

# APPLICATION OF EMBEDDED SYSTEMS IN LOW EARTH ORBIT FOR MEASUREMENT OF IONOSPHERIC ANOMALIES



<http://space.auburn.edu>

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# Summary of Work

In an environment that is as dangerous as space, there is a need for low-cost, quick turnaround space science platforms.

In response to this demand, AUSSP developed a remote controlled space science research platform

- **AubieSat-1**

Capable of Low Earth Orbit operation and Earth Ionospheric science experiments

Background Science

Science Experiment

Embedded Platform

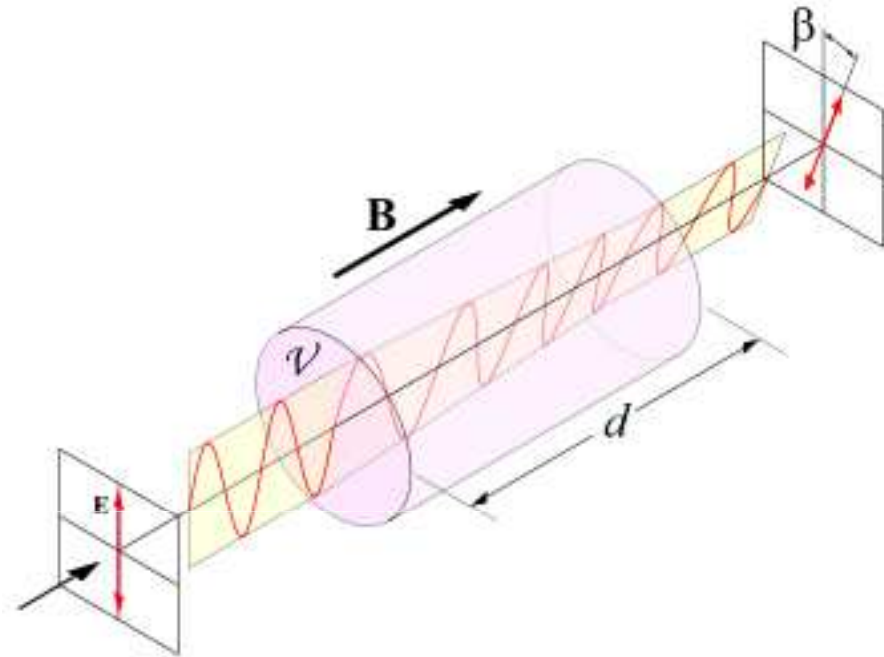
Reusable Science Station

# Faraday Rotations

As electromagnetic waves pass through a region of dense electrons, such as the ionosphere, the electromagnetic waves begin to rotate.

- the Extraordinary wave that propagates along the direction of transmission
- the right – R -polarized wave
- the left – L - polarized wave

As these waves experience an rotational force in this magnetic field, a rotation occurs about the axis of propagation.



$B$  is the magnetic flux density (tesla)

