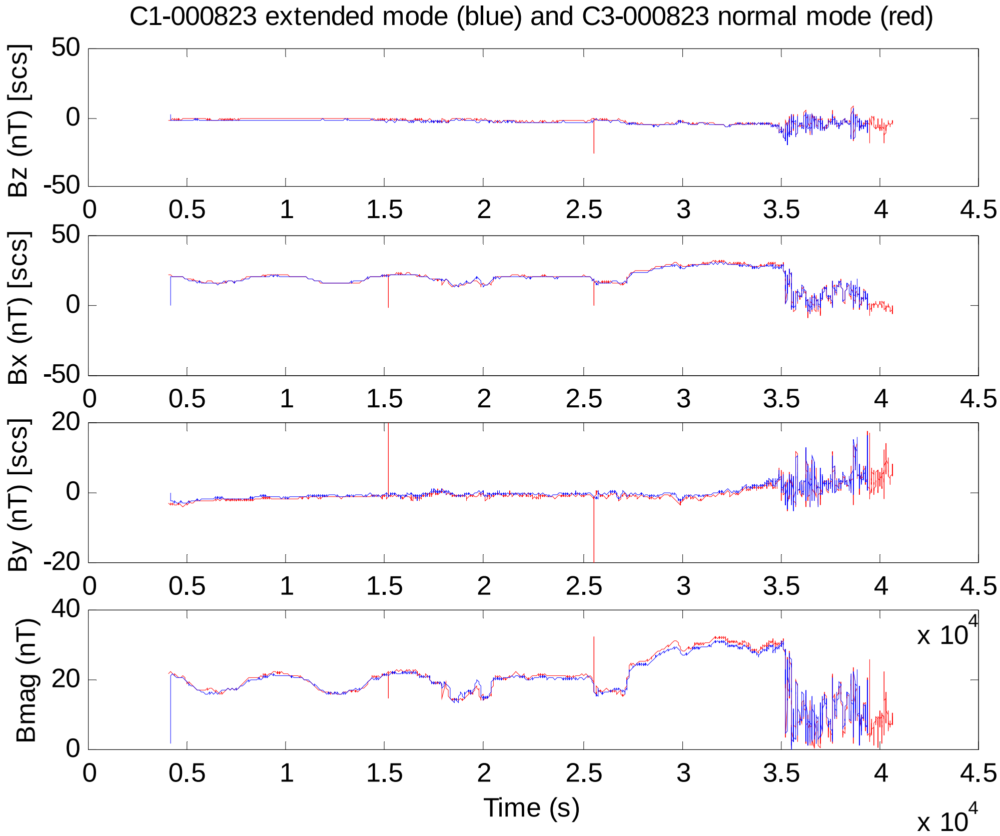


Figure (iii) Extended mode versus Normal Mode data

9. References

Useful references include the following

(i) FGM Users Manual Issue 3 Revision 0
(ii) Latest FGM Data Processing Handbook
(iii) FGM Software Requirements Document Issue 3 Rev 5
(iv) Latest Cluster Data Delivery Interface Document (DDID)
(v) Spin timings and offsets for Cluster Prime Paramaters (Stave Schwarz note)