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The Giotto Dust Impact Detection System

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Abstract

The Dust Impact Detection System (DIDSY) consists of six independent subsystems with the primary aim of registering the impacts of all particulates of significant mass incident on the probe during the post-perihelion encounter with Comet Halley in 1986. Mounted on Giotto’s front dust shield, the detectors will determine the mass spectrum of the dust, with a limiting sensitivity of some 10**-17 g, increasing to the largest grain masses encountered along Giotto’s trajectory through the cometary environment with an ultimate spatial resolution of some 70 km. An additional detector is located on the rear shield to monitor those dust particles (m > ~ 5 X 10**-7 g) that are able to penetrate the front dust shield. An ambient plasma monitor is also incorporated into DIDSY to measure the impact plasma generated by both dust and gas impacts on the spacecraft. The system is controlled and its data processed by a microprocessor-based system that allows the wide range of anticipated impact rates (varying from a few per minute, to ~ 10**6 s**-1 at closest approach) to be handled. The instrument weighs 2.26 kg and consumes 1.9 W of power during normal operation.

1. Scientific Objectives

The mass efflux from a comet generally consists of two quite separate components, which are distinguished by the Type-I (gas) and Type-II (dust) tails under differentiation by the interplanetary environment. The relative importance of the two is variable but, as a general guide, 30% of this efflux is in the form of solid particles. Some may be ice grains which sublimate within a short period of release. Since all comet observations have been remote to date, knowledge of the particulate mass distribution is identified as one of the most fundamental of measurements of cometary behaviour to be undertaken by the Giotto mission. This conclusion can be drawn both from the point of view of the cometary physics, and from the role of comets as the prime source of interplanetary dust within the solar system.

Measurement in the cometary encounter phase is simplified by the head-on encounter direction of dust and a very accurately known impact speed of 69 km/s. The dusty coma and tail will be comparatively static during the encounter, since velocities in the frame of reference of Comet Halley are typically only 0.5 km/s. Measurement and system development are made very difficult by the extreme variability of the impact rate, which varies approximately inversely as the square of the distance of the probe from the comet, and by the highly unpredictable nature of the dust fluxes. Such variations illustrate very clearly the need for in-situ detection, the only means whereby a reliable model can be determined.

1.1 In-situ cometary particulate measurements

Although the approach to a comet is an entirely new venture in the space sciences and in the exploration of the solar system, cometary dust is a common enough constituent of the solar system and has even been recovered terrestrially (Brownlee, 1978).

Observations of the comet’s dust tail yield a line-of-sight, integrated scattering function for the entire dust population effective in this process. However, the motion of the dust, and hence its distribution in the expanding tail, is differentiated both by the dynamics of gas acceleration processes acting away from the evaporative region, and also by the subsequent balance in dynamics between gravitational forces and solar radiation pressure.

Analysis of the motion of such particles was initiated by Bessel (1836). By extending theory, and in particular the calculation of isophotes, Finson & Probstein (1968) were able to utilize the observations of Comet Arend-Roland and derive data relevant to the particle size distribution. Although their observations suggested a minimum size ’cut-off’ in the region of 1 micro m diameter, this inference is erroneous because of the very small contribution of these particles compared with the larger particles of 10 micro m. In-situ spacecraft data confirm this effect for the Zodiacal Cloud at l AU heliocentric distance, where the actual size distribution is found to extend to the region of 0.01 micro m particle size. Such a lack of positive direct observations from comets is obviously a significant shortcoming in the modelling of flux rates, but from the point of view of assuring the science objectives of the experiment. In-situ detection of cometary particles must extend to the smallest of detectable particles. Although it is known that interplanetary space hosts these very small masses, it is not clear whether these are directly expelled from comets or are the products of impact comminution of the larger meteoroid stream particles as they decay towards the Sun in their Pointing-Robertson spiral. First postulated by Zook & Berg (1975), they are then expelled from the solar system as beta meteoroids. Comparison of the size distribution of fresh cometary dust and the equilibrated interplanetary dust will be one of the rich returns of the Goitto mission. We also know, from the terrestrial observations of the Aquarid (May) and Orionid (October) meteor streams, the size distribution of the larger meteoroids actually expelled from Comet Halley (Hughes, 1978). We will measure these actual masses directly from the Giotto Meteoroid Shield Momentum (MSM) Subsystem and determine their size distribution index, so as to be able to deduce the decay mechanisms operative in metcor streams after ejection from a comet.

From the point of view of forces on cometary grains, differentiation occurs according to (i) an area-to-mass ratio during cometary expulsion and gas drag acceleration, and (ii) an albedo-to-mass ratio in subsequent tail development motion. This leads to models of the time-dependence of the impact rate and size distribution during encounter which have considerably different profiles. The DIDSY determination of the size distribution along the whole encounter trajectory with a mass range potentially extending from 10**-17 g to 10**-3 g is expected to offer very strong discrimination against those models that do not assume the ’correct’ parameters for Comet Halley’s grains. Evaporation of the icy filling of the matrix of fluffy grains can also lead to observational differences, and from the penetration of the Impact Plasma and Momentum (IPM) foil and the MSM shield, it may be possible to determine the average density of the grains.

It is generally believed that, close to the cometary nucleus (up to 20 R(nuc)), particles are accelerated by the outstreaming gas. Ice particles are completely or partly evaporated by the Sun’s radiation. Measuring the size distribution of cometary particles at various distances from the nucleus and comparing this with evaporation models should therefore allow the determination of certain material properties of ice particles (e.g. latent heat of ices). References to detailed modelling of the particulate environment are published by Divine (1981), Hellmich & Keller (1981) and Fertig & Schwehm (1984). Other aspects of modelling relevant to cometary intercept missions are offered by Carey et al. (1984).

Cometary rotation also strongly influences modelling. From Comet Swift-Tuttle, Sekanina (1981) deduces the location of active emission regions comprising only a small fraction of the total area; these would relate in their activity to the rotation speed and quite intense forward jetting of dust away from the comet may be observed. Such anisotropies, and in particular the pre- and post-encounter anisotropies, will be strongly reflected in the DIDSY activity profile.

