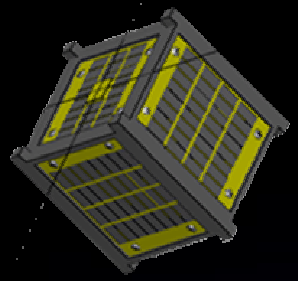


The HABS,KUBESat,KUTESat-1 Technical report; Design of a Modular platform for Picosatellites

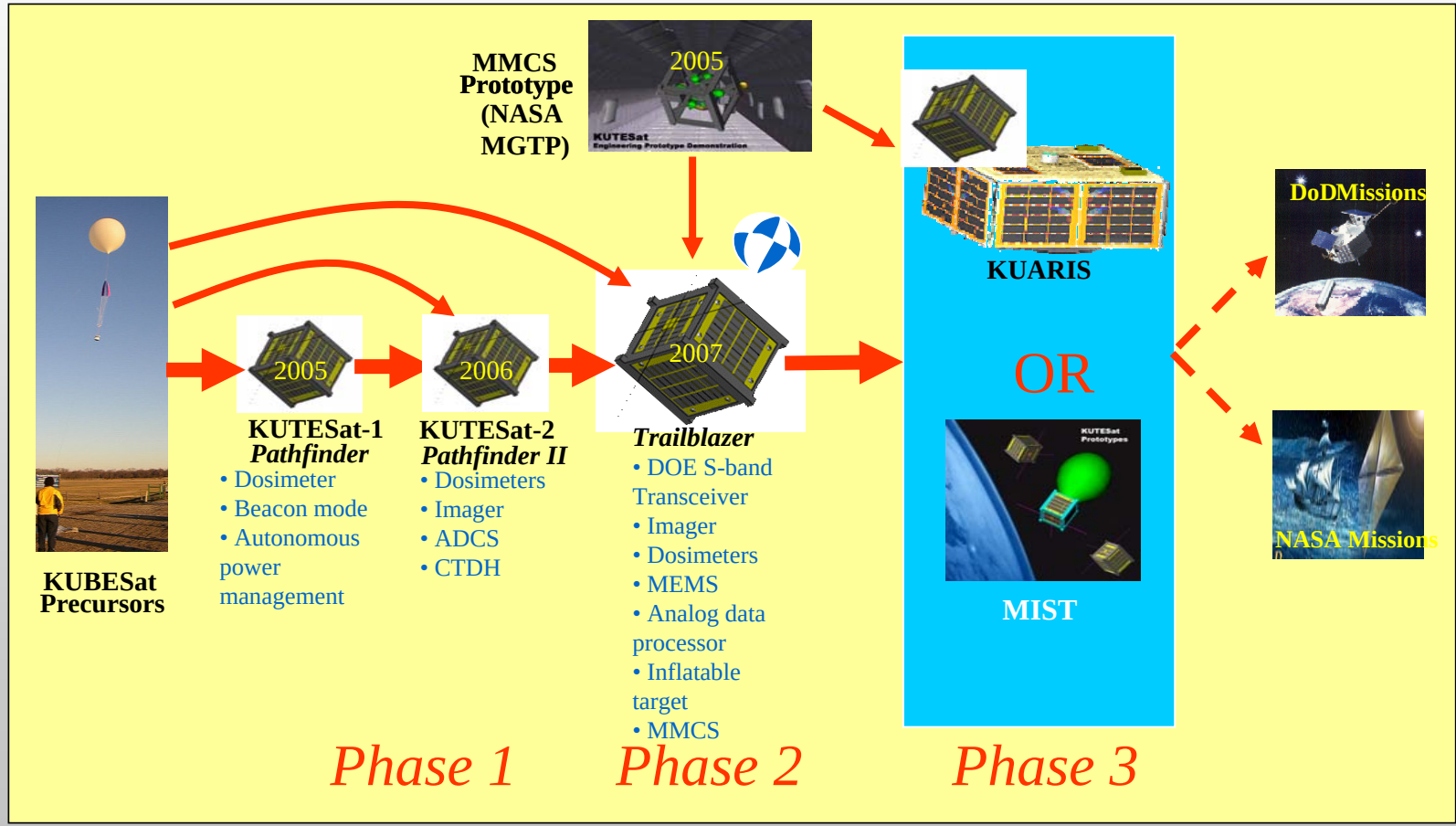
Nikhil Paruchuri

University of Kansas

KUTESat program overview

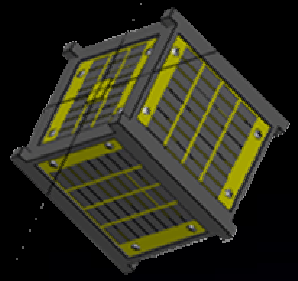
- **Kansas Universities Technology Evaluation Satellite (KUTESat)**
  - **Development and operation of small satellites (< 30 kg) that will be engineering prototypes**
  - **Test latest nanotechnology and MEMS technology**
    - **JPL NASA**
    - **AFRL**
    - **NNSA KCP**
  - **Establish a space industry in Kansas**
  - **Train future space professionals (student run program)**

KUTESat program overview



Objectives

- **Design HABS**
- **Design KUBESats for S-band communication system**
- **Integrate and test KUTESat-1**
- **Design modular platform for future systems**
- **Implementation of modular platform**

