CanSat Program

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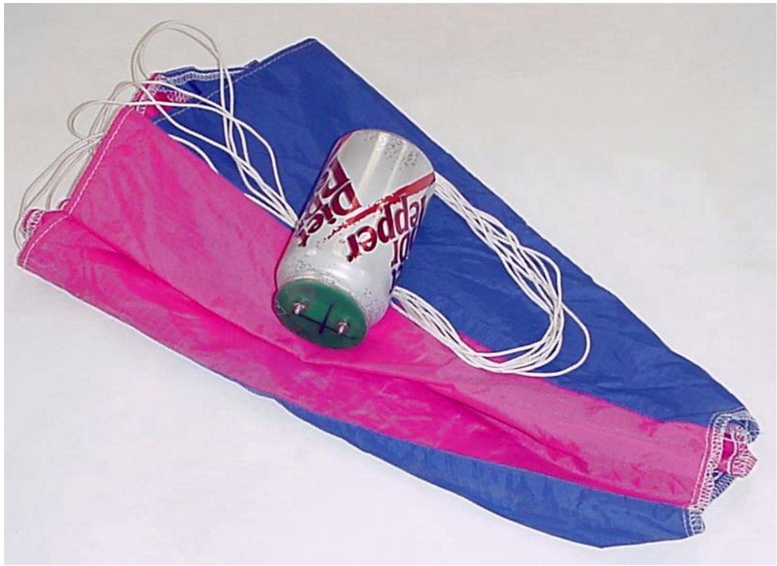
The Mission

- Goals
- Understand the *CanSat* Concept
- Learn the Parts of a Satellite
- Learn the Parts of the *CanSat*

Introduction to *CanSat*

- ***CanSat*** **Is a Simulation of a Real Satellite**
  - **It Performs a Mission and Collects Data**
  - **Typical Missions Can Be Atmospheric Measurements, Video Capture, Picture Taking, Communications, or Navigation**
  - **The Missions Can Be Simple or Complex**
  - **The Only Requirement Is That the Mission Must Fit in a Twelve Ounce Soda Can**



- **This Program Will Introduce You to How** ***CanSats*** **Are Built**
  - **It Includes Most Subsystems Found in Satellites**

The CanSat Mission

- What is the mission
  - Launch a CanSat to at least 2500 feet and be deployed
  - CanSat is to float back to earth on a pararchute
  - CanSat is to measure the atmospheric pressure during flight
  - CanSat is to measure the air temperature during flight
  - CanSat is to transmit the data to a ground station at least once every three seconds
  - Data it to be analysed to determine the maximum altitude

CONOPS

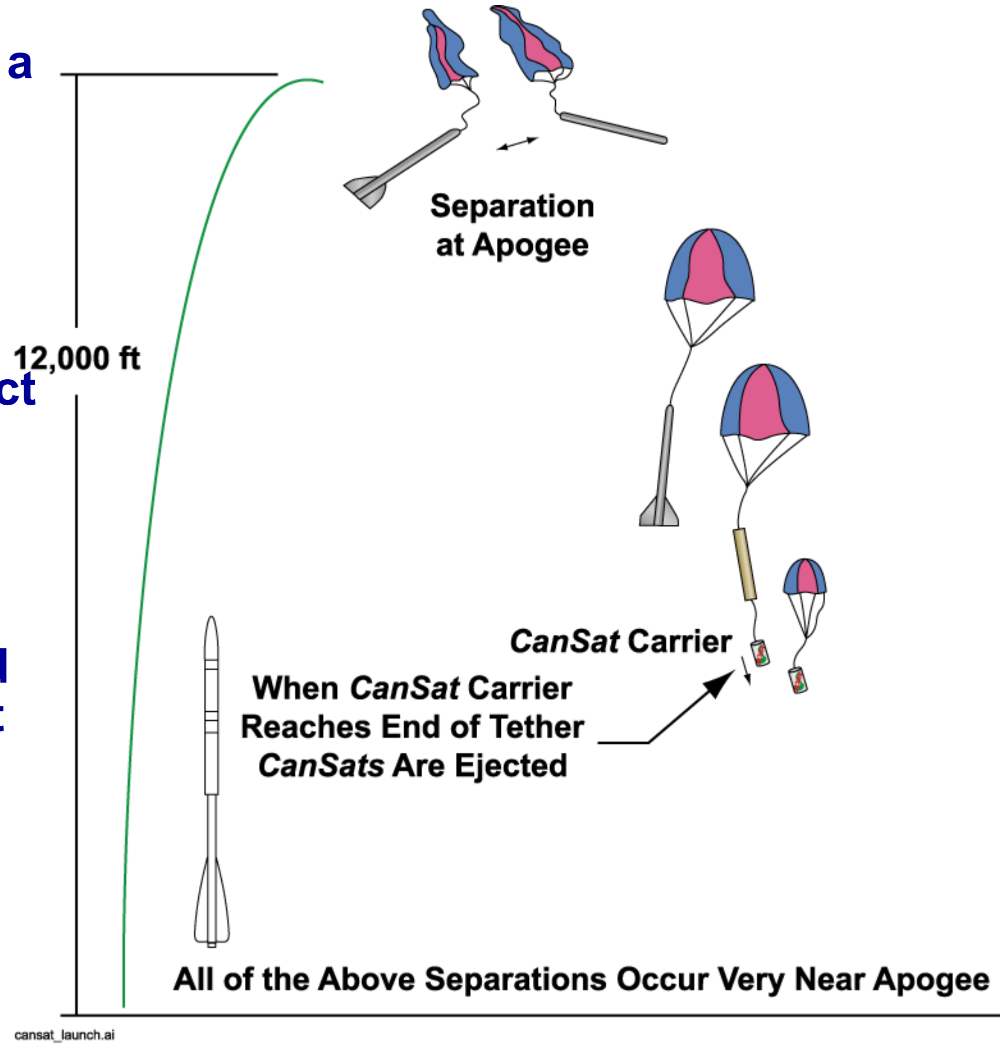
- CONOPS = Concept of Operations
- What is CONOPS
  - Description of the mission operations from the beginning to end
  - Covers all operations
    - Rocket preparations
    - Cansat preparations
    - Ground station preparations
    - Cansat integration into rocket
    - The rocket launch
    - The deployment of the satellite from the rocket
    - The collection of data from the cansat
    - Recovery of the rocket and cansat
    - Task of each person involved in the mission
    - Contingency plans

Mission Requirements

- Satellite requirements
  - Cansat shall measure air pressure and temperature at least once every 3 seconds
  - Cansat shall transmit data to a ground station
  - *CanSat* Shall Be Built to Fit in a Standard 12 Ounce Soda Can (e.g., Coca-Cola or Pepsi)
  - No Parts of the *CanSat* Shall Extend Beyond the Surface of the Soda Can Until Deployed
  - *CanSat* Shall Weigh Less Than a Full Can of Soda (350 Grams)
  - *CanSat* Shall Operate off of Battery or Solar Power
  - Antennas Should Be Flexible and Not Extend More Than 4 Inches When Stowed
  - A Parachute Shall Be Properly Secured to One End of the *CanSat*

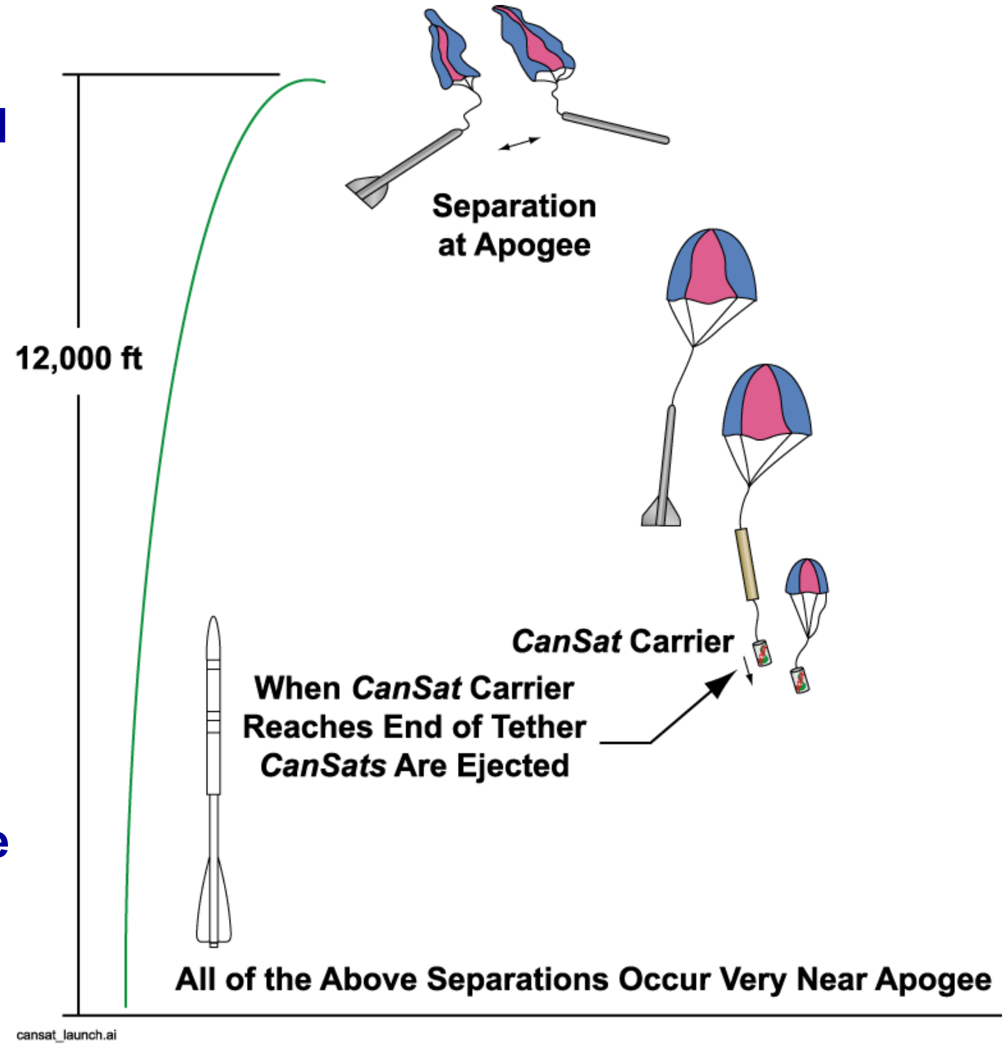
Mission Requirements (cont)

- Ground station requirements
  - The ground station shall have a receiver compatible with the cansat transmitter
  - The ground station shall have an antenna that can track the cansat during flight
  - The ground station shall collect all the data from the cansat during flight and store it for later analysis
- Rocket requirements
  - The rocket shall be configured to carry a cansat and deploy it at apogee
  - The rocket shall use a solid rocket motor with built in ejection set to deploy the cansat and the rocket parachute at apogee



How Is the *CanSat* Launched?

