Self-Steering Antennas for CubeSat Networks

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University of Hawaii

CubeSat Developers Workshop
CalPoly - San Luis Obispo
March 9, 2004

Outline

- Overview of the UH Small-Satellite Program
- Motivation for Self-Steering Antennas
- UH's Self-Steering Antenna Concept
- UH's Mission in the University Nanosat-3 Program
- Overview of Bus Subsystems

Overview of UH Small-Satellite Program

Phase I (2001-2004): Mea Huaka'i I (Voyager)

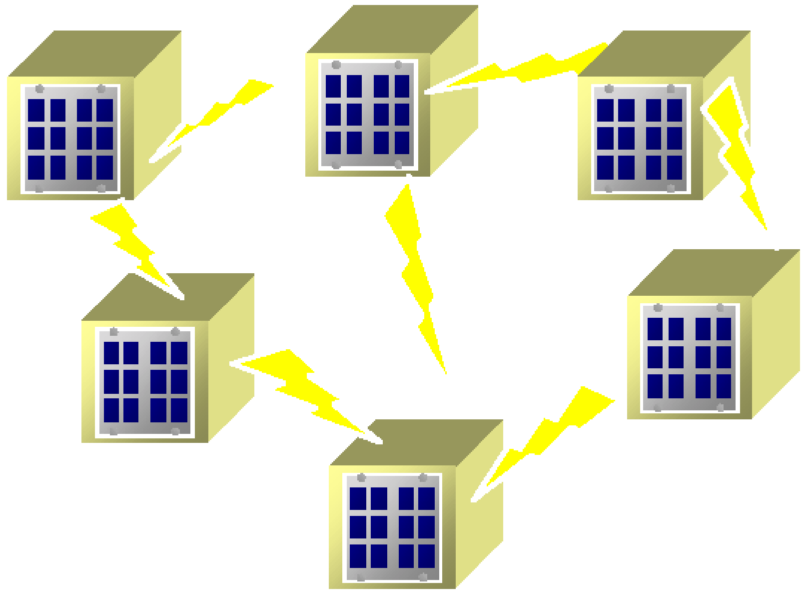
- UH's first student-satellite project
- Mission: Experimental verification of in-house thermal modeling code
- Launch Date: Fall 2004
- Sponsors:
  - Hawaii Space Grant Consortium
  - Northrop Grumman Space Technology
  - Boeing
  - UH College of Engineering

- Mahalo: Jordi Puig-Suari, Roland Coelho, and Simon Lee

Phase II (2003-2005): Mea Huaka'i II - Hokulua (Twin Stars)

- University Nanosat 3 Program (AFRL, AFOSR, NASA, AIAA)
  - One of 13 participating universities
  - UH is the only university developing CubeSat-class satellites
  - Partnership with CalPoly

- Mission: Develop self-steering antenna technology for CubeSat Networks

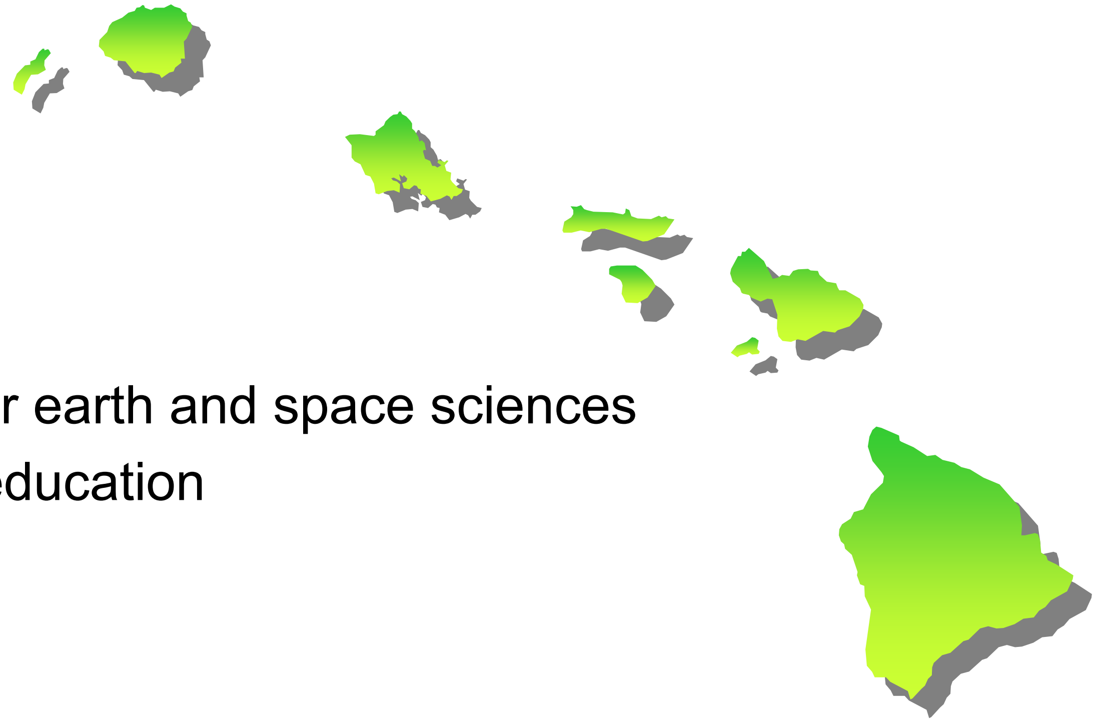


Overview of UH Small-Satellite Program

HiCADRE:

Hawaii Center for Aerospace Deployment, Research, and Education

- Dual civilian/military small-satellite and UAV deployment from Pacific Missile Range Facility
- Launch services for small-satellite developers around the world



- Payload development for earth and space sciences
- Distributed web-based education