$v$  is Verdet constant of material

$d$  is distance traveled

$\beta$  is the angle of perceived rotation

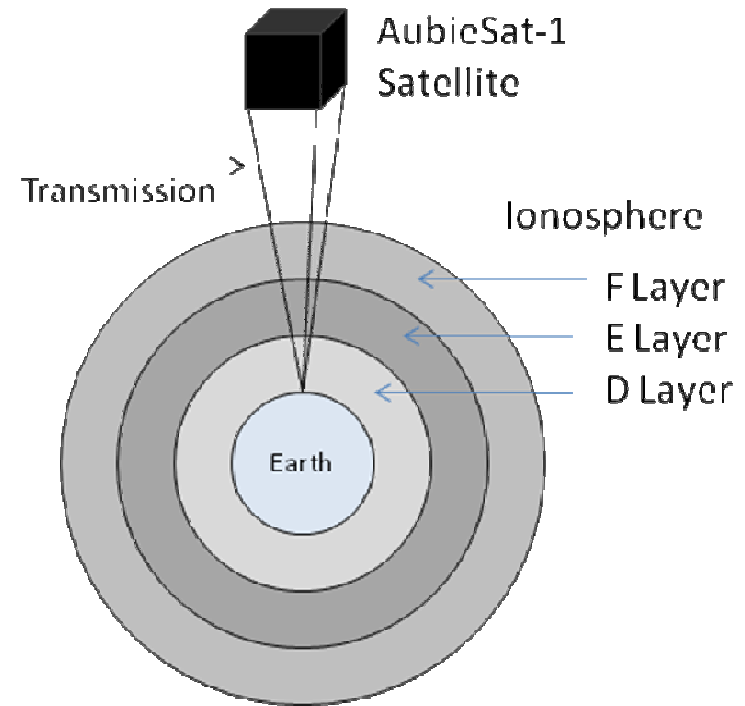
$$\beta = v \cdot B \cdot d$$

# Science Experiment

Electromagnetic radiation from the sun excites the ions within the Ionosphere.

- Periods of low solar radiation result in a low ionization effect and low free electron count
- Inversely, intense solar radiation results in dense ionization and high free electron count