- ***CanSat*** **Is Launched on a High-Powered Model Rocket**
  - **The Rocket Is 3” in Diameter and About 3’ Tall**
  - **Capable of Reaching at least a half mile in Altitude**
  - ***CanSat*** **Is Stowed in the Upper Airframe Below the Nose Cone**
- **The Rocket Is Launched and When It Reaches Apogee, the Rocket Breaks Apart to Eject the Main Parachute**
  - **This Causes the Upper Portion of the Rocket to Point Down**
- **The Nose Cone Will Fall Out and the** ***CanSat*** **Will Fall Afterwards**
- **The Parachute Brings the** ***CanSat*** **Gently Back to Earth**

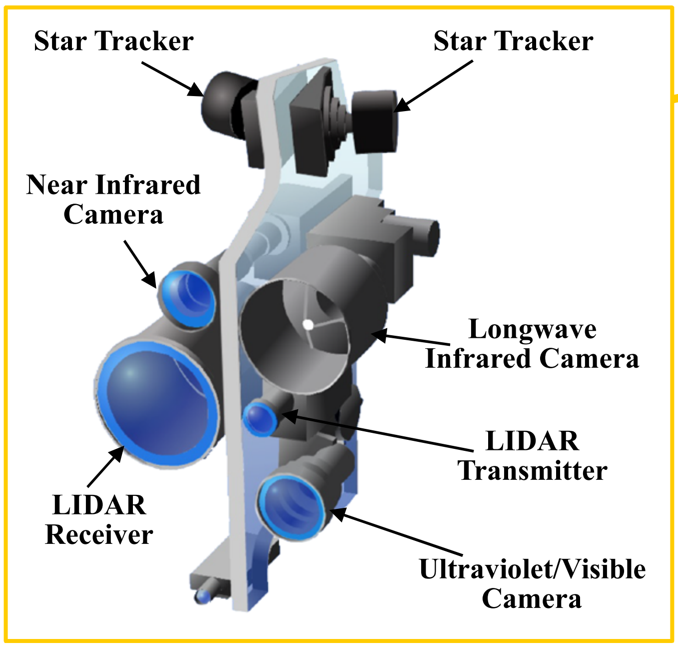


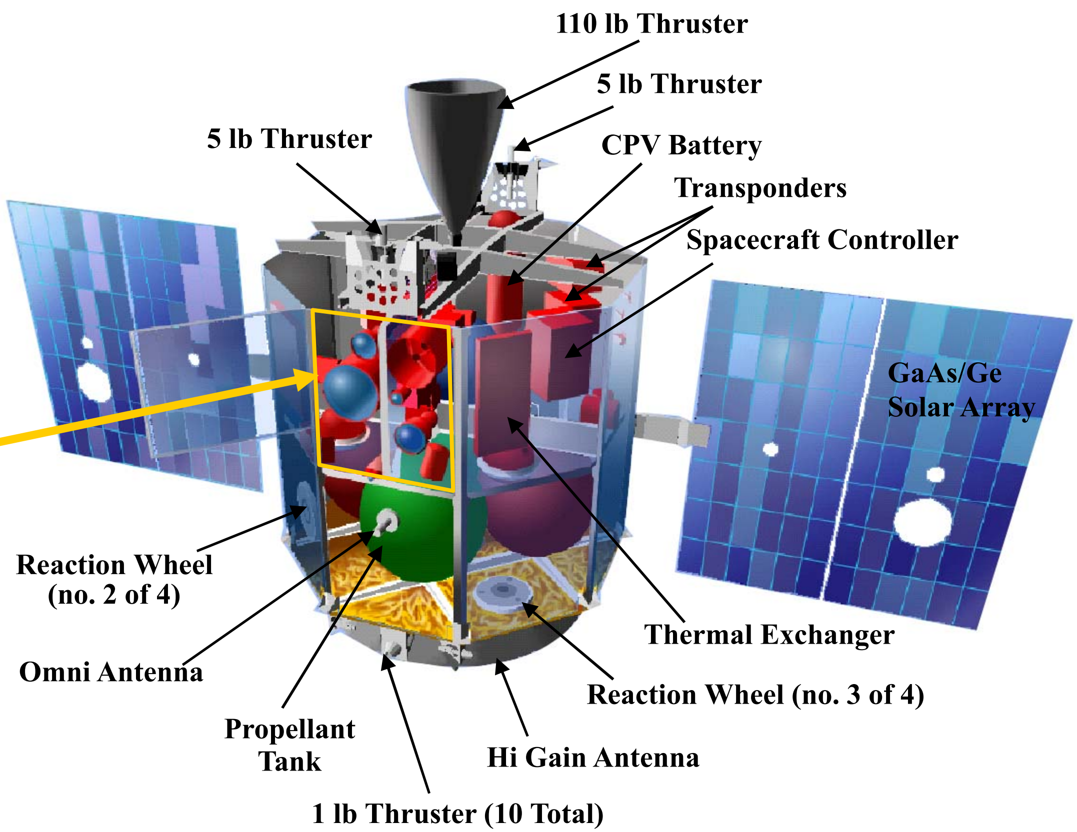
Satellite Subsystems

- **A Satellite Is Made Up of Six Major Subsystems:**
  - **Power Subsystem**
  - **Data Handling Unit**
  - **Communications Subsystem**
  - **Sensor Payload or Subsystems**
  - **Structure**
  - **Attitude Control Subsystem**
- **The Following Pages Describe Each Subsystem in Greater Detail and Use the *Clementine* Spacecraft As An Example (see www.pxi.com/Clementine)**
  - ***Clementine* Launched on January 25, 1994 From Vandenberg Air Force Base on a Mission to Test Lightweight Miniature Sensors and Advanced Spacecraft Components by Exposing Them to the Harsh Environment of Outer Space Over a Long Period of Time**
    - **After Two Earth Flybys, *Clementine* Was Inserted Into Lunar Orbit on February 21**
    - **From 26 Feb Through 22 April, *Clementine* Mapped 100% of the Lunar Surface in 11 Spectral Bands With Greater Than 99% Coverage, Transmitting Over 1.8 Million Digital Images Back to Earth**
    - **These Images Were Quickly Accessible to the General Public via the Internet and World Wide Web**
  - **In 1994, President Clinton Cited *Clementine* As One of the Major National Achievements in Aeronautics in Space; He Stated "*The Relatively Inexpensive, Rapidly Built Spacecraft Constituted a Major Revolution in Spacecraft Management and Design; it Also Contributed Significantly to Lunar Studies by Photographing 1.8 Million Images of the Surface of the Moon.*"**

The *Clementine* Spacecraft

- Six Major Components Make Up a Typical Satellite:
  - Power System
  - Controller
  - Sensors
  - Communications Systems
  - Attitude Control
  - Structure





Power Subsystem
Solar Cells

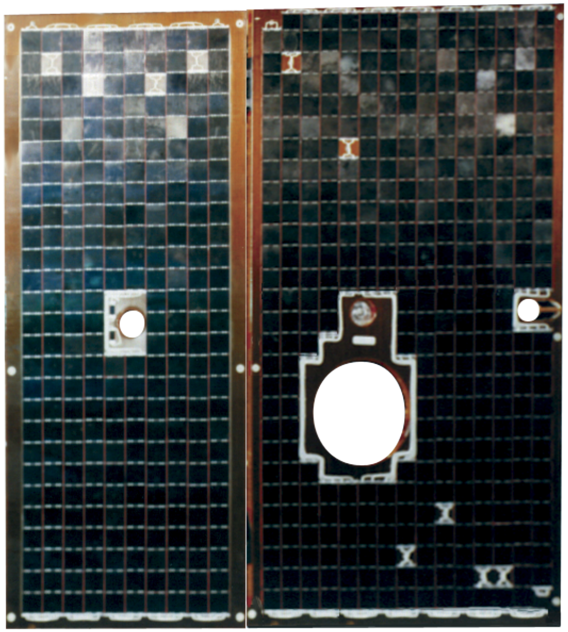
- The Power Subsystem Provides Electrical Power to the Satellite
  - Energy Can Come From Solar Panels, Batteries, or Some Type of Fuel Cell
- Solar Panels Are Comprised of Solar Cells, i.e., Semiconductor Devices Called Photovoltaics
  - As the Word Implies, Photovoltaics (Photo = Light, Voltaic = Electricity), Convert Sunlight Directly Into Electricity
- Wide Variety of Types of Solar Cells (e.g., Silicon (Si), Gallium Arsenide (GaAs), Gallium Arsenide/Germanium (GaAs/Ge), and Amorphous Si Cells; Each Has Different Levels of Efficiency and Manufacturing Costs
  - Amorphous Si Cells Are the Least Efficient and Least Expensive, and Convert Up to 9% of Light Into Electricity
  - Si Cells Are Better and Convert Up to 14% of Light Into Electricity
    - They Are More Expensive Than Amorphous Si Cells
  - GaAs Cells Are More Efficient and Convert Up to 20% of Light to Electricity
    - They Are More Expensive
  - The Newest Cells Are GaAs/Ge Cells With Efficiencies Up to 27%
    - They Are the Most Expensive
- Designers Select the Types of Solar Cells to Meet Their Power Requirements, Budget, Mass, and Size

