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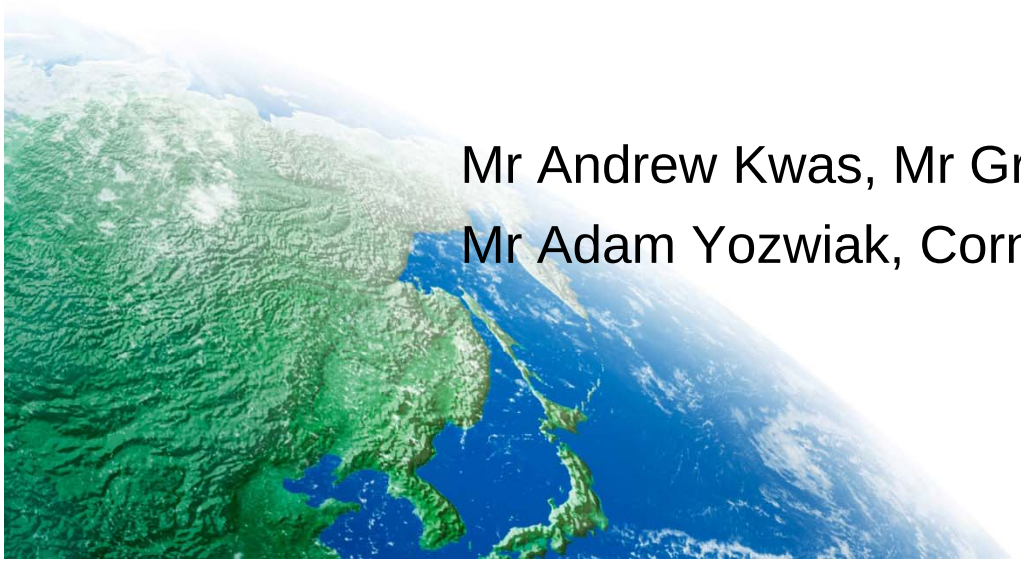
Ground Systems for Small Sats: Simple, Fast, Inexpensive but Effective

15th Ground Systems Architecture Workshop

March 1, 2011



Mr Andrew Kwas, Mr Greg Shreve, Northrop Grumman Corp,
Mr Adam Yozwiak, Cornell University

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"We live in a World of Excessiveness"

Andy Kwas

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We develop large complicated satellites, with large complicated commanding files, that generate large complicated telemetry data, that use large complicated ground systems like the AFSCN or TDRSS, monitored with large complicated GUIs.

And then we bemoan the fact that the mission was complicated and expensive.

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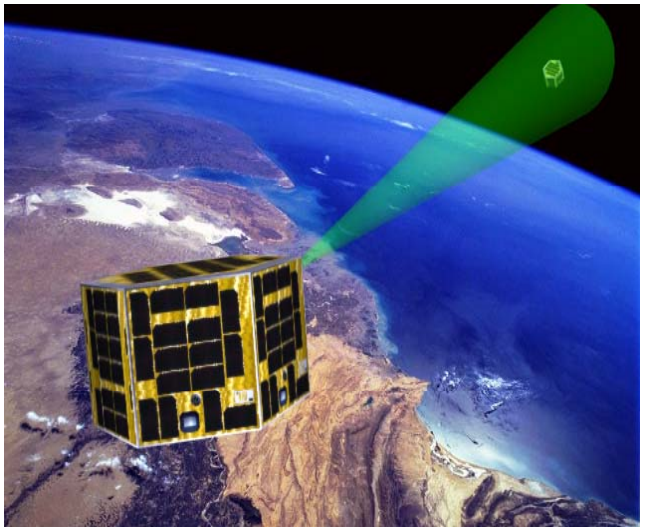
Complexity = $

Agenda

- Why Amateur Sat (AMSAT) frequencies?
- Case study: Cornell University Satellite: CuSat
- CuSat Mission Operations video



