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BURST DETECTOR X-RAY IIR

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Burst Detector X-Ray IIR

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Abstract: The Burst Detector X-Ray (BDX) instrument for the Block IIR series of Global Positioning System satellites is described. The BDX instrument can locate and characterize exoatmospheric nuclear detonations by using four sensors consisting of sets of filters over silicon diodes to detect x rays of various energies from the burst. On the BDX-IIR, a fifth sensor with a response spanning those of the other sensors confirms coincidences among the four main channels. The mechanical and electronic features of the BDX-IIR and its sensors are described. The calibrations and the system tests used in flight are presented. The commands for the BDX-IIR are given. The messages sent from the BDX-IIR are described in detail.

1. Introduction

1.1 X-ray Generation

Initial radiations from a nuclear detonation are gamma rays and neutrons that immediately escape, but most of the energy of the detonation goes into heating the body of the device to an extremely high temperature. At these elevated temperatures the thermal emissions from the bomb debris have a photon energy spectrum peaked in the x-ray region compared, say, with an incandescent light bulb where the spectrum is peaked in the visible wavelengths. In the situation where the burst occurs deep in the atmosphere, the initial and thermal emissions are absorbed by the surrounding air to form a fireball. If the detonation occurs in space, however, these radiations travel radially from the source until they intercept some form of matter, whether that be the Earth's atmosphere, distant objects in space, or monitoring sensors on Global Positioning System (GPS) satellites.

1.2 X-ray Transmission

The BDX sensors are designed for monitoring exoatmospheric bursts. Nonetheless, they have some capability for monitoring bursts within the Earth's atmosphere. This capability is limited by the line-of-sight column of air between the burst and the monitoring sensors. For a given photon energy, the amount of attenuation of the signal is an exponential function of the column density and pressure scale height (g/cm^2) of the air; but at high altitudes the residual amount of air is itself an exponential function of altitude. This combination of an exponential function raised to an exponential gives rise to what is aptly called a "wall." That is, for a particular photon energy there is a depth in the atmosphere below which essentially no photons can escape. The general trend with energy is that higher energy photons (e.g., gamma rays) can escape from deeper within the atmosphere.

1.3 Burst Location

The thermal pulse from a nuclear detonation in (NUDET) space is very brief. Because the x rays made in a NUDET travel out in space at the speed of light in straight lines, each of the BDX instruments observing the event can provide accurate timing information for the x-ray thermal pulse. Data sets from four or more such observations can then be combined on the ground to determine the location of the burst as well as its time of detonation. This Time Difference of Arrival (TDOA) technique is, of course, completely symmetric with the problem of deriving a location based on reception of the Navigation Signals from several GPS satellites by a single receiver.

2. BDX Instrument Description

The BDX instruments flown on the GPS series of satellites, as part of the United States NUDET Detection System, provide global exoatmospheric monitoring for NUDETs. X-ray instruments have been flown in space since the launch of the first Vela satellites in October 1963 to monitor the Limited Test Ban Treaty. Each of the current GPS spacecraft is configured with either a Burst Detector X-Ray (BDX) or Burst Detector Dosimeter (BDD) instrument as part of the Global Burst Detector (GBD) payload. This document describes the BDX-IIR, which will be on many of the earlier Block IIR GPS satellites. Later GPS satellites of the Block IIR and Block IIF series will carry the Combined X-ray Dosimeter (CXD), which combines and extends the capability of the BDX-IIR and BDD-IIR instruments.

The x-ray instrument on the GPS Block I satellite was different from those on Block II, IIA, and IIR satellites, but the design of the Block II, IIA, and IIR x-ray sensors (BDX) on the GPS satellites share fundamentally the same design. This is a broad-band channel design with four bands of x-ray energies sampled. A schematic of the BDX-IIR instrument is shown in Figure 1.

Figure 1. Schematic of the BDX-IIR's box with its four Main Channels and the Confirmation Channel on top.