Power Subsystems
Batteries

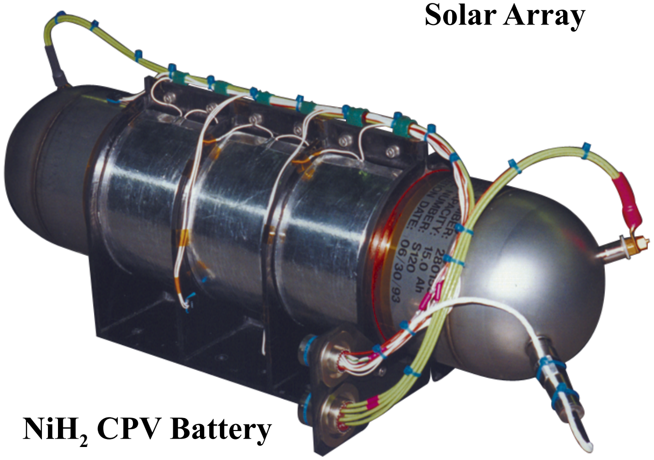
- There Are Only a Few Types of Batteries Commonly Used in Satellites
  - Nickel Cadmium (NiCd) Batteries: the Most Common Type of Battery Today and Similar to Consumer Rechargeable Batteries
    - The NiCd Batteries Are Charged by the Solar Panels and Used to Supply Energy When the Satellite Goes Into Earth's Shadow (Called an Eclipse)
  - Nickel Hydrogen (NiH_2) Batteries: a Relatively New Type Gaining Acceptance for Satellite Use
    - These Batteries Are Contained in a Pressure Vessel
  - Lithium Ion (Li-Ion) Batteries: These Are a New Technology That Is Just Starting to Be Used in Some Satellites
    - These Batteries Provide the Densest Level of Energy
    - They Do Need Some Protection
    - If the Battery Is Overcharged or Discharged Too Much, They May Explode

Clementine's Power Systems

- The Solar Cell Arrays, Developed by Applied Solar Energy Corporation, Provided Power Generation for All Spacecraft Subsystems on *Clementine*
  - The Solar Cells Were the Thinnest (0.14 mm) GaAs/Ge Solar Cells Flown to That Date (1994)
  - The Spacecraft Had Two "Wings" of Solar Arrays
    - Each "Wing" Independently Rotated in a Single Axis and Could Track the Sun Automatically
  - During the Mission, the Solar Panels Generated Up to 360 Watts of Energy (Enough to Light Six 60 Watt Light Bulbs!)
- A Lightweight NiH_2 Common Pressure Vessel (CPV) Battery Provided Energy Storage During Eclipses When the Spacecraft Was in the Earth's Shadow and During High Power Usage Activities
  - The *Clementine* Mission Was the 1st Space Flight Use of a Single Container NiH_2 CPV Battery, It Was Capable of Providing Up to 420 Watts of Power



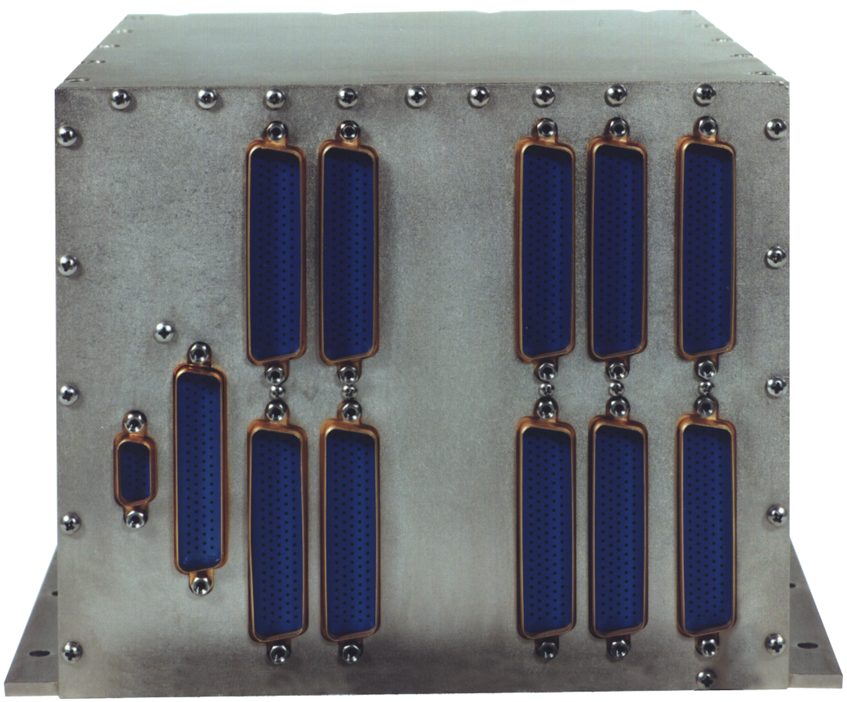
Solar Array



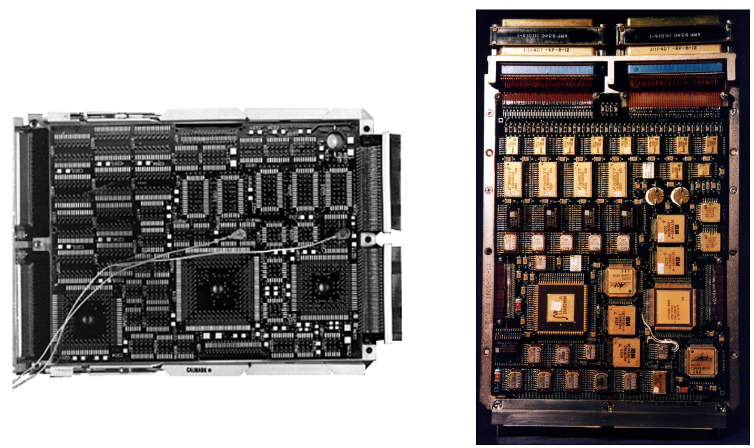
NiH_2 CPV Battery

Data Handling Unit

- The Data Handling Unit (DHU) Is a Computer That Controls the Flow of Data and Instructions
  - It Controls Payloads and Collects Data From the Payloads
  - It Accepts Commands Received by the Communications System and Sends Data to the Communications System for Transmission to the Ground Station
  - It Is the Brains of the Satellite



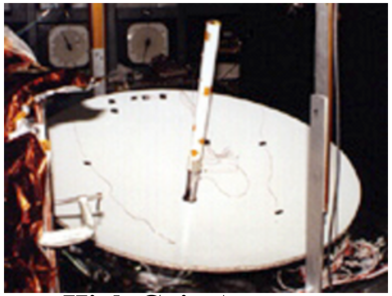
DHU

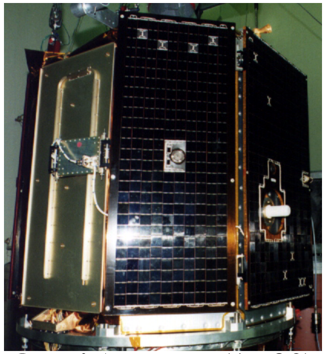


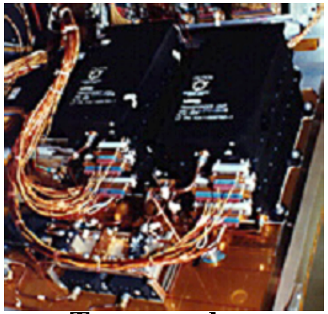
Circuit Boards

Communications System

- The Spacecraft Has a Radio Receiver for Accepting Commands From a Ground Station
  - A Ground Station Is a Location That Has Equipment to Control the Satellite Via Up-Linked Radio Commands
    - Commands Are Generally Short, and the Data Rate at Which the Commands Are Sent Is Usually Slow
    - The Slower Rate Also Helps in Reducing the Complexity of the Spacecraft's Receiver and Reduces the Chances of Errors in Receiving Commands
- The Spacecraft Has a Transmitter Used to Send Telemetry (i.e., the Name for Data Sent or "Down-Linked" From the Spacecraft)
  - The Transmitter Usually Operates at a Higher Data Rate Than the Receiver
  - There Is Much More Data to Be Sent and Due to the Limited Time That the Satellite Is in View of the Ground Station, the Faster the Data Is Sent the More That Can Be Collected
    - High Data Rates Mean More Complex Data Formats Requiring Error Detection and Correction (EDAC) Protocols
    - This Is Fine Because It Is Easier to Have a Complicated Receiver on the Ground Than on a Spacecraft