2. System Design

The DIDSY system has been designed so that, as far as possible, the individual subsystems may operate independently of each other for operational reliability. At the same time, by operating in overlapping ranges of incident particle mass, comparison of results from the different subsystems will yield greater ’scientific’ reliability. Despite independent operation, some coincidence information for individual impacts is exchanged between Subsystems for event validation. However, the failure of one detection subsystem should not in any way affect the correct operation of another. The Central Data Formatter (CDF) performs a primary task of collecting data from each subsystem, processing it as required, and passing it into the telemetry stream. In addition to handling data formatting, the CDF also supplies power to each subsystem via a separate current-limiter so that, for example, a short-circuit in one subsystem does not affect operation of the others. Unregulated power is supplied by the spacecraft power subsystem on a single current-tripped supply.

A buffered star-type interface is used between the CDF and the sensor subsystems; failure on any subsystem does not result in total system failure. The interface operates in a mainly digital manner, each subsystem digitizing its data before passing them to the CDF. In addition, some analogue channels provide housekeeping information (i.e. supply voltages, temperatures, etc.) and also give a limited amount of scientific data. In the unlikely event of failure of the data formatting part of the CDF, some limited data on impact rates are still available.

Data within the DIDSY subsystem are divided into two broad categories, namely: (i) discrete data, which represent a set of measured values for a single event detected by one subsystem, and (ii) cumulative data, which represent the total event amplitude distribution from each sensor and are generated by accumulation of discrete data events within the CDF. Such an approach results from the telemetry allocation, which makes it impossible to transmit full information on all detected impacts, except at very low impact rates. A limited quantity of discrete data are mixed with the cumulative data and passed into the spacecraft telemetry stream by the CDF every 1.3 s during the last hour before closest approach and every 2.83 s prior to this. A brief description of the constituent elements of the DIDSY system is given in Table 1.

Table 1. Constituent elements of DIDSY*

Designation	Description	Location	Mass (g)
DID 1	Impact plasma, momentum and ambient plasma sensor	Located in cut-out in front shield	406
DID 2,3,4	Piezoelectric momentum sensors	Various locations on front shield	8 each
DID 5	Piezoelectric momentum sensor	Rear shield	9
DID 6	Central Data Formatter	Experiment platform	1745
DID 7	Capacitor Impact Sensor	Front shield	22
DID 8	Roll-up cover	Front shield over DID 1	54

* The harness between the sensors and DID 6 is not included in the above mass allocations.

3. Meteoroid Shield Momentum (MSM) and Rear Shield Momentum (RSM) Subsystem

The MSM and RSM sensors and subsystem were designed and developed by the Unit for Space Sciences at the University of Kent at Canterbury. The Rutherford Appleton Laboratory was responsible for the major part of the acoustic design of the front shield.

Three 200 kHz longitudinally resonant PZT 5A piezoelectric microphone elements attached to the rear of the spacecraft front shield and constitute the detectors for MSM subsystem. Each crystal is contained in a hermetically sealed stainless-steel assembly, connection being made through a miniature co-axial connector. Each sensor is attached to the front shield by two titanium bolts in insulating bushes; a kapton washer maintains isolation between sensor and spacecraft grounds. The bolts are tightened to a torque of 30 cNm, this value having been found to give peak output amplitude.

For nonpenetrating impacts on the front shield, there is an initial momentum impulse some 11 times the incident particle momentum. The output pulse amplitude is related to both mass and velocity, but since the velocity of impacting particles during Halley encounter is essentially constant at 69 km/s, pulse amplitude is proportional to incident mass.

Impacts upon the spacecraft rear kevlar shield are sensed by a fourth (RSM) sensor identical to those on the front shield, fixed onto the rear shield by two bolts which screw into threaded inserts. It is positioned underneath the small sector of the front shield. The RSM electronics subsystem is treated as a fourth channel of the MSM.

The original proposal (McDonnell et al., 1981) described three sensors symmetrically placed at 120deg intervals on the periphery of a one-piece front shield, which was ’clean’ with respect to the propagation of flexural waves from localized impacts on the metal plate. A triangulation technique was proposed for estimating the actual location of each impact in order to determine the momentum and mass of the incident particle. As the spacecraft shield design evolved, it became clear that the front shield would not be an acoustically ’clean’ structure.

A programme of laboratory measurements was carried out to estimate the performance of different shield designs (Burton, 1983; Reading & Ridgeley, 1983), using a high-power neodymium glass pulsed laser at the Rutherford Appleton Laboratory to simulate hypervelocity particle impacts on various shield test sections and on full-scale models of different front-shield configurations. The decay time for signals from a simulated impact event on the original front shield design was found to be excessive with consequent degradation of data at high impact rates. The results also indicated that it would not be possible to locate impact events by triangulation methods, because of the nonuniform propagation characteristics of the bumper shield, which had by now become a two-part annulus with several apertures and other structural features. These problems were resolved by isolating a 35deg sector of the annular shield which remained ’clean’, by introducing two ’non-conducting’ radial joints. The joints use a Viton rubber-kevlar double layer sandwiched between two overlapping aluminium plates to provide low transmission and reflectance of the propagating signals. By locating one of the momentum sensors (DID 4) on this isolated clean 35deg sector, it is then possible to obtain a relatively uniform response for reliable estimation of impact mass. A third radial joint permits assembly of the shield structure, but in this case a specially developed ’conducting’ joint allows the larger sector (325deg) of the shield to be used as a single surface with two sensors (DID 2, DID 3) mounted near to the two isolating joints, which separate the large and small sectors. This revised shield design is shown in Figure 1.

3.1 MSM/RSM electronic design

The MSM/RSM electronics subsystem performs both analogue and digital processing of the signals arising at each sensor from a particle impact. Measured values are passed to the CDF within DID for further processing and eventual transmission to the On-Board Data-Handling System (OBDH). The RSM is treated as a fourth channel of the MSM subsystem.

A block diagram of the MSM/RSM electronics subsystem is shown in Figure 2. The 200 kHz component of the signal received from each piezoelectric sensor is extracted by a 600 Ohm six-pole Chebyshev filter which is corrected for cable capacitance and matches the 600 Ohm source impedance, offering a 4 dB insertion loss.

Each signal channel employs Over-Voltage Protection (OVP) at its front end to guard against the potentially large voltages that may be generated by the impact of large particles close to the sensors; two DMOS FETs driven at their gates through 100 V zener diodes connected to the input provide crowbar protection with a ’rounded’ knee at signal levels of 100 V.

Figure 1. Schematic of Giotto front meteoroid
shield showing sensor locations. RSM sensor

(DID 5) is located on the rear shield in the
region below the MSM (DID 2,3,4) sensors

The action of both filter and OVP enables the large dynamic range of sensor output voltages (30 mV - 3 kV amplitude open circuit) to be handled safely and provides a degree of compression. A test input on each channel permits signal injection directly into the front end of each channel through a capacitively coupled 100:1 attenuator network.