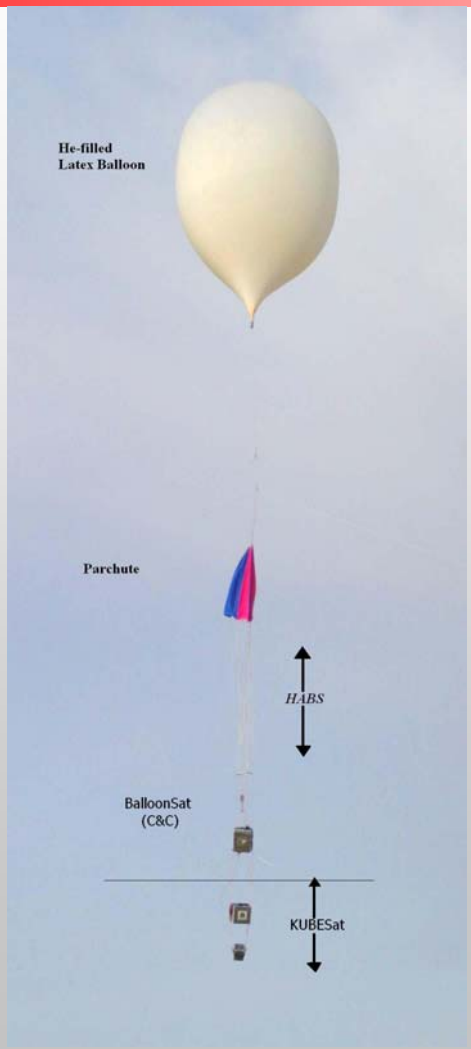


The BalloonSat's

High Altitude Balloon System

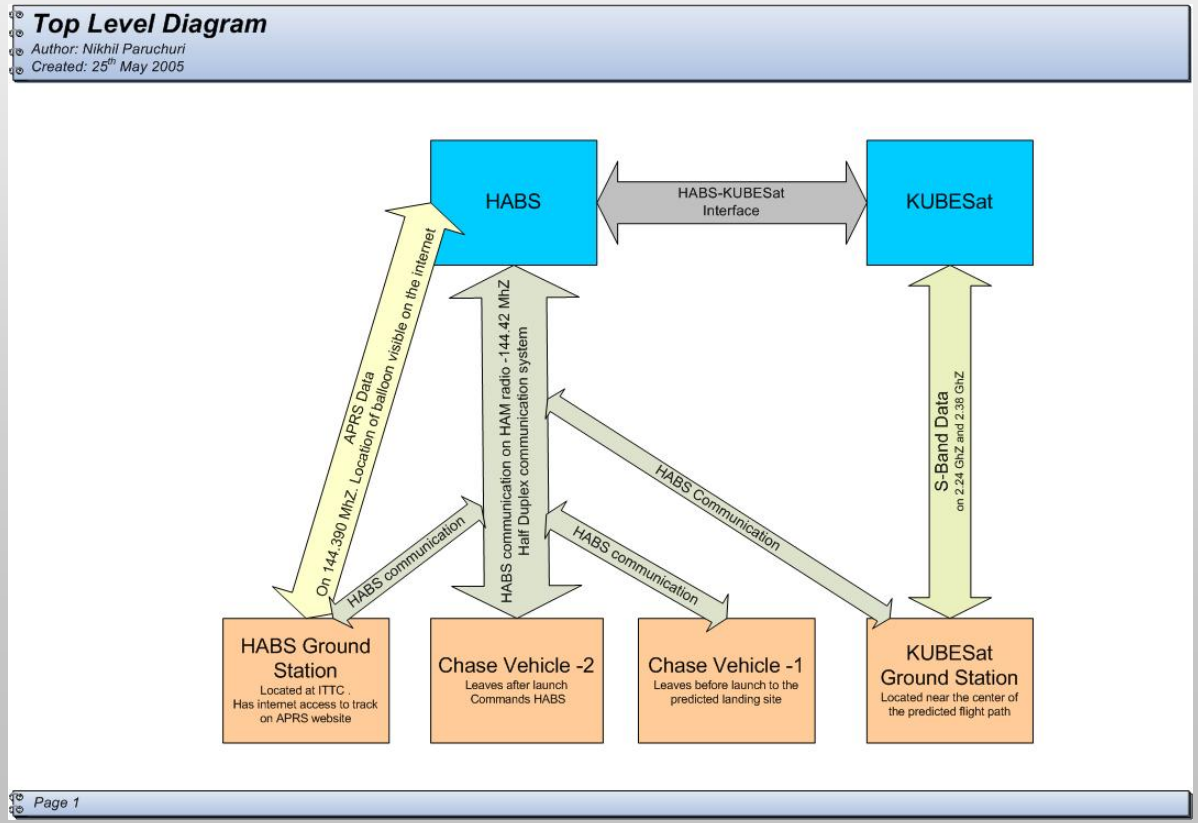
- **Payloads - KUBESats**
- **Near Space Environment testing**
- **100 000 ft, 0.01 atm , -80 ^{o}C**
- **~3 hrs of flight**
- **30-150 miles LOS**
- **12 pounds limit**
- **$500 launch costs**

Balloon Flight



HABS

- **Downlink GPS and Telemetry data**
- **HAM radio, APRS radio**
- **S-band communication system, student payloads**