2.1 Theory of Operation

The BDX designs for the Block IIR spacecraft consist of simple filter/sensor arrangements, as shown schematically in Figure 2. The filter transmits a fraction of the x-ray photons of a given energy; of these, a fraction is absorbed by the sensor. The intensity of the photons of a given energy that are registered by a particular sensor can be expressed by:

$$I(E) = I_0(E) \exp[-\mu_f t_f] (1 - \exp[-\mu_s t_s]),$$

Figure 2. Cross section of the BDX filter/sensors. The Confirmation Channel is on the right, and two Main Channels are on the left.

where E is the photon energy, $I_0(E)$ is the incident intensity at photon energy E , μ are mass attenuation coefficients, t are the mass thicknesses of absorbers in g/cm^2 , and the subscripts f and s stand for filter and sensor, respectively. Mass attenuation coefficients are shown as a function of photon energy in Figure 3 for carbon and silicon. By suitably selecting the materials and the thicknesses of the filters and sensors, various broad energy response functions, $R_f(E)$, can be defined. The $R_f(E)$ also include area and angular factors. The total energy deposited in the i th channel is then given by:

$$E_i = \int I_0(E) R_f(E) dE$$

Measurements of E_i provide a way to estimate I_0 . This estimate, together with a range to the explosion that is calculated from the location determination, then provides a yield estimate for the device.

Figure 3. The mass attenuation coefficients for carbon (left) and silicon (right) as a function of photon energy. (Note that the scale for μ on the right plot is 100 times larger than that for the left plot. Thus x rays in Si are stopped much faster than in C.)

2.2 BDX-IIR Sensors

The BDX-IIR has four Main Channel x-ray sensors, which are very similar to the Block II and Block IIA BDX sensors. It includes a fifth sensor to confirm coincidences among the sensors.

2.2.1 Main Channel Sensors

The four Main Channel x-ray sensors for Block IIR are the same design as the Block II and Block IIA BDX sensors. The design of each channel is a sensor/filter combination. The low-energy response of a given channel is determined by the chemical element (Be, C, or Al) of which the filter is composed, and the high energy roll-off of the channel is determined by the thickness of the silicon sensor behind the filter. This arrangement allows four broad-band energy samples to be made of a source distribution. The sensors have a 55° half-angle field of view (FOV), which allows measurements to be made of possible attacks on other spacecraft in the constellation. The overall thicknesses of the filters in grams/cm^2 are the same for all four channels and are chosen to provide protection to the silicon sensors from radiation damage due to energetic particles in the radiation belts. The relative response functions of these channels are shown in Figure 4 as a function of photon energy.

Figure 4. The relative response functions as a function of photon energy of the four Main Channels and the Confirmation Channel, which covers those of the Main Channels.

2.2.2 Confirmation Channel Sensor

The Confirmation Channel combines the filter of Channel 1 with the sensor of Channel 4. The result is a response function that is the envelope for the four Main Channel sensors (Figure 4). The sensor in this channel stores the energy from a nuclear source as charge for a long time, whereas the sensors in the Main Channels transfer the charge to the electronics instantaneously.

The long storage time allows the electronics to sample the Confirmation Channel after a Main Channel trigger to confirm that charge was created in the sensor. Electronic noise or electrostatic discharge from spacecraft charging do not have sufficient energy to ionize silicon, but the fast nature of noise and discharges can trigger the sensitive electronics in the Main Channels. The sample time is selected by command.

2.3 Mechanical Description

The BDX-IIR sensors are on the outside of a box that is 11.0 inches tall, 8.5 inches wide, and 4.5 inches deep. The top plate extends over the sides of the box. The box is attached to the outside of the Earth-facing panel of the GPS spacecraft. The BDX-IIR weighs 17.2 pounds, and its center of gravity is 6.7 inches above the BDX/spacecraft interface. The electronics, power supplies, and wires are inside the box. The BDX is connected to the Burst Detector Processor (BDP) through the bottom of its box. The BDX has a 55° (half angle) field of view that is 1.5% obstructed by other objects on the Earth-facing panel.

2.4 Electronics

A block diagram of the BDX-IIR electronics (power and communication among modules) is shown in Figure 5. Each of the four Main Channels and the Confirmation Channel consist of a silicon semiconductor sensor and a measurement chain of electronics. The measurement chain for the Main Channels consists of a pre-amplifier, four amplifiers, auto-ranging electronics, and an Analog to Digital Converter (ADC). Command interpretation, instrument control or state, data formatting, and digital communication with the BDP are performed by an 8085 microprocessor contained within the BDX. A test pulse, power, and clock times are provided by the BDP.