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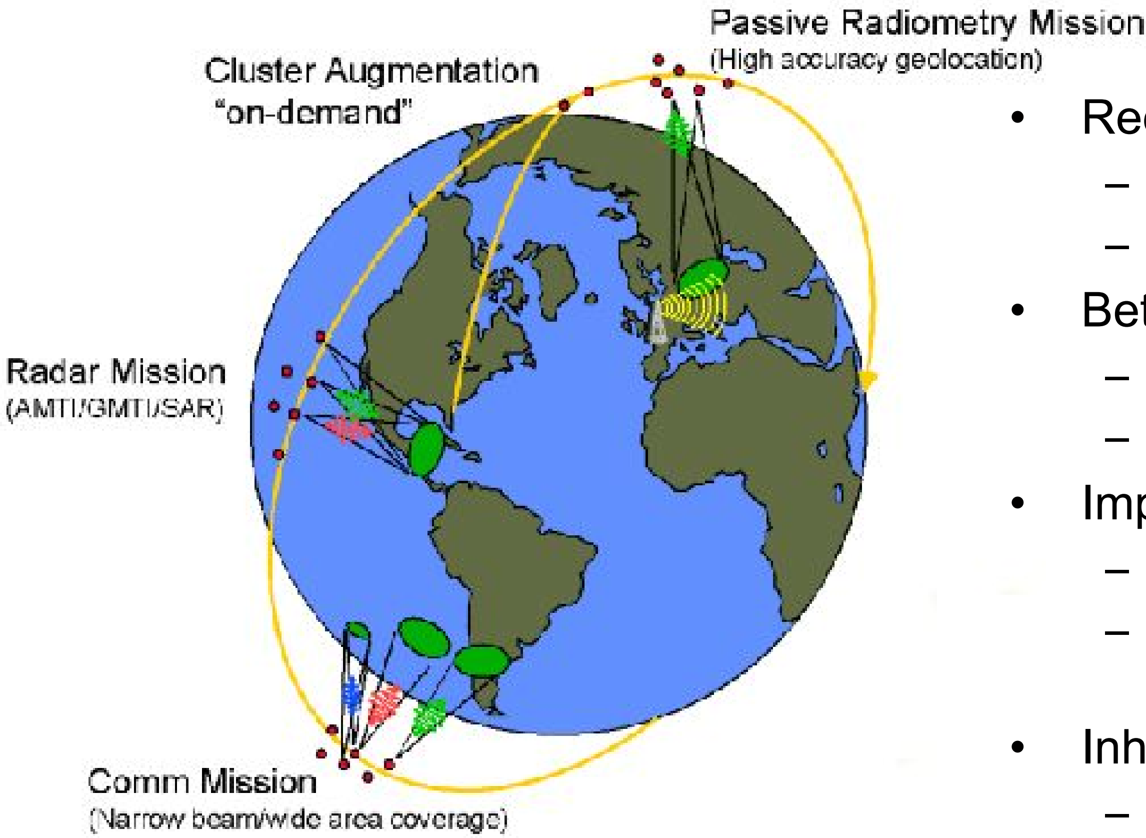
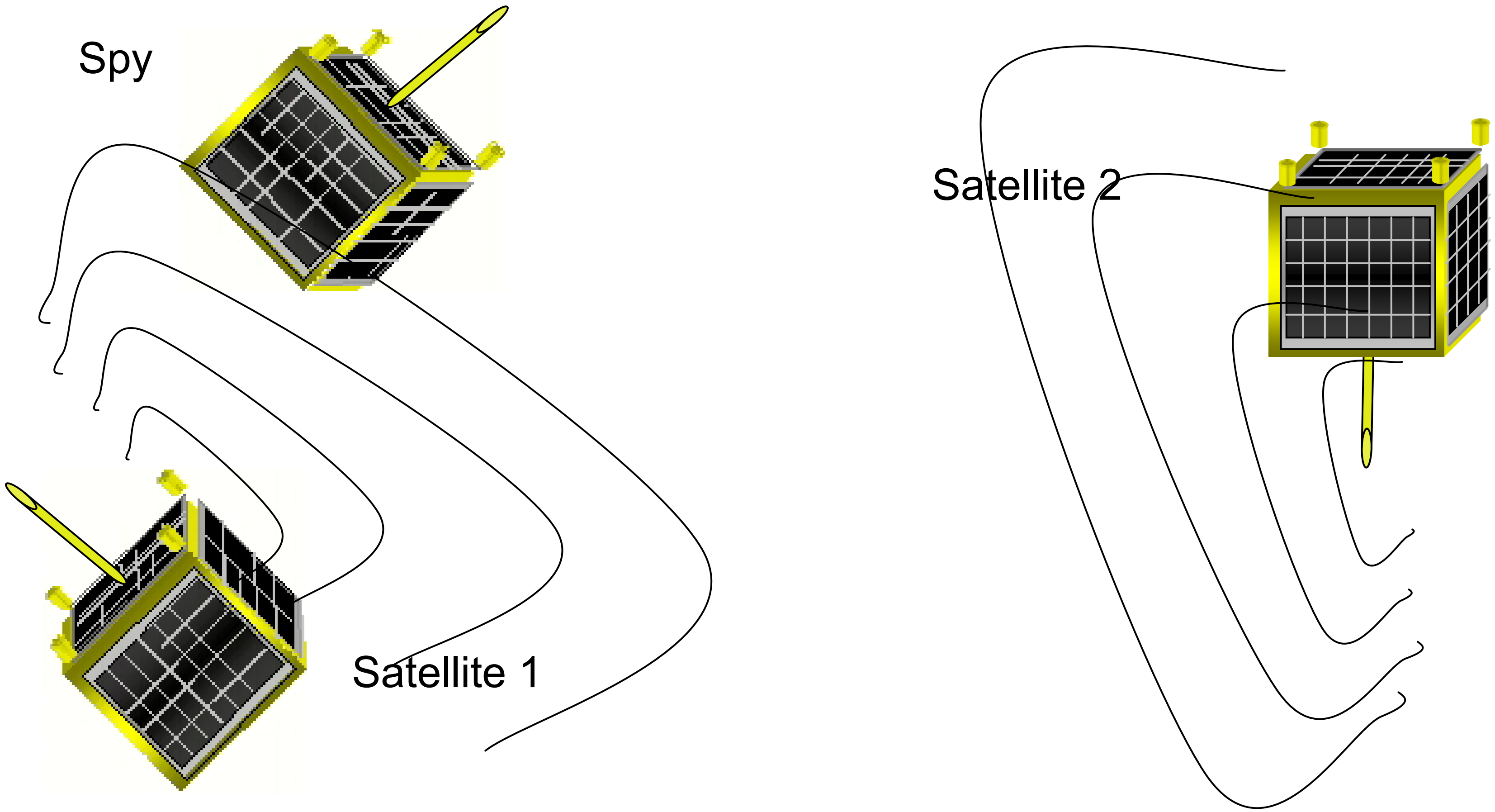
Small-Satellite Networks



Courtesy of TechSat 21 webpage

- Reduced life cycle cost
  - Mass produced identical satellites
  - Reduced launch costs
- Better performance
  - Unlimited effective aperture sizes
  - Multimission capability
- Improved reliability
  - Graceful degradation
  - Reconfigurable to minimize effects of failure
- Inherent adaptability
  - New elements added to accommodate changes in requirements
  - Future technology advances integrated

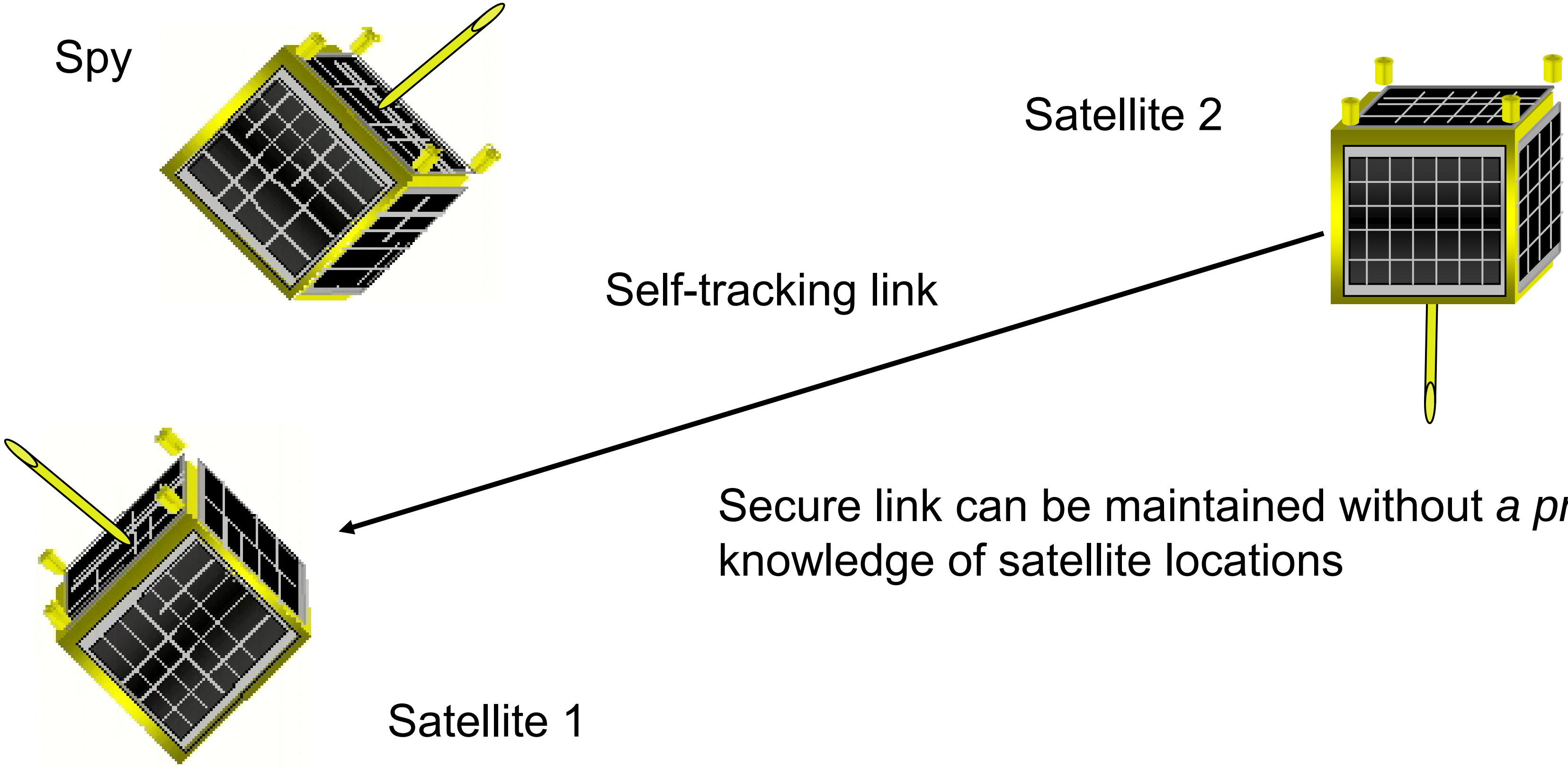
Omnidirectional Crosslinks



Self-Steering Crosslinks

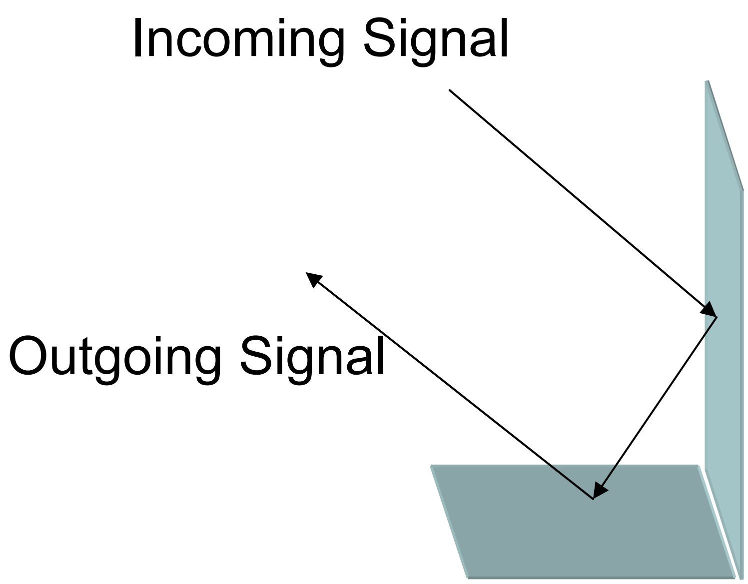
Proposed Solution:

Self-steering antennas **that maintain a secure crosslink as satellites move about in the network**

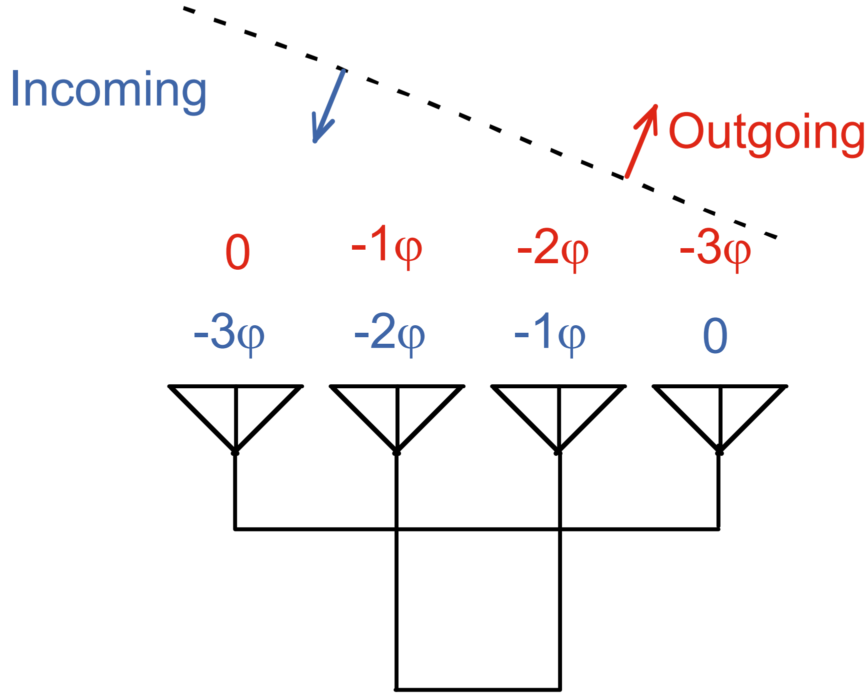


Secure link can be maintained without *a priori* knowledge of satellite locations

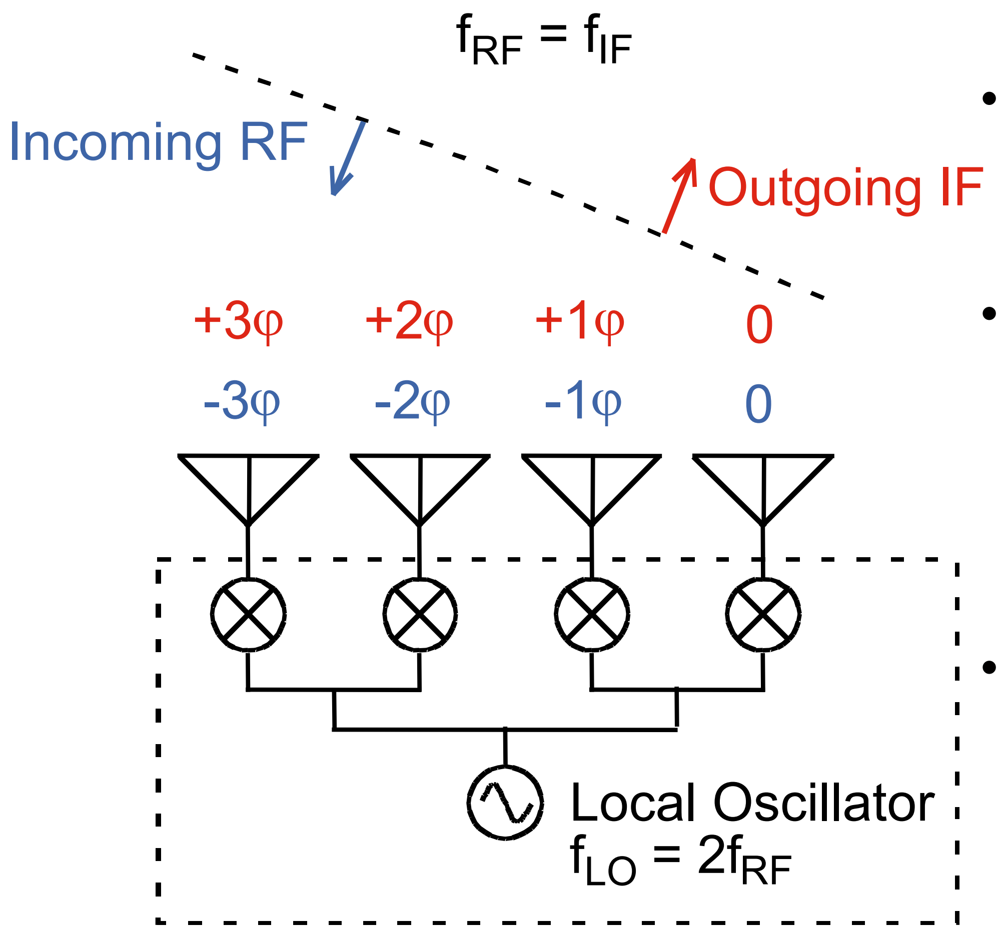
Corner Reflector



Van Atta Array



Heterodyne Method



- Incoming wave
  - From unknown direction
  - Induce phase difference ϕ
- Phase conjugation
  - Heterodyne mixers
  - LO fed in phase
  - fLO = 2 fRF
  - IF = phase conjugated RF
- Outgoing wave
  - In direction of source

$$V_{IF} = V_{RF}\cos\left(\omega_{RF}t + \varphi\right) \times V_{LO}\cos\left(\omega_{LO}t\right)$$

$$= \frac{1}{2}V_{RF}V_{LO}\left[\cos\left(\left(\omega_{LO} - \omega_{RF}\right)t - \varphi\right) + \cos\left(\left(\omega_{LO} + \omega_{RF}\right)t + \varphi\right)\right]$$

If $\omega_{LO} = 2\omega_{RF}$:

$$V_{IF} \propto \cos\left(\omega_{RF}t - \varphi\right) + \cos\left(3\omega_{RF}t + \varphi\right)$$