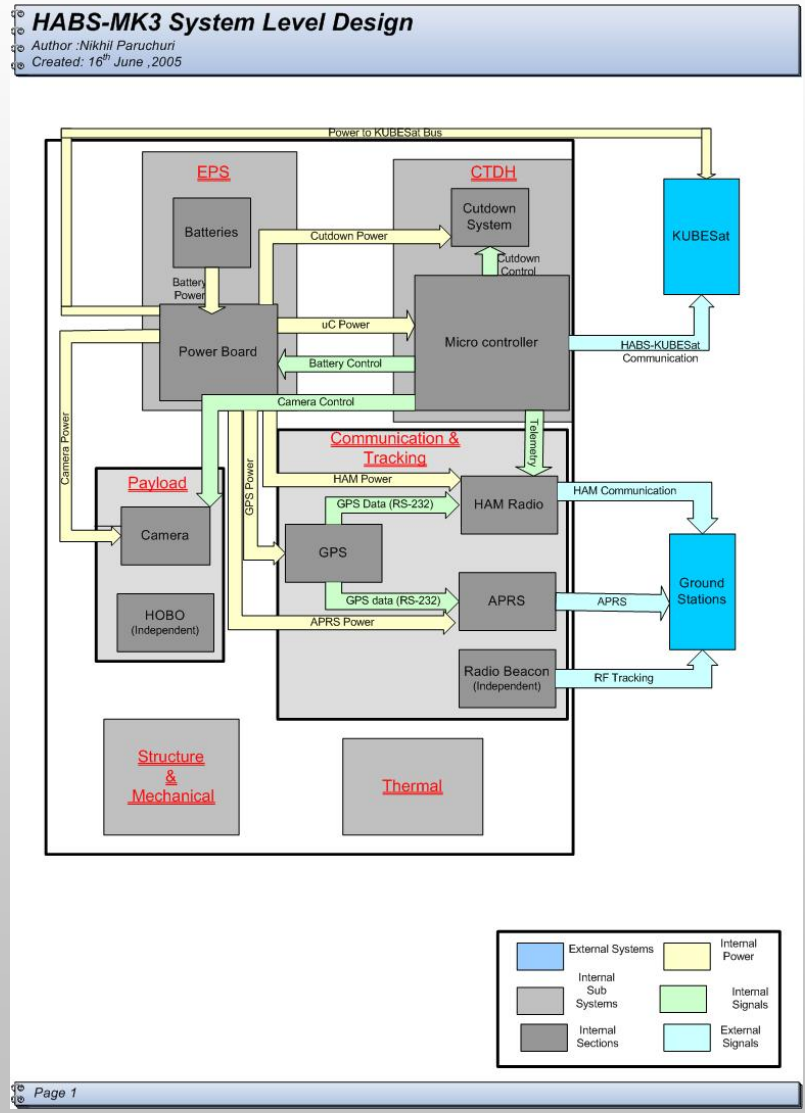
HABS series

- **13 flights since May 2003**
- **3 series built**

Flight	Series	Payloads	Date	Max. Altitude (km)	Tracked w/GPS	Flight termination method	Recovery
HABS-1	Initial	Temperature -HOBO	5/3/2003	Unknown	No	Burst	Yes
HABS-2	MK Ia	Temperature-HOBO	12/20/2003	14	Yes	Cutdown	Yes
HABS-3	MK Ia	Temperature-HOBO	4/3/2004	Unknown	Partly	Burst	Yes
HABS-4	MK II	Camera , Temperature-HOBO	9/24/2004	4.5	Yes	Cutdown	Yes
HABS-5	MK II	Camera , Temperature-HOBO	10/1/2004	32.8	Yes	Burst	Yes
HABS-6	MK II	Camera , Temperature-HOBO	10/23/2004	29.9	Yes	Burst	Yes
HABS-7	MK II	KUBESat-1,Temperature-HOBO	2/26/2005	19.3	Yes	Cutdown	Yes
HABS-8	MK II	AE 265 student modules .HOBO	5/1/2005	10.7	Yes	Cutdown	Yes
HABS-9b	MK II	KUBESat-1,Temperature-HOBO	6/25/2005	26.7	Yes	Cutdown	Yes
HABS-10	MK II	KUBESat-1,Temperature-HOBO	8/17/2005	28.7	Yes	Burst	Yes
HABS-11	MK III	Temperature-HOBO	10/22/2005	28	Yes	Burst	Yes
HABS-12	MK IIIa	Temperature-HOBO	11/5/2005	28.1	Yes	Burst	Yes
HABS-13	MK IIIa	XBS module, HOBO	11/19/2005	6.9	Yes	Cutdown	Yes