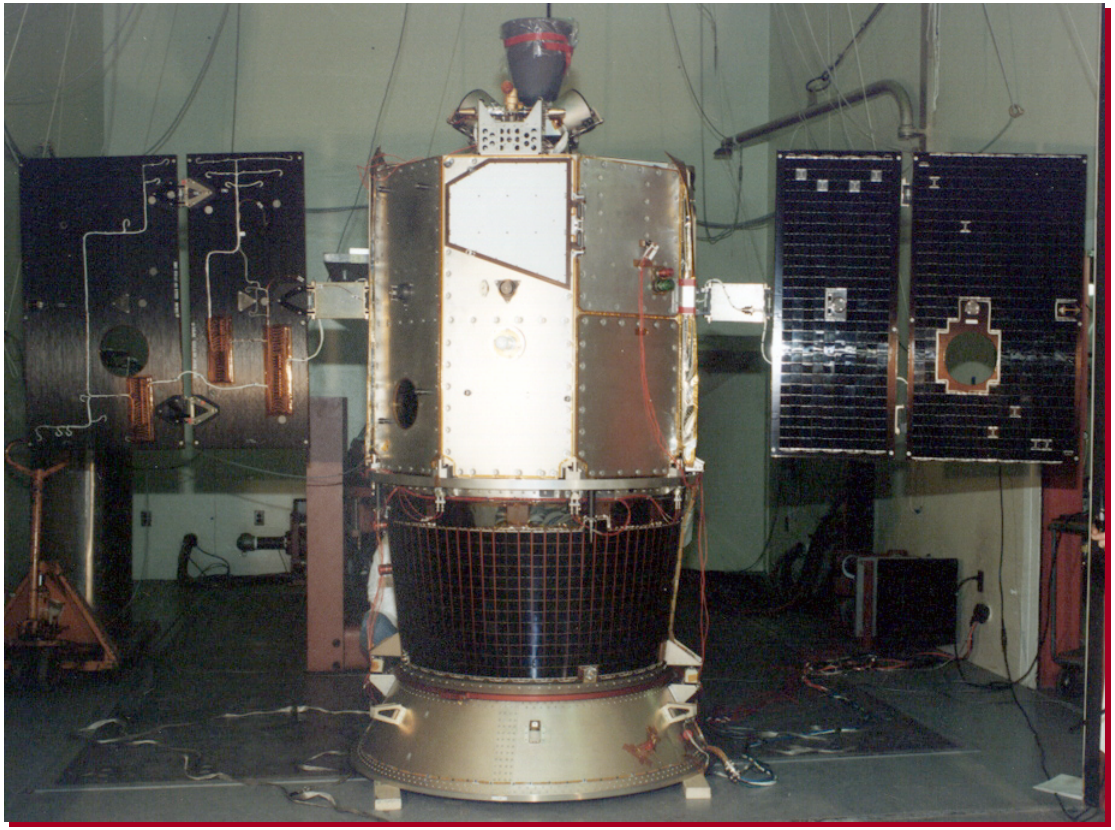

High Gain Antenna


Omni Antenna (1 of 2)


Transponders

Structure

- The Structure of the Spacecraft Is Typically Made of Aluminium
  - The Framing in the Spacecraft Is Extruded Aluminium Bars
  - Panels Are Usually Honey-Comb Panels to Reduce the Weight of the Spacecraft, but Maintain the Structure's Strength



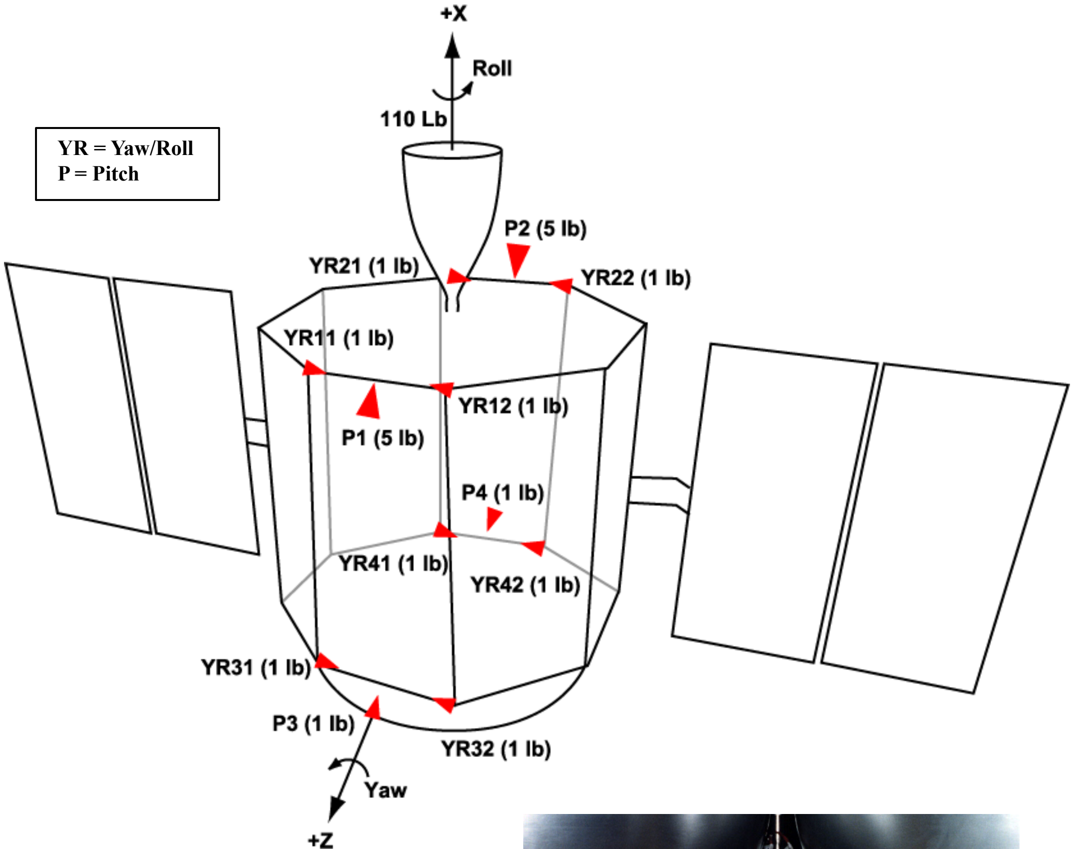
Attitude Control Systems

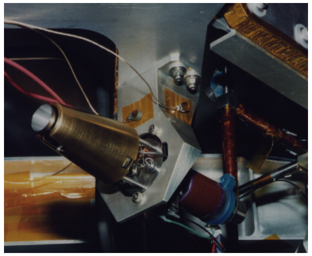
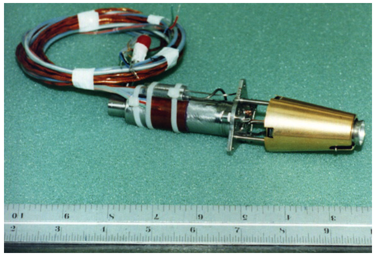
- Attitude Control Systems Allow the Orientation of the Spacecraft to Be Controlled
  - Often, Spacecraft Sensors and Payloads Need to Be Pointed in Certain Directions
  - This Requires the Spacecraft to Be Oriented to Position the Sensors and Maintain the Direction the Sensors Need to Be Pointed
- One Device Used Is a Reaction Wheel
  - It Is a Flywheel That Spins Rapidly
  - To Make the Satellite Rotate in a Certain Direction, the Spin Rate of the Reaction Wheel Is Changed
  - The Change in Spin Rate Causes the Satellite to Rotate in the Opposite Direction of the Spin Change
- To Detect Rotation, a Sensor Called a Gyroscope Is Used
  - The Gyroscope Detects the Rotation Rate of the Spacecraft

Lightweight Reaction Wheel
(9in dia. X 2.3in tall)

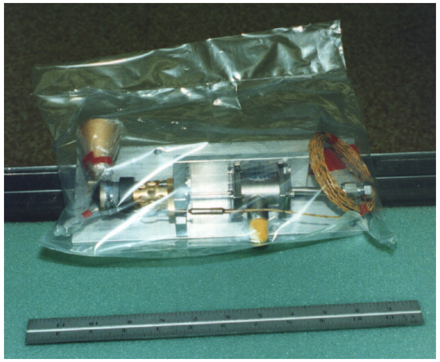
Ring Laser Gyroscope Based Inertial Measurement Unit
(3.5in dia. X 3.2in tall)

Thruster Locations

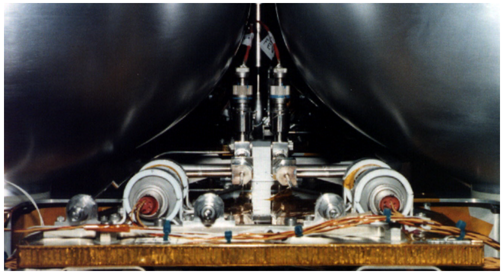


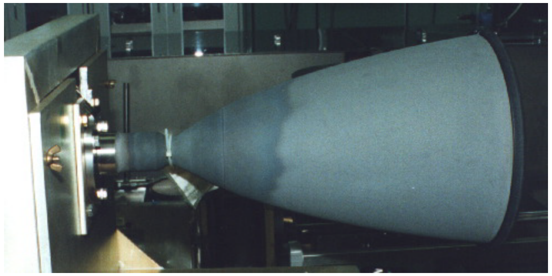
1 lb Thruster



5 lb Thruster



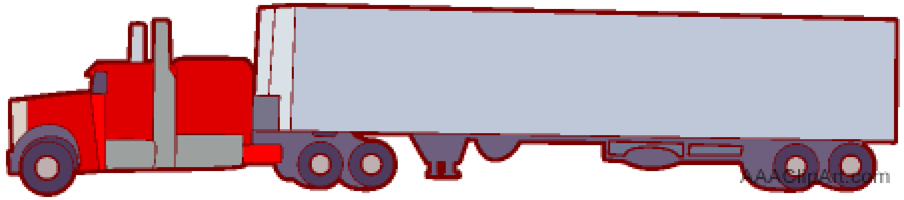
Propulsion Deck



110 lb Thruster

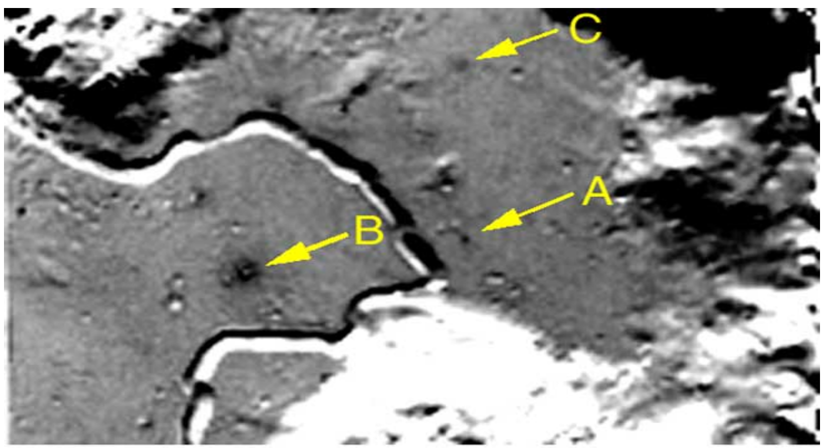
Spacecraft Bus

- The Spacecraft Bus Includes All of the System Components That Have Been Presented
- A Satellite Bus Can Be Compared to a Truck:
  - Data Handling Is the Driver
  - Communications Are the Truck Horn and CB Radio
  - The Battery and Alternator Are the Electric Power
  - The Engine and Drive Train Are the Propulsion
  - Steering Is Equivalent to the Reaction Wheels
  - The Body and Frame of the Truck Are the Structure
- The Bus Contains All the Subsystems and Structure Required to Support the Payloads Which Will Be Described Next