To accommodate the large dynamic range of input signals, the half-wave peak detector within each channel operates from two input sources. For signal levels below approximately 200 mV, two stages of amplification precede detection by a single diode peak detector, in which the reservoir capacitor is in a resistive attenuator network. A bypass diode connected directly to the input (after filter) handles the higher signal range; a single operational amplifier provides buffering and a maximum output outage of 10 V may be achieved. Dual-time-constant (3 ms/30 ms) track and hold action is provided by a logic-switched bleed resistor across the detector’s reservoir capacitor.

The amplified signals from each of the MSM (DID 2,3,4) channels are buffered, summed (equally weighted) and detected with a 100 micro s time constant and then integrated with a 3 s time constant to yield a composite analogue measure of instrument activity for use as an analogue science channel, which is passed to the spacecraft.

After peak detection, each channel is logarithmically amplified and scaled by a separate precision-temperature-compensated circuit containing two operational amplifiers, a precision-matched transistor pair and a constant current source; the input range corresponds to an output range of 0-5 V with a slope of 1 V per decade. Test outputs for each channel are taken from the output of each logarithmic amplifier; a high series resistance ensures that connections do not introduce an EMI hazard. A shared analogue multiplexer and 8-bit ADC connected to all four channels enables the CDF, via the dedicated interface to the subsystem, to measure signals detected on each sensor channel.

Figure 2. MSM/RSM subsystem block diagram

In parallel with the ADC circuitry, an analogue comparator connected to the output of each logarithmic amplifier compares the activity on each channel with a threshold level. The threshold level is generated for each channel by an 8-bit counter and 5 V ADC and is set after each event by the CDF via the digital interface. Once set, the counter decrements by one count every 160 micro s until it reaches zero, causing the threshold level to fall linearly at 122 V/s. The counter period is carefully chosen so that the threshold mimics (with a safe margin) the logarithmic decay of the acoustic signals received by any one sensor following a single impact on the front shield directly at the sensor.

Monostables attached to the comparator outputs cause the peak detector of each channel to be switched to the ’hold’ state for a maximum period of 3 ms following the detection of a threshold triggering on that channel. Gating logic also attached to the comparator outputs sets an interface flag (REQ) to request CDF attention at each event. The gating logic which responds to DID 2 and DID 3 events is mode-dependent, being controlled by a CDF-set Coincidence Control (or mode) Register within the subsystem, and is able to operate in one of four modes (see Section 6.7). After the CDF has ’read’ the digitized signal value for each event, it signals completion by pulsing an interface flag (ACK), the request is cleared, the peak detectors are switched back to the track state and the subsystem is ready to detect another ’event’ which exceeds the falling threshold level.

A Timing-Word Register (TWR) within the subsystem indicates the order in which the comparators on each MSM channel were triggered. A 30 micro s monostable on each comparator output feeds a priority encoder which encodes the channel number into two bits and clocks them along a dual-shift register. The shift register is made available through three-state buffers with the bits re-arranged so that they clock in pairs from bit 2 to bit 7. An RSM coincidence flag appears in bit 1 and a CIS coincidence flag (from the CIS electronics subsystem) appears in bit 0. The decoding of the TWR is shown in Figure 3.

Figure 3. MSM timing-word register coding

4. Impact Plasma and Momentum (IPM) Subsystem

4.1 Subsystem design

The most sensitive detector of DIDSY is the Impact Plasma and Momentum (IPM) subsystem. This detector was designed and developed at the Max-Planck-Institut fur Kernphysik, Heidelberg with the help of the Technical University of Munich and the contractor ARGE-PEES, Wald-Michelbach. The IPM detector was manufactured at C. Gavazzi Controls, Milan, under the supervision of CNR-PSN, Rome and the Physics Departments of the Universities of Bari and Lecce. The sensor (Fig. 4) consists of two impact ionization detectors, IPM-P, each with a sensitive area of 59.6 cm**2 for submicron- and micron-sized particles; a piezoelectric detector (IPM-M), supplied by the University of Kent, Canterbury, and a probe (IPM-A) for monitoring ambient plasma production provided by ESA Space Science Dept.

The sensor is attached to the front shield of the Giotto spacecraft, which has a cut out to allow dust particles to impinge directly on the sensors. One of the impact ionization detectors (IPM-P sensor B) is covered by a 2.5 micro m thick, aluminized mylar film while the other (IPM-P sensor A) is open. Since the penetration limit of the film depends on both the mass and density (Pailer & Grun, 1980) - the impact speed during the Halley flyby is fixed at 69 km/s - the specific density of particulates can therefore be estimated from the comparison of the count rates on both sensors (Grun & McDonnell, 1983). The charges produced on impact on the gold-plated target plate are collected by two oppositely biased (+/- 30 V) electrodes in front of the target plate (Fig. 4). Charge signals of both polarity are amplified and processed by the electronics. The piezoelectric crystal is mounted onto the back of the target plate of both impact ionization detectors. It registers, in coincidence with these detectors, impacts of larger dust particles. A cross-calibration between impact ionization and acoustic detection is thereby provided. The plasma probe (IPM-A) consists of a 1 cm**2 gold-plated electrode which measures the plasma mainly induced by cometary dust and neutral gas impacting onto its surface. Besides being a diagnostic tool for analyzing the ambient plasma, this probe also provides a means of assessing the effects of the induced background plasma on the operation of the impact ionization detectors.

4.2 Mechanical configuration

The main constraints imposed by the Giotto mission on the design of the flight instrument have been the large expected temperature range (-50deg C to +125deg C for the IPM sensor), low weight, acoustic isolation of the sensor from the spacecraft body, and low electrical capacitance of the sensor. These requirements were met by the implementation of suitable manufacturing processes and by extensive testing on dedicated test models.

The IPM sensor is mounted on the outer spacecraft shield, while the electronics are located in the DID electronics box (DID 6) on the main platform inside the spacecraft. The IPM sensor is made from a frame constructed of an aluminium alloy, which is machined in such a way so as to reduce weight as much as possible whilst still maintaining the necessary stiffness and strength. To achieve the necessary acoustic decoupling between the front shield and the acoustic detector fixed to the IPM target plate, the frame is supported by four damping pedestals, which are mounted to the back of the front shield in such a way that a cut-out in the shield allows dust and plasma to reach the sensitive areas of the IPM sensor. The acoustic-damping pedestals permit a damping-factor adjustment upon integration in the spacecraft. The operating temperature range of the damping capability is -90deg C to +150deg C. This has been achieved by using silicone rubber O-rings supported by aluminium-alloy pilots as a damping medium.

