

PAYLOAD SUBSYSTEM FINAL DESIGN REPORT
2001-2002

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Table of Contents

7. PAYLOAD	4
7.1 INTRODUCTION	4
7.2 DESIGN ANALYSIS.....	5
7.2.1 Color Digital Camera	5
7.2.1.1 General Description.....	6
7.2.1.2 Camera Thermal Properties	6
7.2.1.3 Camera Power.....	7
7.2.1.4 Pointing Accuracy.....	7
7.2.1.4.1 Camera Nutation	9
7.2.1.4.2 Camera	
Sweeping.....	10
7.2.1.4.3 Picture	
Taking.....	10
7.2.1.4.4 Camera Filter / Mechanical Filter: Ultra Violet and Infrared Filters.....	11
7.2.1.5 Modifications.....	11
7.2.1.5.1 Pressure Vessels	11
7.2.1.5.2 Conformal Coating.....	11
7.2.1.6 Camera Box Design.....	12
7.2.1.6.1 Surviving the	
Launch.....	13
7.2.1.6.2 Silicon	
Gel.....	14
7.2.1.6.3 Radiation.....	14
7.2.1.6.4 Size and Placement.....	14
7.2.2 Micrometeorite Impact Detector (MMID)	17
7.2.2.1 Description	17
7.2.2.1.1 Schematics.....	18
7.2.2.2 MMID Electronics	19
7.2.2.3 MMID Power	20
7.3 CONSTRUCTION / ASSEMBLY.....	21
7.3.1 Color Digital Camera	21
7.3.1.1 Components /	
Specifications.....	21
7.3.1.2 Camera Modifications.....	22
7.3.1.3 Camera Box Parts.....	22
7.3.1.4 Camera Box Assembly.....	23
7.3.2 Micrometeorite Impact Detector (MMID)	25
7.3.2.1 Specifications.....	25
7.3.2.2 Mounting.....	25
7.4 TESTING.....	27
7.4.1 Color Digital Camera	27
7.4.1.1 Heat Generation	27
7.4.1.1.1 Procedure.....	27
7.4.1.1.2 Results.....	27
7.4.1.1.3 Conclusions.....	27
7.4.1.1.4 Resolution of thermal concerns.....	28
7.4.1.1.5 Copper Braid installation.....	28
7.4.1.2 Power consumption Profile	28
7.4.1.2.1 Theory.....	28
7.4.1.2.2 Procedure.....	28

7.4.1.2.3 Results.....	29
7.4.1.3 Camera Testing Status.....	30
7.4.2 Micrometeorite Impact Detector (MMID)	31
7.4.2.1 MMID Testing.....	31
7.4.2.2 MMID Testing Status.....	31
7.5 OPERATIONS	32
7.5.1 Color Digital Camera	33
7.5.1.1 Camera Operation Procedures.....	33
7.5.1.2 Camera Programming	33
7.5.2 Micrometeorite Impact Detector (MMID)	33
7.5.2.1 MMID Software.....	33
7.6 CONCLUSION.....	35
7.7 REFERENCES.....	36
7.8 APPENDIX.....	37
7.8.1 Appendix A: Paralene C Conformal Coating Specifications and Properties.....	38
7.8.2 Appendix B: Rohacell Foam Specifications and Properties.....	39
7.8.3 Appendix C: Typical Phase-Change Heat Sink Materials.....	40
7.8.4 Appendix D: Payload Subsystem Hardware List	41
7.8.5 Appendix E: Payload Subsystem Adhesives Specifications.....	42
7.8.6 Appendix F: Mechanical Properties of Possible Filters.....	43
7.8.7 Appendix G: Possible Filter Integration Set-ups.....	44
7.8.8 Appendix H: Payload Subsystem Contact List.....	45
7.8.9 Appendix I: Silicon Gel Technical Data Sheet and Processing Application.....	47
7.8.10 Appendix J: MMID Information.....	48

7. PAYLOAD

7.1 Introduction

Spartnik's payloads were chosen to not only be low-cost and easy to produce, but also to demonstrate the significance of a low Earth orbiting (LEO) microsatellite for space related research. Spartnik will be carrying the following payloads:

- Color digital camera
- Micrometeorite Impact Detector (MMID)

The camera will record digital images of Earth from the spacecraft's perspective. The MMID will detect the magnitude and time of occurrence of particle impacts to allow analysis of the environmental characteristics of space. A radiation sensor has been considered as a fourth payload to map profiles of energetic ($\geq 400\text{eV}$) negatively charged particles in the interior of the spacecraft. However, because of its expense and difficulty to integrate, this item was dropped from consideration.

The payload subsystem is located on Tray #3, the top tray. The camera will be mounted to the inner surface of the top face (the + Z face), with the lens facing out of the + Z face. The MMID will be mounted flush to the outer surface of the + Z face near the center. A schematic of the payload placement can be seen in Figure 7-1.

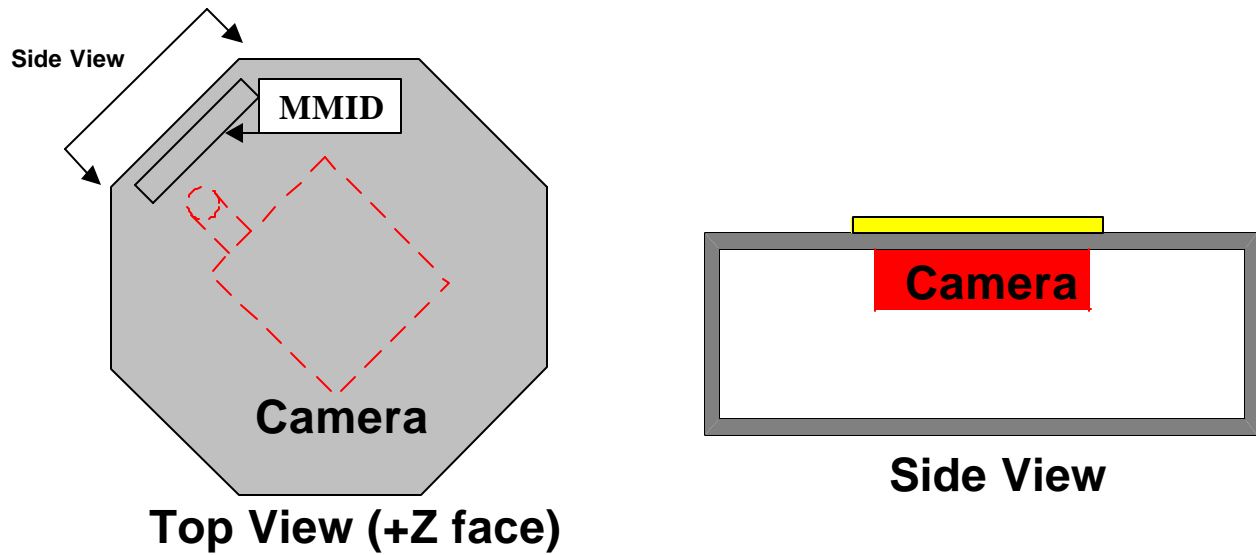


Figure 7-1 Spartnik Payload Placement (not to scale)

7.2 Design Analysis

The primary drivers for the selection and design of the payloads and their mountings were the severe conditions during launch and the harsh environment of space in which the satellite must survive. The vacuum of space can cause difficulties for any non-space rated materials or components. For example, pressure vessels (components that are enclosed and under pressure) might explode in a vacuum. Also some materials, especially plastics, can outgas, a situation in which materials actually release vapors which can then condense on satellite components causing problems for items such as sensors and optics. Furthermore, the radiation found in low Earth orbit can disturb electronic components and computer memories. Lastly, the payloads had to be designed to withstand the several Gs and heavy vibrations that they will experience during launch. These conditions are discussed in detail in the following sections.

7.2.1 Color Digital Camera

Many factors were considered when the digital camera was being researched, some of which are listed below:

- Price
- Durability

- Software processing
- Picture resolution
- Exposure quality
- Modification difficulty
- Zoom capability
- Communication with the manufacturer technology

7.2.1.1 General Description

The selected camera is a Kodak Digital Camera 40™, manufactured by Eastman Kodak. This is an off-the-shelf camera, equipped with four megabytes of Flash RAM internal memory, and additional software compatible with Macintosh or IBM computers. The Flash RAM is a type of electronic memory used by the camera for image storage. This type of memory has never been fully tested in the space environment. We will be testing this application for Kodak by saving some pictures with the Flash RAM and some on Spartnik’s CPU, then comparing the quality of the two. Software is being developed to replace that from Kodak to be implemented by the onboard CPU and the SJSU ground station.

7.2.1.2 Camera Thermal Properties

The required temperature ranges for the camera as specified by Kodak is listed below in Table 7-1. The manufacturer at conditions of 95% relative humidity determined these temperature ranges. Because permanent damage to the camera can occur if the local temperature deviates from the operating range while the camera is on, temperatures near the camera must be controlled and the camera must remain off during times when the temperature is not optimal.

Operating environment	0°C to 40°C
Storage environment	-20°C to 60°C
Thermal dissipation rate	< 1W

Table 7-1 Thermal Requirements of DC40 Camera¹

Sensors are required on the payload tray to ensure the camera and other payloads are within the operating conditions. The on-board computer will either turn power off or will prevent a power up of a payload if the internal temperature of that component does not meet the conditions. The thermal dissipation rate shown here is the power wattage rating. It is assumed that all power supplied to the camera will be dissipated as heat since there is no physical work. Sensors will be located near areas where the most heat is generated (i.e. near a power supply or regulator) to ensure that the spacecraft interior does not become too hot. Also, sensors will be located in the coolest spots of the spacecraft (farthest away from any heat generators) to make sure it is not too cold. For a detailed discussion of the final sensor placement, see Section 19, Thermal Control Systems. The sensors employed will have an accuracy of ±0.024 volts or a temperature ±0.2° C.

7.2.1.3 Camera Power

Either a direct current (DC) or alternating current (AC) power supply is needed to operate the camera. When a DC supply was used (4 lithium AA batteries @ 1.5 volts each), the camera was measured, experimentally, to use 6 volts at 750 mA, or 56.25 mW to take a photograph. When an AC supply was used, 7.5 volts, 2 amperes or 15 watts was needed to take a picture. Since the use of an AC power supply creates problems such as unwanted magnetic fields and added weight for a DC to AC converter, a DC power supply will be used. It was found that the camera would be able to operate at 5 volts DC and therefore the main spacecraft bus will power the camera. Power will be supplied to the camera by connecting the necessary wiring from the main battery bus to the camera's battery contacts. The power for operation of the camera will be obtained from the spacecraft's rechargeable batteries. All the values above were measured before modifications and assumption that the flash device is off.