As radio waves travel through the Ionosphere, they will rotate due to electron density of the multiple layers of the Ionosphere.



$$\beta = RM \cdot \lambda^2$$

$$RM = \frac{e^3}{2\pi m^2 c^4} \int_0^d \eta_e B \cdot ds$$

# ||| Test and Measurement

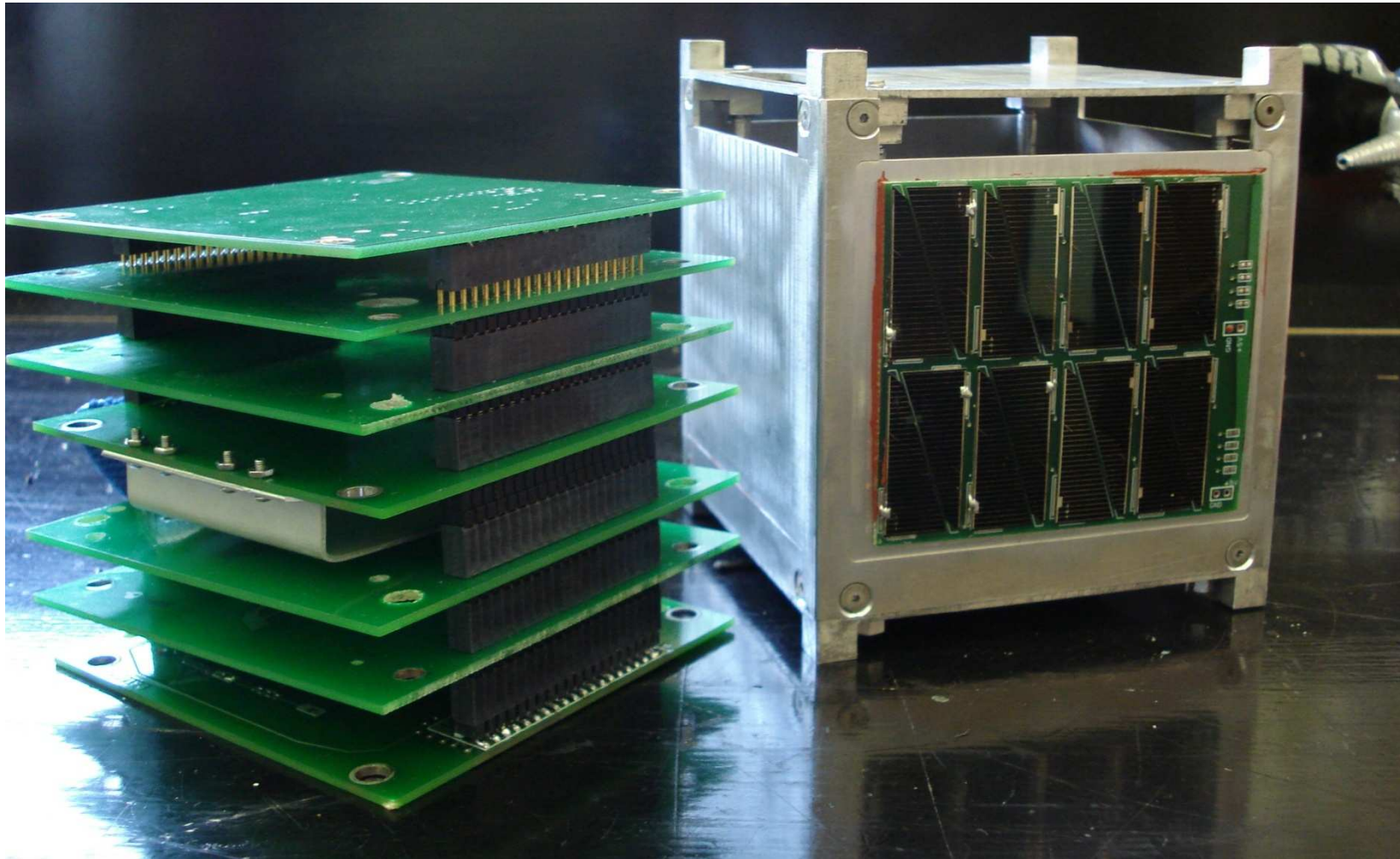
To calculate the density of free electrons present in the ionosphere we need to know:

- the wavelength of the transmitted signal
- the rotation which has occurred
- the magnetic field traversed

$$\beta = RM \cdot \lambda^2$$

$$RM = \frac{e^3}{2\pi m^2 c^4} \int_0^d \eta_e B \cdot ds$$

# || Satellite Platform



# || Satellite Systems

The Satellite consists of:

- Power System
- Primary Communication Systems
- Secondary Communication Systems
- Command and Data Handling
- Payload Science Sensors

Antenna #1

Power System

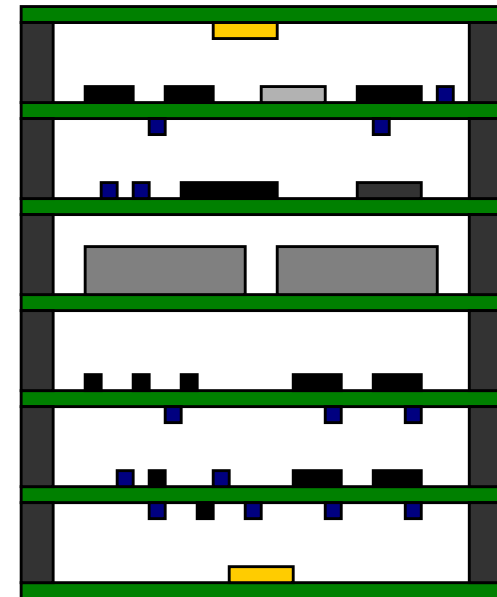
C&DH

Batteries

Primary Comm

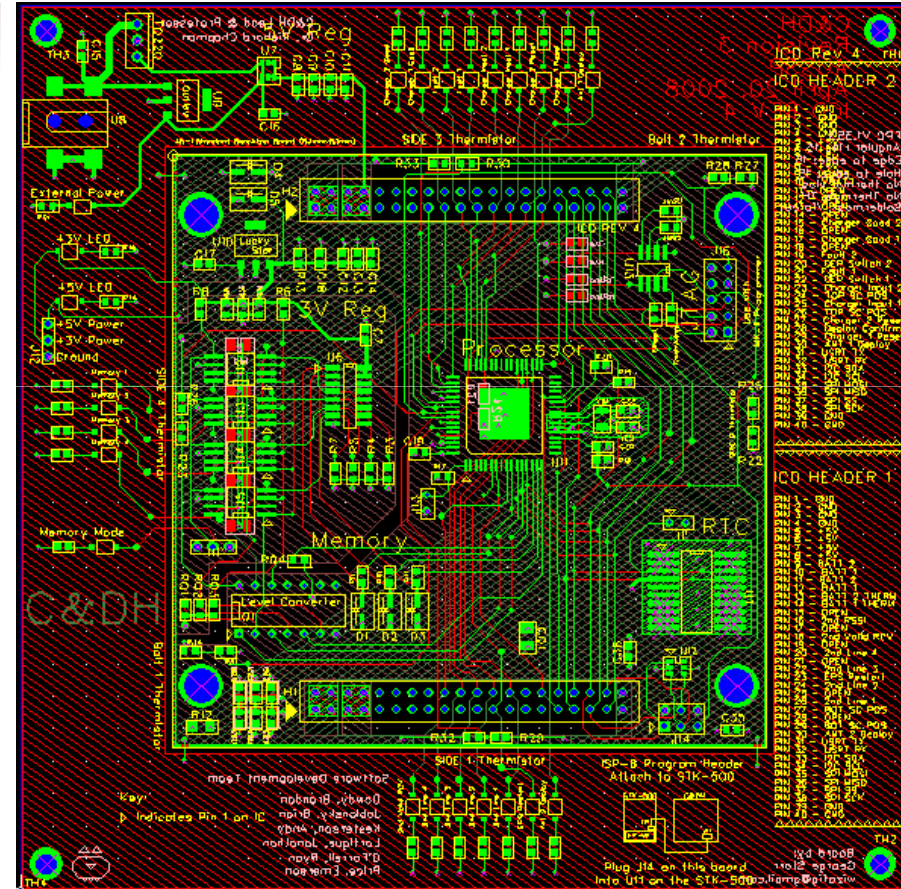
Sec. Comm

Antenna #2



# Command and Data Handling

- Utilizes the ATMEGA128L microprocessor
- External Real Time Clock
- External Watchdog
- External multiple redundant 32Mb Flash Memory
- Communication Interface:
  - SPI - 8MHz
  - I<sup>2</sup>C – 100 kHz
  - USART -9600 Hz



# Operating System and File Management

- A customized operating system has been developed combining MircoC OS-II as the base for our operating system functions and a customized file system.
  - Program code and data sectors are recorded with checksum information to ensure radiation exposure has not corrupted data.
  - In the event of program corruption, an in-system reprogram occurs to correct the bad section of code.
- The file system is designed to record, time stamp, and organize science mission data and system state information.
  - System information is kept in on-chip RAM, but periodically cached to special sectors in flash to restore from brownout.
  - Mission data and copies of new and boot copies of program information are kept in flash.
  - Each sector of flash is tested when a write occurs.

# ||| Communications & Test Generator

- FSK transceiver system to transmit AX-25 encoded frames.
- By manually keying the transmitter we are capable of generating a single tone for the science mission.

Primary Uplink:

- 437.375MHz

Primary Downlink:

- 437.375MHz

Secondary Uplink:

- 435.050MHz

Callsign:

- KI4NQO

# || Remote Termination and Control

- To accommodate International communication regulations, the satellite is equipped with both a primary and secondary communication interface.
- Communication modes include:
  - AX-25 connected Frames
  - AX-25 unconnected Frames
  - Science Mission Signal
  - CW beacon Mode: (Morse Code)
  - Secondary encrypted control