The frame supports the target plate of the sensor; the latter is manufactured from a flat, 1.5 mm-thick aluminium-alloy plate. The edge profile of the target plate has been tapered for optimum response from the acoustic detector. Acoustic isolation between target and frame has been attained by using a high-viscosity silicone compound

Figure 4. IPM (DID 1) sensor schematic including IPM-A, M and P

together with the above-mentioned edge profile. Two square, high-purity, 0.1 mm thick gold foils are glued to the target plate in order to achieve maximum impaction yields. Eight screws help to guarantee the electrical and mechanical connection to the target plate. The target is kept firmly in place by G11 epoxy and the charge collector with an epoxide adhesive and secured by an additional bridging clamp bolted to the target plate. The target is firmly kept in place by G11 epoxy and the charge collector assembly, which is screwed to the frame. The collector assembly is made from two sheets of G11 glass-reinforced epoxy resin. After cutting the slits and gold coating the bottom collector and top shielding surfaces, both sheets are bonded together like a multilayer printed-circuit board. The charge collector assembly of sensor B is covered by a 2.5 micro m thick mylar film, which is coated with 0.16 micro m of aluminium on the inside surface. Solithane 113 is used for glueing the coated mylar to the top collector surface. Provision is made to connect the aluminium coating to the shielding surfaces of the collector electrically.

The plasma probe IPM-A, visible between the two IPM-P sensors (see frontispiece), was manufactured from glass-reinforced epoxy, similar to multilayer printed-circuit board. A 1 cm**2, circular, gold-plated charge-collecting electrode (and electric guard -17V) is exposed in the centre of the collector strip. The rest of the surface is gold-plated and grounded. During launch and the initial phase of interplanetary cruise, the cut-out in the bumper shield for the IPM sensor is covered by a spring-loaded multilayer roll-up cover. All front-end passive electrical components are located in a small electronics box at the side of the IPM sensor. All electrical connections to the IPM sensor are made through a connector at the bottom of the electronics box and include six shielded lines for the signals and six lines for bias voltages and ground.

Figure 5. Block diagram of the IPM-P subsystem electronics

4.3 IPM-P

The signals from the IPM-P sensors (A and B) are processed in parallel. In this way, no dead-time is introduced on one sensor if the other is busy. Figure 5 shows a block diagram of the IPM-P subsystem electronics. For each sensor, the signals from both the positively (electrons) and negatively (ions) biased charge collectors are amplified in charge-sensitive preamplifiers (CSA). The peaks are detected and held while the amplitudes are converted to digital numbers in 6-bit analogue-to-digital converters. The conversion time for each event (i.e. signals exceeding the detection threshold 2.5 X 10**-14C) on one or both charge collectors] is <= 500 micro s. If both ion and electron signals occur within 20 micro s of each other, a coincidence flag is raised. This has been found to be true for all dust impact events and it is therefore an indicator for this type of event.

A typical analogue-to-digital scheme covers the charge range from 2.5 X 10**-14C to 2.5 X 10**-8 C with a resolution of 40%; individual charge-measuring channels may deviate by 20% from each other. To each 6-bit amplitude word, two more bits are added in order to complete an 8-bit data word. The four 8-bit words constitute a set of IPM-P discrete data. The electron-ion coincidence of sensor A and B is indicated in the least significant bits (LSB) of words 1 and 3, respectively. If, within 150 micro s after this coincidence, an IPM-M signal has been detected, bits 2 of words 1 or 3 are set to ’one’. A coincidence between any signal on sensor A and B within 0.5 micro s is indicated in the LSB of word 4. This coincidence indicates a noise event, which has stimulated the electronics of both sensors. Once every 16 data gathering intervals, calibration pulses are generated and fed into the front end of the signal-processing channels; data from these calibration pulses are identified by the two last bits of word 2. Alternating large and small amplitude calibration pulses are generated. The stimulated electron and ion signals occur in coincidence and therefore the LSBs of words 1 and 4 are set to ’one’. After each event (i.e. threshold exceeded on one of the four IPM-P charge-measuring channels), a request flag is set. Within 4 to 10 micro s, the CDF reads out the four IPM-P discrete data words for further processing. If an electron ion coincidence is set for this event, then no further event can overwrite these data before they are read out. No coincidence data are overwritten by subsequent events. In this way, up to 250 discrete events can be read out per second.

Eight 8-bit counters per sensor count coincident events in different amplitude (ion signal) intervals and will be used to establish a coarse charge distribution for dust impacts at times when the impact rate is too high to allow the transmission of all impacts per Data-Gathering Interval (DGI) with their complete information (discrete events). The DIDSY CDF further processes the information received from the IPM-P electronics, as described in Section 6.8. Impact events are expected to occur in categories 2 to 5, while noise events are transmitted as categories 6 and 7 (see Section 6.8). One event (always the last one) of each category or category combination (i.e. 1,6,7) is transmitted during each data-gathering interval.

Additionally, each event of categories 2 to 7 is counted into four different amplitude range counters. The counter is determined by the corresponding ion amplitude value. The four amplitude ranges are digits 1 through 7, 8 through 17, 18 through 31 and 32 through 63. These 24 counters accumulate up to 255 events of a given category and amplitude range per data-gathering interval.

4.4 IPM-M

The IPM-M electronics subsystem performs both analogue and digital processing of signals generated by the piezoelectric microphone mounted on the IPM (DID 1) sensor target plate. In many respects, the hardware is similar in concept and realization to that of the MSM/RSM electronics subsystem described above.

A block diagram of the IPM-M electronics subsystem is shown in Figure 6. Filtering of the signal from the 200 kHz resonant piezoelectric microphone element is performed using a 300 Ohm matched five-pole Chebyshev filter with a 4 dB insertion loss, which is again corrected for cable capacitance.

Over-Voltage Protection (OVP) is provided at the front end. Two back-to-back stacked pairs of small signal transistors provide a sharp knee at signal levels of 1.4 V, which meets the voltage compliance requirements of the sensitive front end whilst passing the relatively low range of sensor output voltages from 1 mV to 300 mV amplitude open circuit. Test signals may be injected into the front end (after OVP) via a capacitively coupled 100:1 attenuator test input network.