7.2.1.4 Pointing Accuracy

The actual area of the Earth that an instrument on a satellite can cover at any instant is called the footprint. The footprint area of the camera can be found using Equations 7-1 and 7-2.

$$A = (B_v)(B_h) \quad (\text{Eq.7-1})$$

where,

- A = total footprint area (km²)
- B_v = vertical footprint (km)
- B_h = horizontal footprint (km)

and,

$$B = 2h \tan\left(\frac{\theta}{2}\right) \quad (\text{Eq.7-2})$$

where,

- B = footprint length (km)
- h = altitude (km)
- θ = field of view (degrees)

The camera's field of view² is specified to be:

- vertical: θ_v = 31.2 °
- horizontal: θ_h = 45.6 °

Figure 7-2 illustrates the camera's footprint area, A, and field of view, θ. As the satellite altitude increases, the footprint area also increases. Table 7-2 and Figure 7-3 displays various altitudes and the corresponding footprint areas.

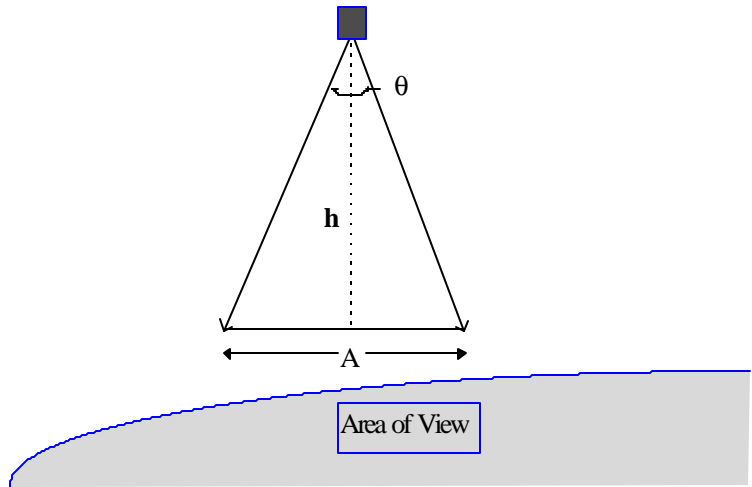


Figure 7-2 Camera Field of View

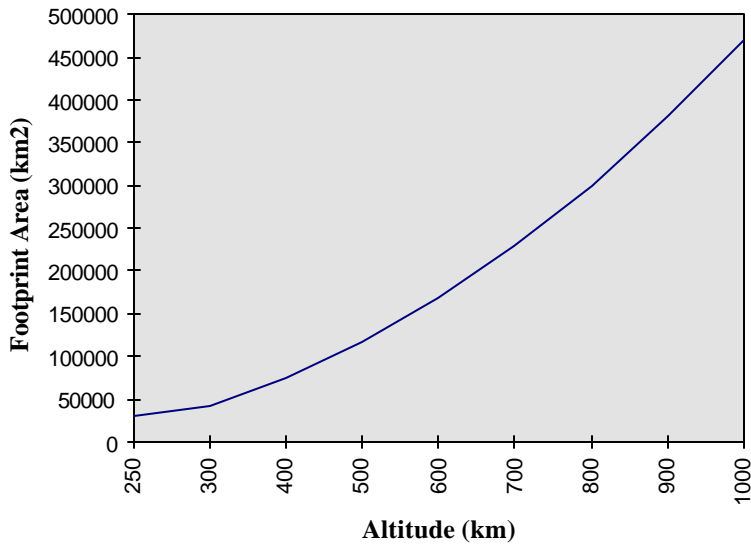


Figure 7-3 Camera Footprint in Relation to Altitude

Altitude	Vertical Field	Horizontal Field	Area
----------	----------------	------------------	------

(km)	(km)	(km)	(km ²)
250	139.6	210.18	29,341.75
300	167.52	252.22	42,252.11
400	223.36	336.29	75,114.87
500	279.21	420.36	117,366.98
600	335.05	504.43	169,008.45
700	390.89	588.51	230,039.28
800	446.73	672.58	300,459.47
900	502.57	756.65	380,269.02
1000	558.41	840.72	469,467.93

Table 7-2 Camera Footprint in Relation to Altitude

7.2.1.4.1 Camera Nutation

While in orbit, the satellite will likely incur a nutation in the (nadir) z-axis. If this happens, Equation 7.3 can be used to calculate the maximum nutation angle that can be experienced and still allow a full view of the desired image.

$$\mathbf{y} = \frac{(\mathbf{q} - \mathbf{f})}{2} \quad (\text{Eq.7-3})$$

where,

$$\mathbf{q} = 2 \tan^{-1} \left(\frac{\mathbf{B}}{2\mathbf{h}} \right) \quad (\text{Eq.7-4})$$

$$\mathbf{f} = 2 \tan^{-1} \left(\frac{\mathbf{L}}{2\mathbf{h}} \right) \quad (\text{Eq.7-5})$$

and,

- ψ = maximum allowable nutation angle (degrees)
- θ = minimum field of view of the camera (degrees)
- ϕ = maximum field of the site (degrees)
- \mathbf{B} = footprint length (km)
- \mathbf{h} = altitude (km)
- \mathbf{L} = length of sight (km)

Thus, for a given camera field of view and desired length of sight, one can determine the largest nutation that may be experienced and still have full view of the desired object. A graphical representation is shown in Figure 7.4.

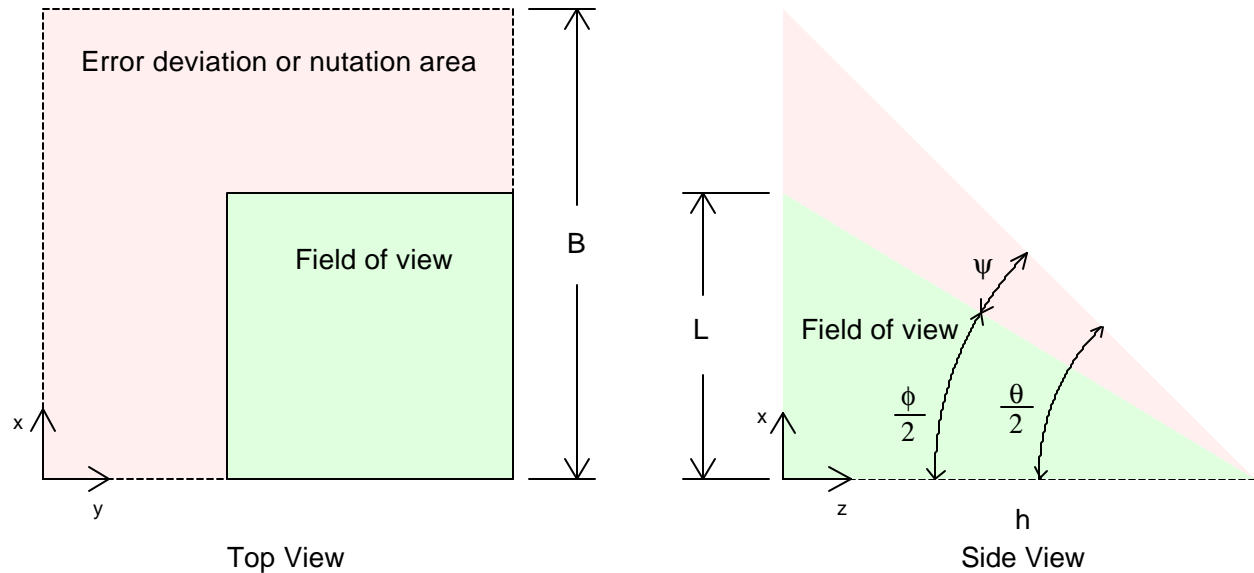


Figure 7-4 Nutation Angle Diagram

To ensure that the camera has the Earth within its field of view, two infrared sensors will be mounted on the + Z face on either side of the lens. For Earth-horizon detection operations refer to Section 5, Attitude Determination and Control.

7.2.1.4.2 Camera Sweeping

While in orbit, the satellite will experience tumbling due to the permanent magnets attached to it. The camera will be in position to take a picture as the + Z face tumbles to face down upon the Earth (or away from the Earth) along the 37° latitude at some angle.

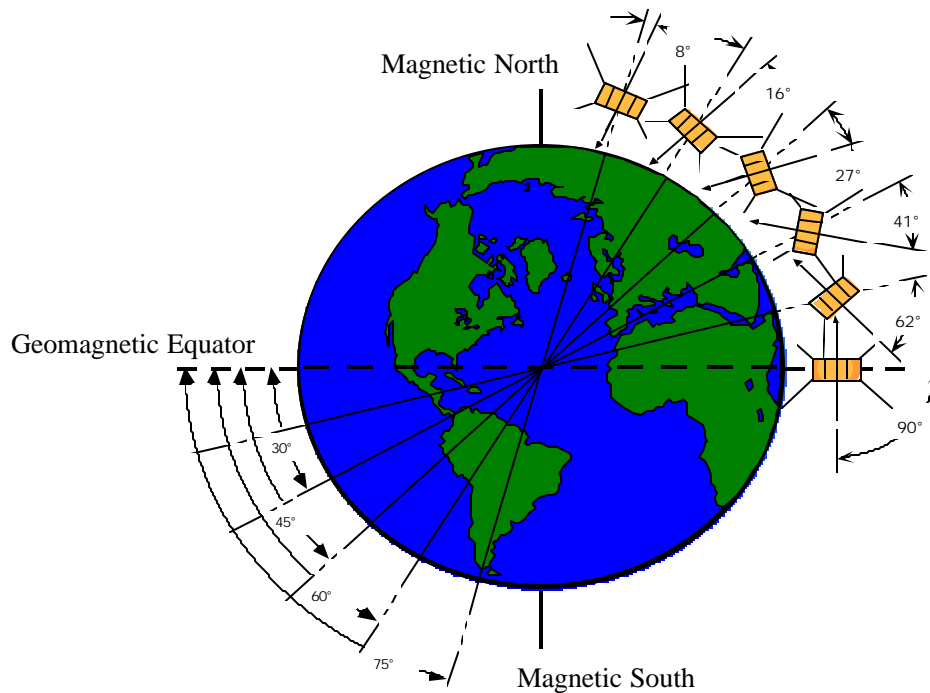


Figure 7-5 Spartnik Attitude for a Quarter Orbit

When facing down, the satellite will act as a push broom. This will be the scanning technique used by Spartnik. Meaning, as it moves along in orbit, Spartnik will sweep the area along track while the + Z face is looking down.

