

Picosat Free Flying Magnetometer Experiment

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Abstract

Individual satellites have been measuring the Earth's magnetic field since 1958. Measurements taken in this way have led to some interesting discoveries about the earth's magnetosphere. However, they have also raised many questions about the magnetosphere's finer texture and dynamic nature. Researchers at JPL have proposed a mission where a single larger satellite ejects several *picosatellites* in order to simultaneously sample a volume of space. Each picosat is to carry a small, two axis, fluxgate magnetometer, several photo detectors for spin rate detection, a micro processor and a high frequency transmitter. After launch from the main satellite, each picosat will transmit its sensor readings back to the main satellite where the data will be stored for retrieval. Issues addressed in this paper are related to the design, manufacture, and planned flight test of the *picosatellite* on OPAL, a Stanford University Student Spacecraft [1].

Introduction

The magnetic field of the earth is very complex and dynamic. It is primarily a dipole field generated largely by currents

in the earth's fluid core. Field lines emerging from near the north pole can extend to very high altitudes before returning to earth near the southern pole and closing the loop. The earth's magnetic field interacts with and shields us from the solar wind, which is composed mostly of protons, free electrons, and alpha particles.

The field strength of the magnetosphere has an average value of around 50,000 nT near the surface of the earth and varies in intensity by about 50 nT at equatorial latitudes on a day to day basis [2]. Coronal mass ejections from the sun cause dramatic changes in the magnetosphere shape and local field strength. Variations in magnetic field strength can be several hundred nT. These dramatic fluctuations are the cause of many fascinating but not completely understood phenomena including the Aroua Borealis, the Van Allen Radiation Belts, and occasional electro magnetic interference to our navigation, communications and power systems. Therefore, development of a more complete understanding of the earth's magnetic field is a very important scientific undertaking.

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Throughout the magnetosphere, plasma dynamics are dominated by the effects of the Earth's magnetic field and the solar wind. The governing equations of magnetohydrodynamics are not solvable in closed form. However, numerical models have been constructed.

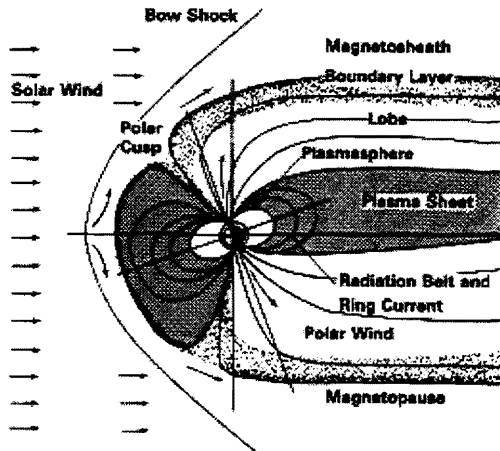


Figure 1. Earth's Magnetosphere (from Larson and Wertz, [3])

If data could be taken simultaneously over a volume of space spanning several kilometers, much more complete models could be generated that include the dynamic nature of the magnetosphere and its response to variations in the solar wind.

The United States Geological Survey and the Office of Naval Research have assembled very detailed maps of the magnetic field on the surface of the earth which can be used for mineral exploration and navigation. But above the earth's atmosphere, mapping must be done by spacecraft. This mapping began with Explorer 1 in January 1958 [4], which detected the Van-Allen Radiation Belts. Today large numbers of communication, scientific and DOD satellites are mapping the earth's magnetic field with great accuracy. However, the most interesting regions of the earth's magnetic fields are in places where it would be ill advised to fly an

expensive satellite. These regions are primarily the Van-Allen Radiation Belts and very low earth orbit near the poles. As a result these regions have not been thoroughly mapped.

Recently, researchers at JPL have begun to study the feasibility of a simple mission that would solve both the problems of sending expensive satellites into hazardous areas and obtaining simultaneous magnetic field readings over a volume of space. The basic concept is to insert a large number of small, disposable, free flying satellites into regions of magnetic interest. These "picosatellites" would have the minimum instrumentation needed to measure the intended magnetic field parameters and transmit this data back to the "mothercraft" traveling in a more permanent and less hazardous orbit.

This unique operations scenario allows an unusual and very efficient configuration to occur.

- 1) The power system can consist of small, off the shelf primary batteries and does not need to be regenerated because the individual mission life is so short.
- 2) The communication system is one way. The picosat simply measures and broadcasts. The mother ship stores and processes the broadcast signals, then relays them to a ground station.
- 3) The fact that there are multiple picosats allows for the possibility of one of them failing. Therefore: Picosats can be less than 99.999% reliable. In addition, picosat missions can be flown to regions that would destroy a more expensive satellite. Picosats can be manufactured on a production line with commercial parts, thus lowering the cost of scientific data.