After filtering, a two-stage preamplifier provides buffering and 33 X voltage gain. A 200 kHz, single-stage, Twin-T active filter with Q=4 improves the system signal-to-noise ratio by about 7 dB and provides 11 X voltage gain. A two-stage peak detector and single-stage buffer similar to those in the MSM operate in two ranges and incorporate logic-controlled (3 ms/30 ms) track/hold time-constant switching. The attenuator network across the reservoir capacitor is not required; feedback between the first peak detector stage and the Twin-T filter aids stability. An analogue-science output based upon 100 micro s detection and 3 s integration is passed to the spacecraft. A logarithmic amplifier compresses the detected signal to a 0-5 V range and scales it to 1 V per decade prior to digitization. A test output is taken from the output of the logarithmic amplifier.

Figure 6. Block diagram of the IPM-M
subsystem electronics

An analogue comparator on the output of the peak detector provides coincidence information to IPM-P by triggering a l ms monostable pulse for each output signal that exceeds 1 mV. The maximum delay between a particle impact and coincidence signal generation of 600 micro s results mainly from acoustic propagation across the target plate. Following an event or the receipt of a coincidence pulse from IPM-P, the peak detector is switched to the track state for approximately 1 ms.

A single-channel 5 V ADC, a 5 V decrementing DAC and an analogue comparator allow detected signals to be measured and threshold levels to be set under CDF control. The ADC performs continuous conversions every 25 micro s, placing each result into an 8-bit register. Upon detection of an impact or receipt of a coincidence signal, the register contents are frozen, making a pre-event value related to the acoustic noise environment on the target plate available to the CDF. Reading the pre-event value restarts ADC conversions and makes available the post-event value. Request (REQ)/Acknowledge (ACK) handshaking is provided on the CDF interface.

4.5 IPM-A

The saturation current of the secondary electrons emitted by impact of the gas and dust components of the cometary coma is measured by this sensor. This current is converted to a voltage and then logarithmically compressed to yield coverage of more than six decades of current density. The output is fed to the experiment housekeeping format and is sampled approximately once per second in the nominal encounter format. The 8-bit telemetry digitization yields a nominal resolution of 5% over most of the sensitive range of 10**-6 to 0.3 A/m**2.

A block diagram of the IPM-A subsystem electronics is shown in Figure 7.

Figure 7. Block diagram of the IPM-A subsystem electronics.

4.6 IPM cover

The efflux envelope of the spacecraft transfer propulsion system includes the sensitive surface of the IPM sensor. Due to the conditions prevailing at the time of engine ignition, the sensor surface would be cold; there is therefore a high probability that products of combustion would be deposited on the sensor surface, causing significant deterioration in performance.

Spacecraft resources precluded the conventional approach of a motor-driven latching cover. The solution adopted meets the constraints imposed and also improves the thermal environment of the IPM. The design utilizes a three-layer thermal blanket, which has three embedded, flat strip spring elements. When released, the cover is rolled up compactly to one side of the sensor aperture (Fig. 8). During launch and for the greater part of the cruise phase of the mission, the cover is extended over the sensor and held in place by a short length of nylon filament, which passes over a heater wire. The release operation consists simply of melting through the filament. A spring loaded carrier ensures consistent contact between the heater wire and filament; as the melting operation proceeds, the heater wire cuts through the filament.

Since no data lines are available to confirm release, use is made of a sensor-mounted thermistor to sense the change in temperature as solar radiation falls on the sensor through the open aperture. Incorporation into the cover design of the thermal blanket results in an improved thermal environment for the sensor.

5. Capacitor Impact Sensor

This sensor measures the spatial distribution of dust particles in the 1-5 micro m range; such particles form a major part of the comet and meteorite dust distribution. The measurement range is intermediate between those of the IPM-P and RSM sensors. The CIS sensor subsystem was designed and developed at ONE/CERT, Toulouse with the assistance of the contractor Steel, Mazeres/Salat.

The CIS records the discharge of a parallel-plate capacitor when impacted by a particle whose mass exceeds a threshold value. This type of sensor has previously been used in space for detecting micrometeoroids, in particular for the Pegasus series of satellites (Broderick, 1968; Dozier, 1966). The detection threshold can be determined precisely. The operational reliability is good and the technology is relatively simple.

Figure 8. The IPM sensor positioned beneath its aperture in the front shield. Note the DID 8 cover and its release mechanism after deployment

For the Giotto mission, although the impact velocity is very high (of the order of 69 km/s), it is well known, and this makes it relatively simple to interpret the measurements.

The detailed construction of the CIS sensor is shown in Figure 9. It comprises a 20 micro m thick aluminium sheet bonded onto 25 micro m kapton dielectric whose opposite face has a 1000 A vacuum-deposited coating of aluminium. The system forms a 100 nF capacitor with a 1000 cm**2 surface area.

The sensor is bonded to the outer face of the spacecraft front shield with a 10 micro m insulating kapton layer, using an adhesive capable of withstanding the high temperatures that may be experienced during the mission. The sensor thickness was chosen such that the detection threshold occurs at particle mass of approximately 10**-10 g at the expected cometary flyby velocity. The many studies made on high-velocity impacts (Pailer & Grun, 1980; Igenbergs et al., 1982; Mandeville, 1979; Swift et al., 1982) allow the marginal penetration of thin films to be accurately defined, providing a calibration point midway between the 10**-15 g and the 10**-7 g penetration limits of the IPM-P 2.5 micro m aluminium penetration foil and the Giotto front shield respectively.

The usable surface area of the sensor was chosen to obtain a significant number of impacts far from the cometary core and to avoid saturation during the final phase of the mission. The CIS subsystem contained in the DID 6 electronics box includes a discharge signal-shaping circuit with a fixed detection threshold, a pulse counter and a sensor charge circuit with a time delay and current limiter. The intermediate electrode of the capacitor is charged from the DID power converter, using a fixed 50 V (no load) supply. The top electrode of the sensor is connected to the experiment ground so that the potential on the outer part of the sensor is close to that of the satellite structure (see Fig. 9). The CDF reads the 8-bit counter four times per DGI.

The count rate is limited to about 1000 impacts by the recharge time and by the use of a fixed, known dead time of about 1 ms. The actual impact rate may be calculated from the recorded count using:

R = N/(1 - NT)

where R is the real impact rate, N the recorded impact rate and T the dead time.