AMSAT VHF-UHF Band in Context of Space Communications

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RF Band	Key Characteristics	Typical Usage
VHF-UHF	• Low bandwidth • Very low cost space and ground segment	University Sats – command and telemetry, mission data downlink, relay
S-band	• Low to medium bandwidth • Good civil infrastructure (many compatible ground stations)	Amateur band (2.4 GHz) data downlink and relay, civil / commercial / military command and telemetry
X-band	• Wideband (10's of MHz and more)	Current generation of civil space-to-earth mission data downlink
Ka-band	• Very wideband data • High gain antennas • Rain attenuation	Next generation of civil space-to-earth mission data downlink

Features of a simple ground segment approach: Advantages

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- Simple satellite and communication designs
  - eg whip antennas for UHF, software defined radios
  - Single UHF band “packet data” or B-mode dual band (UHF/VHF), UHF and L-Band up and down link for small added costs
- Commercial Off-the-Shelf (COTS) ground components
  - Less risk of faulty custom design
  - Less required development time
  - AMSAT leverages off many lessons learned from other amateur enthusiasts
  - Simple replacement in the event of a significant equipment failure
- Remote Operation
  - Software written for ground segment can be designed to have minimal human intervention
  - Simple to support with multiple independent ground stations

Features of a simple ground segment approach: Limitations

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- AMSAT frequencies cannot be used for commercial applications for transmitting
- Licensed amateur radio control operators need to operate and maintain transmitting ground stations
- Limited bandwidth (in VHF-UHF bands), thus restriction on data rates
- Use amateur and WRC bandplans and AMSAT frequency assignments
- Correctly balance on board processing as well as available power and thermal considerations for optimal design
- Ground Station antenna gain is only 10 to 20 dB, using Yagi antennas

A Case Study: CuSat

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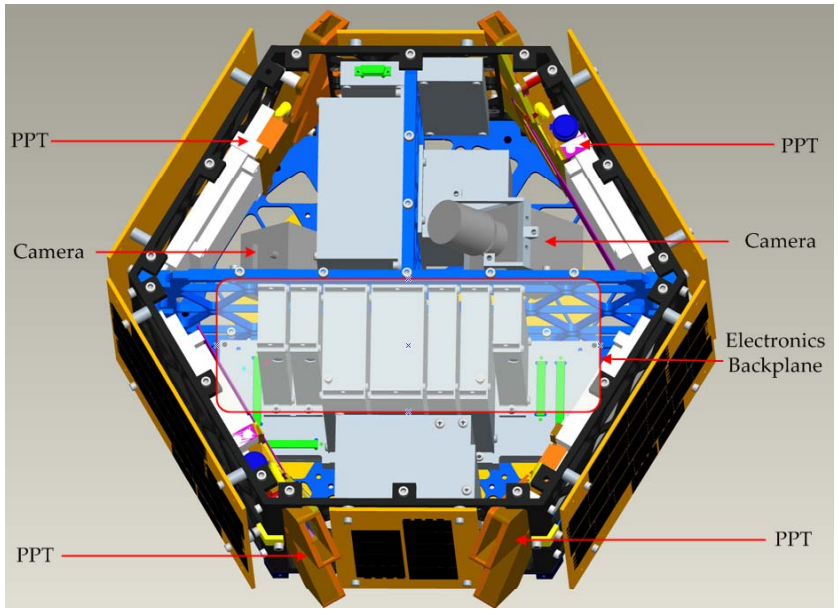
- University Nanosatellite Program : Sponsored by the AFRL, AFOSR, AIAA, and NASA

- CuSat Mission (Winner of UNP4):
  - Autonomous on-orbit inspection allowing in-space diagnosis and autonomous assessment of space assets
- CuSat Primary Experiment: Carrier-phase Differential GPS (CDGPS)
  - Sub-centimeter level accuracy
  - Gyroless attitude and position sensing
  - First on-orbit demonstration of simultaneous attitude and relative navigation for formation flight