To prevent spent picosatellites from polluting up orbits, they will be ejected into highly elliptical orbits that will decay in a short time. In this way even high altitude data can be obtained without endangering other satellites.

Preliminary studies of this scenario at Stanford and at JPL have identified off the shelf technologies to meet almost all of the technical requirements of the picosat. In many ways the cellular phone contains almost all of the necessary technology for such a mission: It is small, can communicate, can sense and process physical signals, is robust and is readily available. Additional elements required are a suitable high performance micro magnetometer, and a launch mechanism. Our research has focused on the design and construction of a flight testable launcher suitable for a NASA mission and a prototype picosatellite that will return information about the success of the launcher.

The launcher and three picosats will be flown and tested on the OPAL satellite, a smallsat being developed by the Stanford Space Systems Development Laboratory [5]. The launcher is required to eject a picosat with a user commanded linear and angular velocity and with minimal perturbations to these characteristics, particularly to the angular velocity. To carry out a launcher test we need to develop a test picosatellite capable of measuring its own orientation and dynamics after launch. The closer we can model the functionality of future picosatellites the more useful this test will be.

To determine attitude dynamics of the picosat we decided to reverse the problem that will be faced by future picosatellites. OPAL will be flying in an orbit that has a relatively stable magnetic field. Since the rate of change of the field vector is much

slower than the dynamic response of a picosatellite, the field vector can be used as a reference. The picosatellite and the mothercraft, OPAL, are instrumented with magnetometers. The field is assumed constant in time and the motion of the picosat is measured relative to it. In this way we can confirm whether we have built a launcher that will meet the full picosat mission requirements. Also, by this approach we come as close as possible to anticipating the design issues that will be faced by the JPL team. Our prototype picosat contains every component that is anticipated to be on the science mission picosatellite.

Overview

The rest of this paper presents the picosat system and discusses each subsystem in moderate detail. The overall picosat system is introduced first, followed by a tour through the various subsystems describing the current state of each, and the trade-offs and design decisions that led to them. Towards the end the ejection mechanism and ejection sequence are briefly discussed to support design constraints on the picosat that we feel are essential to the success of the mission. Finally, conclusions about the viability of picosatellites and extremely small satellite systems are presented.

Picosat System Overview

The basic operation of a picosat is very straightforward. It is a one way data logger, taking measurements and transmitting them via radio. The basic functions and relevant components are diagrammed below.

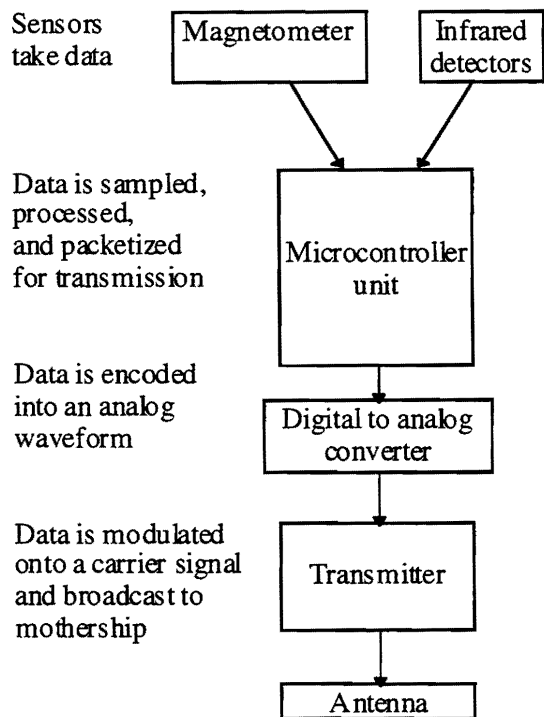


Figure 2. Basic picosat functionality and data flow

In addition to the hardware and software directly required for functionality, the picosat requires a power source and a structure. The structure must be properly balanced to provide a steady platform when the picosat is spin stabilized, and provide a thermal environment in which all chips remain within operational temperature limits.

The picosat system layout is shown below, along with a list of major parts. Each component is described in the following sections roughly in order of the previously mentioned data flow, followed by the packaging, power, and a discussion of thermal and inertia tensor balancing considerations.