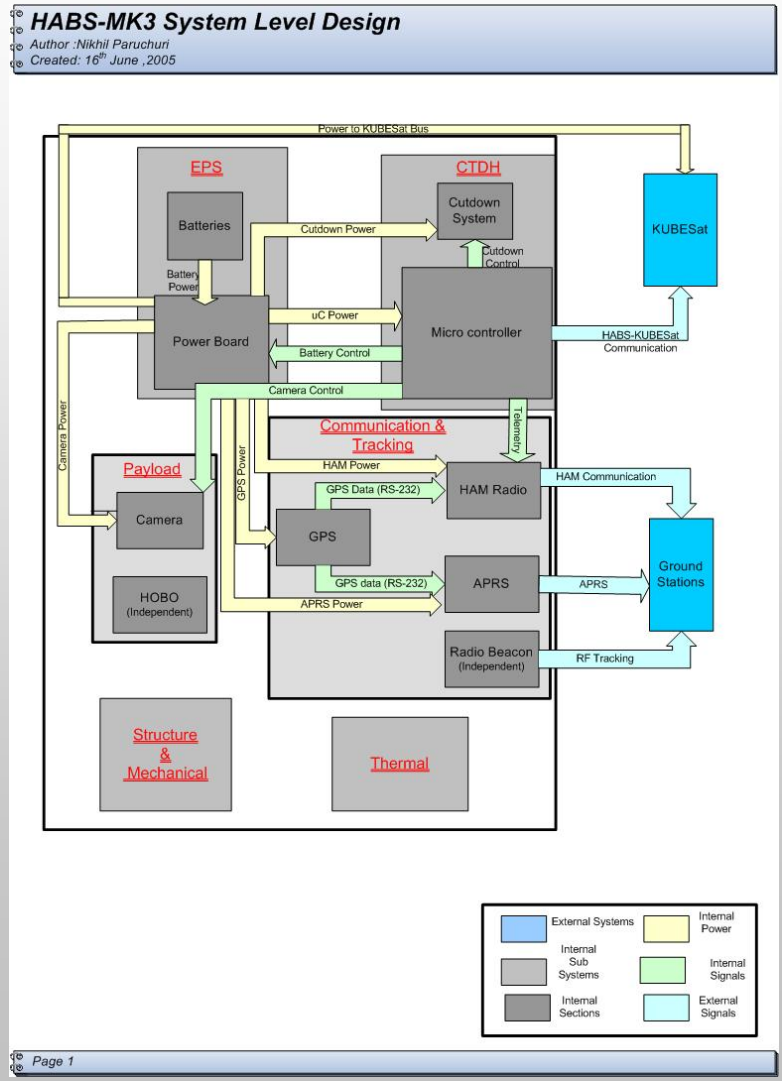
HABS –Mk2 system design

- **HABS-Mk1**
  - **2 flights**
  - **Unreliable**
- **HABS-Mk2**
  - **Redundant tracking system**
  - **Secondary batteries**
  - **GPS unit**
  - **Uplink commands from Ground Station**
  - **Film camera**



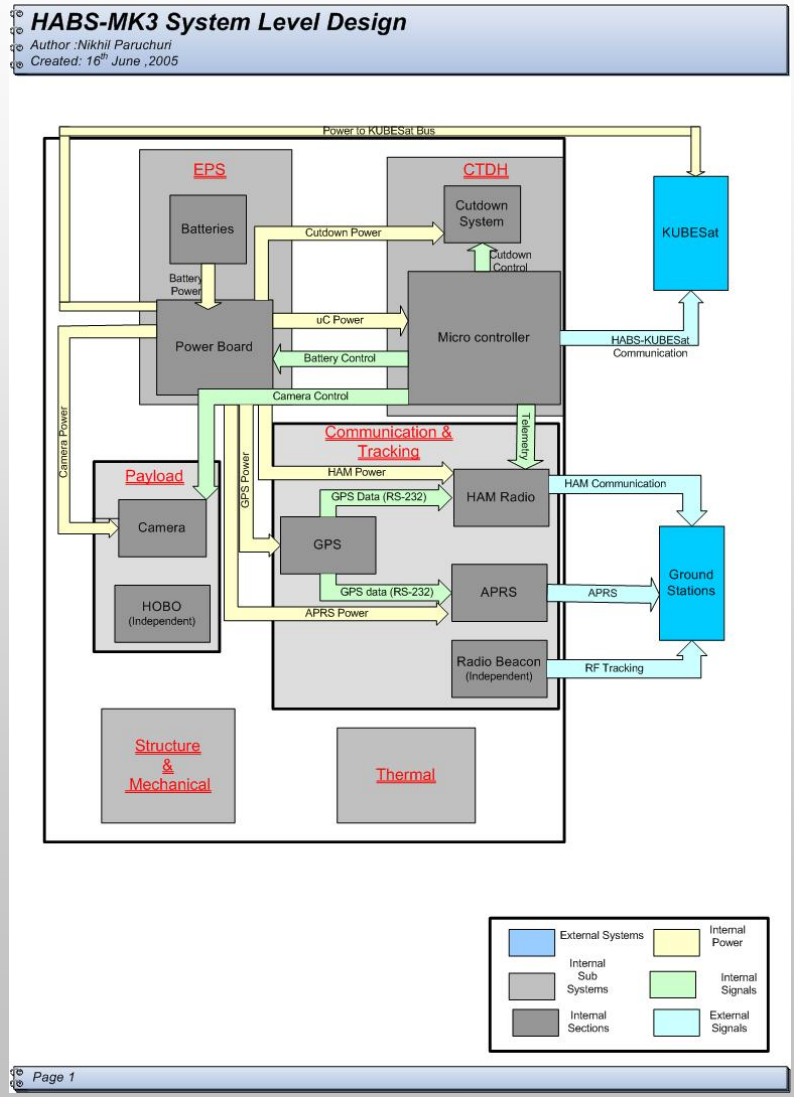
HABS-Mk2 ,subsystems

- **Control Telemetry and Data Handling (CTDH)**
  - **Telemetry**
    - **Batteries, Temperature, Cutdown status**
  - **GPS data**
  - **Cutdown**
  - **Camera**
  - **Choose from Primary and Secondary power sources**