Sensors

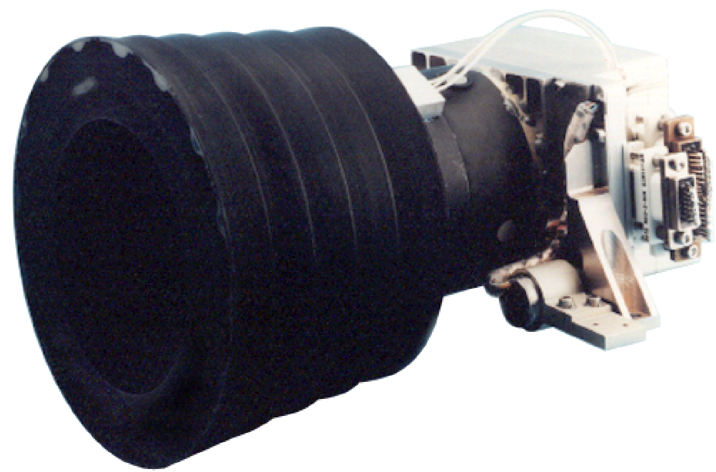
- Payloads on a Satellite Are Generally Some Type of Sensor
  - It Can Be a Radio Receiver Designed to Detect Certain Types of Signals
  - It Can Be a Camera Used to Take Pictures of the Earth in Various Light Spectrums
  - It Can Be Radiation Detectors, or Any Type of Sensor to Detect Something



Map of the photometric anomolies around the Apollo 15 landing site. Images taken by the Clementine spacecraft have resulted in spotting disturbed lunar terrain around the touchdown zone.
Arrow A points to a diffuse dark spot exactly at the locale of the lunar module, Falcon, believed created by the craft's engine blast.
Arrows B and C point to other dark spots that are photmetric anomalies related to small fresh craters.
CREDIT: KRESLAVSKY & SHKURATOV

Map of the Photometric Anamolies Around the Apollo 15 Landing Site. Images Taken by the *Clementine* Spacecraft Have Resulted in Spotting Disturbed Lunar Terrain Around the Touchdown Zone.
Arrow A Points to a Diffuse Dark Spot Exactly at the Locale of the Lunar Module, Falcon, Believed Created by Craft's Engine Blast.
Arrows B & C Point to Other Dark Spots That Are Photometric Anomolies Related to Small Fresh Craters.

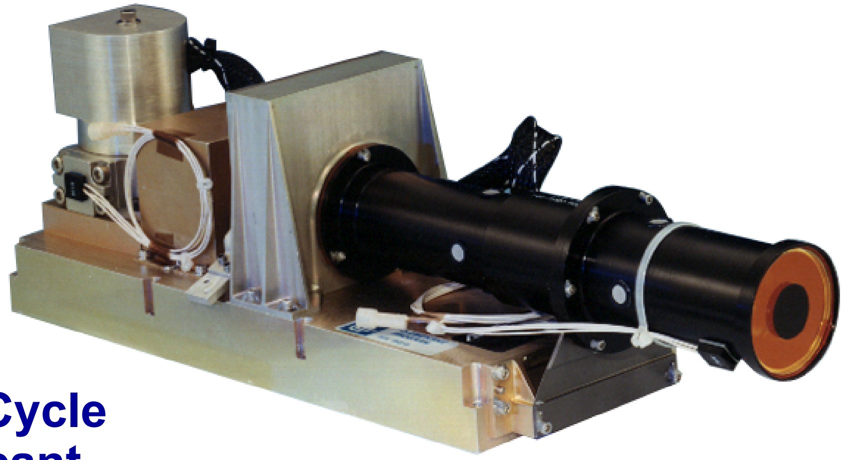
Credit: KRESLAVSKY & SHKURATOV



This Is an Ultraviolet (UV) Camera Used in Mapping the Surface of the Moon – Note the Picture of the Apollo 15 Landing Site From an ~100km Orbit (The Ground Sample Distance (GSD) Ranged From 325 to 450 Meters) Landing Site (A) is Approx 5x5 Pixels and represents 1.5 Km Feature

Near-Infrared Camera

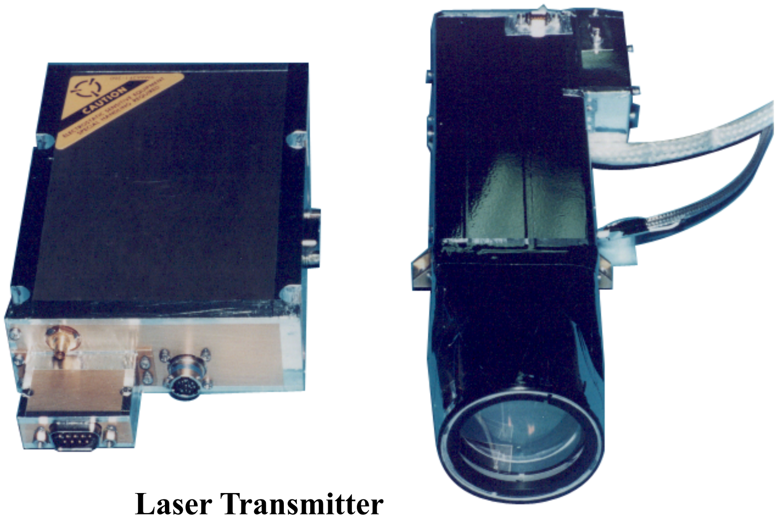
- The Near-Infrared (NIR) Camera Used an Indium Antimonide (InSb), 256 x 256 Pixel Array Mechanically Cooled to 70 Deg K and Sensitive to Light Wavelengths Between 0.9 and 3.1 Micrometers
- Its Field-of-View (FOV) Was 5.6 Degrees x 5.6 Degrees, With an Instantaneous FOV (IFOV) of 396 Micro-Radians
- As Developed by Lawrence Livermore National Laboratory (LLNL), the NIR Camera Had a Single Pass Band
- A Six-Position Filter Wheel Was Added to Sensor At the Request of the NASA Science Advisory Committee
  - All But the Longest-Wavelength Passband Were Selected by the Science Advisory Committee
  - Each of the Six Pass Bands Were Used to Image the Lunar Surface
- The NIR Camera Used on *Clementine* Weighed 1920 g, Including the Stirling-Cycle Cryocooler; This Represented a Significant Decrease in Mass When Compared to Similar Sensors



Near-Infrared Camera

Laser Transmitter

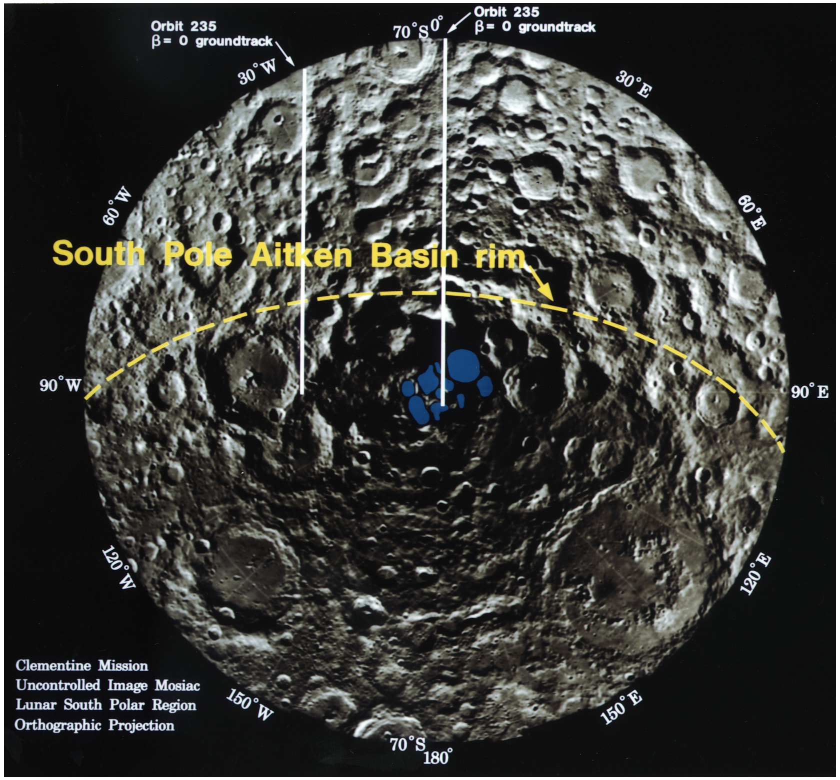
- Lawrence Livermore National Laboratory (LLNL) Developed a Laser-Ranging System That Was Used for Lunar Altimetry
- The Transmitter Was a Diode-Pumped Nd:YAG Laser Emitting at 1064 nm With 180 mJ per Pulse and a Pulse Duration of 10 ns
- The Transmitter Ran Continuously at a 1 Hz Pulse Rate With Short Bursts at 8 Hz Limited by Thermal Effects



Laser Transmitter

- The Laser Transmitter and Power Supply Weighed 1.25 kg and Were Very Compact
- They Represented a Factor of 10x Improvement in Mass and Volume When Compared to Earlier Units
- The Receiver for the Laser Ranger Was an Avalanche Photodiode Within the HiRes Camera and Shared Its Optics
- Range Measurements Could Be Made to a Maximum of 640 km, With a Resolution of 40 m