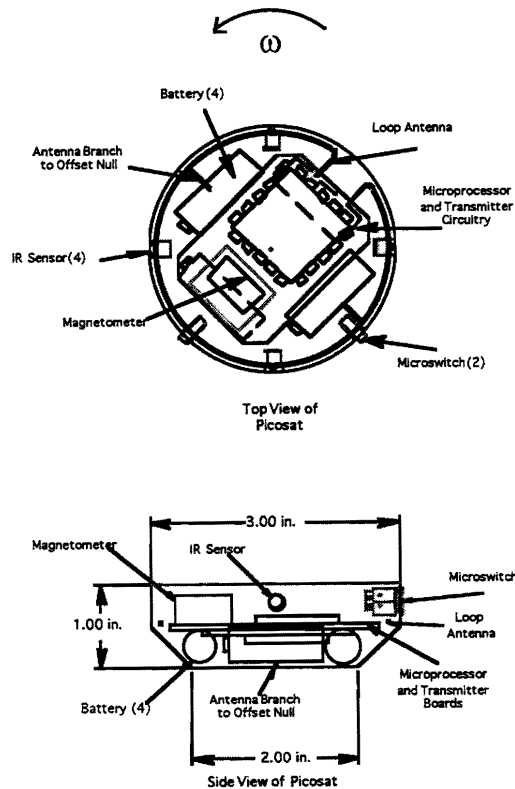


Figure 3. Picosat overview

Major Parts List:

- Magnetometer:
Core: Infinetics, Inc. [6]
Windings: Precision Winding, Inc. [7]
- IR Detectors: Optek [8]
- Microcontroller unit: 68HC11 family; Motorola [9]
- Digital to analog converter: Maxim [10]
- FM Transmitter: Motorola [11]
- Wire Loop Antenna: Made in house
- Ultra Sub Miniature Microswitch: Cherry Electronics [12]
- Four 1.5V AAA cells: Radio Shack [13]
- Chassis is vacuum rated molded epoxy: TBD

Magnetometer and Attitude Dynamics

The picosat carries a two axis flux-gate magnetometer consisting of a wrapped toroid core encircled by two sensing coils. Supporting electronics generate a repeating, oscillatory function which is run through the coil wrapping the core. This signal induces current in the two orthogonal sensing coils, which is then processed electronically. In the absence of a magnetic field, the returned signals clip at a certain positive and negative level. An external magnetic field biases the returned signal, which shows up as a difference in amount of time spent clipped at either the positive or negative extreme [14].

The magnetometer has a range of +/- ~0.75 gauss with a sensitivity of ~0.33 volts/gauss and an accuracy: ~1%.[7] Output from the magnetometer is in the form of a 0 to 4.5V signal. The picosat can take magnetic field strength measurements in three axes by having one axis of the magnetometer aligned with the spin axis of the picosat and the other axis orthogonal to it, scanning as the picosat rotates. As long as the spin axis is not exactly aligned with the magnetic field, spin rate can be determined by examining the highest frequency oscillations of the magnetometer output. If the picosat is nutating, oscillations in field strength readings from the spin about the principal axis will be superimposed on a lower frequency sinusoid caused by the nutation. From the nutation rate and angle we can infer the dynamics of the launch. A detailed study of how the picosatellite dynamics can be derived from magnetometer data and used in ejection diagnostics is presented elsewhere in these proceedings [15].

As an additional check to confirm rotation rate for the picosat, four IR

sensors are positioned about the perimeter of the satellite body and set to different gains. In certain orientations these may detect Earth horizon crossings or sun location, which will supplement magnetometer data.

The magnetometer signals and the IR sensor outputs are sampled by the analog to digital ports on the microcontroller. To reduce noise in the signals, all lines are sampled 8 times in the course of 0.5 ms and averaged.

Samples are taken 10 times per rotation to satisfy practical Nyquist criteria for data collection of a sinusoidal oscillation. This should be sufficient to characterize the spin rate as well as the lower frequency nutation rate if there is wobble present.

Microcontroller Unit

A 68HC11 microcontroller unit coordinates picosat operations. Its function, in principle, is very straightforward. Once the picosat turns on, the MCU begins an endless loop in which it 1) takes data from the magnetometer and IR sensors, 2) processes the data, 3) formats the data for transmission, and 4) sends it to the transmitter. This cycle repeats until the batteries run out.

The 68HC11 family was chosen for the picosat after a brief survey of other available microcontrollers. In addition to the fact that it has the necessary outputs, A/D capability, speed, and surface mount packaging, the primary influence on selection was the extensive experience and support available at Stanford for this processor.

Many variations on the basic MCU are available in the Motorola 68HC11 family. Although the program, with its 1.5K of

look-up tables, was initially being designed to fit into the 2K EEPROM available on some models, a 68HC11 model with 12K EPROM was located, loosening the tight memory constraints.

The selected model was purchased in two versions, the XC68HC711E9CFS2 and the MC68HC711E9CFU2. The first is a PLCC package with a window allowing the on-board EPROM to be erased and reprogrammed. The second is a 64 pin surface mount chip without the window. It is only one-time programmable. Both operate at 2 MHz, have 512K RAM and 512K EEPROM (as well as the previously mentioned EPROM), can execute 4 A/D conversions in 64 μ s, have two 8 bit output ports, will operate on a 4.5-5.5V supply, and have an operating temperature range of -40 to 85°C.