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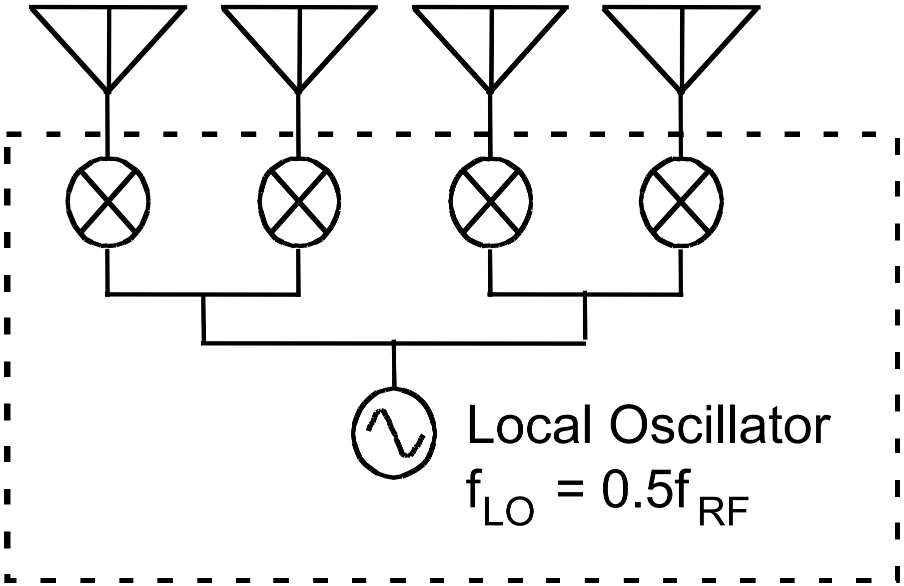
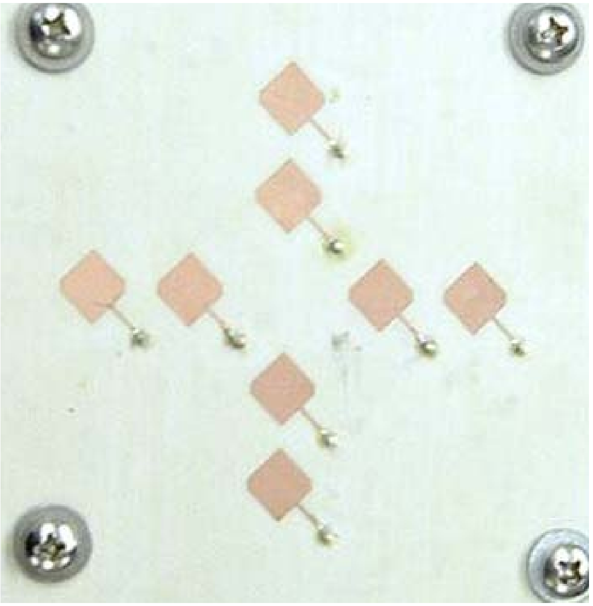
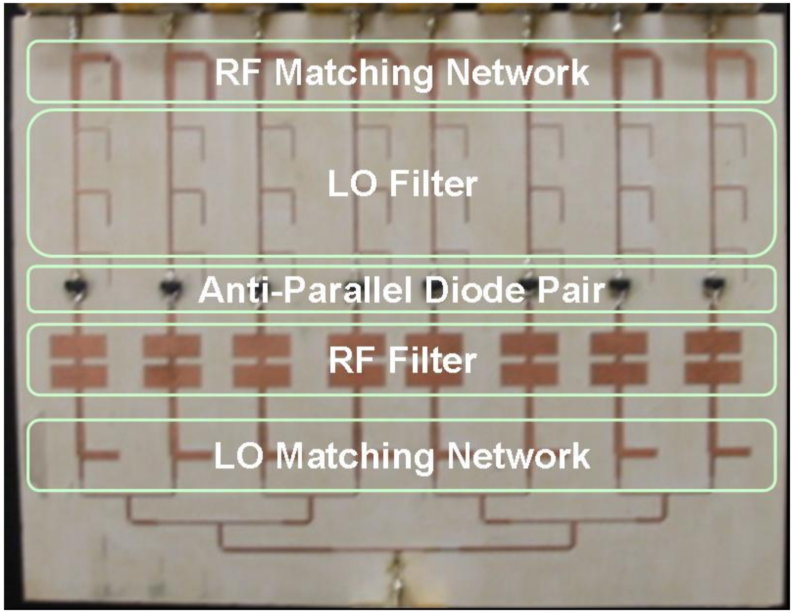
UH Retrodirective Antenna Array