7.2.1.4.3 Picture Taking¹¹

The Kodak DC40 digital camera has a focus-free lens with a range from 4 ft. to infinity. Which means that focusing will not pose a problem. However, the speed of the satellite relative to the spinning of the Earth will cause some blurriness in the image. The shutter speed of the camera ranges from 1/30 to 1/175 s. Using the fastest shutter speed range allowed will enable us to receive a sharp image while sweeping across track.

7.2.1.4.4 Camera Filter / Mechanical Filter: Ultra-violet and Infrared Filters

The CCD, the sensors installed in the payload camera that will produce optical images, will detect infrared (IR), visible light and ultra violet (UV) lights. Since Spartnik's mission is only to produce optical images (under visible light) of earth and possible other near interstellar objects, UV and IR need to be minimized or eliminated.

Appendix F: Filter Catalog shows mechanical properties of possible filters that will be used to limit ultraviolet and infrared. UV and IR filters will be purchased at Edmunds Scientific of New Jersey. As shown in Appendix F, Part C45-720 will filter most of the UV and Part C54-039 will filter IR. Integration of these filters to the camera lens is still to be determined. These filters are subject to be tested in the laboratory to ensure its mechanical properties will withstand the harsh effects of the space environment.

7.2.1.5 *Modifications*

As discussed previously, the environment in space is very harsh, a situation which necessitates either the use of special space-rated materials or modifications to over-the-counter items. The problems related to component survival in a vacuum are primary areas of concern.

7.2.1.5.1 Pressure Vessels

In space, the camera's flash component will become a pressure vessel, and as such, might explode. The flash is only necessary to increase light levels in a low light level environment. Given the brightness of Earth's albedo, this function is unnecessary. Furthermore, the flash consumes a significant amount of power. For these reasons, the flash was removed from the camera. The Liquid Crystal Display (LCD) has been removed for the same reasons. Original modification plans called for the removal of the LCD circuit board as well; however, information provided by Kodak has shown that related circuits in the display circuit board are needed for camera operations. As a result, the LCD circuit has been left on for flight. Lastly, since electrolytic capacitors are also incompatible with vacuum environments, all electrolytic capacitors were replaced by solid tantalum capacitors.

7.2.1.5.2 Conformal Coating

In space many materials, especially plastics, release gasses, which then condense on components in the satellite. This phenomenon, called outgassing, can cause serious problems, particularly when the gasses condense on optics or sensors. To minimize the outgassing effect (and to maximize radiation protection as well) a conformal coating will be applied to all circuit boards and plastic parts. In researching the type of conformal coating to be used, several items were considered, including the material's properties, the application method, cost, shelf life (storage), and mixture thickness. Also, as safety is an important factor, minimizing hazardous chemical properties was important. It was determined that the best protection would be given by a type of conformal coating called Paralene C.

Paralene is the generic name for a unique polymer series. The basic member of the series, called Polymer N, is poly-para-xylene, which is a completely linear, highly crystalline material. Paralene N is a primary dielectric, exhibiting a very low dissipation factor, high dielectric strength, and a dielectric constant invariant with frequency. This form has the highest penetrating power of all the Paralene's. Paralene C is produced from the same monomer modified only by the substitution of a chlorine atom for one of the aromatic hydrogens. Paralene C has a useful combination of electrical and physical

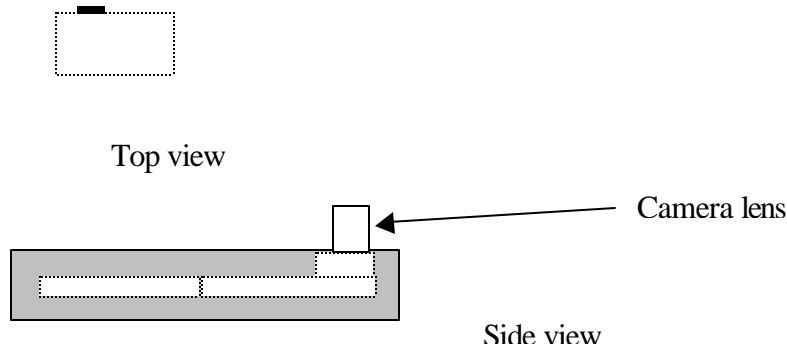


Figure 7-7 Placement of the PCBs (printed circuit boards)

The lens will protrude outside the silicon gel as illustrated by figure 7-7 (side view). Since the lens is directly pointing towards space from the top plate cavity it will experience extreme temperature differences. Therefore, a thick glass will be placed on the top plate.

7.2.1.6.1 Surviving Launch

The Kodak DC40 camera is an off-the-shelf camera, and as such, was not specifically designed to withstand the vertical and vibrational forces that will be applied during launch. For this reason, a creative protective box and mounting design had to be developed. A previous design had been put through a vibration test but failed. During the test, the circuit boards had acted like cantilever beams, resulting in high frequency vibrations, which knocked many electrical components from their mountings. For the final design of the camera box, it was decided that the camera would be left in its original (most stable) configuration and protected from vibrations by enclosing it in space-rated foam. The foam will not only protect the camera from the vibrational environment, but it will also add support. During launch the camera will experience several G's, which can cause the camera to impact the sides, bottom or top of the box. For this reason, it was critical to find foam that will only deform slightly and keep the camera from moving within the box. Several different types of foams were considered, such as Polystyrene, Polyethylene, Poron, and Polymethacrylimide. Polymethacrylimide, or Rohacell foam, has been chosen because of its high yield strength, tensile and compressive strengths, and because of its lightweight. Detailed information on Rohacell's properties can be found in Appendix B. This foam was donated by the Richmond Aircraft Products Company in thicknesses of 1 mm, 3 mm, 12.7 mm & 19.05 mm.

It appeared that the “off-the-shell” camera, which is basically a plastic plate with electronic components on it, has a very complex shape. Having the foam fitting snugly around it was not really possible. It was decided as an option to enclose the camera in a brick of silicon gel, which would itself be enclosed between layers of foam.

7.2.1.6.2 Silicon Gel

VI-SIL™ V-1022 by Rhodia will be used to enclose and protect the camera from the vibrations generated during launch. This silicon gel was chosen because it meets the following criteria:

- It is able to withstand the range of temperatures it will be exposed to inside the spacecraft and in contact with the camera (-54 °C to 204 °C)
- It will not react with the parylene C of the conformal coating
- It has a high thermal conductivity (0.18 W/m²K)
- It has a stiffness that enables the camera to sustain itself firmly, but still helps to dampen the vibrations that could harm the camera
- It can withstand the environment of space (vacuum)
- It can be easily applied and processed

Refer to Appendix I for technical data sheet and processing application.

7.2.1.6.3 Radiation

The radiation that is found in low-Earth orbits makes space a harsh environment. Radiation can cause single event upsets that can corrupt image data or create problems with the electronic circuitry. Thus, in order to protect the camera components from this environment, it was decided that the camera box should be enclosed in a 2024-T6 aluminum box which would then be mounted to the inner surface of the satellite. The camera will be protected from most of the radiation on the sides and bottom by other components in the satellite. However, since the camera is flush against the top surface of the satellite, the top surface of the camera is the most exposed area to radiation. Therefore, the aluminum box will have a 0.25-inch thick top plate and 0.125 inch sides and bottom. This aluminum casing will not only provide radiation protection, but will also minimize the temperature gradients.

7.2.1.6.4 Size and Placement

For specific dimensions of the camera box and the top plate refer to Figures 7-8 and 7-9. The camera will be placed inside the camera box, which will be mounted onto the inner surface, and center, of the +Z face with a 45° rotation from the horizontal axis. This can be seen in Figure 7-9.

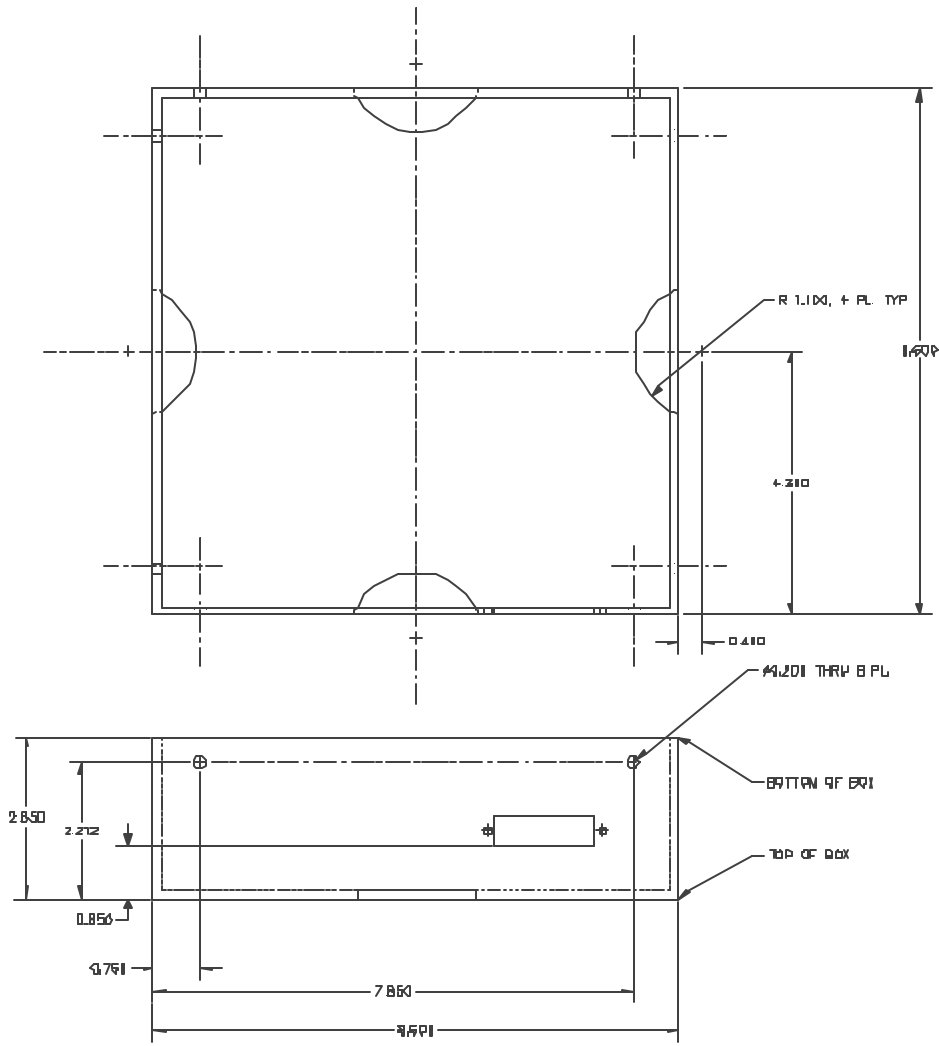


Figure 7-8 Camera Box Dimensions (inches)