Figure 5. Schematic of the electronics for the BDX-IIR, including power to the modules, the two system tests, and communication among sensors, modules, and the BDP.

2.4.1 Thresholding and Coincidence

The four Main Channel sensors each contribute to the generation of the coincidence pulse that defines an event and initiates collection of event data. Each channel has a preset threshold for the total energy deposited in the sensor. The first sensor to cross its threshold generates a time gate. The other channels contributing to the coincidence must cross their respective thresholds within this time gate in order for a valid coincidence pulse to be generated. The number of channels required for coincidence can be one (used for ground checkout), two, or three. This number is determined by the state of the BDX instrument and can be changed by ground command.

2.4.2 Confirmation Channel

The Confirmation Channel is designed to store the energy from a NUDET as charge. After a coincidence pulse is generated by the Main Channels, the Confirmation Channel is sampled at an instant delayed by 2, 5, 10, or 20 μ s. The delay time is selected by ground command. If the coincidence pulse was generated by a transient electronic noise pulse or a spacecraft discharge, then there should be no charge in the confirmation sensor. If, on the other hand, a NUDET actually occurred, the sensor should retain stored charge for a significant length of time, and the sampling of this channel will confirm the NUDET.

2.4.3 Time Tagging

The time associated with the event corresponds to the time of threshold crossing for the last Main Channel contributing to the coincidence. For example, if the BDX is in two-fold coincidence mode and three channels have signals above threshold, the second fastest rising signal would be used to time the event. Although the actual signal shape is a convolution of the time profile of the x-ray pulse and the time response of the amplifiers, the time of the peak can be no faster than the time constant of the amplifiers. If the peak is very large compared to the threshold, the time to cross threshold is small; if the peak is equal to the threshold, the time to cross threshold is approximately equal to the amplifier's time constant. This correction to the "zero" time of an event is well known to designers of nuclear electronics and is usually designated by the term "walk."

The walk time has been measured using an oscilloscope triggered by an external pulser and looking at the output of the logic signal generated by the level detection circuit. The time delay has then been measured by setting a cursor on the edge of this pulse and using the oscilloscope's programmed function to readout the time. This manual method has been replaced with special circuits designed by LANL's Group NIS-3 for use with the Ground Support Equipment. The walk determined for the BDX-IIR decreases monotonically with increasing deposited energy, with the change in the walk for increasing peak intensity being rapid for lower intensity peaks and small for larger peaks. The effect of walk can be corrected using ground-based algorithms.

2.4.4 Auto-Ranging and Pulse Height Analysis

The sensor input to the electronics is presented to four amplifiers connected in series. Level Discriminators (LDs) are connected to the outputs of these amplifiers. The last LD, which views the product of all four amplifiers, corresponds to the threshold set for that particular channel. Associated logic decides -- "auto-ranges" -- which amplifier will be used for subsequent analysis. The output of the selected amplifier is then directed to a peak-hold circuit. The output of this circuit is in turn presented to an Analog to Digital Converter (ADC) for conversion to digital form.

for temporary storage within the BDX. Each amplifier produces a linear output for its input range, and each range is approximately a factor of ten larger than the proceeding one. The effect is to generate a pseudo-logarithmic response function that is piecewise linear (see Figure 6). The digital count for each channel transmitted to the ground can be converted to an actual energy in that sensor.

2.4.5 Trigger Rate Counter

The number of times the various channels cross threshold are recorded and transmitted to ground on a periodic basis. This number should increment for each system test, but excess counts above this level are indicative of background or noise. Occasional background counts may be expected from cosmic-ray showers generated within the spacecraft.

2.4.6 X Triggers Y

There is an option where the BDY is triggered by a valid coincidence in the BDX, and this BDY data is transmitted to the ground. At present, there are no plans to turn on this option, although the capability may be enabled using SMC 34.