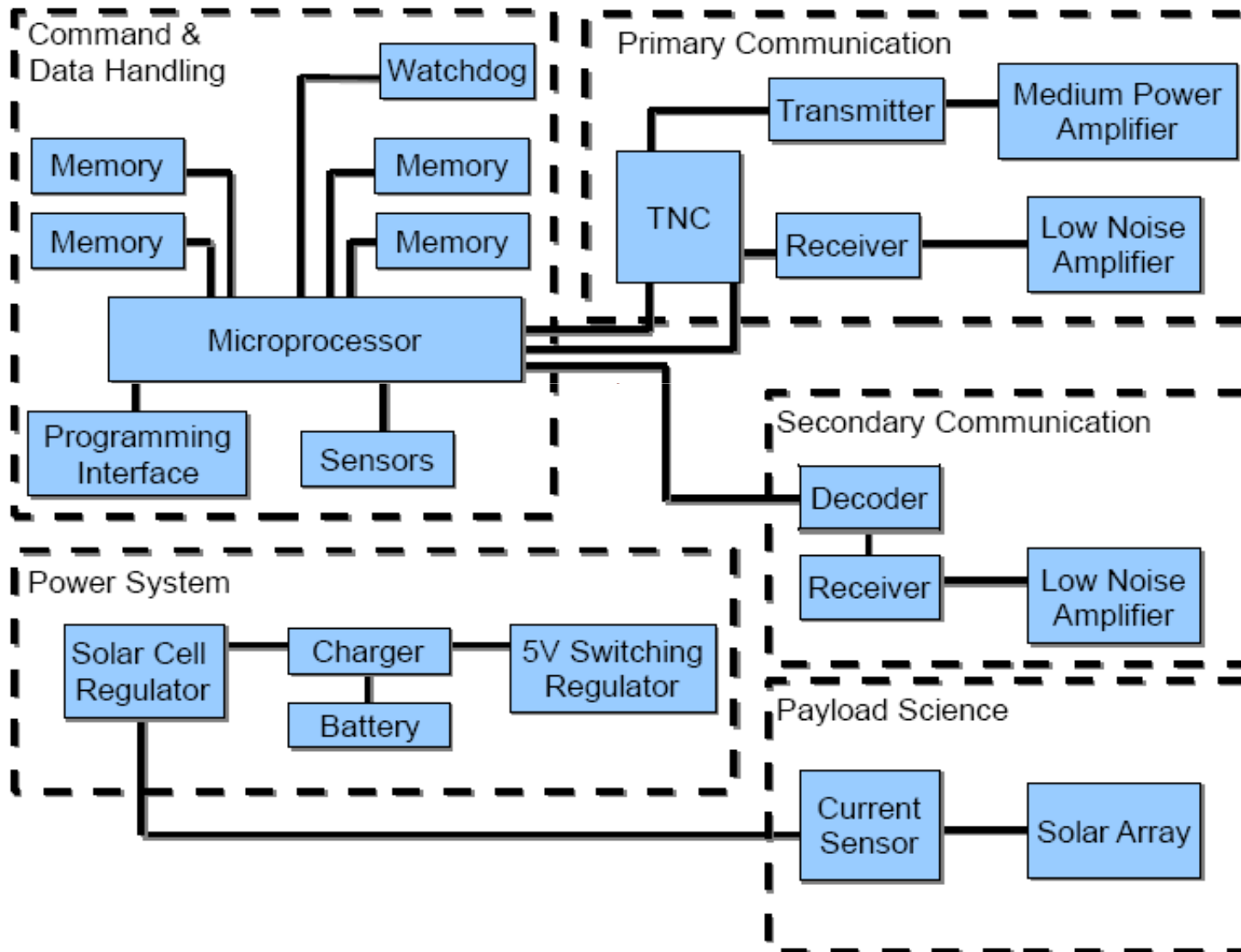
# || Power Generation and Regulation

- Power is generated by solar cells located around the outer walls of the satellite.
- This energy is stored in 3.3V Li-Ion Batteries.
- Then regulated using a buck-boost switching regulators to supply 3.3V and 5V power rails.
- In the 90 minute orbit, approximately 50 minutes are in sunlight.
- Estimated Power Generation: 1.8 Watts
- Allows for 50 minutes of transmissions per day.

# || Attitude Determination and Control

- The Solar Cells which serve as power collection devices also serve as solar angle detectors.
- By measuring the current generated by each solar cell, we are capable of calculating the relative orientation of the satellite in reference to the sun by using the sun's energy. To a lesser extent, albedo from earth becomes negligible yet still detectable.
- In combination with Keplerian elements, we can extract the position and orientation of the satellite to within a small margin of error.

# System Overview



# || Conclusion

- A low cost space science platform can be developed utilizing the efficiency of an embedded system.
- Reuse and reprogrammability can be implemented in conjunction with internal error detection and correction methods to increase the life of satellite and range of applications.



# Questions



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Photograph taken by AeroCube-2, April 17, 2007

Photograph courtesy of California Polytechnic Institute CubeSat Program