NOTES: 1) NOT ALL HIDDEN LINES SHOWN FOR CLARITY
 2) PART IS SYMMETRIC ABOUT CENTERLINES

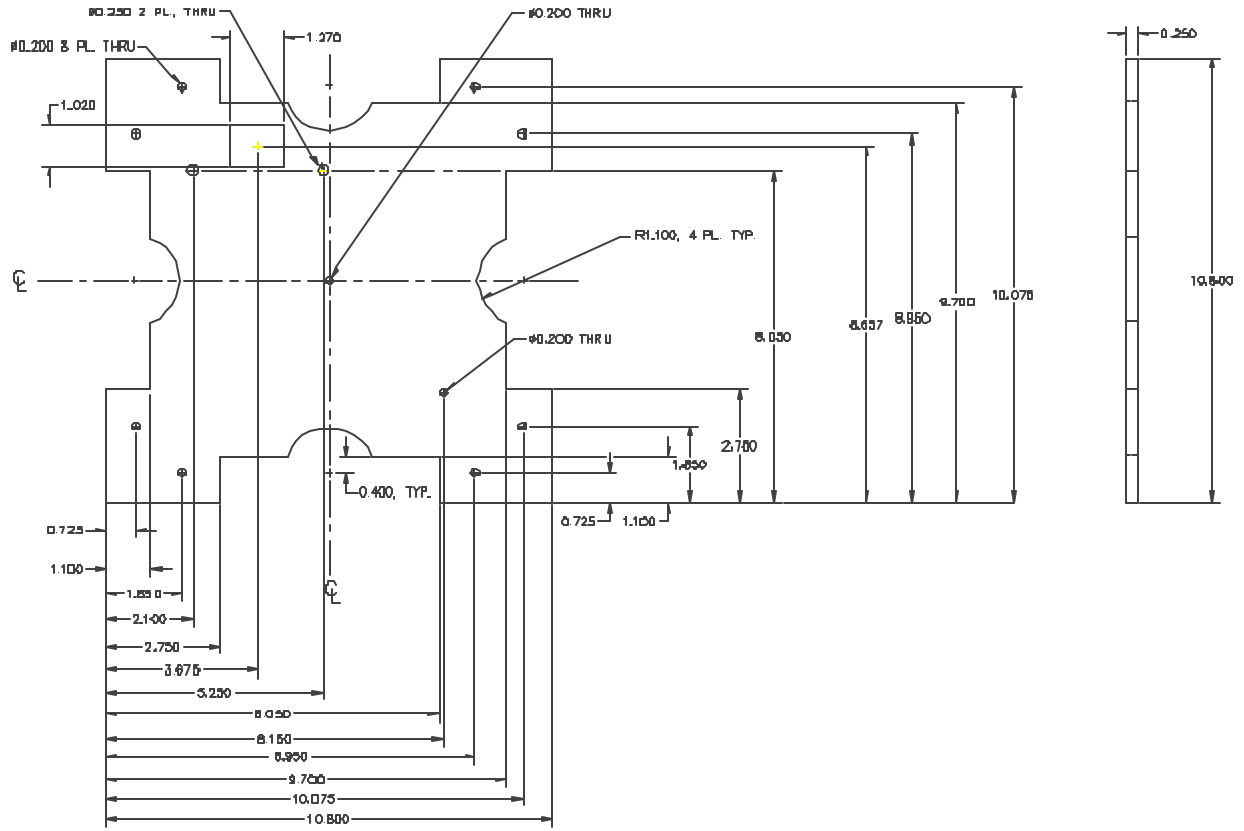


Figure 7-9 Camera Plate Dimensions (inches)

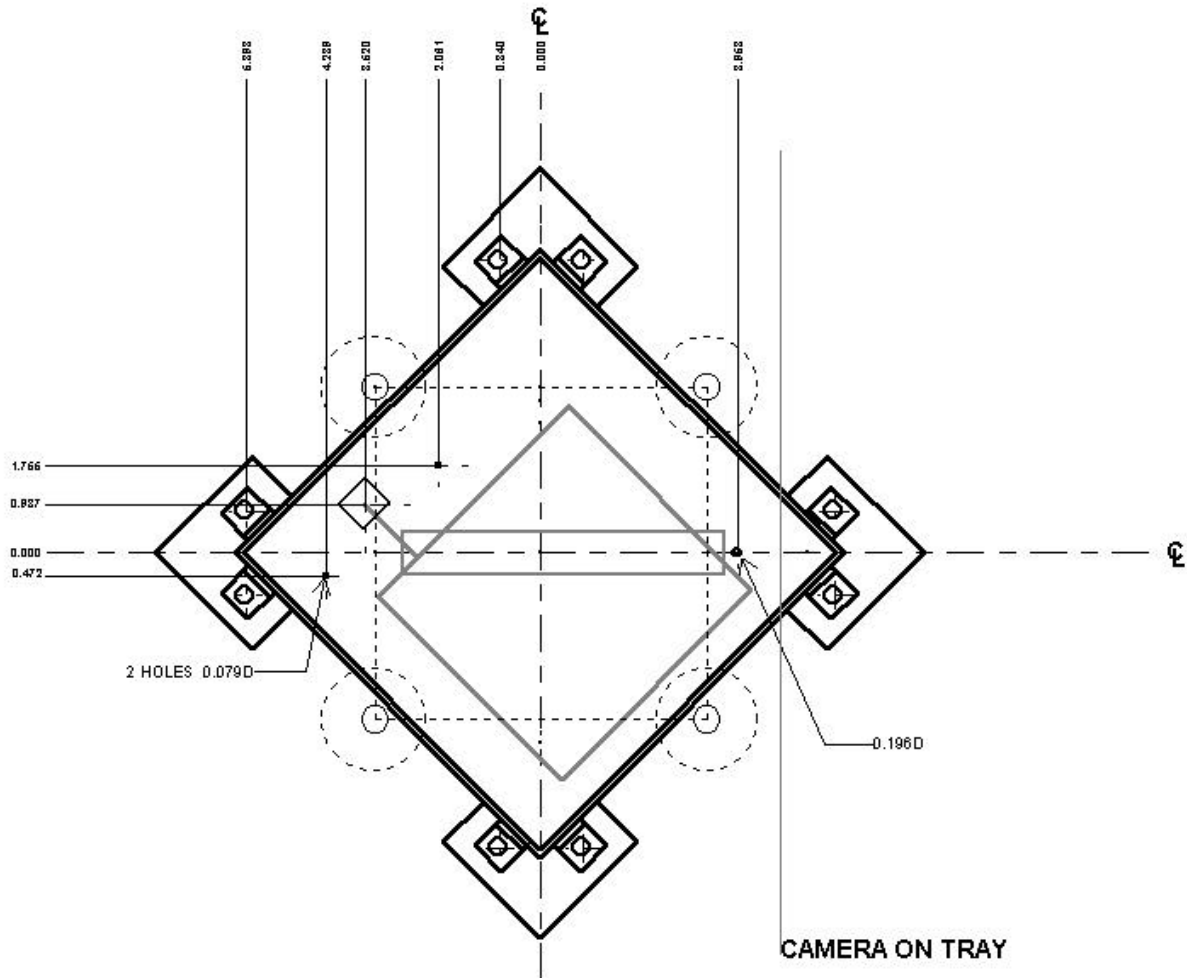


Figure 7-10 Camera and Box Mounting with Respect to the Horizontal Axis

7.2.2 Micrometeorite Impact Detector (MMID)

7.2.2.1 Description

The micrometeorite impact detector aboard Spartnik is similar in concept to that used by the Weber State University microsatellite, WEBERSAT¹. A piezoelectric strip is used as the sensor, and is mounted on the +Z surface of the spacecraft. When an impact on the sensor occurs, it outputs a voltage spike, the strength of which is linearly related to the impact force of the moving particle. Spartnik's MMID will be constructed so that it can perform both as a counter of events and a recorder of event magnitudes. Additionally, it will be possible to program the voltage threshold of the MMID from the ground in order to specifically look for impacts above predetermined strengths. By time-stamping micrometeorite events and recording their magnitudes, and then comparing the data with values obtained from NASA studies, it will be possible to develop a rough model of the LEO micrometeorite environment for future microsatellites.

The MMID will be used to record both event occurrence and event magnitude. Every collision that occurs will be recorded as a voltage pulse, which will then be recorded on the computer. More specifically, the electrical signal from a collision will go through a band-pass filter to eliminate thermal disturbances; into a comparator, to determine whether or not the event is above a programmable threshold voltage (V_{ref}), then into an analog-to-digital (A/D) converter. At this point, the signal will then interrupt the main processor, prompting it to record the reading into a register and time-tag it. A peak-hold built into the MMID circuitry downstream from the comparator will send the maximum event voltage to the CPU for recording. The circuitry will then be reset in preparation for the next event. The counter and peak register would be programmed to reset when the allocated memory is full. Before resetting the counter, the data from the main CPU would have to be downloaded from the transponder to the ground station, or the accumulated collision data would be lost. Further details of the intended software program can be found in the software specification subsection.