Figure 6. Schematic of the output from a BDX sensor as a function of the count, showing the effects of "auto-ranging" to one of the four amplifiers.

2.4.7 Power

The BDX has dual power supplies, providing redundancy for this critical electronic component of the instrument. The BDP provides the input power (28 volts-DC) to the BDX power supplies. "Break-before-make" circuitry in the BDP insures that only one power supply is on at a time.

3. Calibrations

Each instrument is separately calibrated to ensure that the responses are as similar among units as is reasonably possible and to record the minor differences that inevitably exist. The data are recorded in a GPS database maintained by Group NIS-3 at Los Alamos. The data are reduced, and the results are recorded in tables that are used by Sandia's Integrated Correlation and Display System (ICADS) and by off-line software developed by Los Alamos. The calibrations developed during the testing phase of each instrument can not be repeated after delivery; however, there is a quick calibration check done after acceptance testing that verifies the stability of the more detailed calibrations.

4. System Tests

The BDX-IIR instrument includes electronic system test functions (in-flight tests) that allow stimulation of the electronics in two ways, either by injecting a single test pulse or using light emitting diodes (LEDs). A fixed amount of charge can be injected via the electronic test input capacitor into the charge-sensitive preamplifiers, or the detectors can be excited with LEDs for an "end-to-end" test of each channel. In either case, the system test module, denoted "SYS TEST" in Figure 5, sends 1 electronic pulse into each channel. Because the light output of the LEDs depends on temperature, the light pulse may not be sufficient to stimulate the correct channels at extreme instrument temperatures, although they will perform correctly for the nominal operational specifications.

During routine operation, an electronic system test will be performed once per day. The BDX system test occurs during the test sequence for the other GBD instruments. The BDX system test is enabled by bit D1 of SMC 28 and executed when bit 5 of SMC 28 is 1. The system test occurs at the system test trigger, which can be commanded by SMC 28 to be the next X1 epoch (almost immediately) or when a time specified in SMC 27 occurs (which occurs within 384 s of receipt of the command). If a system test occurs, it is indicated by a bit in the BDX L3 data frame.

A discrete system test for the BDX, BDY, and BDW is initiated by SMC 29. Bit D5 of SMC 29 must be 1 for this system test to be enabled. If enabled, the BDP issues a 1.6-ms pulse immediately. The output from the discrete system test is different from that of the routine GBD system test. The test outputs are expected to be identical, day-to-day, if the instrument is performing properly.

5. Commands to the BDX

5.1 BDX Commands

Serial magnitude commands (SMCs) 38, 39, 3A, and 3B are sent to the BDX (or the BDD). These commands are stored in the BDP upon receipt. They are sent to the BDX/BDD if it is

enabled. Upon receipt of the commands, the BDX/BDD stores them and performs the required actions. SMC 38 is only for the BDX. SMC 39 is only for the BDD (and is not given here). SMC 3A and 3B apply to both the BDX and BDD. The important parameters in these commands are summarized in Table 1 and in the text below.

Table 1. BDX Commands

SMC	MSB D7	D6	D5	D4	D3	D2	D1	LSB D0
38	X	X	Confirmation Time		Channel Coincidence		System Test (Elect./LED)	BDX Trigger Disable
3A	X	X	X	Disable BDX Events	X	Disable MRO Function	Disable SOH Messages	Disable Status Messages
3B	X	BDX Channel GIM Reset	Select GIM Parity	X	Reset "set" Commands	Reset Pointers, Counters, & Flags	Reset GIM Error Checking	Send BDX SOH

For the commands below, there are two states: Initial State and Standard Configuration State. The Initial State is the value that the byte gets set to on initialization of the GBD. The Standard Configuration State is the value that the byte gets set to if the GBD does not receive any valid command within approximately three minutes of the completion of an initialization or if a command is sent for the GBD to go to the Standard Configuration. The eight bits in a byte goes from the most significant bit (MSB), bit D7, to the least significant bit (LSB), bit D0.

• SMC 38 (BDXCMD)

SMC 38 controls the BDX channel coincidence parameters. Bit 6 and 7 are not used and can be anything.