Imagery From the *Clementine* Sensors



Lunar South Pole Topography Derived From Clementine Imagery

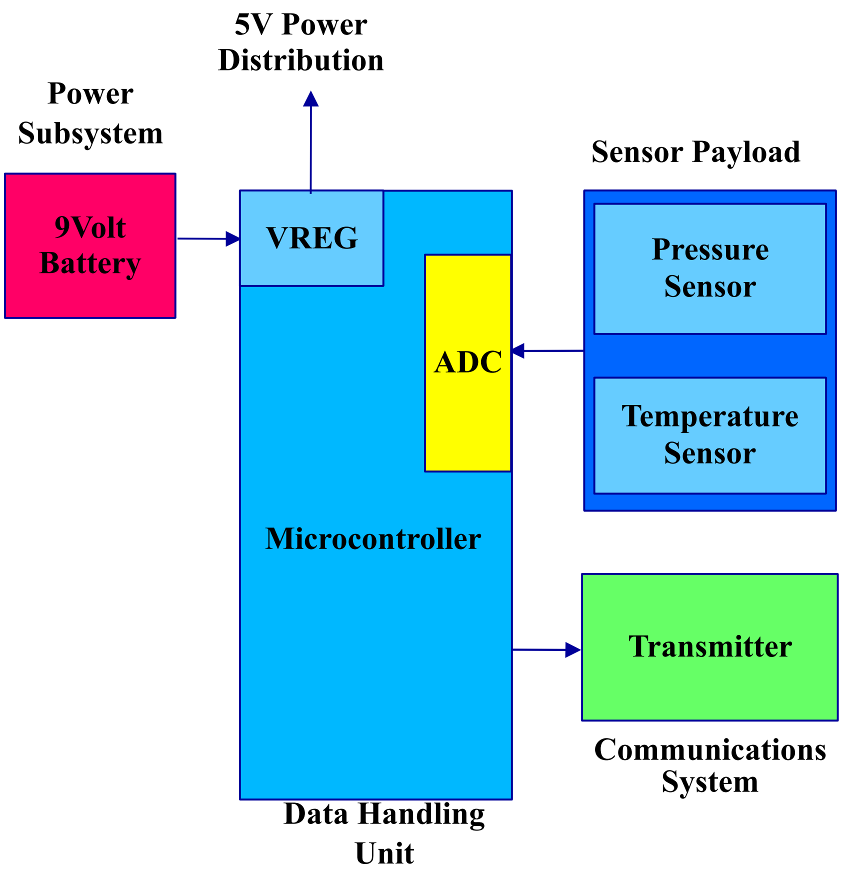
Color Mosaic of the Full Earth Taken While the Spacecraft Was Orbiting the Moon. Over 70 High Resolution Images Were Taken and Put Together to Form This Mosaic. Africa Can Be Seen to the Right, South America at Lower Left, and North America and Europe at the Top Mostly Hidden by Clouds. The Earth Is 12,750 Km in Diameter

and North Is at Roughly 11:30. (*Clementine*, USGS Earth Mosaic)

CanSat Components

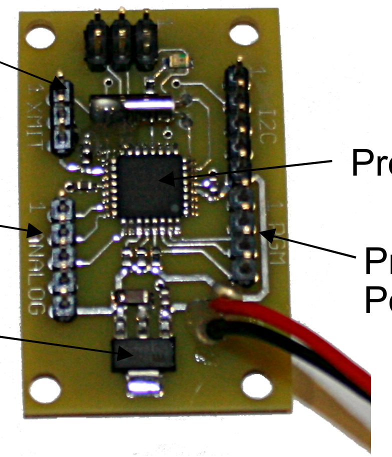
CanSat Bus

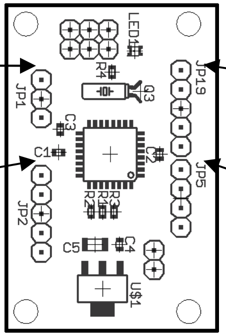
- To meet the mission requirements, the cansat needs several subsystems.The *CanSat* Bus Contains Most of the Same Subsystems or Components As Described of the *Clementine* Spacecraft Bus
  - The Power System Is a 9 Volt Battery Which Powers the Rest of the Bus
  - The Microcontroller Is the Data Handling Unit That Provides Interfaces to the Sensor Payload
  - The Communications Subsystem Is the Transmitter Used to Send Data to the Ground Station
- The Block Diagram Shows How the Various Subsystems Connect
- The Mechanical Portion Is Not Shown



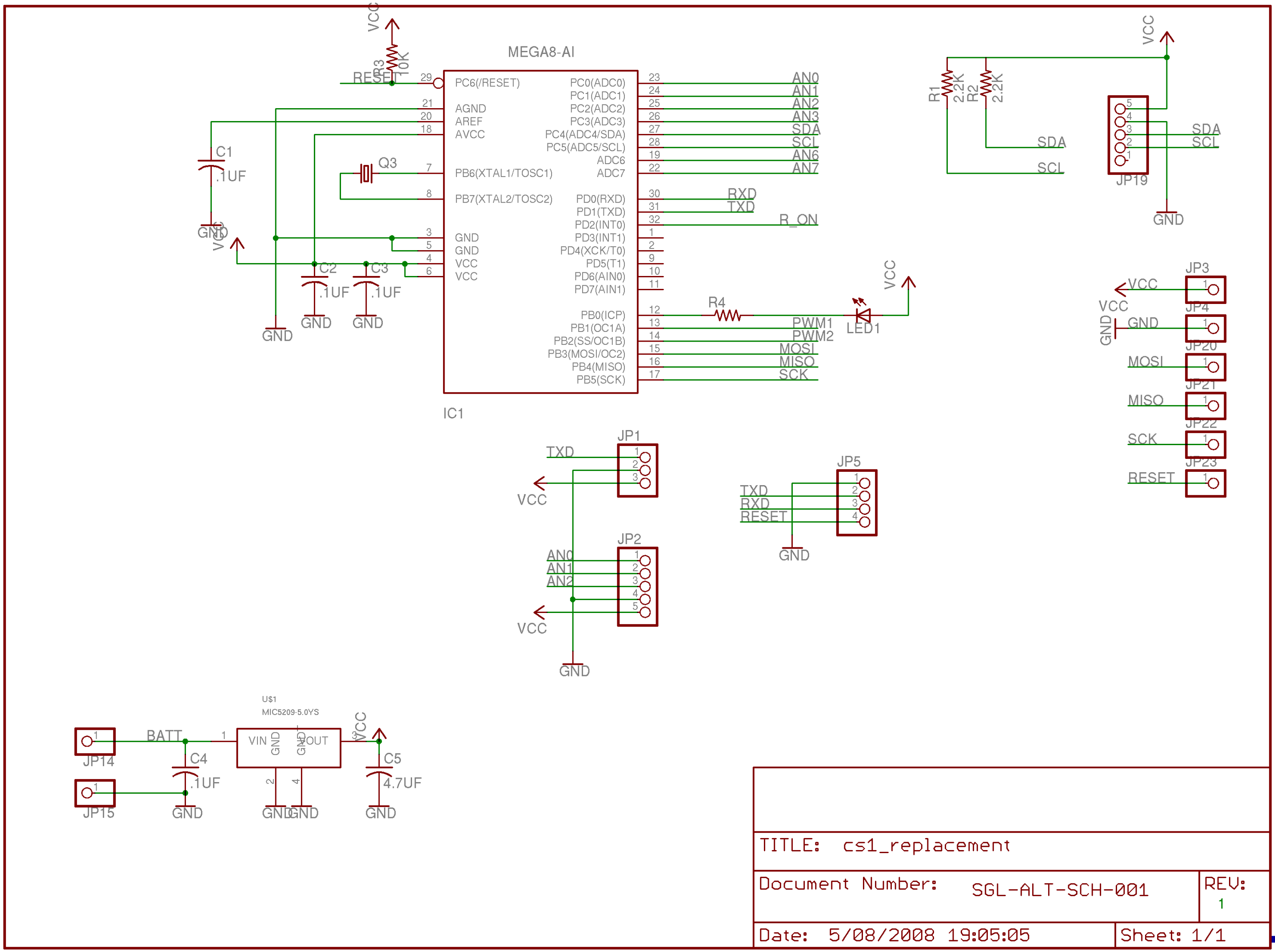
Data Handling Unit

- **The Computer or Data Handling Portion of the *CanSat* Uses The Atmel Atmega168 Microcontroller**
  - **It Has 1 Kilobytes of RAM and 16 Kilobytes of Program Memory**
  - **This Is Much Less Than a Desktop Computer**
  - **The Processor Can Execute Up to 16 Million Instructions per Second**
- **The Computer Has Built-in Analog-to-Digital Converters Which Convert Voltages to Digital Numbers**
  - **This Is Needed for Working With Sensors**
- **The Computer Has Digital Inputs and Outputs That Can Be Used to Detect Logic Levels and Control Devices**
  - **Switching Between Logic Levels Is Like Turning a Light ‘on’ and ‘off’**
  - **There Are Only Two States**