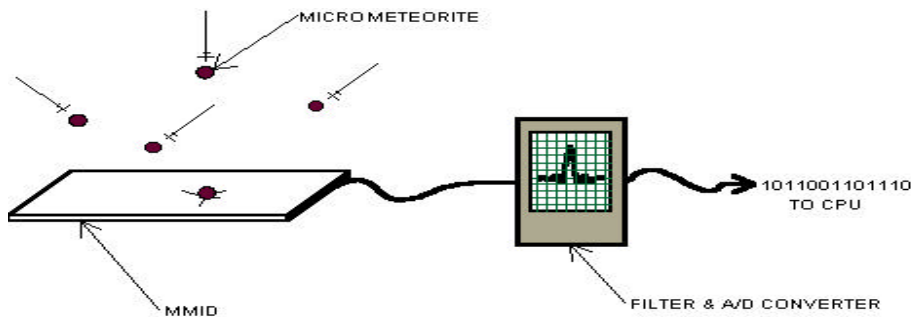


Figure 7-11 Micrometeorite Schematic

The original MMID design for Spartnik consisted of two sensors: one on the outer and another on the inner surface of the +Z face, with the inside sensor being mounted directly beneath the outside sensor. This was the design used on WEBERSAT, and theoretically enabled distinction between a legitimate impact (desired measurement) and a false signal due to thermal stress. However, laboratory tests, along with the results from the shake test (see Structures section) have indicated that the inner sensor is unnecessary. Thermal disturbances, in Spartnik’s case, will be bulk, low-frequency (~1 Hz) phenomena that are easily accounted for by the placement of a band-pass filter (BPF) prior to the amplifier.

7.2.2.1.1 Schematics

The MMID uses a piezoelectric film made of polyvinylidene fluoride (PVDF) as the sensor. The sensor specifications are listed below in Table 7-3. The sensor is a standard, 0.00807-inch thick, pre-cut rectangular shape, with a total surface area of 5.78 square inches. The film is coated with silver,

and protected by a Mylar exterior. The sensitivity of the sensor is a function of the piezo film's thickness. A thin film gives a small cross sectional area. Thus relatively small longitudinal forces will create very large stresses within the material.²

Manufacturer: Model:	Measurement Specialties LDT4-028K
Sensor Material	Polyvinylidene fluoride (PVDF)
Metallization	Silver (Ag) Ink, "Thick" metallization
Sensor Dimension (in)	6.72 x 0.86
Active Dimension (in)	6.13 x 0.74
Thickness (in)	8.07 x 10 ⁻³
Piezo Film Capacitance (F)	11 x 10 ⁻⁹
Maximum Applied Force	6 - 9 kgF, yields voltage output of 830 to 1275 V. (Linear relation)

Table 7-3 MMID Specifications⁶

7.2.2.2 *MMID Electronics*

Originally, the intent was for Spartnik to duplicate the WEBERSAT MMID circuit. Upon further review, a need to redesign the circuit became clear. Factors contributing to this decision were:

- The findings of the shake test that the structure acts as a cantilever beam
- The fact that different equipment is being used on Spartnik (i.e., a different manufacturer provided WEBERSAT's sensors and that manufacturer further designed the WEBERSAT circuit).

The redesigned MMID circuit on Spartnik has the following features:

- A "peak hold" amplifier/capacitor combination will give Spartnik the capability to measure micrometeorite event magnitudes by taking advantage of the linear relationship of impact strength/output voltage with Spartnik's sensors. This will hold the peak voltage of an event in a capacitor (which will be discharged in isolation upon receipt of a reset command), and will send it to the A/D converter for CPU recording.
- A comparator will be used to filter out signals that are below a programmable threshold. The CPU will feed the signals to a D/A converter and then into the comparator. In this manner it will be possible for a Spartnik ground operator to adjust the threshold voltage and "filter" for impacts above certain strengths.
- The output voltage will be scaled to facilitate the comparator described above; the piezoelectric strip sensor has output voltages ranging from 100µV to 400 V. For simplicity, this will be scaled to a voltage spread of 0-12V, with 256 available increments.

- A Band-Pass Filter (BPF) will enable Spartnik to do away with the second sensor that was necessary on WEBERSAT. As false signals due to thermal disturbances will be low-frequency (~1 Hz), the BPF will filter out such disturbances and thus eliminate the need for an inner sensor.

Given the phenomenon of "latency", which is essentially the time lag between a CPU interrupt and the CPU response to same, a hardware counter was considered. This counter would keep a record of events occurring while the CPU was processing the interrupt from a micrometeorite event and then dump that data into the main counter when the interrupt processing was complete. However, given that the maximum expected micrometeorite flux in Spartnik's most likely potential orbit is 0.07 events/(m² sec), and that the active area of the MMID sensor is only .0024 m², it is unlikely such a device would be necessary. Therefore, this proposal was rejected for the MMID. The complete wiring for the MMID is shown in Figure 7-12.

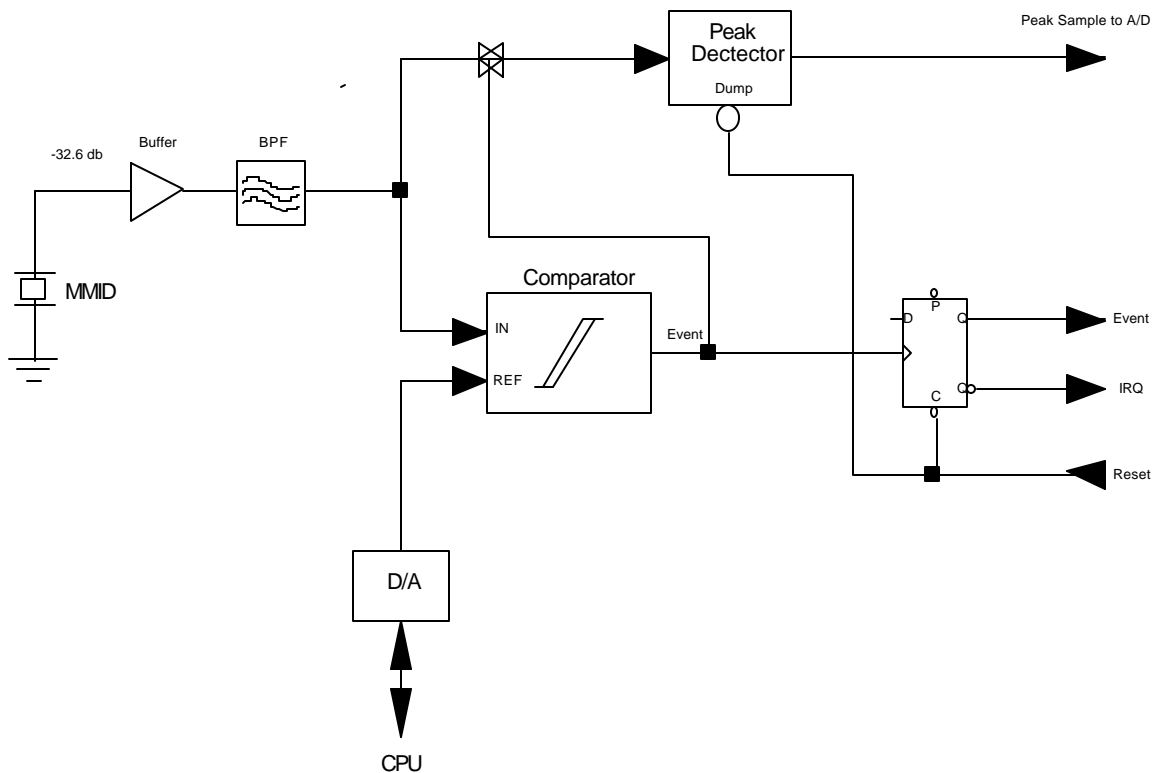


Figure 7-12 MMID Block Diagram

7.2.2.3 MMID Power

The power required to run the MMID will vary but will never exceed 1 Watt, as shown in Figure 7-13. Leaving the detector on continuously would enable recording of all impacts without concern for power consumption. However, it may become necessary to turn off the MMID for unforeseen events such as

a loss of power or computer problems. It is planned to activate the MMID in the acquisition mode and leave it on. During this mode, major system checks would be accomplished.

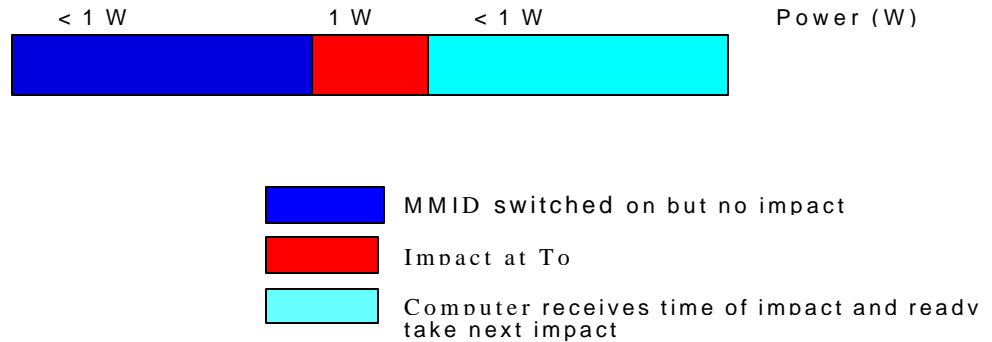


Figure 7-13 Power Duty Cycle for MMID

7.3 Construction / Assembly

This section discusses the specific methods with which the payloads and their accessories were fabricated, modified and mounted.

7.3.1 Color Digital Camera

7.3.1.1 Components / Specifications

The Kodak Color Digital 40 Camera is comprised of five circuit boards, a lens assembly and a plastic cover. Table 7-4 gives the dimensions of the camera components. The total weight is slightly less than 1 pound.

Camera Size L x W x H (in.)	5.9 x 5.5 x 2.04
Process Board (in.)	4.96 x 3.54 x 0.25
MCU Board (in.)	4.96 x 3.54 x 1.18
CCD Board (in.)	2.75 x 1.96 x 1.60
LCD board (in.)	2.75 x 3.54 x 1.18
Connect Board (in.)	1.6 x 1.0

Table 7-4 Kodak DC40 Dimensions

The “off-the-shelf” Digital 40 Camera consists of:

- 4MB of internal memory
- picture resolution of 512 x 756 pixels in millions of colors
- focus free lens with range from 4 ft. – infinity
- shutter speed range of 1/30 – 1/175 s.
- aperture range of f/2.8 – f/16
- computer requirements:
 - IBM PC or equivalent with 80386 or higher CPU and 6 MB RAM available
 - Operating system: WINDOWS Software 3.1 or later

7.3.1.2 Camera Modifications

As previously discussed, several modifications of the camera were needed in order to withstand harsh space environments:

- Removal of flash
- Removal of LCD
- Replacement of electrolytic capacitors with solid tantalum capacitors

Because Kodak would not release specific camera schematics and to ensure that the camera’s proprietary information would not be compromised, these modifications were all performed by Eastman Kodak.