- The BDX Confirmation Time (bits D5 and D4) is the time within which the coincidences must occur: 00 = 2 μ s, 01 = 5 μ s, 10 = 10 μ s, and 11 = 20 μ s. The normal configuration is for 20 μ s.
- The BDX Channel Coincidence (bits D3 and D2) is the number of the four Main Channels that must trigger for a event to be sent to the BDP: 00 = 3, 01 = 1, 10 = 2, and 11 = 3. The normal configuration is for 2 channels.
- The system test (bit D1) can be selected to be either electronic (1) or with the light emitting diodes (LEDs) (0). The system test normally is an electronic one.
- It is possible to disable the collection of BDX data frames by making bit D0 = 1.

The initial state is 02_H (00000010_B), and the standard configuration is 3A_H (00111010_B).

• SMC 3A (XMESSOF)

SMC 3A (XMESSOF) is used to control the transfer of BDX messages to the BDP. This command can be generated internally by the BDP. Bits 3, 5, 6, and 7 are not used and can be anything.

- The Disable BDX Collection Messages bit (D4) tells the BDX not to send any BDX collections until this bit is a zero. The BDX keeps collecting data, up to 421 events, but does not overwrite memory. In a high-event rate situation in which an L3 readout is active, the BDP Main Processor is allowed to overtake the part of the BDP's memory assigned to non-event data to store event data. In this case, the BDP may issue a command making bit 4 = 1 to stop the transfer of event data from the BDX. A command from the ground is needed to reset this bit to 0 and restate collection transfer.

- The Disable BDX Memory Read Out (MRO) Message bit (D2) tells the BDX to ignore any MRO commands from the BDP until this bit is 0. If the BDX is currently transferring a MRO, it is finished but no more are sent.

- The Disable BDX State of Health (SOH) Message bit (D1) tell the BDX not to transfer any more SOH messages until this bit is 0. If the BDX is currently transferring a SOH message, it is finished but no more are sent. If this bit is a 1, then bit 0 of SMC 3B has no effect.

- The Disable Status Messages bit (D0) tells the BDX not to send any status messages. Status message transfer is allowed when this bit is changed to 0.

The initial state is 00_H, and the standard configuration is not applicable to this command.

• SMC 3B (XGIMFNC)

SMC 3B is used to force a Global Interface Module (GIM) reset, select BDX GIM parity options, enable/disable BDX message receive error checking, and to force a BDX SOH transfer. This command will be generated internally by the BDP where (1) the BDP has not received a valid transfer from the BDX in a predetermined amount of time and such transfers are enabled, (2) when the BDP gets lost in a transfer to the BDP and cannot find a valid set of end-of-messages bytes, or (3) when the BDX communicates to the BDP that it is not correctly receiving incoming messages. Bits 4 and 7 are not used and can be anything.

- The Channel GIM Reset bit (D6) tells the BDX to reset the GIM in the BDX and to send 16 end-of-message bytes to the BDP.

- The Select BDX Channel GIM Parity Options bit (D5) selects the parity option (even or no parity) used by the GIM during data transfers. Reset to a 0, the BDX programs the GIM with even parity.

- The Reset BDX "set" Commands bit (D3) tells the BDX to clear the BDX set command bits to a zero value. The command bits reset to zero are SMC 28 bit D5, SMC 29 bit D5, SMC 2C bits D7 and D6, and bits D6, D2, and D0 (but not bit D3) of this command.

- The Reset BDX Pointers, Counters and Flags bit (D2) tells the BDX to perform a "soft" reset. This allows events and data collections to be stored as if a sensor initialization had occurred but does not initialize command registers. (This differs from a hard initialization in that command registers are left in their current states and the GIM and hardware are not reset.)

- The Enable BDX GIM Error Checking bit (D1) tells the BDX to ignore certain messages from the BDP if an error is found in the message (framing, overrun, or parity error). When this bit is reset to 0, then the BDX tries to use all received messages.

- The Send BDX SOH bit (D0) tells the BDX to send a state-of-health (SOH) message to the BDP (unless bit D1 of SMC 3A is 1).

The initial state is 20_H (00100000_B), and the standard configuration is not applicable to this command.