The software development plan begins making a functioning system using a commercially available development board with easily programmable external memory [16]. Once developed, the software will be transferred to the E9 PLCC package where debugging specific to the E9 can be conducted. Once operating to satisfaction there, the program can be burnt into the surface mount chips, which will actually go into the picosats and final picosat prototypes.

Communications System

Ultimately, to reach the ground, picosat data must be transmitted to the mother satellite, stored, and forwarded to the ground station during the next pass.

Although the possibility of adding a separate picosat radio receiver onboard OPAL was examined, the decision was made to use the existing communications hardware already on the satellite for ground communications: a 437.1 MHz

radio antenna and receiver, a 9600 baud terminal node controller (modem), and the OPAL CPU.

The requirements on the picosat to support this interface include the ability to generate a compatible transmit waveform and a transmitter to frequency modulate the waveform onto a 437.1 MHz carrier signal. The waveform generation and transmitter will be discussed in the next two sections.

Microcontroller Software: Data Formatting and Waveform Generation

The OPAL TNC, donated by NavSymm [17], uses AX.25 amateur radio protocol for packetizing information and a G3RUH design for generating the transmitted waveform. AX.25 is a standard method used by amateur radio operators to package information and send it in bursts, or "packets" across a channel [18]. The protocol includes labels and error check information along with the actual data so that a receive station can tell if the packet was being sent to it specifically, how to handle the incoming data, and whether any part of the packet was corrupted during transmission. The G3RUH waveform is simply a particularly efficient way to encode digital data to be sent through what is inherently an analog system [19]. Although this entire process is commonly done with many discrete IC's, it can be implemented almost entirely in software. Due to volume limitations, the 6811 does most of the steps onboard. These steps, summarized in Figure 4, are described below.

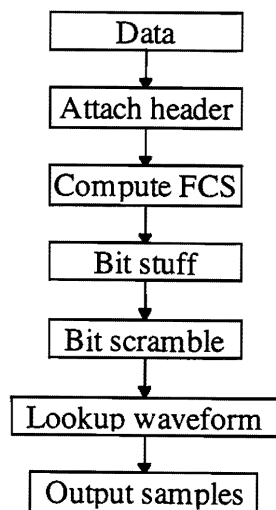


Figure 4. Stages in generating waveform in 6811 software.

After the data is processed (sampled and averaged) and ready to be sent, a standard header is copied from memory. The header includes the call signs of the sender and desired recipient of the packet and several control bits which specify how the receiver should handle the following bytes. It is preceded by a series of start bytes (repeated sequences of 01111110) which alert the receiver to an incoming packet and help to synchronize the receive clock.

Next, a frame check sequence (FCS) is calculated for the message. An FCS is basically an advanced form of parity check consisting of two bytes which can detect a number of bit flip errors. Software at the receiver end will use the FCS to determine if any data was corrupted during transmission and if so, reject the packet.

The entire message is then checked for any sequences of five consecutive 1's. Since six consecutive ones occur in stop bytes, which are identical to the start bytes mentioned above, a zero must be

inserted after five 1's to prevent an accidental premature end to the message.

Then the bits are scrambled by XORing each bit with the 17th and 12th bits to be transmitted before it. This in effect adds a timing signal to the information, preventing long strings of 1's or 0's from causing the receive clock to desynchronize.

Next, the "eye" function is generated. To minimize interference with nearby channels, a finite impulse response filter is used [20]. Through clever manipulation of the impulses that differentiate 1's from 0's, this yields a signal with a very narrow, raised cosine spectrum. For each bit, depending on the four bits before and after it, a waveform is generated by looking up the appropriate location in memory where a series of four samples are stored. Because this process is too slow to do "on the fly" as the data is transmitted, the locations to look up for each bit are stored in RAM. Naturally this limits the length of a sendable packet because a byte long look-up location must be stored RAM for each bit being sent. Thus a total of nine bytes, one for the original byte of data and eight for the look-up locations of each bit, must be stored for every byte that will be sent. However, the speed of the processor makes this unavoidable.

Finally, the program sends the samples through one of the 68HC11 IO ports at a rate of 9600 baud. The data runs directly to an 8-bit digital to analog converter chip and is converted to a stairstep function, a discretized version of the final desired eye function. A passive RC lowpass filter smooths this into a continuous signal which can be output to the transmitter.

Sampling Strategy and Link Budget

Two possible strategies exist for data collection. Each sample could be processed and transmitted as soon as it is taken, or a batch of samples could be taken and transmitted together in one packet. Given that the picosat baseline spin rate will be 2 rotations per second, the first strategy would require a sample/process/transmit sequence every 50 ms. Since actual transmission of a single sample packet at 9600 baud would take around 20 ms and the current program takes roughly 40 ms to prepare the data for transmission, the first strategy will not work.