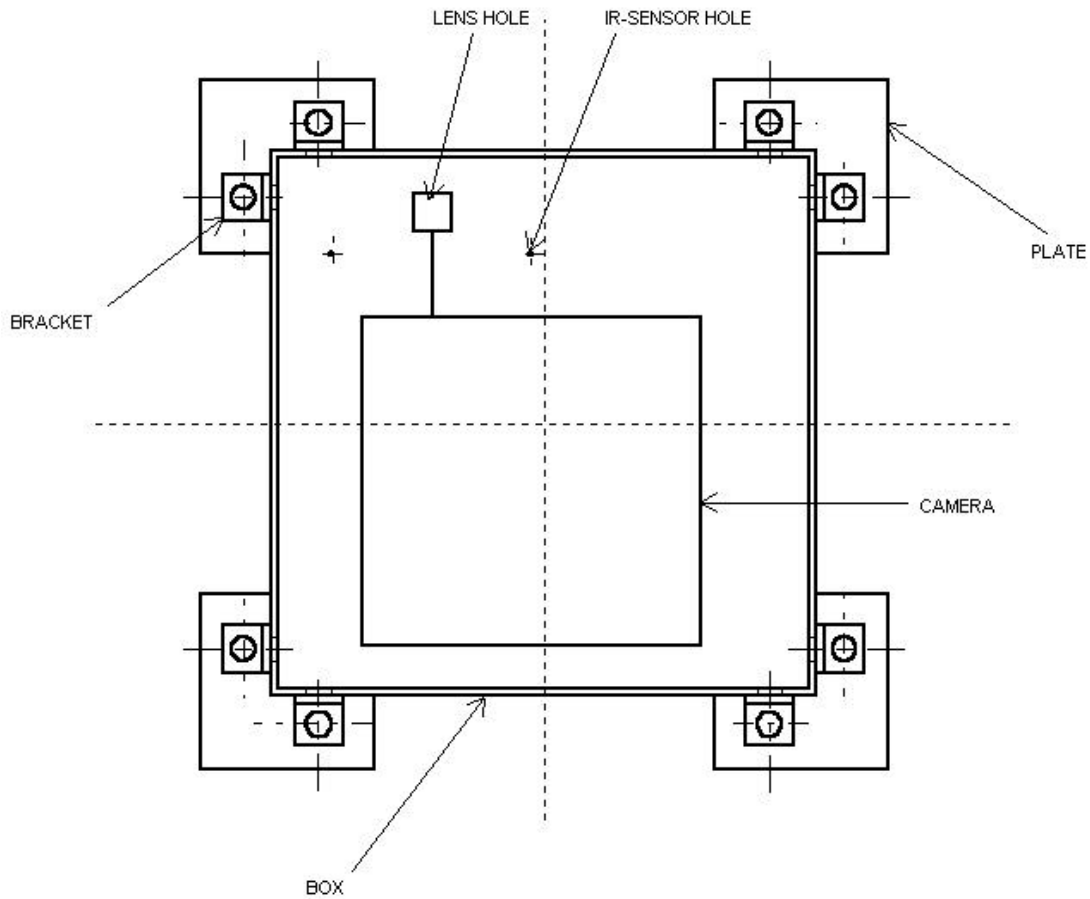
7.3.1.3 Camera Box Parts

Following is a list of the camera box components:

- 0.125 inch thick aluminum open faced box, four sides and bottom (Figure 7-8)
- 0.250 inch thick aluminum top plate (Figure 7-9)
- 0.125 inch thick aluminum L-brackets (Figure 7-14)
- Rohacell foam, 2 sheets of .039”(1mm), 2 sheets of .118”(3mm), 2 sheets of .50” (12.7mm), & 1 sheet of .75” (19.05mm) thickness
- 16 / 10-23 bolts
- silicon gel (VI-SIL™ V-1022 by Rhodia)

conform to the silicon brick casing. The foam will be cut into two horizontal sections (i.e. a top half and a bottom half).

- Holes must be made through the top half foam piece for wires from the MMID, IR Sensors and Temperature sensors. These holes must line up with those on the top plate and +Z face
- Obtain the satellite shell and turn it with the +Z face down
- Place the aluminum top plate onto the inner surface of the +Z face, making sure to align the holes
- Attach L-brackets to the top plate.
- Using 10-32 bolts, bolt through both the L-brackets and the top face, fastening the top plate to the +Z face
- Feed the MMID, IR Sensor and Temperature sensor wires through the top plate
- Attach one end of 0.25" thick copper braid to the camera's DC regulator by both gluing it to the black plastic vertical face and putting a nylon screw through braid and hole in black plastic piece. The copper braid should be fed between the circuit boards, between the plastic covers and left sticking out the side of the camera. (This application of the copper braid may be modified pending verification from Bob Clark and analysis with Dr. Lambert.)
- Enclose the camera in the silicon gel using the mold designed for that purpose. Special care must be taken in the lens area. A hole must be left in the silicon brick to enable the opening of the periscope to fit the lens of the camera. The copper braid and other wires will protrude from the silicon gel brick
- Place upper part of foam on top plate, feeding the above mentioned wires through their prospective holes and placing them towards side 2 near the connector location.
- Place camera (and copper braid) enclosed in the brick of silicon on the foam in the camera box, putting the camera's wires together with the previously mentioned wires, and laying the copper braid on the foam towards side of the camera box. Bend the braid in two places so that it will follow down the side of the box, and then horizontally along the bottom corner.
- Cover the camera by placing the second (bottom) half of foam on top, leaving wires and copper braid sticking out.
- Place spacers around camera box by fitting the flanges into the curved cutaway areas.
- While holding the spacers in place around the camera box, put the box onto the foam/camera construction, pulling wires through connector hole, and making sure copper braid remains adjacent to the box side. It should be a snug fit.
- Using 10-32 bolts, bolt through the L-brackets fastening the camera box to the top plate.
- Adhere a 0.20 inch thick layer of foam to the outer surface of the bottom of the camera box (which will act as a buffer between the box and the payload tray)
- Standoff rods can be slipped through the spacers and Spartnik's shell and the remainder of the internal components can be constructed as discussed in other sections.



CAMERA BOX ASSEMBLY

Figure 7-15 Camera Box Assembly

7.3.2 Micrometeorite Impact Detector (MMID)

7.3.2.1 Specifications

The MMID sensor is a standard, 0.008-inch thick, pre-cut rectangular strip of a polyvinylidene fluoride (PVDF) piezoelectric film. Detailed sensor specifications are listed in Table 7-3.

7.3.2.2 *Mounting*

The MMID sensor will be mounted with Loctite 411 adhesive in the center of the outer surface of the +Z face of the satellite (Figure 7-1). This face was selected because solar cells will be located on the other parts of the body. The sensor is wired to the main CPU's Analog/Digital converter. The piezoelectric sensor can be mounted in either in compression or tension. When the sensor is mounted in tension, it is allowed to deflect like a drumhead, such that it will respond strongly to impacts. A tension mount can be done by placing the sensor on supports at either end, allowing it to deflect, or by placing the sensor on top of a soft, sponge-like material. A disadvantage to this type of mount is that the sensor would be susceptible to tearing or other damage during handling. Simply placing the sensor flush against the spacecraft surface does a compression mount. This mount is much simpler than that in tension; however, the sensor is not allowed to deflect as much, thus yielding a weaker response. The compression mount was selected for simplicity and durability of the piezoelectric material. Moreover, testing revealed that the compression mount did not result in a significant decrease in the sensitivity of the sensor when compared to the same in tension.

7.4 Testing

7.4.1 Color Digital Camera

After receiving the modified camera from Kodak, several tests had to be performed. First, the operation had to be checked. Happily, it was found that the modified camera still was able to take good quality pictures. Other tests performed are described below.

7.4.1.1 Heat Generation

There was some concern that, since foam, an insulator as well as a vibration damper will surround the camera, there might be a problem with it getting too hot. For this reason, the camera was tested to see if it had any components that would be significant sources of heat during operation. It should be noted that these tests were conducted in air. This is not a true measure of the heat generation of the camera in a vacuum environment. This test, however, is a good indicator of where the critical components are located.

7.4.1.1.1 Procedure

A thermocouple temperature sensor was used as a probe for measuring temperature changes around various circuit board components while pictures were taken with the modified camera. The equipment used was not calibrated for the particular sensor. For this reason, the test determined only changes in temperature, not actual temperature readings. The change in temperature of the sensor resulted in a change in the voltage across a known resistor. A change in temperature of 1 °C resulted in a change of 83.3 mV².

7.4.1.1.2 Results

Most components experienced a change in voltage of 0.13 V to 0.20 V, giving a temperature rise of only 1.5 °C to 2.5 °C. The most significant source of heat was found to be the 5V DC Regulator, which is located on the MCU board. Fourteen pictures were taken while the probe was on this component that resulted in a change in voltage of almost 1 V, or a heat rise of 8.4°C. This component also generated a temperature rise of 7.0 °C when the pictures were downloaded and 3.0 °C when the pictures were deleted.

7.4.1.1.3 Conclusions

Heat generation will probably not be a major concern for most parts of the camera. The only problem could be the 5V DC regulator. For this reason, a conduction path must be made, mounted to this component, and then attached to the aluminum camera box. We will be using a copper braid as the conduction path. In this way, the copper braid will conduct the heat from the regulator and the aluminum will then radiate it away from the camera.

7.4.1.1.4 Resolution of thermal concerns

It is obvious that a conduction heat path must be made. The camera is enclosed in silicon and Rohacell foam, insulating the camera. Since there is no convection heat transfer in space, we must rely completely on conduction and radiation. There is no path for radiation from the DC regulator to the camera box. This then shifts the burden of heat dissipation to conduction.

7.4.1.1.5 Copper Braid installation

The DC regulator is comprised of a transformer, transistor, and several capacitors mounted on a printed circuit board. Testing must be done to verify the location of the most critical areas on the DC regulator. Operating the camera in a vacuum environment to measure the temperature of the components will do this. The copper braid must be mounted onto this assembly. Since the copper braid is a conducting metal, there is a chance that the braid might short-circuit the DC regulator. The regulator must then be encapsulated in a dielectric material. The copper braid is then adhered using Stycast 2850 Thermally Conductive Epoxy Encapsulment to the dielectric material.

7.4.1.2 *Power Consumption Profile*

In order to determine the number of pictures that can be taken per pass, and to find the amount of power that will be available to other satellite components, the actual power draw of the modified camera had to be determined.