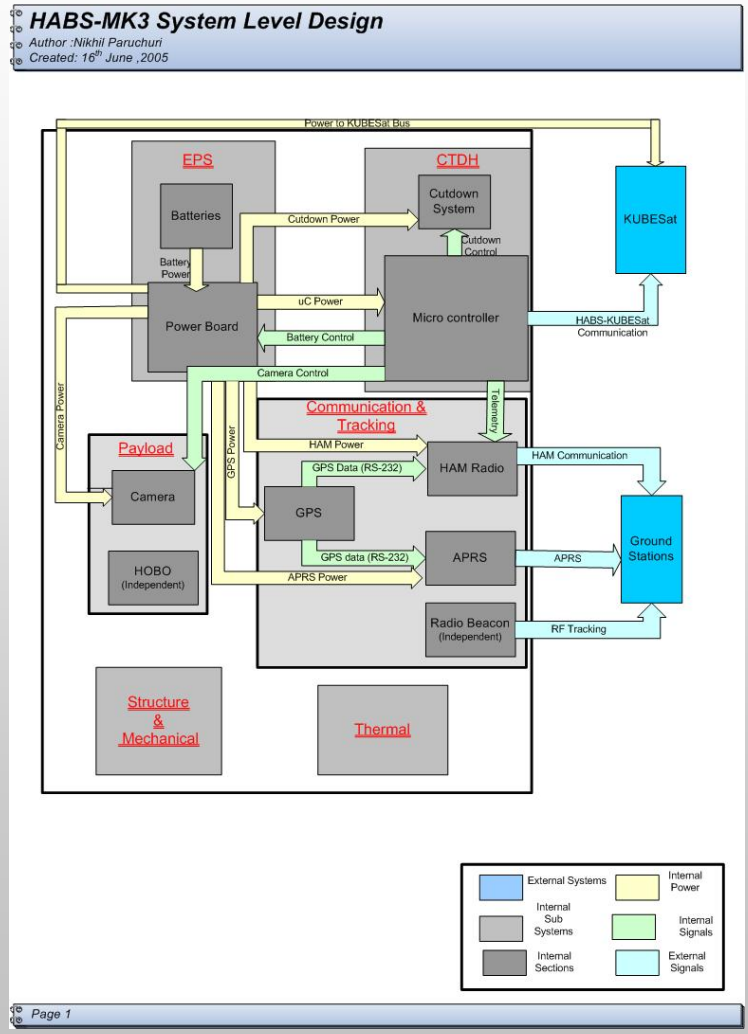
HABS-Mk2 ,subsystems

- **HAM radio**
  - **144.42 MHz**
  - **Call Sign**
  - **TH-D7AG**
- **Automatic Packet Reporting System (APRS)**
  - **Redundancy**
  - **144.39 MHz**
- **GPS**
  - **1 second updates**
  - **Garmin GPS-25**
  - **External antenna**