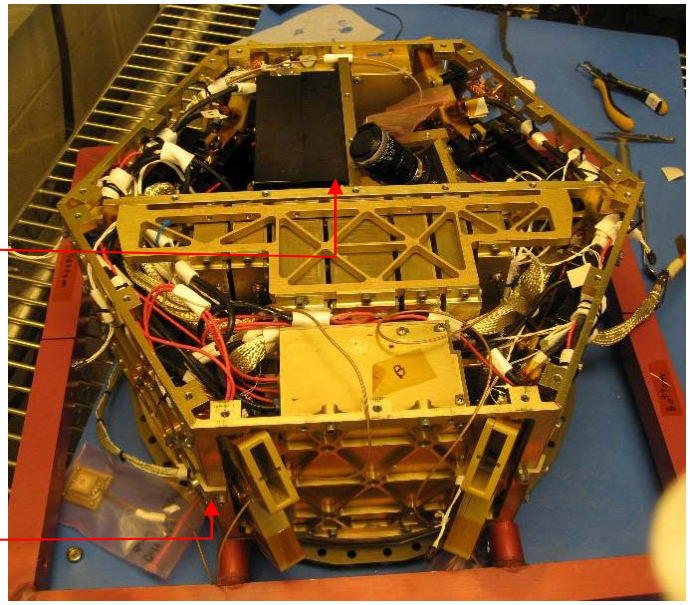
Space Segment Architecture

- Two Functionally Identical Satellites
  - 2 Cameras
  - 8 Pulsed Plasma Thrusters (PPTs)
  - 3 GPS Receivers
  - Reaction Wheel Assembly

Stacked Configuration



Protoflight Unit CAD Model



Mid-Assembly Flight Unit

CuSat Ground Segment Approach

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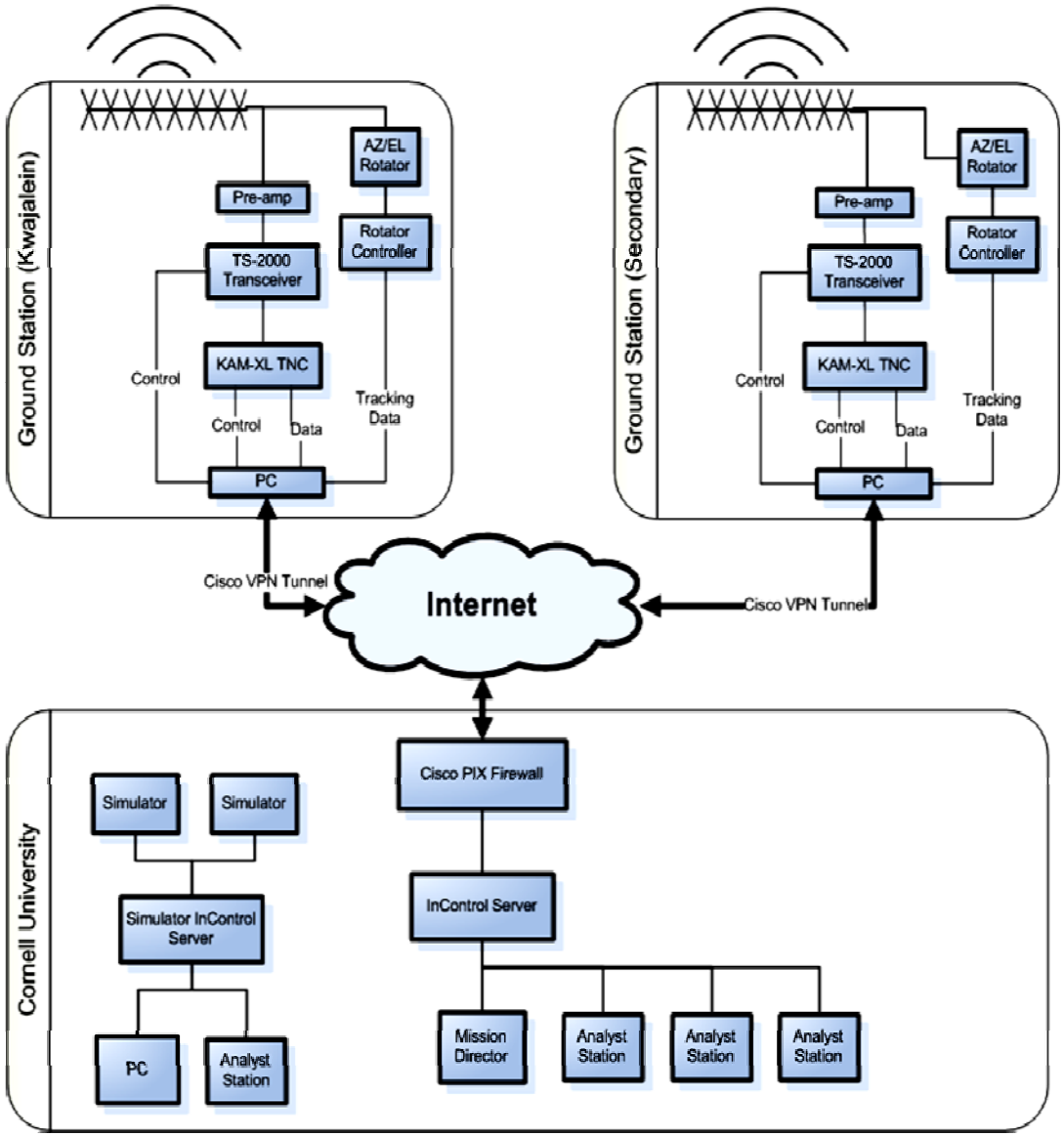
GS Design Motivation:

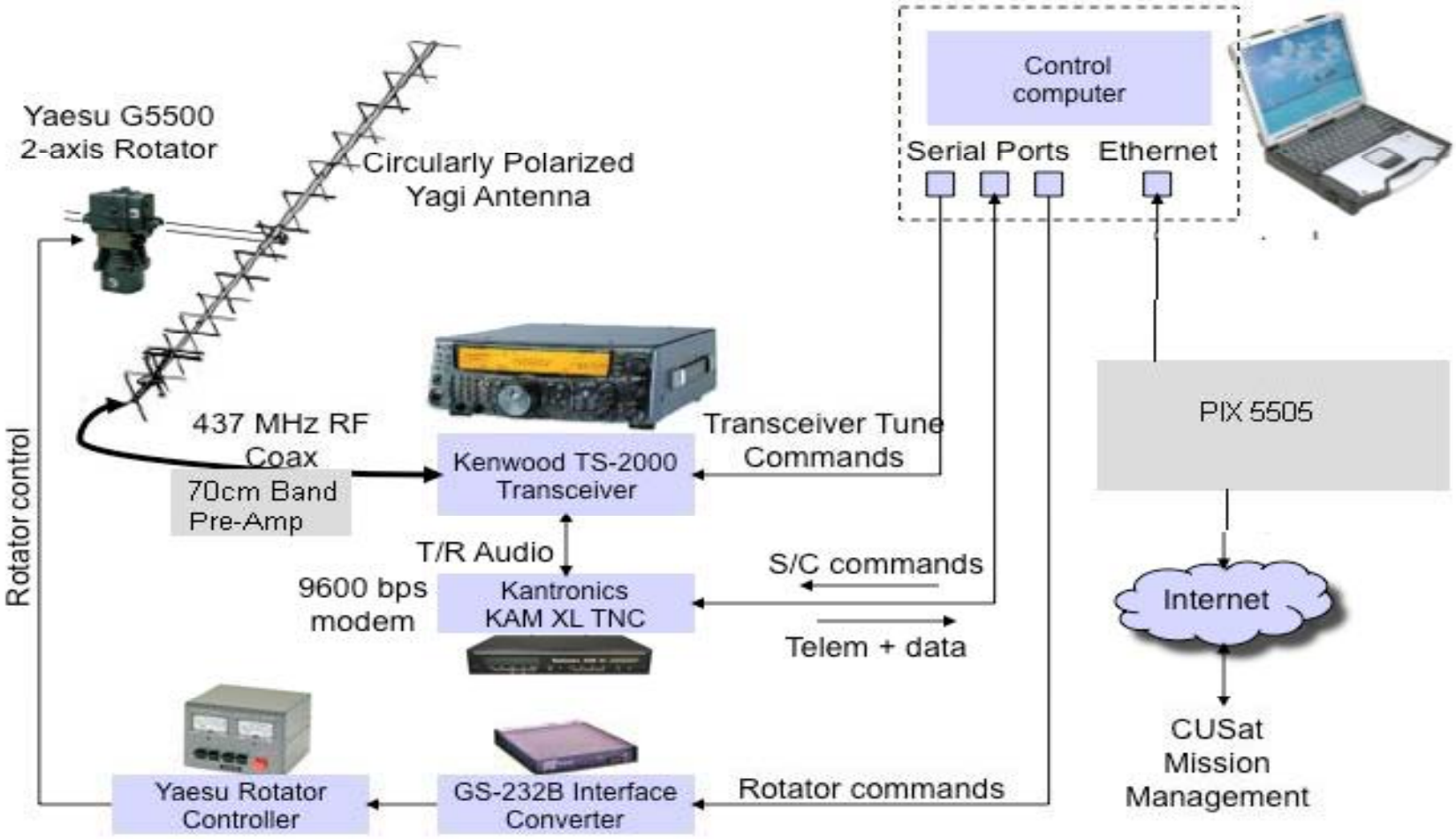
- Architecture requires modularity and flexibility
- Minimize human intervention/ costs