7.4.1.2.1 Theory

The modified camera will receive a constant voltage from Spartnik's power supply, such that the current draw will vary with the load. In other words, the current through the camera will vary depending on the operation the camera is performing. The camera will be used in the following modes:

- Sleeping
- Standby
- Operating/taking a picture
- Downloading
- Deleting

7.4.1.2.2 Procedure

The following information needed to be determined for the modified camera:

- The minimum voltage required to take a picture

- The current draw for each operational mode
- The time period spent at each operational mode
- How the current varied with the applied voltage

The camera can be powered by 4 - 1.5 V batteries. It was determined that the actual open circuit battery voltage was 6.40 V. This value was used as a nominal voltage level to begin the test. A circuit was arranged with a voltage source in series with a regulator (to insure a constant voltage) and a digital ammeter. The camera was positioned in parallel as the varying load. Current readings were taken for each mode at three voltages: 6.0, 6.4, and 7.0 V. Next, the voltage was set to 5.0 V, a level too low to allow a picture to be taken. The voltage was then increased by 0.1 V increments to determine the minimum voltage required. Finally, the pictures taken during the experiment were downloaded and deleted. The current draw and time duration for each operation were again measured.

7.4.1.2.3 Results

Detailed current readings at the nominal voltage of 6.40 V were used to generate a current time history for the taking of a picture (Figure 7-16). In observing the current draws for each of the three voltage levels, it was determined that changing the voltage resulted in a negligible change in the current. The acquired data is listed in Table 7-5 below. The minimum voltage required was found to be 5.70 V. Lastly, the memory needed per picture was observed to vary with the amount of light available and the brightness of the colors taken, resulting in a maximum of approximately 94 Kbytes for one picture taken of a variety of colors in full sun.

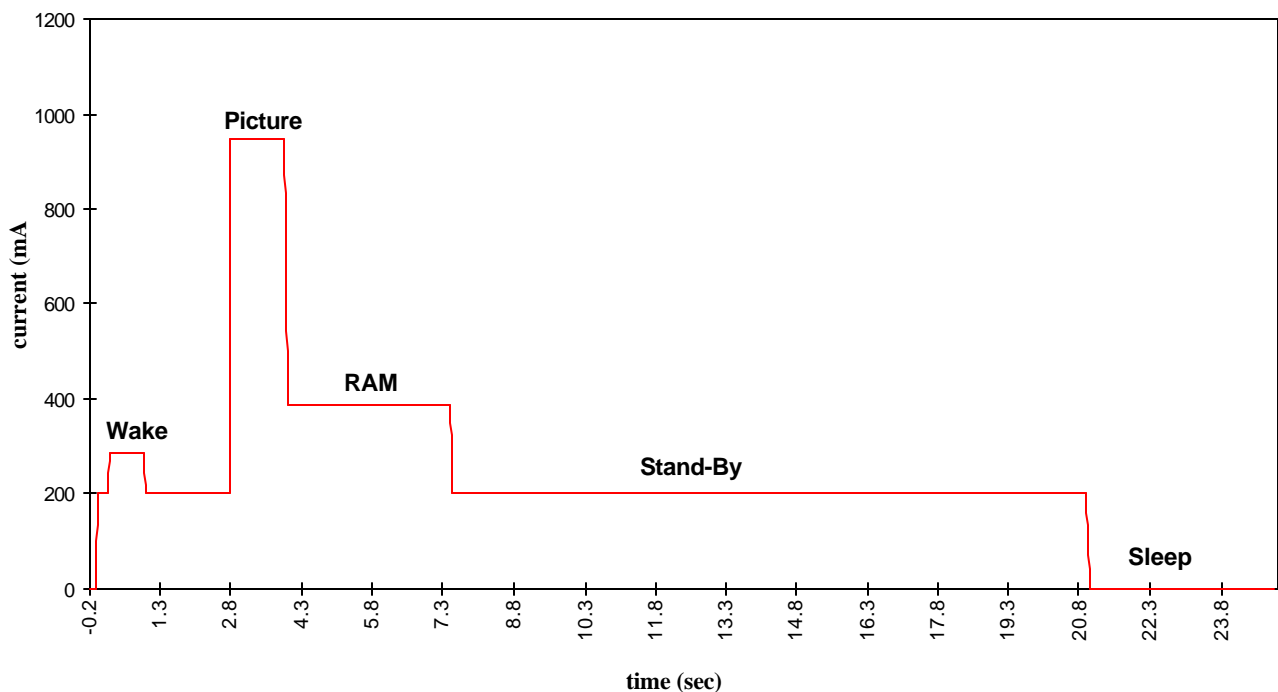


Figure 7-16 Current Draw Time History at Nominal Voltage

MODE	CURRENT (mA)	POWER (W)	TIME (sec)
Standby	200	1.28	* 16
CPU housekeeping	285	1.82	0.75
Taking picture	950	6.08	1.2
Putting into RAM	385	2.464	3.5
Sleep	0.20	0.0013	N/a
Downloading to CPU	200	1.28	7
Deleting picture	200 - 300	1.28 - 1.92	26

*** Depends on sleep setting**

Table 7-5 Power Consumption at Nominal Voltage

7.4.1.3 *Camera Testing Status*

A few tests remain to be completed.

- The camera must be tested to determine how much blur will incur during picture taking. (Motion Blur Test)
- Measurement of component temperature in a vacuum environment
- The camera will be tested in a thermal vacuum chamber to meet design specification of at least 1×10^{-5} torr to verify the soundness of the hardware and the camera's operation.
- Vibration Test
- Camera software must be integrated and tested simulating satellite operations.
- Uploading data to the camera and download data to the ground station must be tested.

7.4.2 Micrometeorite Impact Detector (MMID)

7.4.2.1 *MMID Testing*

Since the MMID system consists of the sensor and related circuitry, the MMID module is integrated into the main CPU. The MMID hardware (i.e. sensor, comparator, peak-hold circuit, and trigger-current for interrupt) has been tested as discussed below. The sensor has been tested separately to ensure proper function of the piezo crystals. The sensors has also been attached to the structure and subjected to shake testing with no adverse effect on the adhesive. One of the piezoelectric sensors was attached to a piece of aluminum honeycomb, which was then subjected to heating and cooling. As predicted, the thermal disturbances were of approximately 1Hz frequency, validating the removal of the inner sensor requirement. Additionally, it has been decided to set the sensitivity of the sensor such that only impacts directly upon it will register. The reasoning for this is that, in order to register indirect impacts, the BPF would have to be removed. This is necessary as the BPF prevents structural vibration from being read as an impact. It would then be impossible to distinguish an indirect impact from a thermal disturbance, even if the inner sensor was restored.

The MMID has also been hooked to an oscilloscope and subjected to impacts of varying strength. Observations have tended to verify the linear relationship between impact strength and output voltage. Later, after the MMID sensors are hooked to the A/D converter and the onboard computer is functional, the impact testing should be repeated in order to determine that the counter is incrementing and that voltage peaks are being properly recorded.

7.4.2.2 *MMID Testing Status*

Other tests that remain to be performed are listed below.

- Time stamping of data - pending software
- Data acquisition from main CPU to ground station - pending software
- Software code debugging- see Software Section
- Ground station download test - pending CPU, software, and communication system integration

7.5 Operations

It was originally planned to control each payload with a payload-specific computer, intended to lessen the load on the main CPU. However, the plan is now that the camera will and the MMID will communicate directly with the Spartnik's onboard computer. Each camera program will have an added interrupt routine that will interface with the main CPU. Before the picture is to be taken, the program executing the picture will note the time and IR sensor readings. The acquired position readings will be stored and retrieved later when pictures are downloaded through the computer algorithm. The MMID is a completely interrupt driven processor. It is wired to the A/D converter, which will then interrupt the main CPU when a reading is received. The main CPU receives "packet" commands from the ground, which will call for it to download data to the ground station and/or to execute some functions. The CPU will utilize the necessary programs and relay this information to the appropriate payload.

Communication between the camera to the main CPU is accomplished through a standard RS-232 serial port. The RS-232 serial interface can communicate at speeds ranging from 9600 baud to 115,200 baud⁸. The actual rate may depend on the serial hardware used on the computer. However, the software is designed for the maximum efficiency to download to the station as quickly as possible.

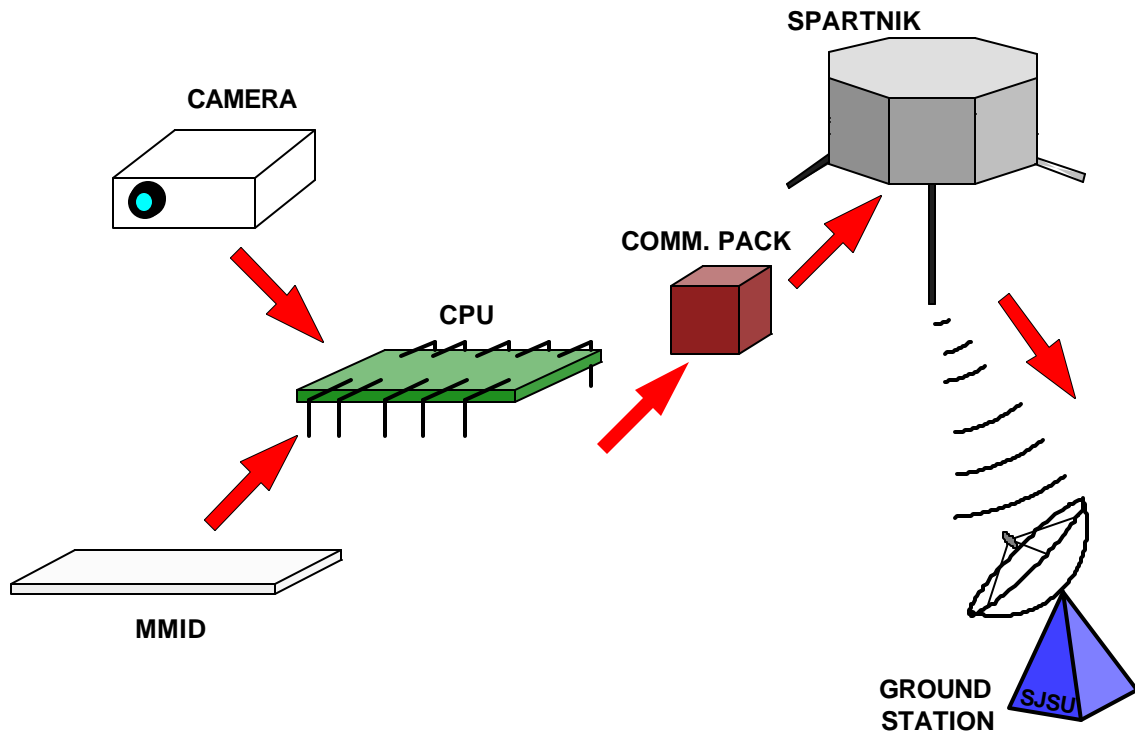


Figure 7-17 Payload Block Diagram

7.5.1 Color Digital Camera

7.5.1.1 Camera Operation Procedures

Many features that came with the camera will be used such as time stamping, idle mode, sleep mode (the camera automatically turns off after 60 seconds to save energy), and automatic focus. Basic camera operations and maintenance are done through computer programs. By executing a specific program the camera can power on or off, take pictures, switch resolutions, erase the picture images (all images or just the previous image), send pictures or send just the thumbnails (previews) of the pictures. The camera can also send its status and any errors to the main CPU. The main CPU sends a command to the camera, either through a program or a direct command from the ground, and the camera can respond with its current status.