Processor Schematic



Processor Board Pin Definitions

2x3 Header

Pin	Function
1	MISO
2	5 Volts
3	SCK
4	MOSI
5	Reset
6	Ground

2x3 Header

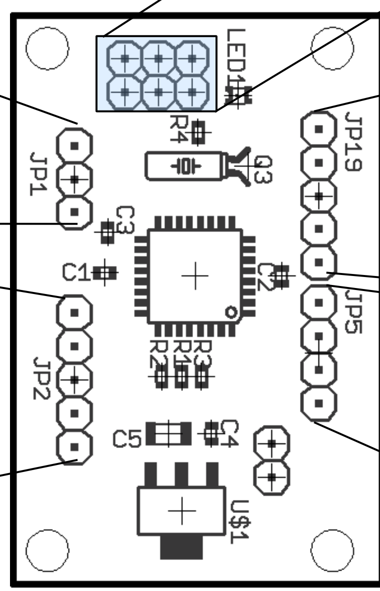
5	3	1
6	4	2

Transmit JP1

Pin	Function
1	Transmit
2	Ground
3	5 Volts

Sensors JP2

Pin	Function
1	ADC0
2	ADC1
3	ADC2
4	Ground
5	5 Volts



I2C Interface JP19

Pin	Function
1	no connect
2	SCL
3	SDA
4	Ground
5	5 Volts

Programmer JP5

Pin	Function
1	Ground
2	Serial Transmit
3	Serial Receive
4	Reset

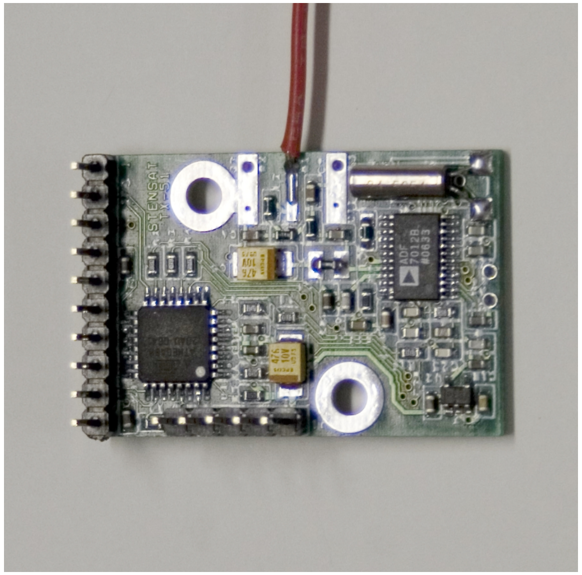
Power System

- The Power System Used in the *CanSat* Is a 9 Volt Rectangular Battery
  - The Alkaline Battery Has a Capacity of at Least ½ Half Ampere Hour (0.5 Ah)
  - This Means the Battery Can Theoretically Provide 1/2 Ampere for One Hour
  - In a Typical Application, These Batteries Can Provide Only 1/10 Ampere Continuously, So It Will Last Five Hours
  - Used in Typical Portable MP3 Player, the Battery Would Operate for About 17 Hours
- The *CanSat* Electronics Requires 5 Volts Direct Current (Vdc)
  - 5 Vdc Is a Standard Voltage Used in Electronics, Especially in Computers
- There Is a Voltage Regulator Built Into the Processor Module; It Provides a Specific Voltage Independent of the Input Supply Voltage
  - The Alkaline Battery Puts Out Nine Vdc
  - The Voltage Regulator Converts the 9 Vdc to 5 Vdc
  - As the Battery Drains and the Battery Output Voltage Drops, the Regulator Will Maintain the 5 Vdc Output Until the Battery Drops Below 5Vdc

9Vdc Battery

Communications Subsystem

- **The Communications Subsystem Is a Transmitter Radio Used to Transmit Telemetry Which Is the Data Collected in the *CanSat***
  - **The Transmitter Includes Its Own Processor That Accepts Data From the *CanSat* Computer and Formats It Into an AX.25 Protocol**
  - **The AX.25 Protocol Is a Method of Sending Information**
    - **It Formats the Data and Adds Additional Information to Help in Detecting Errors in the Transmission of the Telemetry**



Communications Protocols

- Most Communications Use Some Type of Protocol
  - A Protocol Is Basically a Method of Formatting Information and a Communication Method
  - A Data Structure Is Used That Contains Information for Addressing a Receiver, Identifying the Transmitter, Identifying the Type of Data, and Error Checking and Correction
- A Protocol Can Also Include Sequence of Operations; for Instance, There Can Be a Protocol for Requesting a Connection, Acknowledging Receipt of Data, Request for Retransmission, Etc.
- A Protocol Can Be a Simple As a Description of the Transmission Format
- For Example:

Header	Data bytes (32)	Checksum
8 bits	32 bytes	16 bits

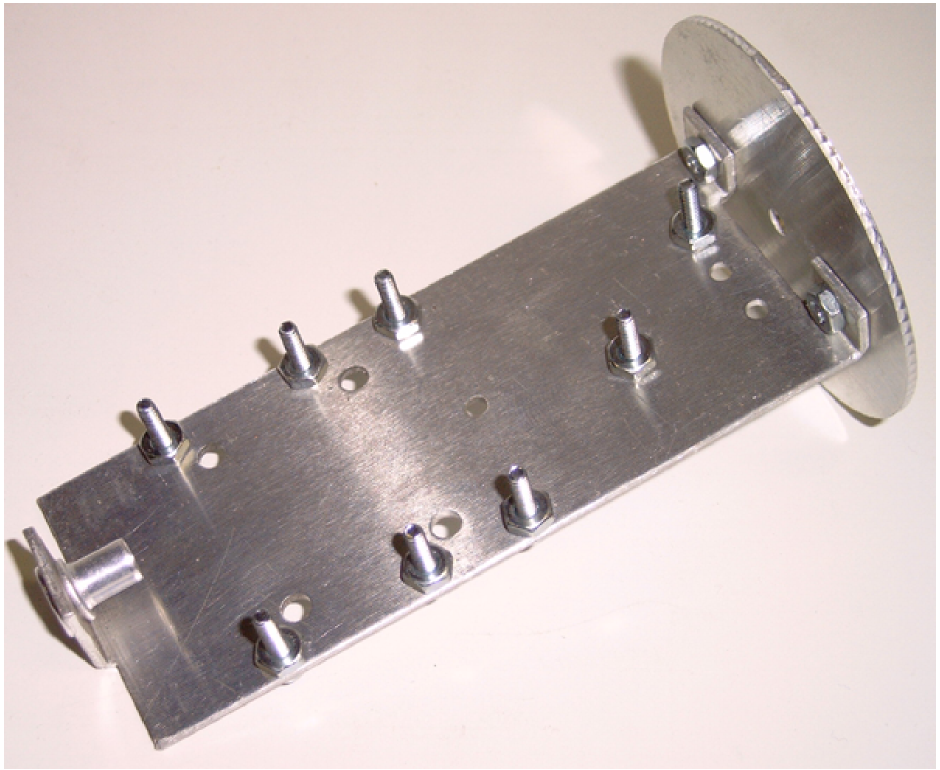
- The Protocol on the Right Is Nothing More Than a Format
  - The First Eight Bits Are the Header Which Would Be Used by the Receiver to Detect the Start of a Message
  - The Next Thirty-Two Bytes Are the Data
  - The Last Sixteen Bits Are for the Checksum Which Is Used by the Receiver to Determine If All the Data Was Received Without Error

Attitude Control

- The *CanSat* Does Have a Simple Attitude Control System; It Is the Parachute
  - The Parachute Is Used to Maintain the Pointing Direction of the *CanSat*
  - It Keeps the Transmitter Antenna Pointed Toward the Ground
  - The *CanSat* Spins, but Only Along One Axis
  - The Parachute Keeps the *CanSat* From Rotating or Tumbling Around the Horizontal Axis
  - The Parachute Functions Similar to a Reaction Wheel (Described Earlier) to Maintain Orientation During Descent

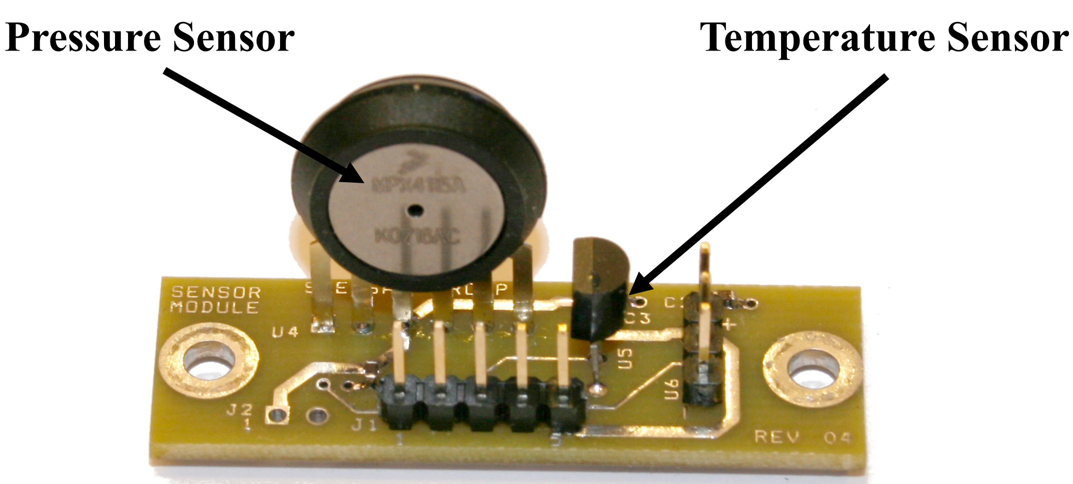
CanSat Structure

- The CanSat Structure Is Designed to Be Simple and Rugged
  - It Consists of a Fibreglass Board for Component Mounting
  - Holes Are Drilled to Support Mounting of the Computer Board, the Sensor Board, Transmitter Board, and Battery
  - It Has a Mounting Hole for Parachute Attachment



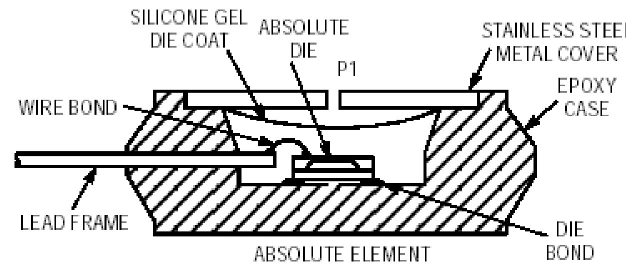
Sensors Payload

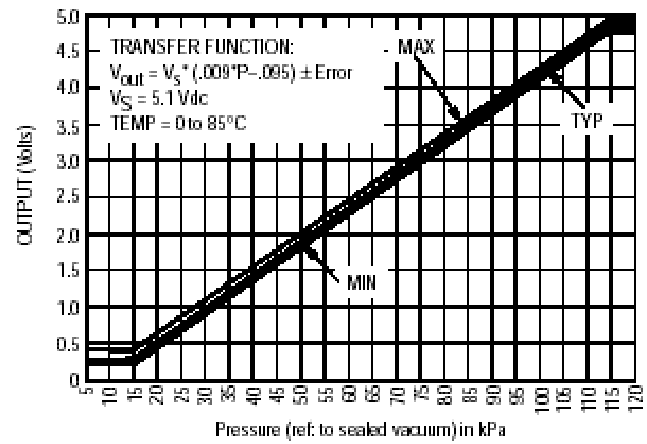
- There Are Two Sensors Used for the *CanSat*
  - Pressure Sensor
  - Temperature Sensor
- The Sensors Are Together on the Sensor Module
- These Devices Get Connected to the Computer Analog-to-Digital Converter Because the Devices Generate a Voltage Based on Their Measurements