Two-dimensional steering
Circularly polarized

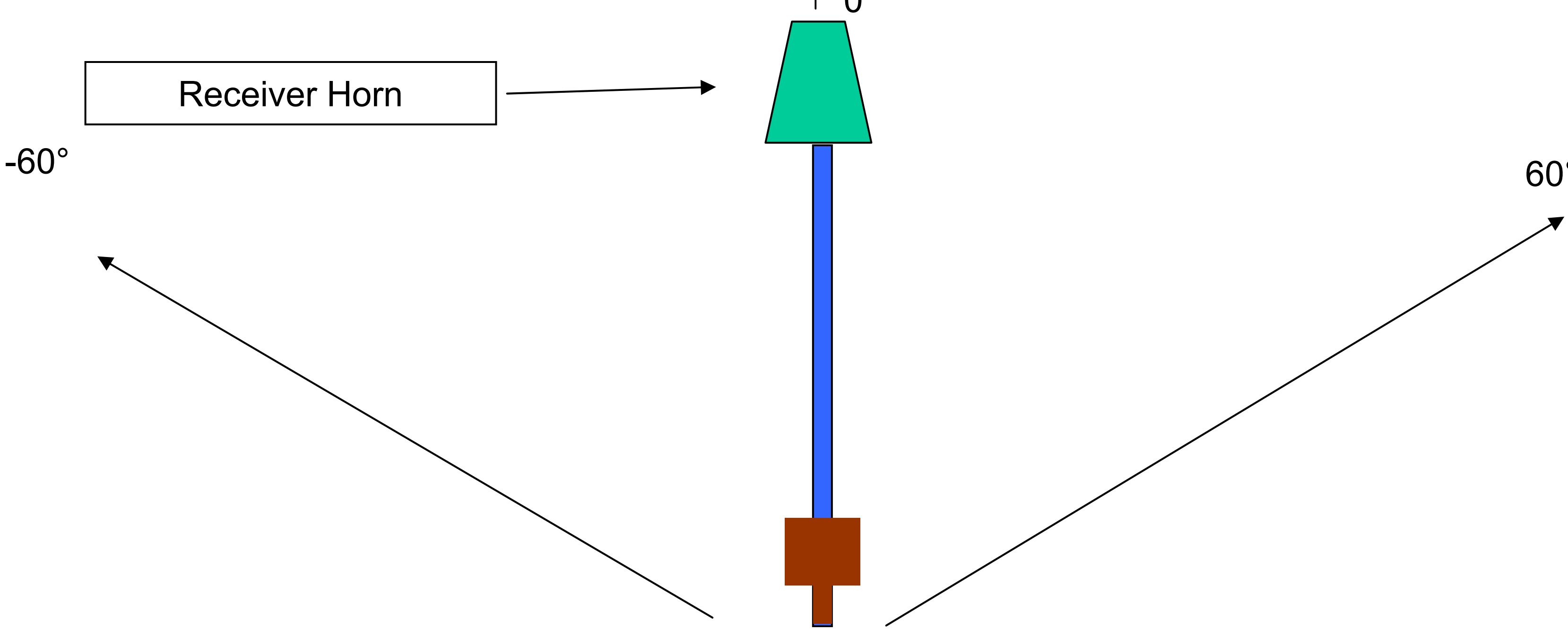


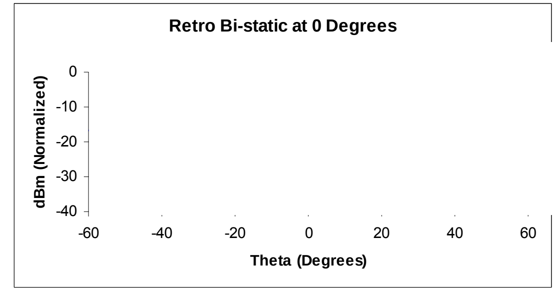




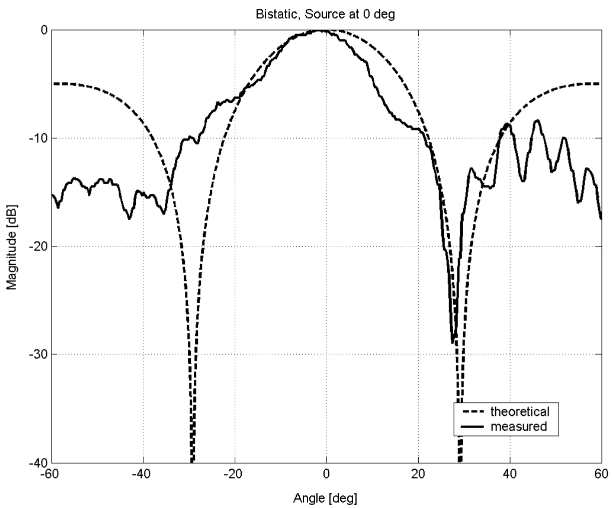
Photos not to scale

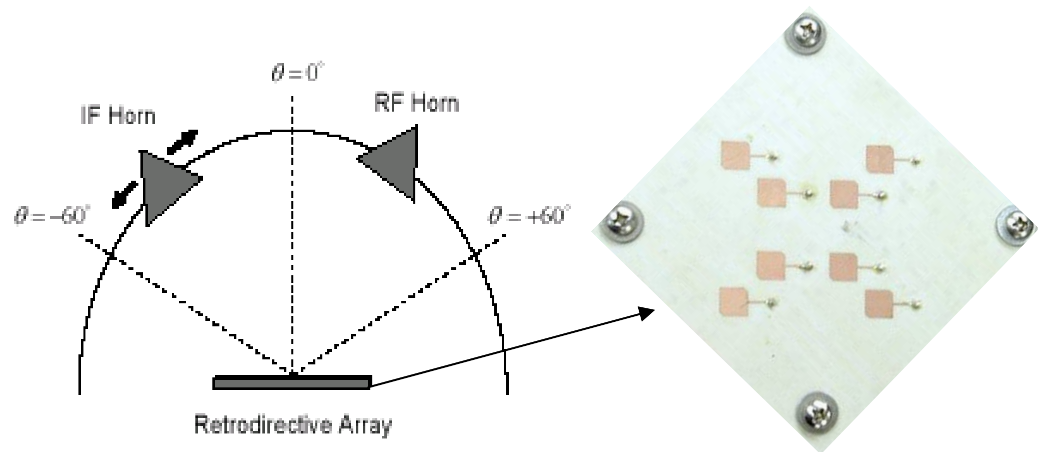
Bistatic Radiation Cross Section Set Up

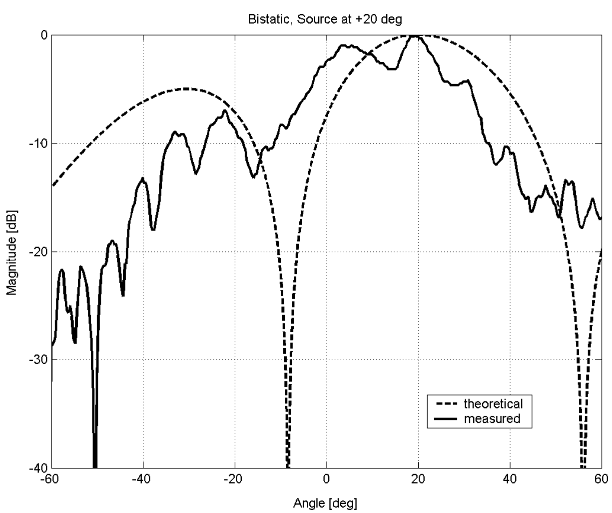


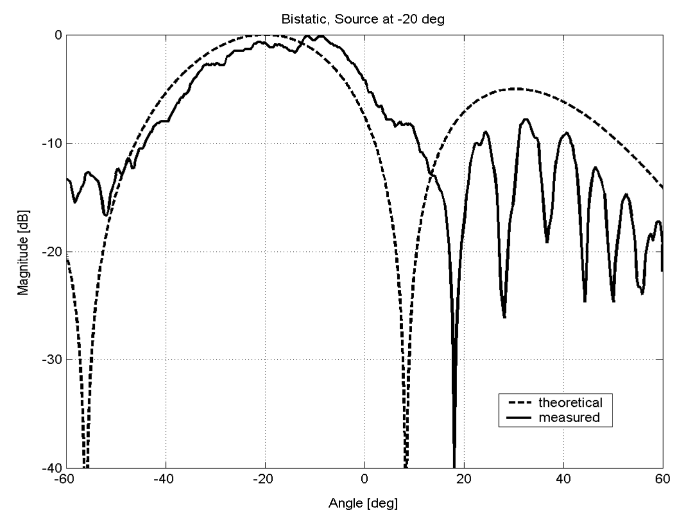


Bistatic Radar Cross Section









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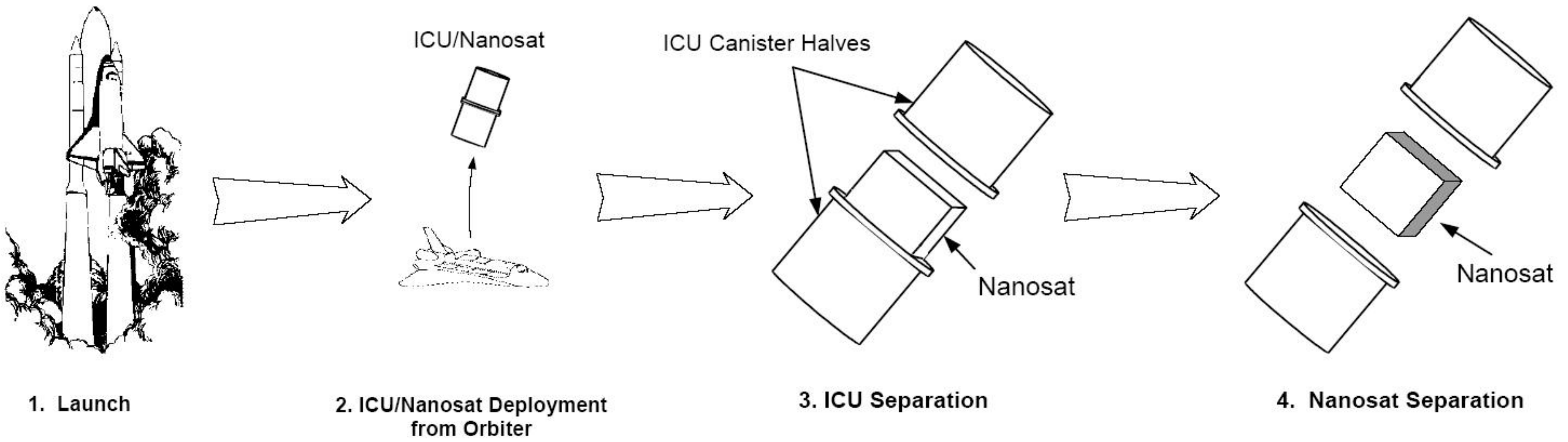
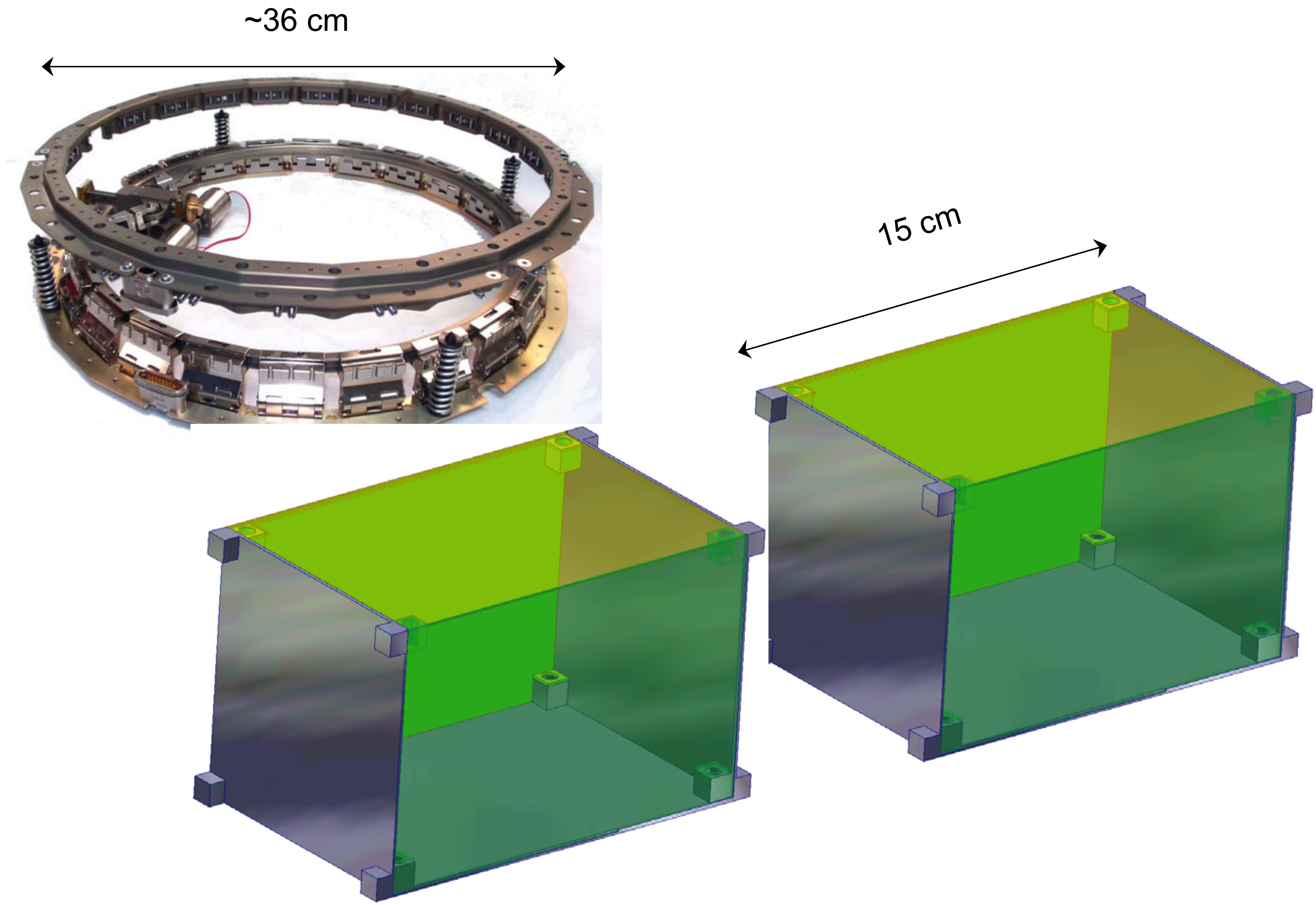
Deployment Sequence