The basic functions that are programmed into the main CPU include:

- Taking pictures
- Downloading to static ram
- Downloading to ground station
- Wake up
- Adjusting f-stops (shutter speed)
- Upload new software into the flash-ram

7.5.1.2 Camera Programming

Since the camera is designed to operate manually, software has been designed such that the camera CPU will execute the commands for the camera to do its programmed functions. Section 8, Computer Software, will explain the full details of the software design for the camera. When downloading pictures from the camera to the ground, for example, the main CPU executes a program that will retrieve the pictures from the camera's storage RAM, and send them to the transmitter downlinking to the ground station.

7.5.2 Micrometeorite Impact Detector (MMID)

7.5.2.1 MMID Software

The MMID is a completely interrupt driven processor. It is wired to the A/D converter that interrupts the main CPU when taking a reading.

The following general algorithm may be used over the operational life of the MMID:

1. **Turn MMID on (or off)** - Nominally, the MMID will be active at all times. However, there might be times when it must be deactivated (in times of power shortages, when downloading impact data,

or when other unexpected events occur). This assumes that MMID-driven interrupts are masked at time of initialization.

- a. Set threshold voltage (V_{ref})
- b. Reset system
- c. Unmask interrupts

2. Operating Mode (Interrupt acknowledge)

- a. Read & store voltage peak
- b. Process data
- c. Time-stamp data
- d. Increment counter
- e. Send reset

3. Reprogramming V_{ref} (Voltage threshold)

- a. Mask interrupts
- b. Enter new V_{ref}
- c. Reset
- d. Unmask interrupts

4. **Download data** - used to download data in the form of packets. This will use the Input-Output (I/O) space in the form of a hexadecimal memory address, which will transfer data one byte at a time and will function as a memory register. The Hardware Team will provide the actual hexadecimal address. During download, the interrupts should again be masked.

5. **Erase data** - enables control of data to be erased on command, when storage becomes full, or at a pre-determined time in the orbit.

7.6 Conclusion

The payload's subsystem design and analysis for Spartnik is basically complete. The only remaining significant items remaining are listed below.

- The camera must be tested to determine how much blur will incur during picture taking. (Motion Blur Test)
- Measurement of component temperature in a vacuum environment
- The camera will be tested in a thermal vacuum chamber to meet design specification of at least 1×10^{-5} torr to verify the soundness of the hardware and the camera's operation.
- Vibration Test
- Camera software must be integrated and tested simulating satellite operations.
- Uploading data to the camera and download data to the ground station must be tested.
- MMID software must be integrated into the final flight model and tested to simulate satellite operations.

7.7 References

- ¹ Jeff Mills, Eastman Kodak (NY).
- ² Paralene Conformal Coatings Specifications and Properties, Specialty Coating Systems.
- ³ Webersat Users Handbook, Edition 1.1, Weber State Univ., Aug. 1991, Ch. 13.
- ⁴ Webersat Users Handbook, Edition 1.1, Weber State Univ., Aug. 1991, Ch. 13, p. 3.
- ⁵ Measurement Specialties Product Catalog, LDT4-028K, 1999, p.6.
- ⁶ Calculations with Stephen Peterson.
- ⁷ Kevin Mackey, Senior Software Engineer, Logitech/Kodak Technical Support.
- ⁸ Dr. Eric Abrahamson, SC Solutions
- ⁹ Bob Clark, Lockheed Martin Missiles and Space
- ¹⁰ Dr. Michael Lambert, Associate Professor, San Jose State University
- ¹¹ Dr. Richard Desautel, Professor, San Jose State University

7.8 Appendix

7.8.1 Appendix A: Paralene C Conformal Coating Specifications

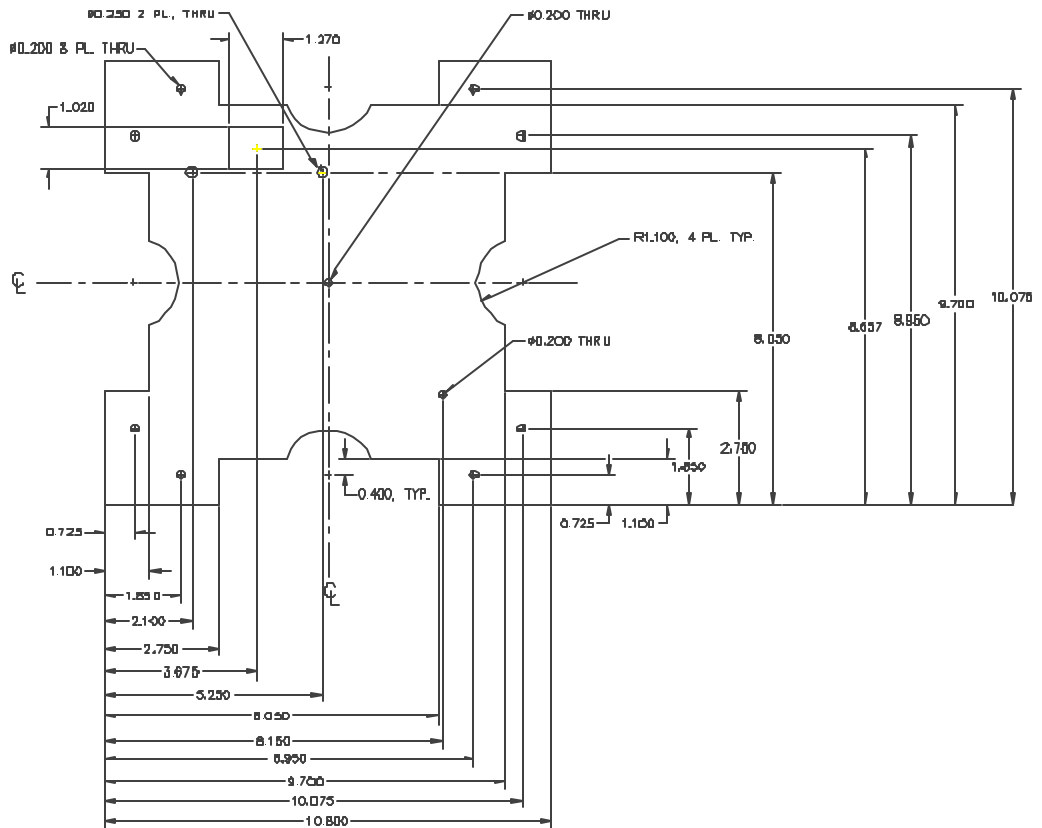
7.8.2 Appendix B: Rohacell Foam Specifications and Properties

7.8.3 Appendix C: Typical Phase-change Heat Sink Materials

7.8.4 Appendix D: Payload Subsystem Hardware List

- 0.125 inch thick aluminum open faced box, four sides and bottom (Figure 7-7)
- 0.250 inch thick aluminum top plate (Figure 7-8)

NOTES: 1) NOT ALL HIDDEN LINES SHOWN FOR CLARITY
 2) PART IS SYMMETRIC ABOUT CENTERLINES



- 0.125 inch thick aluminum L-brackets (Figure 7-15)
- Rohacell foam, 2 sheets of .039" (1mm), 2 sheets of .118" (3mm), 2 sheets of .50" (12.7mm), & 1 sheet of .75" (19.05mm) thickness

- 16 10-23 bolts
- Insulfoam Expanded Polystyrene Adhesive
- Loctite 411 Adhesive
- Stycast 2850 Thermally Conductive Epoxy Encapsulment
- Kodak DC40 Digital Camera

7.8.5 Appendix E: Payload Subsystem Adhesive Specifications

7.8.6 Appendix F: Mechanical Properties of Possible Filters

7.8.7 Appendix G: Possible Filter Integration Set-Ups

7.8.8 Appendix H: Payload Subsystem Contacts

Measurement Specialties

950 Forge Avenue

Norristown, PA 19403

Contact: Pete Smith (916) 983-8644

Product: LDT4-028K Piezo Film

<http://www.msiusa.com>

Kodak Camera

Contact: Donald Lewis (716) 781-1008

Marketing and Sales Manager

<http://www.kodak.com>

Product: DC-40 Digital Camera

Emerson and Cuming Specialty Polymers

55 Hayden Avenue

Lexington, MA 02173

1-800-832-4929

Product: STYCAST® 2850 FT Thermally Conductive Epoxy Encapsulant

Richmond Aircraft Products

Contact: Steve Dubois (562) 404-9011

Product: Rohacell Foam

Edmund Scientific Industrial Optics Division

101 East Gloucester Pike

Barrington, NJ 08007-1380

(609) 573-6250

<http://www.edsci.com>

Product: Right angle mirror and lenses (this was for the original design of implementing a periscope)

Specialty Coating System

4435 East. Airport Drive, Suite 100

Ontario, CA 91761

Contact: Michael Smith (909) 390-8818

Fax: (909) 390-8822

Product: Conformal Coating of Camera

House of Foam

Palo Alto, CA

Contact: Bob Tallman (415) 327-4300

Product: Rohacell Foam Cutting

Rhodia

Contact: Pat Goyer (800) 356-7560 ext 6332

Patricia.goyer@us.rhodia.com

www.silicones.us.rhodia.com

Product: VI-SILä V-1022

Kistler

Contact: Susan Davis (716) 691-5100

Sue.davis@kistler.com

Product: accelerometers used in vibration testing

7.8.9 Appendix I: Silicon Gel Technical Data Sheet and Processing Application

7.8.10 Appendix J: MMID Information