Solution:

- Commercial-off-the-shelf (COTS) components
- Ground Station is a “dumb” relay for packetized data
- Amateur frequencies



CuSat Ground Hardware



Total Hardware cost per station =$5000

CuSat Mission data Requirements

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- Mission Control Center at Cornell University (Ithaca, NY)
  - Interface with remote ground stations via VPN over Internet
  - Remote ground stations: Ithaca, NY (Cornell), Redondo Beach, CA (NGIS), Colorado Springs, CO (NGIS), Kwajalein Atoll (MIT)
- Ground Pass Analysis
  - LEO, low eccentricity orbit with ~330km altitude and ~50° inclination
  - Simulations predict 9-12 minute ground passes and average 9-10% daily coverage
- CUSat Data Products
  - 9600 bit/second physical layer TNC modulation rate
  - Images: 250-500KB after compression, ~7 min to downlink w/o telemetry
  - Telemetry Beacon (once every 30s): 288B, ~1/4s to downlink

Satellite TT&C - L3s, InControl

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- What is InControl?
  - Fully customizable command and control software application for control of multiple satellites, applications and functions from a single system.

- Key features:
  - Powerful displays based on JAVA technology
  - Real-time scripting & scheduling
  - Equipment management/configuration
  - Capture, display, archive spacecraft telemetry
  - Reconfigurable front-end user Interface
  - Server/Client Architecture
    - Server is loaded onto a Windows Server 2003 computer residing on the CUSat network at Cornell
    - Client software can reside on any computer that can connect to the CUSat network
    - Any client can view telemetry, only one client with a “control token” can send commands

CUSat
Mission Operations

Summary

- Significant space science and responsive space operation missions can be accomplished by simple satellite programs
- AMSAT VHF-UHF equipment enable low cost entry to space communications
- AMSAT VHF-UHF missions can leverage the ground stations of scores of worldwide space ham operators, using the internet to create many more downlink opportunities than commercial / civil missions


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Back Up

Ground Operations for CuSat Data flow

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Uplink Data Flow

- Satellite signal received and unencrypted by 70cm ground antenna and detected by the TS-2000 transceiver
- KAM-XL TNC digitizes the signal and sends it to a GS laptop
- GS laptop forwards the packets over TCP/IP to the InControl server over a secure VPN connection to the MCC
- Packet is decommutated and assembled by the InControl Server and displayed to the satellite operators

Downlink Data Flow

- Spacecraft command packets are encapsulated in IP packets and sent over a secure VPN to the appropriate ground station
- Ground station software receives IP packet, extracts the spacecraft command packet
- Command packet sent through the KAM-XL TNC and TS-2000 transceiver
- Transceiver transmits the command to the space segment through the antenna

Program Milestones

• System Concept Review	February 2005
• Preliminary Design Review	August 2005
• Critical Design Review	February 2006
• Proto Qualification Review	August 2006
• Flight Competition Review	March 2007
• Completed environmental testing	June 2008
• Manifested as a secondary payload	November 2010
• ***Launch on a SpaceX Falcon 9***	***Fall 2011***