An analogue channel measures the mean voltage across the capacitor, providing a check on sensor operation and a signal inversely proportional to the discharge rate.

A coincidence signal is passed to the MSM/RSM subsystem to identify impacts occurring on the CIS sensor.

5.1 Sensor operation

Depending on the impact conditions, one of two processes may come into play (Storti et al., 1968; Laney et al., 1964).

When a particle strikes or passes through the sensor, a conduction path is set up which discharges the capacitor. This may be due to an electromechanical failure of the dielectric, i.e. by a compression due to the passage of a shock wave. This is true for a marginal impact having too little energy to perforate the sensor. Alternatively, it may result from the formation of a plasma, by evaporation and ionization of the sensor material during a partial or complete perforation. Under the high impact speeds during the Halley flyby, the second process is likely to be dominant.

Figure 9. Schematic of the CIS sensor (DID 7)
showing the multilayer construction

The local evaporation of the electrode materials prevents a permanent short-circuit, which would otherwise degrade the operation of the sensor. The sensor, once recharged, recovers its initial properties and is ready to detect a new impact.

5.2 CIS performance

The sensor’s operation was verified by simulating a discharge with a FET circuit triggered by a pulse generator. To verify the behaviour of the compressor circuit, a random pulse generator was used. Best results were obtained by triggering the discharge circuit with random pulses from a radioactive source.

6. Central Data Formatter

6.1 Circuit description

The DIDSY Central Data Formatter (CDF) outlined in Figure 10 consists of an RCA CDP1802 CPU together with 1024 bytes of fusible-link PROM and 320 bytes of static RAM. Interfacing with the experiment sensor subsystems is by means of memory-mapped I/0.

In order to minimize power consumption, mass and volume, the CDF was designed utilizing CMOS technology throughout, except for one subsystem interface where V-MOS transistors have been used for level shifting.

Flat-pack devices have been used wherever possible, but for the LSI units it was necessary to use dual-in-line variants. The power consumption of the CDF is approximately 100 mW from a single 5 V supply.

6.2 CDF/Remote Terminal Unit (RTU) interface

The spacecraft On-Board Data Handling (OBDH) system collects bytes of experiment data via the RTU and the 8-bit Data Output Register at fixed times during the spacecraft telemetry frame. After the transfer of a word, the output register is loaded with the next word using the Direct Memory Access (DMA) facility of the 1802 processor. Command of the experiment modes is via a serial-in/parallel-out shift register. Receipt of a command by the CDF causes Event Flag I of the 1802 to be asserted. The command remains in the register and is acted upon at the beginning of the next telemetry format.

Five bi-level status signals from the DID experiment are inserted into the housekeeping telemetry format to indicate the state of the MSM subsystem and data-handling programme. Four experiment subsystems (CIS, MSM, IPM-A & IPM-M) produce analogue data which is transferred directly to the RTU for digitization. Sixteen parameters within the experiment electronics box are monitored (fifteen supply voltages and one temperature sensor). These signals are conditioned and multiplexed within the experiment before being transferred to the RTU.

Figure 10. Block diagram of the DID Central Data Formatter (CDF)

The CDF has been designed and programmed such that there are an integral number of experiment Data Gathering Intervals (DGI) in a spacecraft telemetry format. Timing of the experiment data gathering and formatting is controlled by the DMA data-transfer function, and the process is synchronized by use of the onboard format pulse, which causes a CDF hardware reset. The first format pulse received by the CDF after power-on initializes the internal byte transfer counter and thus establishes synchronism.

6.3 CDF-subsystem interfaces

The CDF communicates with the experiment subsystems via memory-mapped bi-directional parallel ports. Each port has associated with it a number of address and handshake lines, and one of the 1802 event flags which are polled in the main program to determine when a particular subsystem requires servicing.

6.4 System memory

The CDF program is contained in two Harris HM6641 fusible link PROM devices. The executable code occupies 96% of the available 1024 bytes with a further 3% being occupied by look-up tables.

There are 320 bytes of static RAM in the CDF, 256 bytes of which constitute the data output buffers. 32 bytes are used exclusively for the uncompressed IPM-P hardware-accumulated data. The remaining 32 bytes are used for a program stack and a general scratchpad area.

6.5 Operation

At power-on and at the start of each telemetry format, the CDF receives a hardware reset. In this way any loss of synchronism between spacecraft and CDF is rectified. Digital science data are transferred from the experiment to the OBDH in the form of a 128-byte Did Data Block (DDB). The system is arranged so that as one DDB is being - output from one 128-byte section of memory, by DMA transfer, data received from the subsystems are stored in a second 128-byte section. A continuous check is made on the DMA process so that when transfer of a DDB is complete, operations on the two memory sections are interchanged and the process repeats. Afler each DDB byte transfer, the memory location is cleared, so ensuring that the buffer is completely empty at the start of each DDB transfer. The time taken to transfer one DDB is defined as a DGI and it follows that the information contained in a DDB is that which was collected in the previous DGI. The first two bytes in every DDB contain a 16-bit counter which identifies a block in any period of continuous operation of the experiment.

The total number of telemetry words allocated to the DID experiment in Format 1 is 1024 words/format and in Format 2 2560 words/format. Hence there are 8 DDB and 20 DDB in Formats 1 and 2, respectively.

The DGI is also a function of spacecraft telemetry rate. The relationship between format, data rate, DDB and DGI is shown in Table 2.

6.6 Data formatting

The scientific data are contained in a fixed format in the 128-byte DDB as follows:

Table 2. Relationship between format, telemetry rate, DDB and DGI

		Format 1 1024 DID words 8 DDB	Format 2 2560 DID words 20 DDB
Data rate (kbit/s)	Format time (s)	Average time-DGI (s)	
23	45.33	5.67	2.27
46	22.67	2.83	1.13