5.2 Other Commands Affecting the BDX

Besides the BDX commands (SMCs 38, 3A, and 3B), other commands can affect the BDX and its data. Such commands generated by the BDP are not considered here. Some of the more important ones that are sent from the ground are given here. Other commands can affect what is sent from the BDX to the ground by the BDP, such as SOH frames, but are not discussed here.

System tests by the BDX are affected by community commands SMCs 26, 27, 28, and 29. Bit D1 of SMC 28 set to 1 enables the BDX system test. Bits D3-D0 of SMC 26 sets the BDX system test enable timer, with the time the value of the four bits times 24 seconds. The default value is 144 seconds (0110_B for bits D3-D0 of SMC 26). Bit D5 of SMC 28 set to 1 executes a system test. Other commands discussed in Section 7.3.5 determine the nature of the system-test trigger (on the next X1 Epoch, on a ZTIME match with a time in SMC 27, or a delayed system test with SMC 4B).

Community command SMC 2C can be used to clear and test the BDX's memory, but such memory tests and clears are normally not done because they destroy the memory's contents. SMC 33 controls the transfer of a memory read out from the BDX for an S-band dump.

Several commands to the BDP affect the BDX. Bit D5 of SMC 41 set to 1 initializes the BDX's processor. Bit D6 of SMC 42 set to 1 disables the BDX's functions. Bit D0 of SMC 43 turns the BDX power on if 1 and off if 0. Bit D1 of SMC 43 selects BDX power from A if 0 and from B if 1.

6. BDX Message Formats

The BDX sends five types of messages serially to the BDP. Four of these are status messages, state-of-health messages, data collections, and memory readouts. Each of these four messages is identified by a byte (eight bits) as a header and includes the ZTIME after the header. Bits 7 and 6 are different for these four types of messages. The fifth message type comprises EOM byte pairs sent to the BDP upon initialization and GIM resets. All messages end with two end-of-message bytes.

6.1 BDX Status Messages

The BDX has three status messages. The header contains all zeros. One confirms a recent initialization (second byte = 18_H). The second tells the BDP that the BDX cannot sync-up on the ender message bytes and that the BDP should reset the Global Interface Module (GIM) connected to the BDX serial link (second byte = 42_H). The third tells the BDP that the BDX acknowledges a GIM reset command (second byte = 24_H).

6.2 BDX State-of-Health Messages

The BDX provides state-of-health (SOH) messages to the Interface Processor of the BDP about every six seconds. There are two types of SOH messages, regular and extended. Bits D5 and D4 in the header identify the type of SOH message. The regular SOH message contains a header byte, two ZTIME bytes, 48 data bytes, and the two EOM bytes (for a total of 53 bytes). The extended SOH messages included an additional 77 bytes (mainly memory test error buffer bytes)

for a total of 125 data bytes plus the five other header or EOM bytes. The data in the SOH messages are summarized in Table 2.

Table 2. State-of-Health Message (BDX to the BDP's Interface Processor)

HEADER	0 1 I ₅ I ₄ 1 Z ₁₈ Z ₁₇ Z ₁₆ I ₅ I ₄ = 00 indicates a regular SOH message I ₅ I ₄ = 11 indicates an extended SOH message
ZTIME 1 and 2	Bits 15 to 0 of the ZTIME (Z ₁₅ to Z ₀)
DATA 1 to 26	Command Registers 26 _H to 3F _H
DATA 27	Serial Data Error Count
DATA 28	Command Error Count
DATA 29	No Operation Performed Error Count
DATA 30	+5 Volt Monitor
DATA 31	-5 Volt Monitor
DATA 32	+12 Volt Monitor
DATA 33	-12 Volt Monitor
DATA 34	+250 Volt Bias Voltage
DATA 35	+250 Volt Monitor
DATA 36	Temperature 1 (SOH Electronic Card)
DATA 37	Temperature 2 (Sensor Deck)
DATA 38	XRAY Trigger Count - High Byte
DATA 39	XRAY Trigger Count - Low Byte
DATA 40	S1 Singles
DATA 41	S2 Singles
DATA 42	S3 Singles
DATA 43	S4 Singles
DATA 44	BDX Status Word (Read of Port 10 _H)
DATA 45	Last Idle Loop Counter - Low Byte
DATA 46	Last Idle Loop Counter - High Byte
DATA 47	Software Version
DATA 48	PROM Checksum