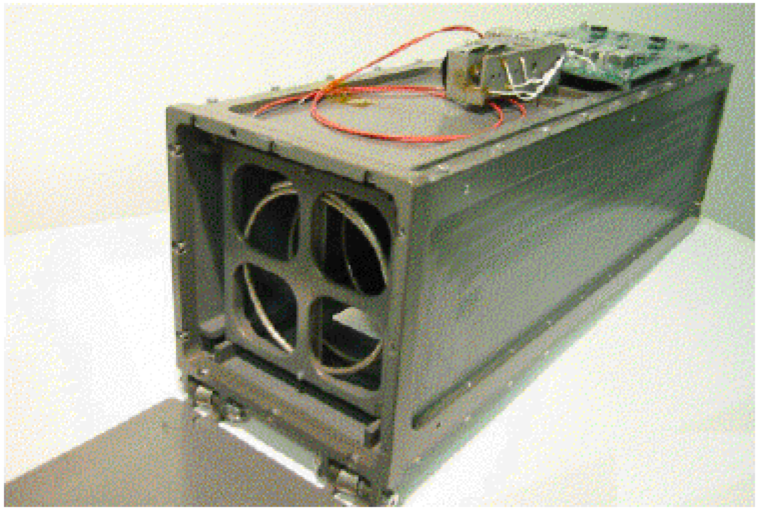


Launch Vehicle Interface

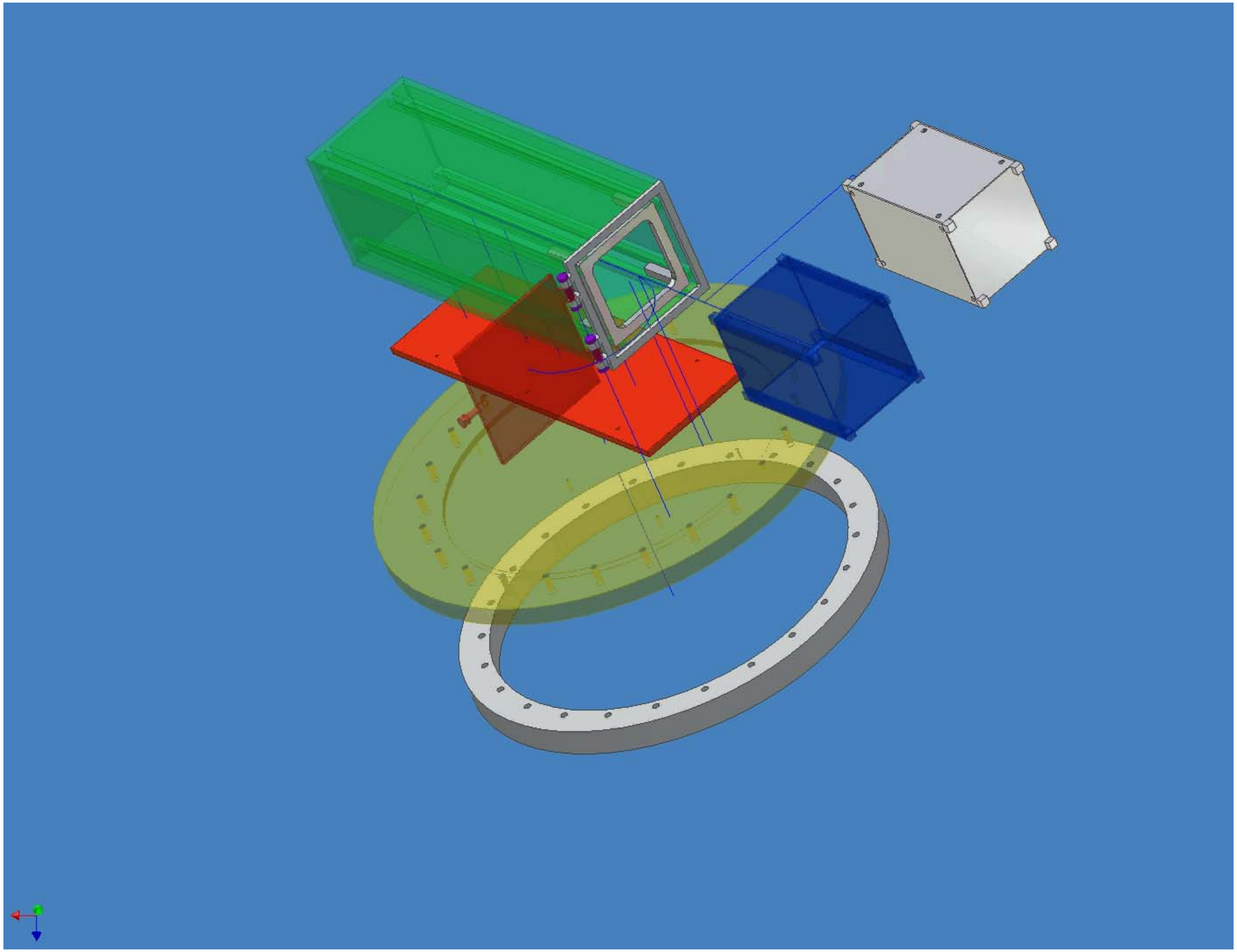


CalPoly P-POD

- Well-established standardized interface
- Tested and qualified to NASA worst case vibration and thermal-vacuum environments
- Door deployer will be triggered by deployment switch or launch vehicle



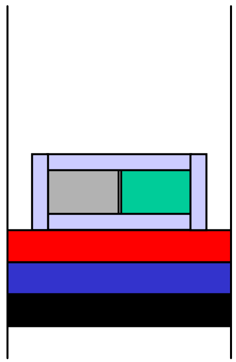
Launch Vehicle Interface



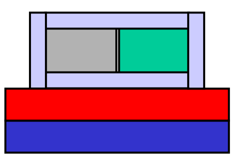
Deployment Sequence

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

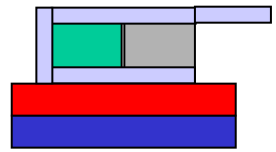
University Nanosat-3 Mission Timeline



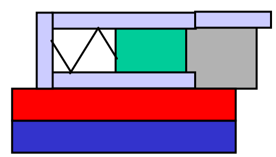
P-POD within ICU



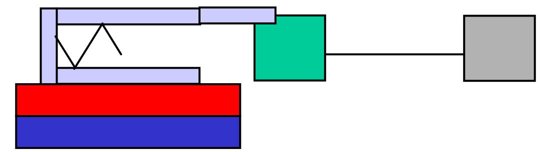
P-POD ejected from ICU



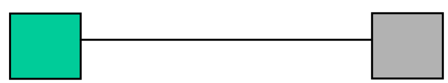
P-POD door released



Satellites deploy from P-POD



Tether is deployed



Tether is fully deployed

ICU

Lightband Integration

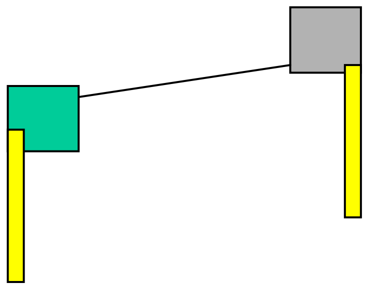
Interface plate

P-POD

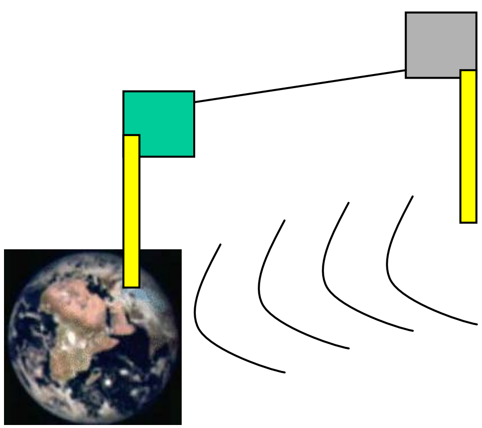
Sat 1

Sat 2

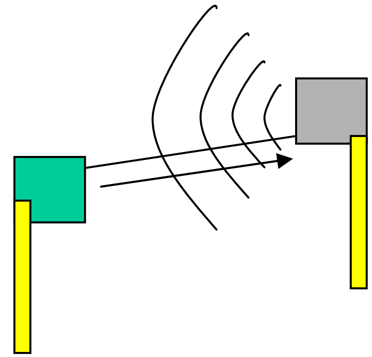
University Nanosat-3 Mission Timeline



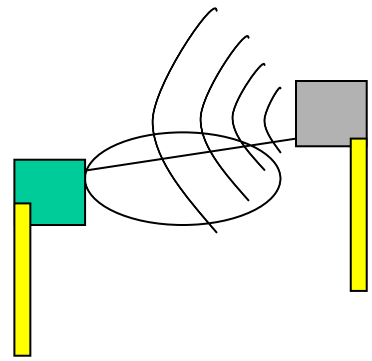
After battery is 80% charged and 1 hour has elapsed monopole antennas deploy