Bytes 0-1	16-bit DDB Counter incremented every DGI. Loss of power, loss of onboard sync. or bad data transmission show as a corrupted sequence in the counter value.	
Byte 2	MSM Mode	
	Bit 7 (MSB)	MSM auto sampling on
	Bits 6,5	MSM ’base’ mode in which the MSM operates except for 3 DDB/format in auto mode
	Bits 4,3,2	No meaning
	Bits 1,0	Actual MSM mode active in this DDB
Bytes 3, 4	16-bit value of total number of DID 7 (CIS) events	
Bytes 5-10	DID 2/3 (MSM) Event magnitude bins Calculation of magnitude for DID 2/3 depends on MSM mode	
Bytes 11-16	DID 4 (MSM) Event magnitude bins	
Bytes 17-20	DID 5 (MSM) Event magnitude bins	
Bytes 21-24	DID 1 M (IPM-M) Event magnitude bins	
Bytes 25-28	DID 1P (IPM-P) Category 2 event/magnitude counter	
Bytes		
Bytes 29-32	DID 1P (IPM-P) Category 3 event/magnitude counter	
Bytes 33-36	DID 1P (IPM-P) Category 4 event/magnitude counter	
Bytes 37-40	DID 1P (IPM-P) Category 5 event/magnitude counter	
Bytes 41-44	DID 1P (IPM-P) Category 6 event/magnitude counter	
Bytes 45-48	DID 1P (IPM-P) Category 7 event/magnitude counter	
Bytes 49-54	DID 1P (IPM-P) Category 2 event data	
Bytes 55-60	DID 1P (IPM-P) Category 3 event data	
Bytes 61-66	DID 1P (IPM-P) Category 4 event data	
Bytes 67-72	DID 1P (IPM-P) Category 5 event data	
Bytes 73-78	DID 1P (IPM-P) Category cal/6/7 event data	

Bytes 79,80	DID 1M (IPM-M) Discrete event data
Bytes 81-85	MSM Category event counters
Bytes 86-90	MSM Category 1 event data
Bytes 91-95	MSM Category 2 event data
Bytes 96-100	MSM Category 3 event data
Bytes 101-105	MSM Category 4 event data
Bytes 106-110	MSM Category 5 event data
Byte 111	MSM Maximum event magnitude (DID 2,3,4)
Bytes 112-127	Hardware accumulated data (compressed)

For the MSM and IPM-P (DID 1P) subsystems each event is categorized by testing for internal and external co-incidence. The number of events in each DGI is totalled and the complete data set for the last example in each category is held in the DDB. For both subsystems, the categories are mutually exclusive and thus the total number of events processed in each DGI is the sum of the category event counters in the corresponding DDB, provided that none of the counters have saturated. In the case of the IPM-P subsystem, the data from the once-per-format calibration event are retained and not overwritten by any category-6 or -7 events. The relevant event counters are not affected.

IPM-P hardware accumulated data are collected from the subsystem at various times during a DGI. The counts for each accumulator are totalled at the end of the DGI and compressed into one 8-bit word per channel.

DID 7 (CIS) counts are collected four times per DGI and are totalled before insertion into the DDB.

IPM-M (DID 1M) data are always collected in conjunction with IPM-P data, and are dealt with in the same manner as those collected after an individual IPM-M flag request. There is no categorization, the magnitude binning and discrete data formatting being done in the same manner as for MSM.

6.7 MSM data handling

Event Flag 4 signifies that an impact has occurred and the CDF collects the event magnitude bytes from the analogue-to-digital converter associated with each MSM sensor together with the timing word, which contains information of internal MSM and MSM/C1S coincidence. Threshold levels are written back to the subsystem, producing dead-times proportional to the event magnitude. These are followed by an acknowledge pulse to reactivate the subsystem.

The event is then categorized and the appropriate category counter incremented. There are five categories:

Category 1	CIS coincidence with either DID 2, DID 3, DID 4 singly or in any combination.
Category 2	Coincidence between DID 2, DID 3, DID 4, but only in the absence of CIS
Category 3	DID 5 (RSM) without DID 2, DID 3 or DID 4
Category 4	DID 4 only
Category 5	Any other event not in categories 1 to 4.

The discrete data for the event are put into the DDB in a position fixed by the category determined above. Data from events containing RSM data are, however, always written into the category-3 slot. Any data previously written into the selected category slot during the DGI is automatically overwritten.

Over the period of a DGI, the magnitude of outputs from sensors DID 2, 3 and 4 are compared for every MSM event. The highest value is held in byte 111 of the DDP. In order to indicate the source, the low 2 bits of the number are masked out and replaced with a sensor identification code:

Sensor	Number
DID 2	01
DID 3	10

DID 4	11

Finally, a counter corresponding to the signal magnitude is incremented. The handling of DID 2 and DID 3 values is dependent upon the MSM mode. In Mode 1, the DID 3 value is ignored and the DID 2 value is used, whereas in Mode 2 it is the DID 3 value which is taken. In modes 0 and 3, the values of the two signals are added and divided by 2; the resulting number is used as the event magnitude.

DID 2 and DID 3 sensors can be operated in four hardware modes, for which there are corresponding CDF program variations. These modes are:

Mode	Operation
0	DID-2 and DID-3 coincidence is required before the event is recognized
l	DID-2 only. DID-3 is ignored
2	DID-3 only. DID-2 is ignored
3	Either DID-2 or DID-3, no coincidence is required.

DID 4 and DID 5 functioning is not affected by mode selection. When switched to ’auto sample’, three DDBs in each format contain modes other than the selected ’base’ mode.

The arrangement is as follows:

	DDB in format							
Base mode	l	2	3	4	5	.	.	.	8 (FORMAT 1) 20 (FORMAT 2)
0	0	3	2	l	0	.	.	.	0
l	l	0	3	2	1	.	.	.	l
2	2	l	0	3	2	.	.	.	2
3	3	2	l	0	3	.	.	.	3

At power-on, the experiment starts in Mode 0 Auto Sample. The mode can be changed at any time by command; the new mode selected takes effect at the start of the format following receipt of the command by the CDF.

6.8 IPM-P discrete event data handling

The IPM-P subsystem contains two sections which are accessed through the same port. Data from individual events, signalled by Event flag 2, are read from the four addresses and acknowledged. Following an IPM-P read operation, the IPM-M sensor data are collected, ensuring that any coincident information is gathered.

In addition to the discrete outputs, there are 16 high-speed hardware counters, which are read 18 times per DGI. The timing for this operation is derived from the Experiment/OBDH data transfer (see Section 6.1).

The IPM-P subsystem digital electronics operates from 10 V rather than the 5 V level used for the CDF. Conversion from 5 to 10 V is achieved using V-MOS transistors with resistive pull-ups. Conversion down to 5 V is achieved by simple 2:1 resistive dividers.