For a regular SOH message, the two EOM bytes go here. For an extended SOH message, the following data bytes are included:

DATA 49	Extended SOH Sync Byte (FB _H)
DATA 50	Value of Last Command 2C at Start of Memory Test
DATA 51	Low Byte of ZTIME at End of Memory Test
DATA 52	4 MSBs of Memory Test Counter, Incremented at End of Memory Test; Then 4 MSBs (19-16) of Memory Test Error Count
DATA 53	Next 8 MSBs of 20-Bit Memory Test Error Count
DATA 54	8 LSBs of 20-Bit Memory Test Error Count
DATA 55	8 MSBs of first RAM Test Error Address
DATA 56	8 LSBs of first Error Address (zeros if no errors)
DATA 57 to 124	2 Bytes Each for 2nd through 35th Error Address
DATA 125	0
EOM 1 and 2	

MSBs (LSBs) = Most (Least) Significant Bits; X_H means X is hexadecimal.

6.3 BDX Event Messages

The BDX sends data from its x-ray sensors to the ground when the BDX's main sensors have met a trigger requirement that is verified by the Confirmation Channel. These data are sent to the BDP and then to the ground over the L3 downlink as event-initiated data. Event-initiated data from the BDX, BDY, and BDW are formatted into the L3 event-initiated data block, which has 65 bytes of event data starting in byte 7 of a 75 byte block. The first 5 bits of byte 5 of this block, bits D7 to D3, contain the BDX event counter. If the number of events detected by the BDX is more than 31, this counter rolls over to zero.

The BDX data frame is shown in Table 3. The first 5 bits of byte 2 identifies this as a BDX data frame. The time of the event are in bytes 2 to 7, with ZTIME in units of 1.5 seconds and the least significant bit of the fine time being 391 ns. Bit D0 of byte 7 is 1 when a BDX system test occurred during the event. The status word (byte 8) is the configuration of the BDX determined by SMC 38 (confirmation delay time, number of channels required for a trigger, and type of system test). The last 5 bytes are the counts generated by the BDX for the energy deposited in each of the four Main Channels and in the Confirmation Channel.

Table 3. Bytes in BDX L3 Data Frame

BDX 1	Sync pattern (11101011)
BDX 2	00100 then bits 18 to 16 of the ZTIME
BDX 3 and 4	Contains bits 15 to 0 of the ZTIME ($Z_{15} - Z_0$)
BDX 5 and 6	Bits 23 to 8 of the fine time ($F_{23} - F_8$)
BDX 7	Bits 7 to 2 of the fine time ($F_7 - F_2$), then 0 in bit D1 and the system test indicator in bit D0 (1 = system test occurred during the event)
BDX 8	Status Word (from SMC 38) Bits D7-D6: Not used D5-D4: Confirmation delay time (00=2, 01=5, 10=10, 11=20 μ s) D3-D2: Channel coincidence (00=3, 01=1, 10=2, 11=3 channels) D1: System test (1 = electronic, 0 = LED) D0: Not used
BDX 9	Counts in BDX channel 1 (8 bits)
BDX 10	Counts in BDX channel 2 (8 bits)
BDX 11	Counts in BDX channel 3 (8 bits)
BDX 12	Counts in BDX channel 4 (8 bits)
BDX 13	Counts in BDX confirmation channel (8 bits)

Data from the BDX are also sent down by S-band as part of the stored state of health (SSOH) data. Besides temperatures, voltages, and copies of the BDX's SMCs, the BDX trigger counts and singles counts for the four main sensors are sent as SSOH bytes 418 - 422.

6.4 BDX Memory Readout

The BDX can dump the contents of its memory to the BDP upon command by command byte 33. The BDX has two 16K byte memory sections. A memory readout (MRO) provides 16K bytes that are broken down into 64 contiguous messages with 256 data bytes each. Each MRO messages has three header bytes (that identify the message as a MRO and contain the starting address of memory) and the two EOM bytes.

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