Instead, data will be collected for as many samples as can be held in memory, which is 11. Since this takes about 44 ms to send and about 400 ms to prepare, it will be half a rotation before data samples can be taken again. Thus the picosat will sample for a full rotation, use half a rotation for communication, then sample a full rotation again, etc. Picosat dynamics can be estimated from this data via Kalman filtering of the raw information on the ground

The link budget for this system provides for a minimum 15 dB signal to noise ratio out to 1 km from the mother satellite. The primary limitation comes from the picosat transmitter, which outputs only 6 dbm to the antenna. Although the radio and receive antenna gain on OPAL have been determined, the link budget is still preliminary, as most of the picosat transmit capabilities are theoretical at this point. Several candidate antenna designs will be prototyped and tested. The link will be fully characterized only after empirical testing with all hardware.

Transmitter and Antenna

The transmitter is a Motorola MC 13176D UHF FM/AM driver, operating at 437.1 MHz. The antenna is a simple loop antenna with a branch at the aft of the picosatellite to reduce the null in the direction of the satellite immediately after launch. The most serious concern about integrating the antenna is that it might interfere with the magnetometer or other circuitry. In particular, the concern is that the transmitter could effect the dc offset of the op-amps in the gain stages of the magnetometer. The switching frequencies of the antenna and the magnetometer are far enough apart, that there is less concern about crosstalk or inductive coupling. To verify or alleviate our concerns, a loop antenna driven by the picosat transmitter was placed at various locations around the magnetometer circuit and measurements taken for different transmit powers and magnetic field strengths. There was no cross talk between the two circuits but there was a slight dc bias introduced into the output of the magnetometer that rose linearly with transmit power. The offset at twice the expected transmit power amounted to 0.03 V, which is less than 5% of the expected signal. The present solution to this problem is to turn the transmitter off while reading magnetometer data.

Packaging

The picosat is intended to fit the required data collection hardware in as small a package as possible and still maintain favorable inertia characteristics. The Picosat must also have a rigid shell and the internal components fixed so that it interacts with the launch mechanism in a repeatable manner, and can survive loads during the launch from earth.

The dynamic and packaging requirements, as well as the interface requirements to the launcher, constrained the picosatellite geometry to a hard disc shape. Several methods for housing the picosatellite have been considered and two prototypes have been built. The most obvious choice would be to machine the housing out of metal and attach the components to fixed points on the inside. Unfortunately, the transmitter is adversely affected by an exterior metal shell. This led to a search for a non conductive shell that meets the strength and rigidity requirements. Plastics that met the rigidity requirements required wall thickness that made the Picosat much larger than we liked. We currently plan to use a molded epoxy construction.

Epoxy molding provides a very rigid and durable body that permits a great deal of flexibility in the layout of parts and in the final balancing of the picosat once it is constructed. Potting of complex electrical circuits for rugged marine applications is a common practice and makes a precedence for this approach. The only disadvantage is that we cannot change the location of a component once the mold is cast.

Battery

There are only three subsystems requiring power in the picosat: the magnetometer, MCU, and transmitter. Power requirements for the picosat are summarized below.

Subsystem	supply voltage (V)	current drain (mA)	power (mW)
Magnetometer	8	65	520
MCU and DAC	5	25	125
Transmitter	5	4	20
Total	5	133	665

All systems are designed for 5V operation except for the magnetometer, which requires 8V. The magnetometer dc voltage conversion is done with a MAX761 [21] chip donated by Maxim.

The major criteria for battery selection were that they must supply 133 mA at 5V or higher for the mission lifetime (1 hour desired, 15 minutes required), and must fit within the tightly constrained geometry of the picosat.

Most commercially available batteries that are within the size range of the picosat do not source enough current. Many batteries exist with nominal amp-hour values that, if divided by the hour we plan to use them for, yield a current over 133 mA. However the amp-hour figure is misleading because most will only source a certain maximum current (well below our required value), even when shorted. For example a lithium-manganese dioxide cell, roughly the size of a silver dollar, is rated at 155 mAh but can source only microamperes of current, which it is designed to do for hundreds of hours.

Because of the geometric constraints and a desire for symmetric arrangement of components, thin flat cells were investigated. Thin film lithium batteries, designed primarily for PCMCIA card applications, were geometrically promising but had inferior current sourcing capability [22]. The P91 Polapulse battery, manufactured by Powercard Corp. for use in Polaroid film cartridges [23], is capable of sourcing the necessary current. Unfortunately this battery is slightly too long and experiments in which the battery is cut to size and immediately potted in epoxy to prevent leakage have not shown promising results.

Because of this concern with battery size, and due to other constraints, the picosat design is now based on potting all components in epoxy. With this design, components can actually touch the outside edge of the picosat envelope. This allows the use of standard commercially available cell sizes. Possibilities include four AAA cells, four N cells, or two "2/3A" cells, all available from Radio Shack. The current design, pending vacuum and thermal testing, uses the N cells. Clearly, this is a challenging design problem, and we expect to do several packaging experiments before fixing on a final design.