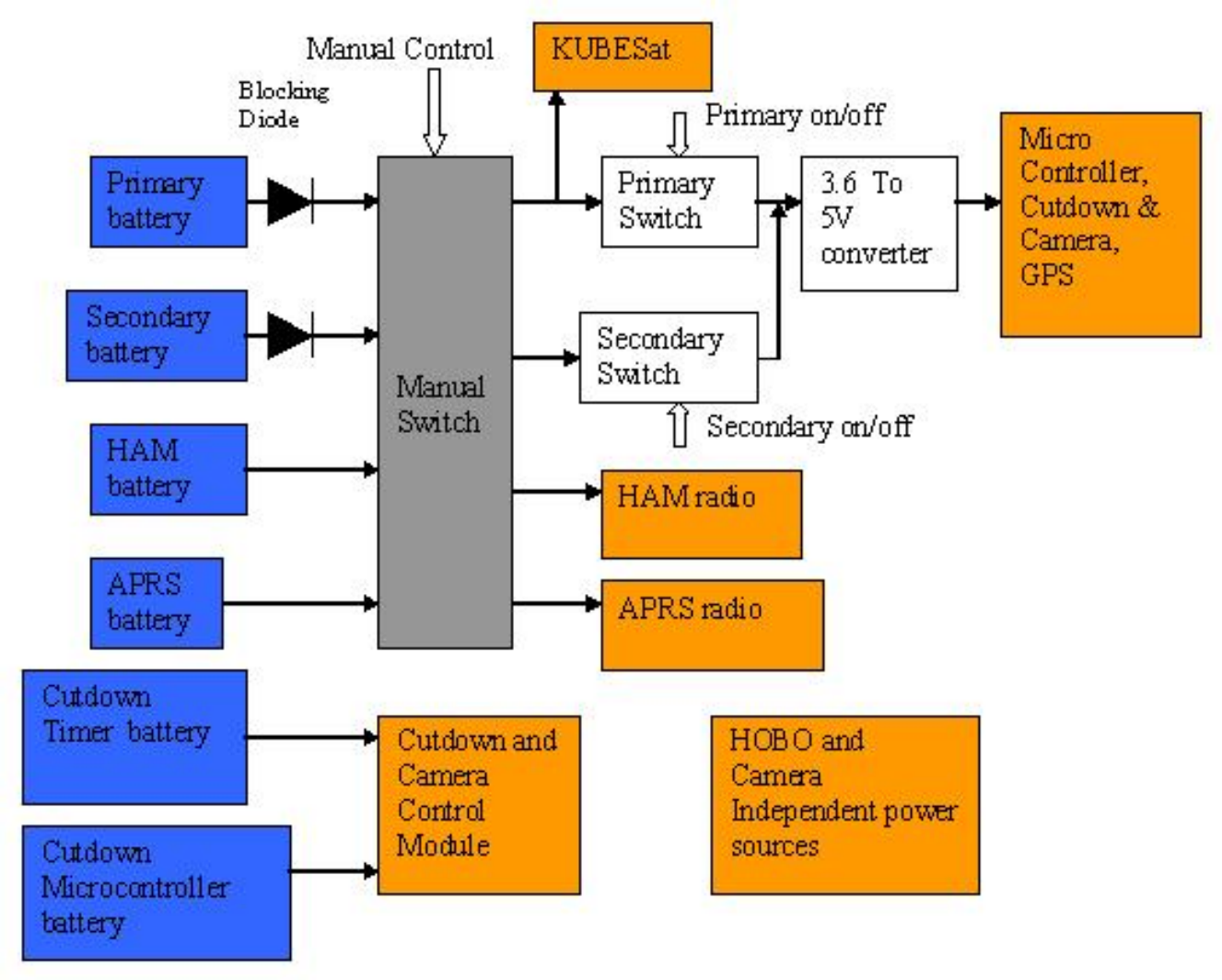


HABS-Mk2, subsytems

- **Payload**
  - **Film Camera**
  - **HOBO**
- **Electrical Power System (EPS)**
  - **Primary and Secondary battery sources for Main system.**
  - **Independent battery sources for radios, Cutdown**



EPS cont.

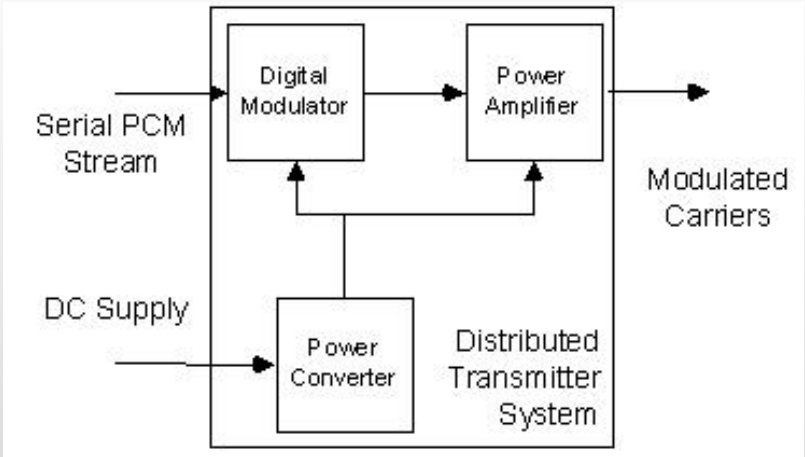

Manual Control
KUBESat
Blocking Diode
Primary on/off
Primary battery
Primary Switch
3.6 To 5V converter
Micro Controller, Cutdown & Camera, GPS
Secondary battery
Secondary Switch
Manual Switch
Secondary on/off
HAM battery
HAM radio
APRS battery
APRS radio
Cutdown Timer battery
Cutdown and Camera Control Module
HOBO and Camera Independent power sources
Cutdown Microcontroller battery

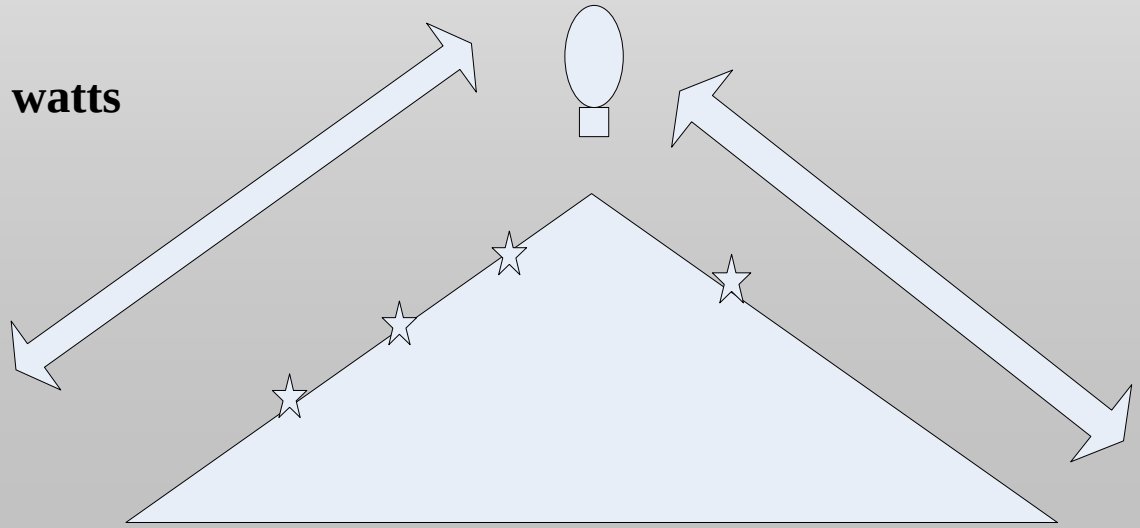
EPS cont.

	Required		Available								
System	**Energy (Wh)- Ren**	**Max Current (A)**	**Battery Model**	**Chemsitry**	**Configuration**	**Nominal Voltage (V)**	**Capacity (Ah)**	**Max Current (A)**	**Energy (Wh) Aen**	**Energy Density (Wh/g)**	**Safety factor= (Aen/Ren)**
5V bus , KUBESat	21.41	0.675	Samsung ICR18650 -22	Li-ion	3 cells in parallel	3.7	6.6	6.6	24.42	0.1769	1.1405202
5Vbus, backup	16.05	0.312	Samsung ICR18650 -22	Li-ion	3 cells in parallel	3.7	6.6	6.6	24.42	0.1769	1.5213738
HAM radio	5.63	0.52	Energizer e2 Lithium	Li/FeS2	4 cells in series	6	3	2	18	0.3103	3.1942078
APRS radio	0.869	0.11	Ultralife U9VL-J	Li/MnO2	1 cell	9	1.2	0.12	10.8	0.2967	12.417219
Cutdown	0.375	1.5	Kroeger 9V	Alkaline	2 cells in parallel	9	0.2	-	1.8	0.0197	4.8