The four sensor output bytes from the IPM-P discrete-event section contain six bits of magnitude information and two bits of coincidence calibration flags. If either of the calibration flags is set, the four data bytes are written into bytes 73-76 of the DDB, and no other processing is done. Otherwise the coincidence bits are tested, first for Categories 3, 5 or 7 (sensor B) and then for Categories 2,4 or 6 (sensor A). The overall arrangement is:

Category	Event Type
1	Calibration data
2	Sensor A electron/ion coincidence
3	Sensor B electron/ion coincidence

4	Sensor A/IPM-M coincidence
5	Sensor B/IPM-M coincidence
6	Sensor A no coincidence data
7	Sensor B no coincidence data

Except for the calibration data, the A and B sensors are treated separately. When the category of the event has been determined, the appropriate event/magnitude counter in the DDB is incremented and the data written into the correct event data slot. In the case of Category 6 or 7 events, a test is made to ensure that no calibration data are overwritten. As with the MSM, the data present in the event discrete data slots are those from the last event of that category to occur before the end of the DGI.

A reset pulse is sent to the IPM-P subsystem to re-enable event detection.

Over the period of one DGI, the 16 IPM-P hardware accumulator bytes are transferred 18 times. After each read function, the data are added into 16 two-byte scratchpad registers, thus providing a maximum possible count of 262144. At the end of the DGI, the count contained in each register is compressed into an 8-bit word and put into the DDB. Counts less than 128 are uncompressed, but are shifted left once and the LSB is forced to zero. Numbers greater than 127 are shifted right until the most significant bit is in the bit-8 position. The bottom four bits are then masked out and replaced by a number indicating the number of right shifis. The LSB (bit 0) is forced to 1 to indicate that compression has occurred.

Example 1: Unshifted count

Actual count	Value in DDB
01011101	10111010

Example 2: Shifted count

Actual count
0000101110101111

shift right 3 times
1 01110101

mask out lower 4 bits
1 01110000

add in number of shifts
1 01110110

force LSB= 1
1 01110111

final value	Value in DDB
(1) 01110111	01110111
note implied leading bit	

A maximum error of - 3% is caused by truncation when the number is compressed.

6.9 IPM-M data handling

The IPM-M subsystem shares the MSM port hardware. Two addresses are used. After Event flag 3 has been detected, the IPM-M data output is read twice, the subsystem threshold is set, and the operation is acknowledged. The IPM-M is also read in conjunction with the IPM-P. The data present at the interface at the start of a read correspond to the signal level just prior to the event. This pre-event value is read and stored and another conversion is made by the IPM-M in order to determine the event value. The magnitude counter corresponding to the event is incremented and the event and pre-event data are put in the DDB.

6.10 CIS data handling

The CIS-CDF interface transfers one 8-bit word 4 times per DGI. The data transferred are accumulated in bytes 3 and 4 of the DDB for the duration of one DGI. No processing of these data are carried out.

6.11 Event-magnitude computation

A single subroutine is used for all calculations of event magnitude and incrementing the appropriate counter. The subroutine is called with two parameters: counter address and start of look-up table. Separate look-up tables are provided for DID-2/3, DID-4, DID-5, IPM-M and IPM-P.

The first lookup-table value is subtracted from the input value being tested. If the result is negative, the first magnitude counter is incremented; if the result is positive, the look-up table and counter pointers are incremented and the process repeats until the result finally goes negative.

When incrementing the counters a check is made and the count stops at 255 to prevent roll-over.

7. Power Converter

The requirement for electrical isolation between subsystems and the need for many different supply-voltage levels results in a DC-DC converter with 16 separate outputs. The converter is a high-frequency-driven, two-phase device (Fig. 11).

The internal oscillator runs free at approximately 122 kHz and drives a bi-stable multivibrator to produce 1:1 mark/space square-wave signals to drive two HEXFET transistors, which in turn drive the converter transformer. For reasons of mass, volume and efficiency no regulation is provided on the outputs: the limited input voltage swing and relatively constant load ensure adequate performance.

A synchronizing signal from the spacecraft feeds the input to the phase-locked loop system, thus locking the converter to the desired frequency.

For mass, volume and efficiency reasons, no regulation is provided on the outputs, the input level of 26.9 +/- 0.9 V being adequate for the needs of the experiment. The overall efficiency of the converter is 85%.

The output supplies provided by the unit are:

Output	Voltage	Rectification	Purpose
1	+ 30	Half wave	IPM-P sensor bias
2	- 30	Half wave	IPM-P sensor bias
3	+ 30	Half wave	IPM-P sensor bias
4	- 30	Half wave	IPM-P sensor bias
5	+ 10	Full wave	IPM-P analogue circuits
6	- 10	Full wave	IPM-P analogue circuits
7	+ 10	Full wave	IPM-P digital circuits
8	+ 10	Full wave	MSM/IPM-M analogue circuits
9	- 10	Full wave	MSM/IPM-M analogue circuits
10	+ 5	Full wave	MSM/IPM-M digital circuits
11	+ 10	Full wave	IPM-A analogue circuit
12	- 25	Full wave	IPM-A sensor bias
13	+ 50	Half wave	CIS sensor bias
14	+ 5	Full wave	CIS digital circuits
15	+ 5	Full wave	CDF digital circuits
16	2.5		DID 1 cover release

7.1 Analogue housekeeping data

Fifteen supply rail voltages and one internal temperature sensor are monitored. The voltages are conditioned to be between 0 and + 5 V and are multiplexed within the experiment. Each value appears once per telemetry format.

7.2 DID-1 cover release

The circuit of the DID-1 cover-release unit and driver is shown in Figure 12. The two HEXFET transistors in series form an efficient AC switch. Under normal conditions, both transistors are turned off. Application of a 5 V pulse at the switch input triggers the latch formed by the cross-coupled gates, which turns on the HEXFET switch, thus applying a 60 kHz, 4 V peak-peak square wave to the heater wire. The 250 mW dissipation is sufficient to melt the plastic retainer, thus releasing the cover. The circuit is reset after use by powering down the experiment.

Figure 11. Block diagram of DID power converter

Figure 12. DID 8 cover-release circuit

8. First In-Flight Results

DIDSY was switched on for the first time in flight at 0418 UTC on 8 October 1985. All housekeeping channels indicated nominal operation. Calibration pulses in the IPM-P subsystem indicated correct operation of the IPM-P and CDF. All eight modes of the MSM subsystem were commanded and verified. After some 50 h of operation, no impacts have been detected, but none would have been expected in this period. Of note, however, was that, coincident with the actuation of a pyrotechnic device to remove the cover over the OPE entrance aperture, five noise events (no coincident signals) were detected in the IPM-P subsystem due to acoustic coupling or electrical interference.

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