Thermal Considerations

Once the picosat is free from OPAL, its temperature will be entirely dependent on radiative heat transfer into and out of its surface, which depends on the surface absorptivity and emissivity properties. If these properties are not controlled properly, the picosat may experience a dramatic temperature swing that will pull its electronic components out of operating range, ending the mission.

The initial analysis of the picosat thermal environment examines the two temperature extremes that the picosat might encounter in orbit. The maximum temperature would occur when the picosat was facing the sun with the earth behind it.



Fig 5. Maximum temperature situation

This situation exposes the most surface area to sunlight and an equal area to reflected sunlight and thermal emissions

from the earth. The minimum temperature would occur when the picosat was in eclipse and edge on to the earth.



Fig 6. Minimum temperature situation

This situation exposes a maximum of surface area to radiate to deep space and a minimum of surface area to absorb infrared radiation from the earth.

To minimize temperature swings between these two configurations a possible surface coating strategy suggests itself. To minimize temperature in the maximum temperature case the faces, exposed to sunlight, should have absorptances as low as possible. The faces and edges should have emittances as high as possible to facilitate radiation of heat in the IR band. To maximize temperature in the minimum temperature case the emissivity of all surfaces should be minimized. The majority of the surface sees deep space in this case and the energy absorbed from the earth when the satellite is below the earth's blackbody temperature does not equal the energy lost to space.

Analyses of the equilibrium temperature in each situation demonstrate a range of as great as -130°C to 200°C , depending on surface coatings. These extremes are well outside the operating range of the commercial electronics we plan to fly. However, a transient analysis indicates that, given appropriate coatings and a reasonable initial temperature upon release from OPAL, the picosats will never reach such extremes. As long as the temperature upon release is between 0 and 53°C , the picosats will stay within

their operation range of 0 to 70°C throughout an entire orbit. Although the thermal capacity of the satellite is small, about 260 J/°C, its surface area is also small, which significantly limits heat transfer through radiation. A simple discretized simulation shows that a coating with both low absorptivity and emissivity, such as polished aluminum, will keep the picosat temperature within this operational range.

If the picosat manufacturing process or transmitter constraints prevent a reflective surface, the faces will be painted black and the sides white instead. In general the paints have much higher emissivities, which means the picosat temperature can drop much faster than with a polished surface. The black face compensates slightly by increasing solar input through higher absorptance in the maximum temperature situation (a white face would reflect too much energy and actually drop the picosat below operating range), but little can be done to improve the eclipse situation. With these coatings, the picosats can be launched at a temperature between 13 and 70°C and still remain operational for their required 15 minute lifetimes. Heaters could be added to prolong this time, but available power is not sufficient to significantly improve the 13° figure. We are continuing our search for coatings that can mitigate thermal limits on picosat function.

The picosat temperature profile in the hottest and coldest cases are illustrated below for both the aluminum and paint coatings

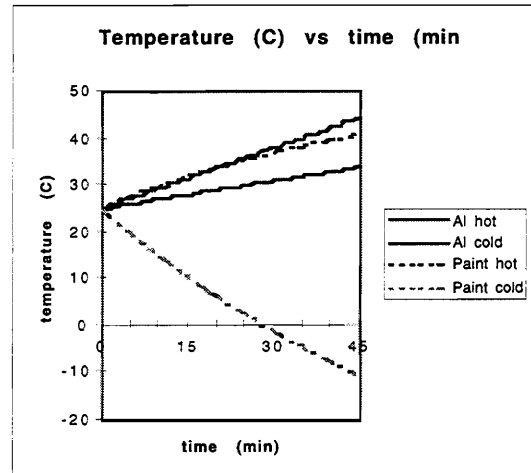


Figure 7. Picosat Temperature Profiles

Mass Distribution

Accurate balancing of the picosat is essential to the success of the experiment. Picosatellites are spin stabilized. The body of the picosat is the gyro from which magnetic field measurements are referenced to. For our experiment, any nutation in the angular velocity vector is assumed to come from perturbations during launch.

Perturbations to the desired ejection parameters may be caused by tip-off from the gripper fingers or exit hole, or they may be caused by a mechanical malfunction, such as a motor binding during the launch sequence.

In order for the picosat to fly correctly, spinning about an axis fixed in inertial space, the picosat must be ejected so that it spins about its axis of maximum moment of inertia. After release from OPAL the picosat will experience no other torques. Thus it is critical that the body axis, which will be the axis of the angular momentum vector, be aligned very closely with the maximum moment of inertia axis. Misalignment will cause nutation, which could degrade picosatellite data and will give false data on the release mechanism of our test picosat. Additionally, the center of mass

of the picosat must be located along its spin axis to ensure a clean release from the ejector.