KUBESat-1 : Introduction

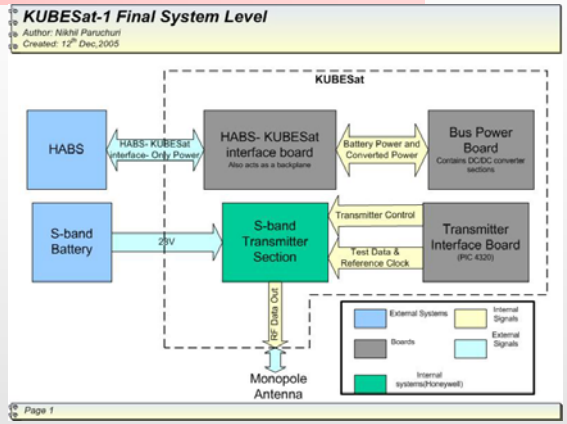
- **S-band Transmitter**
- **Characterizing**
  - **Modulation**
    - **FSK,SOQPSK**
  - **Filtering**
  - **Data Rate**
    - **1,5,10,20 Mbps**
  - **RF power**
    - **1,2,4,10 watts**

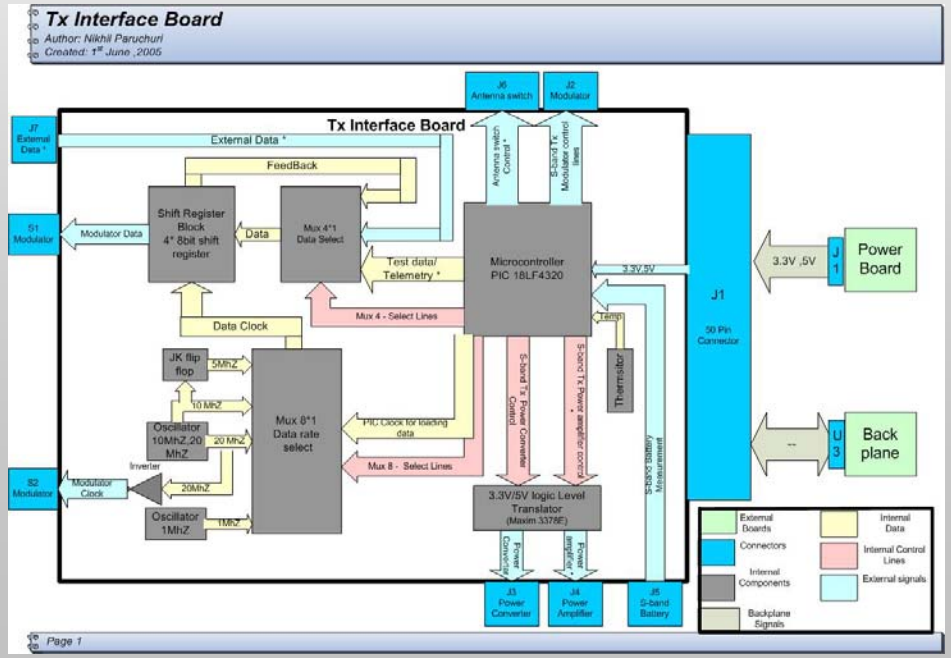




KUBESat-1 System Design

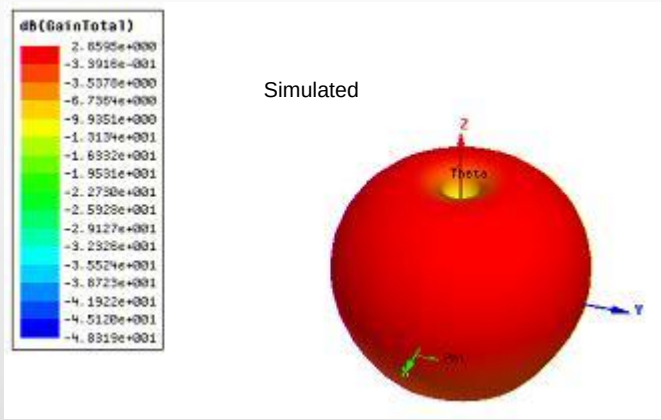
- **HABS interface**
- **S-band Control and Data interface**
  - **Control**
  - **Test Data**
  - **Clock**