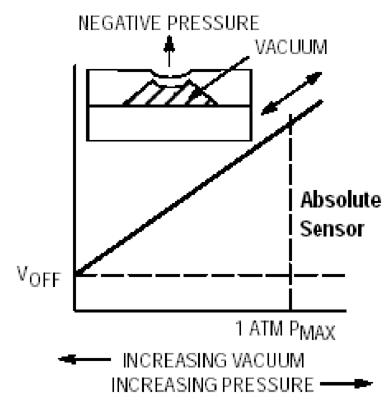


Pressure Sensors

- The *CanSat* Uses Two Sensors
  - The First Sensor Is a Pressure Sensor
  - It Measures Air Pressure
  - The Sensor Generates a Voltage in Proportion to the Air Pressure It Detects
  - It Is a Linear Relationship
  - The Voltage Increases With Increasing Air Pressure
  - The Plot on the Right Shows the Voltage and Air Pressure Relationship
- The Structure of the Pressure Sensor Is Shown on the Right
  - It Uses a Piezoresistive Material That Changes Resistance Based on the Pressure Applied Against It
  - It Is Mounted on the Absolute Die
  - Below the Piezoresistive Material Is a Chamber Which Is Under Vacuum
  - The Vacuum Is the Reference Pressure As Shown in the Lower Right
  - At Normal Atmosphere, the Piezoresistive Material Is Detecting Maximum Pressure
  - As the Air Pressure Goes Down, There Is Less Pressure Against the Piezoresistive Material and As Can Be Seen, the Output Voltage Goes Lower
  - The Sensor Has Electronics Inside to Convert the Resistance Change to a Voltage As Seen in the Plot

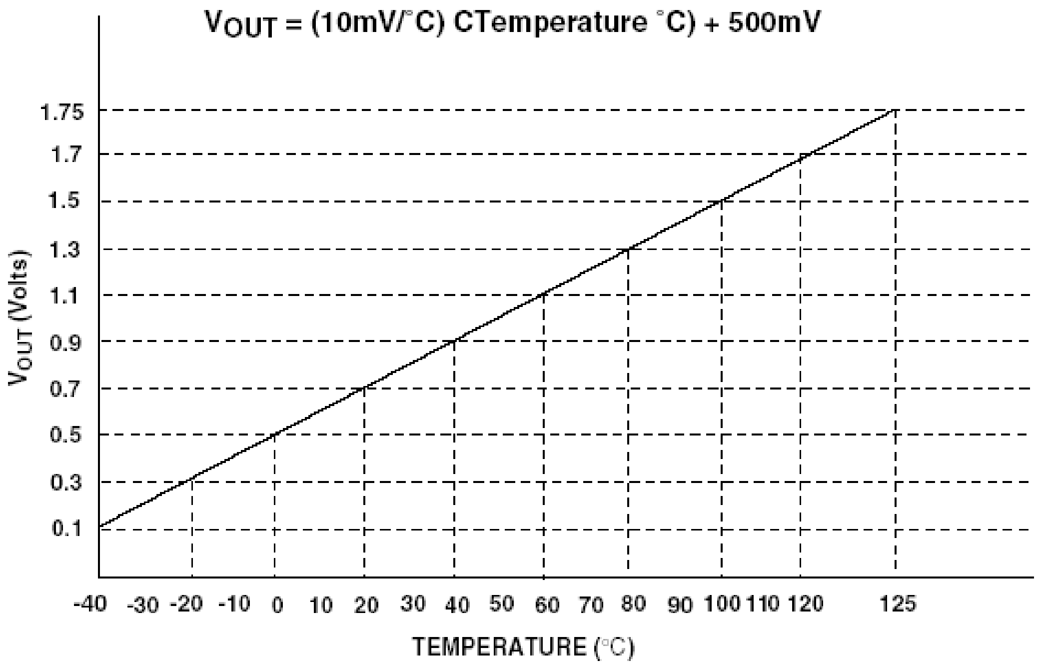


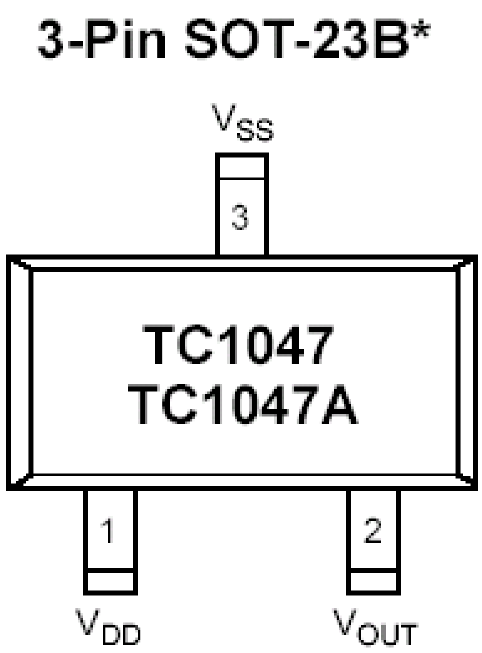




Temperature Sensor

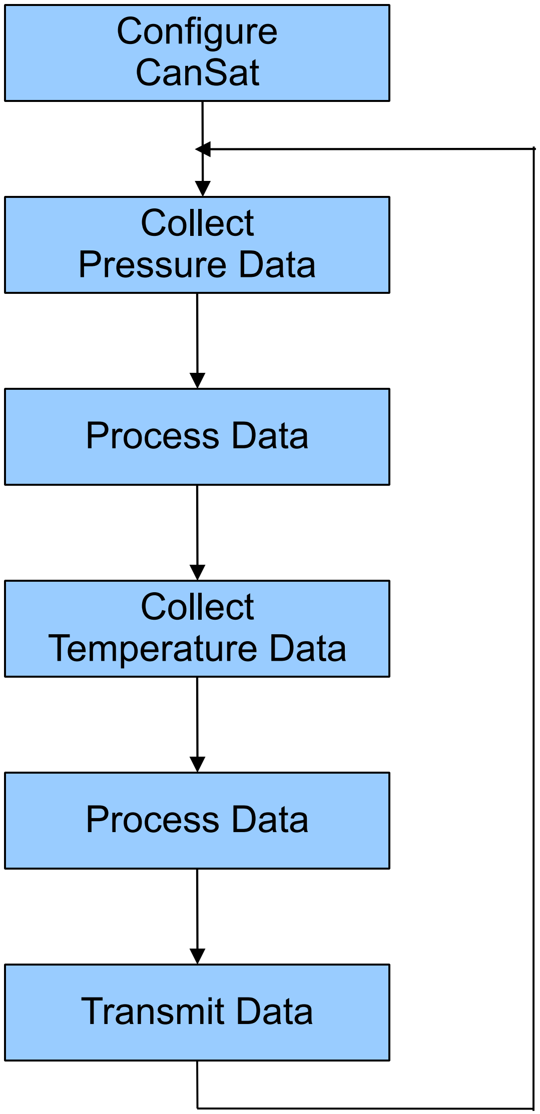
- The Temperature Sensor Is the Tiny Integrated Circuit
- It Uses a Diode to Detect the Temperature
- The Diode Changes Its Conductive Characteristics Dependent on Temperature Meaning As the Temperature Changes, the Amount of Electricity Through the Diode Changes
- The Sensor Uses That Characteristic to Generate a Voltage Proportional to the Temperature





CanSat Operations

- The CanSat operations is straight forward.
- The CanSat collects the pressure sensor data
- The pressure sensor data is processesd to an understandable value
- The temperature sensor data is collected
- The temperature sensor data is processed to an understandable value
- The pressure and temperature data are transmitted to the ground.
- Go back to collect more sensor data



Ground Station Operations

- The ground station operations are as follows:
- Allow the user to specify a file name to store the data
- Decode transmissions from the radio receiver
- Display the raw data on the screen
- Display a graph of the data
- Store the data into the specified file until it is stopped by the user

Concept of Operations

- Description of all activities
  – Field operations
    – Set up ground station
      – Assemble canopy
      – Assemble table and chair for ground station equipment and operator
      – Set up the laptop computer, battery, power inverter and radio
      – Connect all cables
    – Prepare cansat
      – Verify cansat is assembled properly
      – Connect 9 volt battery and secure with electrical tape
      – Verify cansat is transmitter to the ground station
  – Prepare rocket
    – Prepare rocket motor and install
    – Pack rocket parachute and install
    – Insert cansat into the rocket
    – Insert nose cone
  – Launch operations
    – Check rocket in to range safety officer
    – Place rocket on launch pad and insert igniter in motor
    – Launch rocket
  – Flight operations
    – Track cansat by pointing antenna at cansat
    – Recover cansat and rocket when cansat lands

Concept of Operations (cont)

- Data analysis
  - Collect data and process
  - Observe flight profile and any temperature changes during flight
  - Calculate peak altitude

Summary

- **This Section Described the Subsystems of a Satellite and of the *CanSat***
- **You Should Have an Understanding of the Functions of Each Subsystem and How the *CanSat* Subsystems Relate to a Satellite's Subsystems**
- **You should have an understanding of the Concept of Operations or CONOPS**