Maintaining symmetry in the layout of components will help this tremendously, as will the density homogenizing effect of potting the entire satellite in epoxy. Spin balancing techniques will be used to adjust the moment of inertia tensor. Mass will be added, if necessary, by drilling holes in the epoxy and filling them with denser material. Mass can also be removed by simply leaving the holes empty.

Final spin balance will have to be performed using more sophisticated equipment, which we hope to access via local industrial contacts.

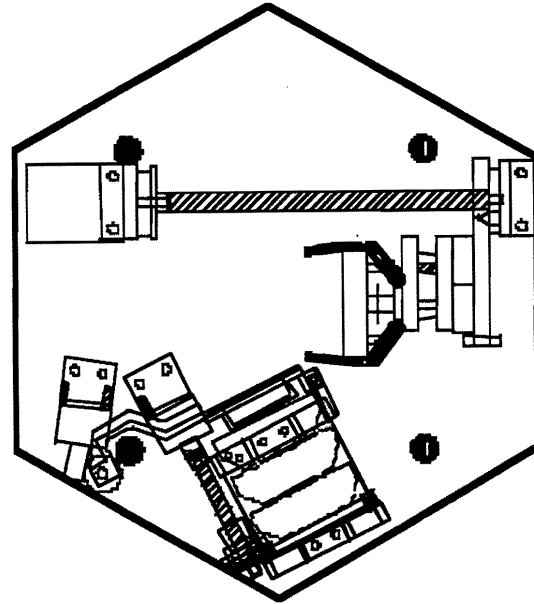
Ejection Mechanism and Operation

The goal of the picosat launcher is to control both the picosat spin rate and separation velocity to a high degree of precision, repeatably.

During storage and launch picosats are contained in a cylindrical canister sealed at one end by the loader arm and at the other end by a stack advance mechanism.

After the command to launch has been given OPAL's CPU runs through the launch sequence:

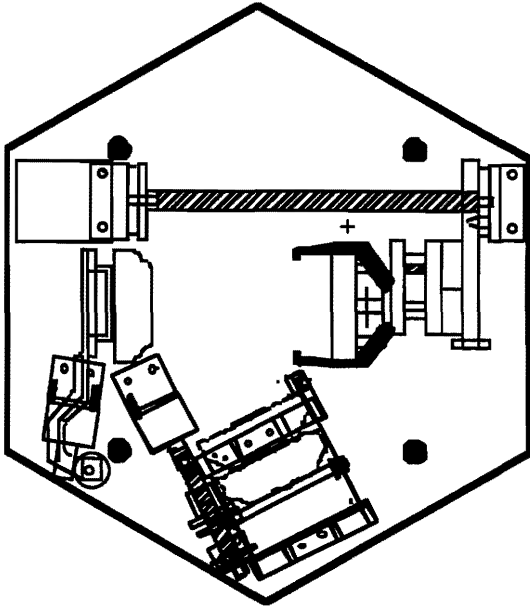
1) The loader arm presses a velcro patch against a matching velcro patch on the front of the picosat.



Start

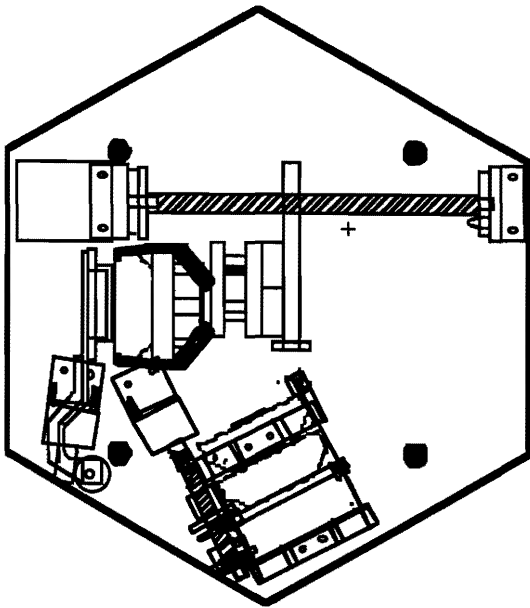
2) The loader arm pulls the picosat from the stack and the stack advances one picosat width. The remaining picosats are restrained by springs at the opening of the canister.

3) The loader arm and picosat swing into position in front of the ejector plate.