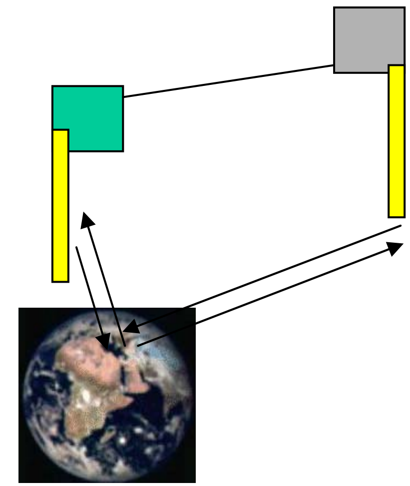
Satellites alternate beacon to Earth, autonomous operation



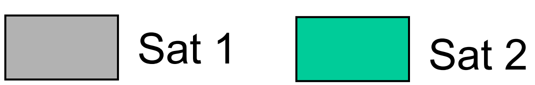
Begin antenna experiment: Self-Steering Mode



Switch antenna modes: Fixed-Beam Mode

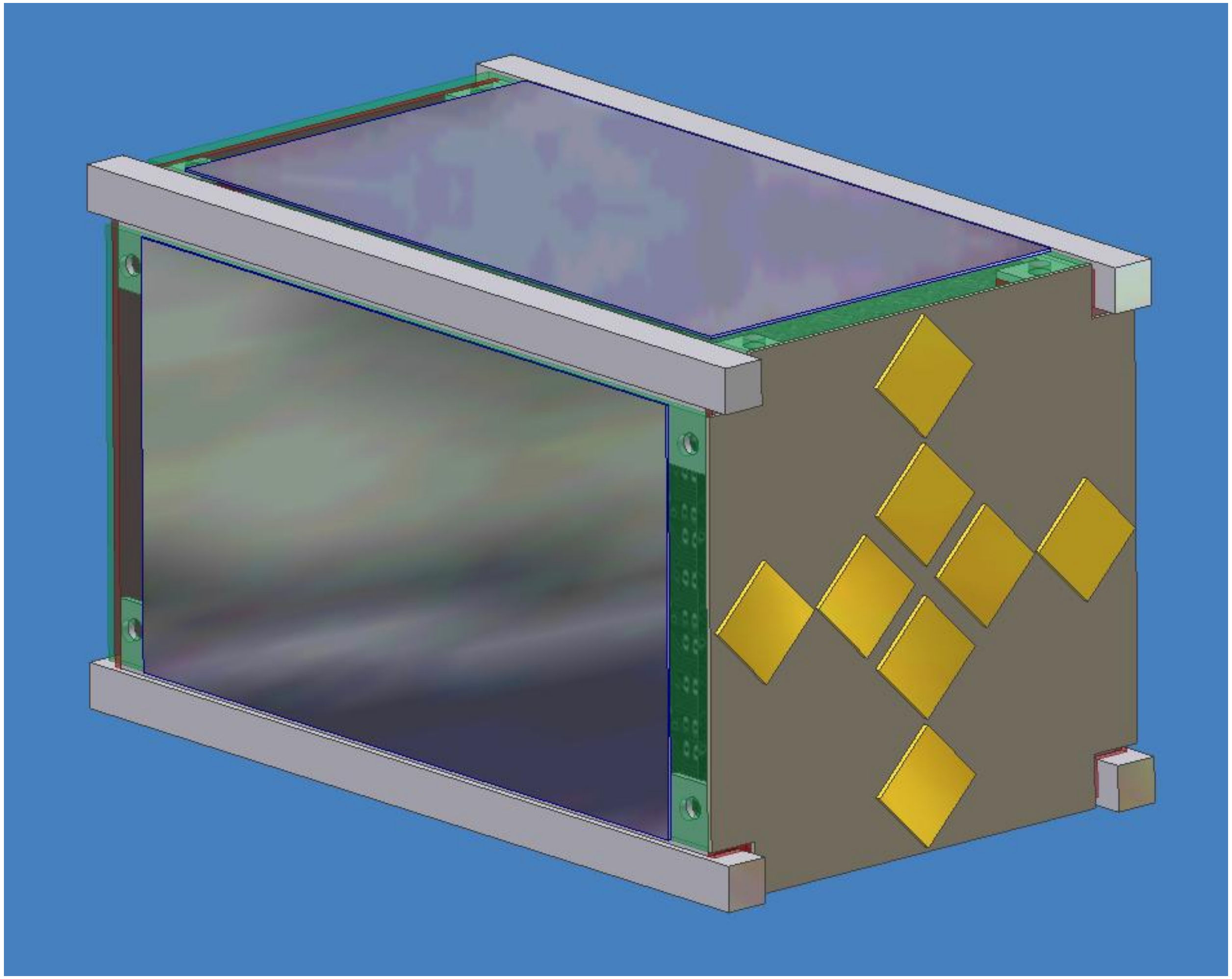


Upon receipt of ground signal receive command/downlink data

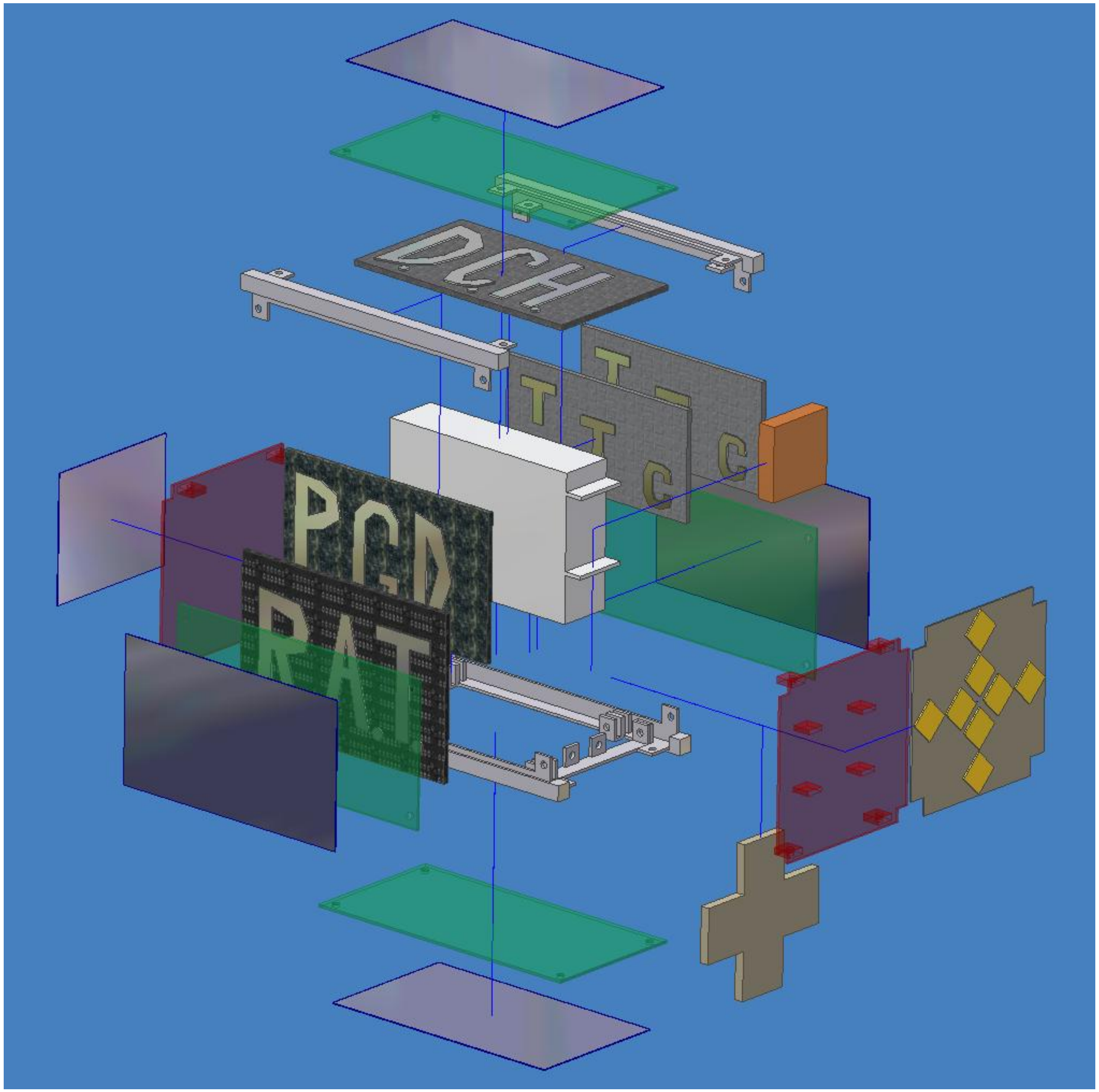


Structures Subsystem

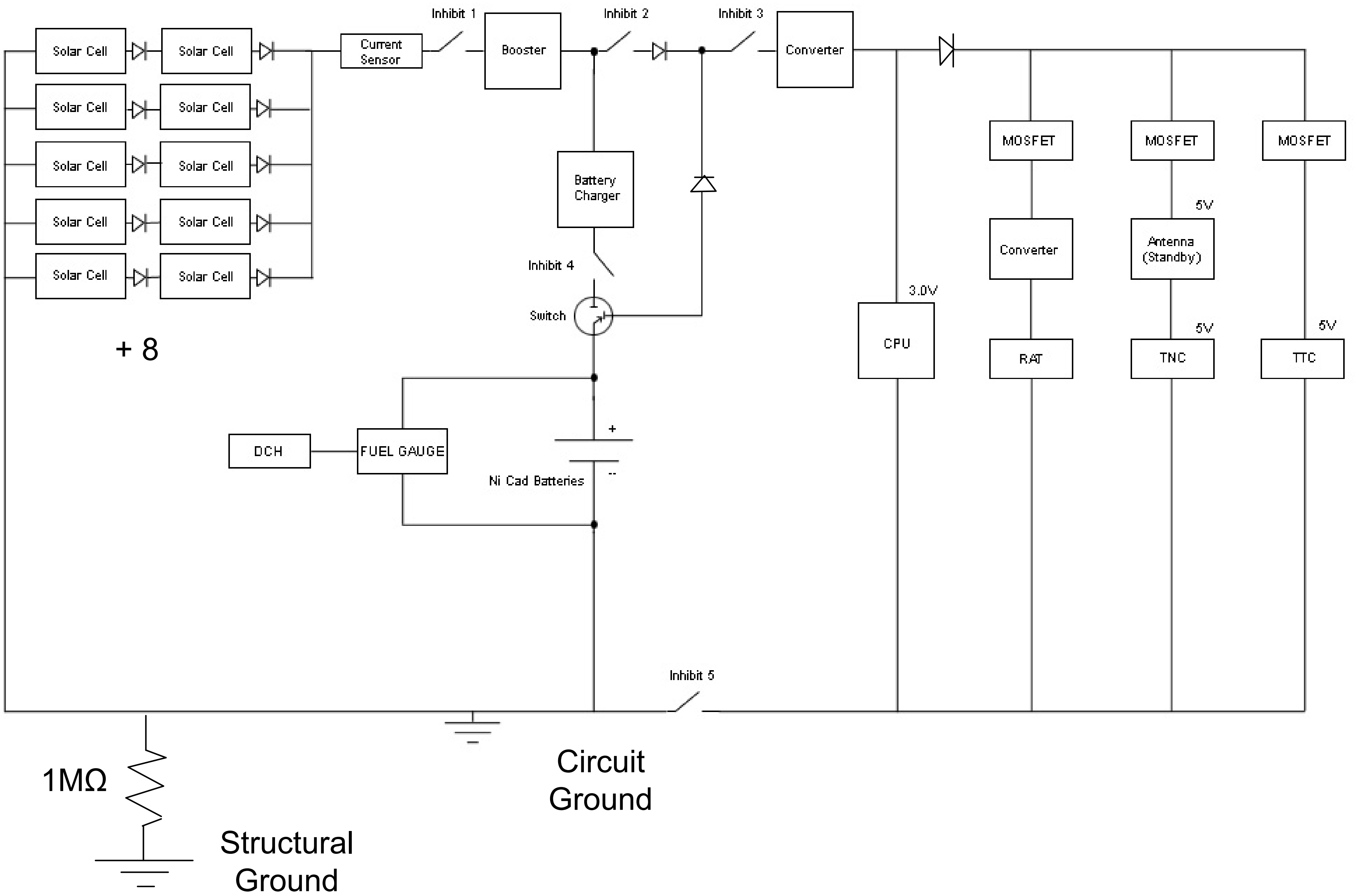
- T6 Aluminum Housing



Exploded View



Power Generation and Distribution



Communications Systems - Kenwood TH-D7A

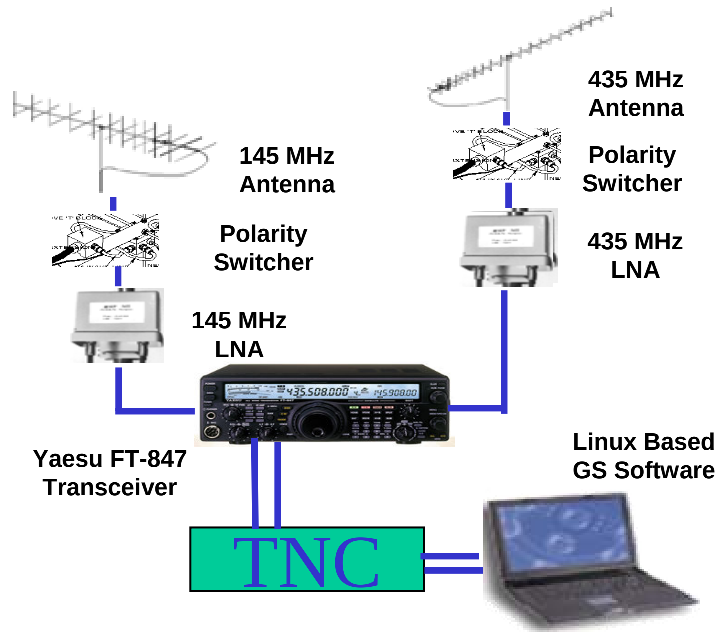
Frequency (HAM)	430–450 MHz
RF output	0.5 Watts (Low Mode)

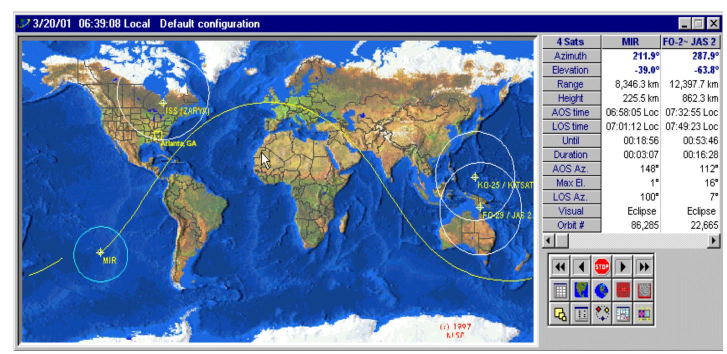
RCM3400 Technical Specs

- 29.4 MHz internal clock
- +3 to +3.45 V DC supply voltage @ 97mA
- Programmable in C (using Dynamic C)
- 512K FLASH memory
- 512K SRAM
- 12-bit A-to-D Converter

Ground Station

- Operations
  - HAM certified operators
  - Antenna and equipment a top University of Hawaii – Holmes Hall
  - NOVA tracking software
- Hardware
  - Yagi Antenna
  - Yaesu Antenna Rotator/Controller
  - LNA
  - Yaesu FT-847 Transceiver
  - PaComm PicoPacket TNC
  - Linux/PC Computer
- Software
  - NOVA software tracks satellite/steers antenna via rotator/rotator controller (COM port serial interface)
  - Custom signal verification/handshaking protocol
  - Command/data GUI in development





Conclusion

- UH will continue to be a strong contributor to and supporter of the CubeSat community
- Demonstration of the first self-steering crosslinks for picosatellite communications
- Thanks again to CalPoly