Loader Arm pulls Picosat off Stack; Stack advances

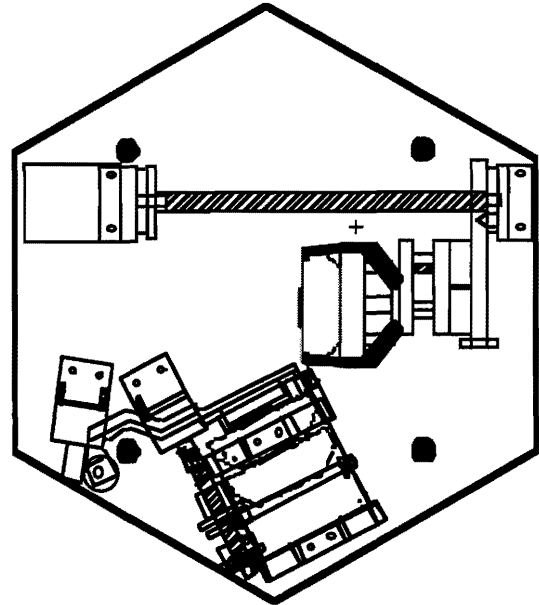
4) The ejector plate advances forward until it can grip the picosat.



Ejector system moves forward to grab Picosat

5) Once the picosat is firmly held by the fingers of the ejector plate it returns to its home position.

6) The loader arm returns to its home position.



Ejector system retracts; Loader Arm returns to Stack

7) The picosat is spun up to the commanded rate.

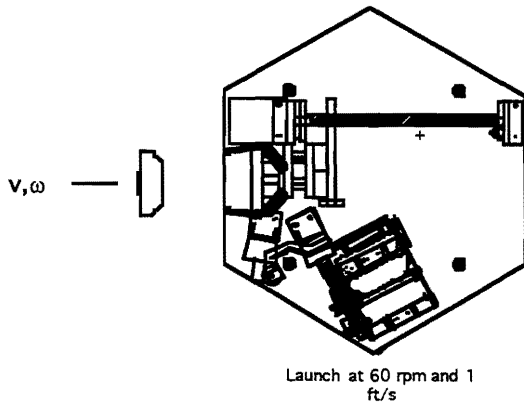
8) Once the proper spin rate is achieved the ejector plate accelerates towards the opening in the side of the space craft.

The acceleration profile of the ejector plate is controllable in software.

9) While the plate is still accelerating the gripper fingers pull back. This is to prevent them from catching on the edges of the picosat upon release.

The picosat is chamfered and the ejector plate is cupped so that small mass imbalances in the picosat and small reaction moments from OPAL will not cause the picosat to slide off the ejector plate.

10) As the picosat reaches the opening in the satellite the ejector plate decelerates leaving the picosat to continue on its own.



This launch scenario is favored because it offers the best chance of a smooth, inertial release. It also features the capability for broad adjustability of both linear and angular velocity. Demonstration and validation of this launcher is an important step for its acceptance on future NASA missions.

Conclusion

We have begun the design and construction of a prototype picosatellite mission as a precursor to a NASA magnetometer mission. We have already identified or demonstrated solutions to most of the design constraints imposed by this scenario. We look forward to completion of the spacecraft and a successful flight.

Acknowledgements

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- [8] Optek; 1215 W. Crosby Rd. Carrollton, TX 75006. (214) 323-2200 - Part Number: OP804TXV
- [9] Motorola; <http://www.mot.com/> - Part Number: XC68HC711E9CFU2
- [10] Maxim Corp.; <http://206.65.84.190/> - Part Number: MAX505
- [11] Motorola; <http://www.mot.com/> - Part Number: MC 13176D UHF FM/AM Transmitter
- [12] Cherry Electrical Products; Waukegan, Ill 60087. (847) 662-9200, supplied by: DigiKey; <http://www.digikey.com/> , 1-800-DIGIKEY - Part Number: CH171-ND
- [13] Radio Shack; Use local franchises - Part Description: *Energcell Long Lasting AAA Cell*. Note that this part is still being tested and may be changed.
- [14] For a detailed description of a two-axis fluxgate magnetometer refer to Acuna, Pellerin. *A Miniature Two-Axis Fluxgate Magnetometer*. IEEE Transaction on Geosciences Electronics, Vol. GE-7, No. 4, October 1969.
- [15] Paul Graven, Jaewoo Jung, Tom Kenny, Robert Twiggs *Attitude Determination and Launch Diagnostics for a Picosatellite via Kalman filtering of Magnetometer Data..* Proceedings of the 10th Annual USU / AIAA Conference on Small Satellites, Logan, UT, September 16-19, 1996.
- [16] 68HC11 development board from New Micros Inc; <http://www.newmicros.com/> - Part Number: NMIT-0022.
- [17] NavSymm; Sarasota, FL 34236, 813-366-6338
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- [21] Maxim Corp.; <http://206.65.84.190/> - Part Number: MAX761
- [22] Thin film lithium batteries (brand name Powerdex) are available in a variety of thicknesses and voltages from Gould Electronics Inc. Electronic Power Sources, 1-800-722-7890.
- [23] Information on Polapulse batteries as well as very economic designer's kits are available from Powercard Corporation, (617) 890-6789.