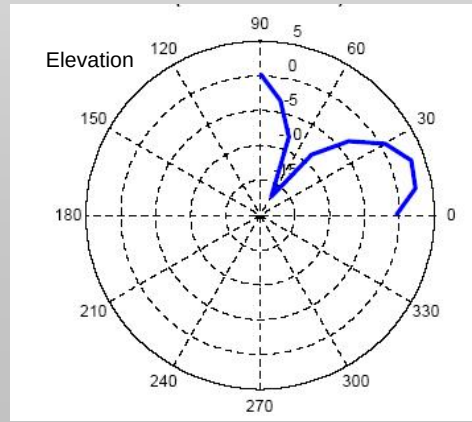




KUBESat-1 system design

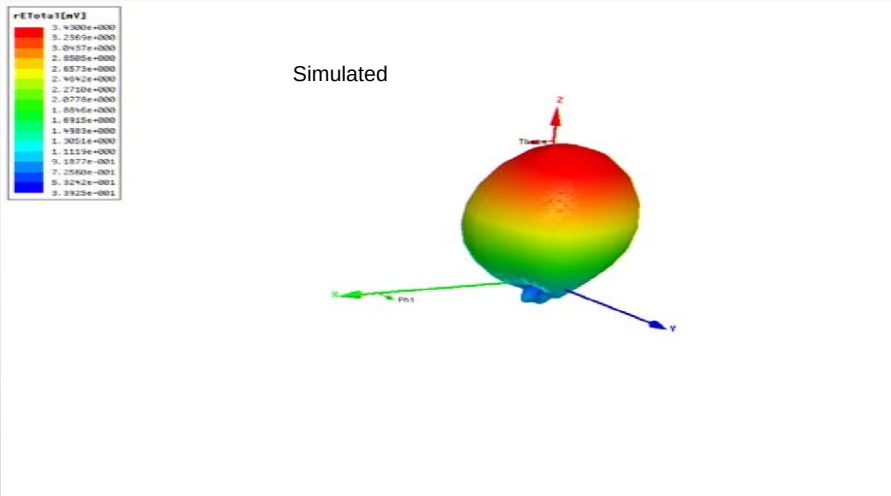
- **Antennas**
  - **Designed by EE Senior Classes**
  - **Balloon**
    - **Monopole**
    - **Characteristics**

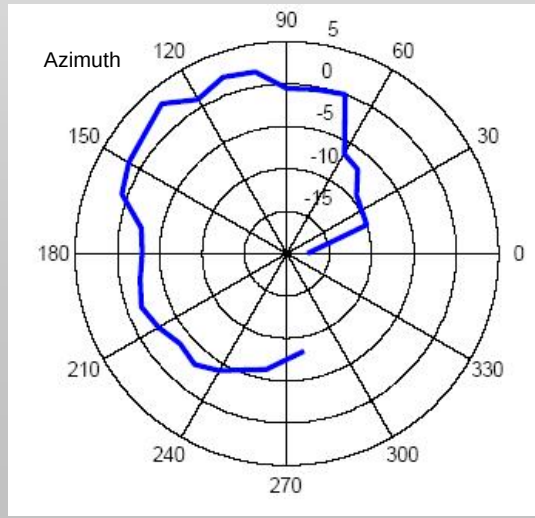


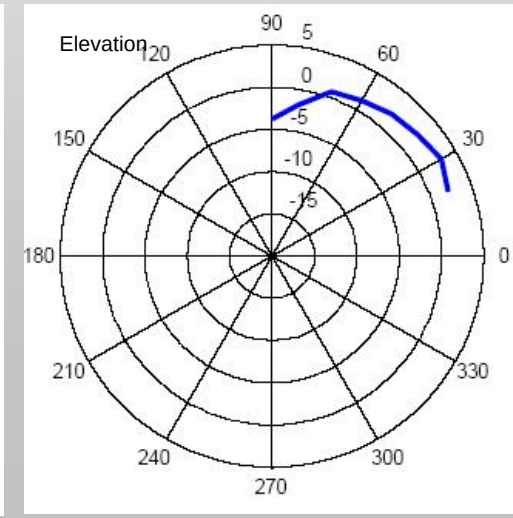


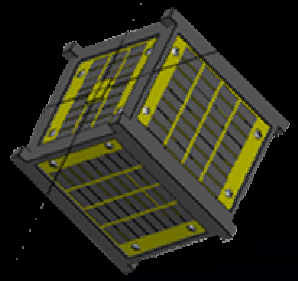
KUBESat-1 system design

- **Antennas cont..**
  - **Ground Station**
    - **Patch**
    - **Characteristics**

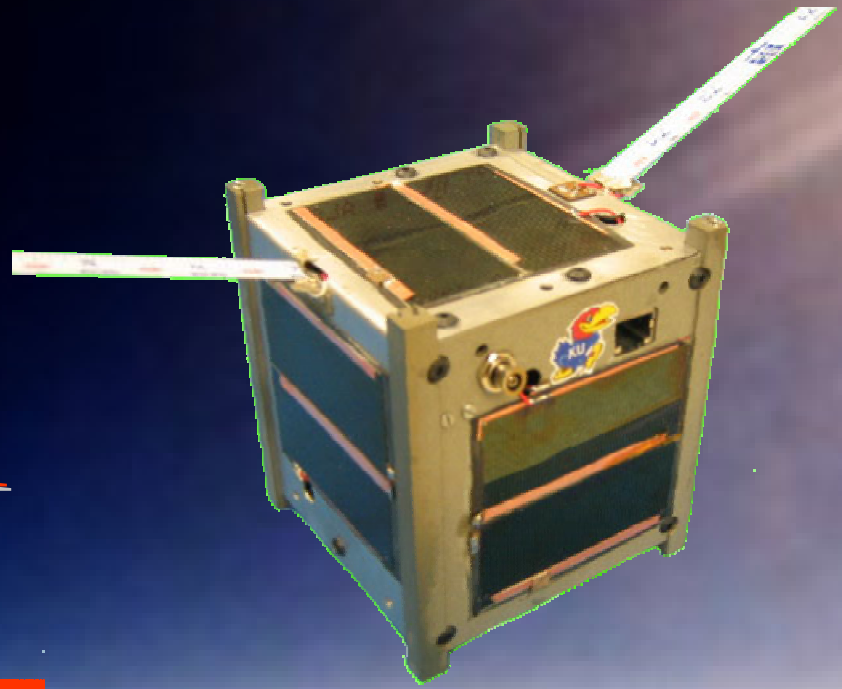






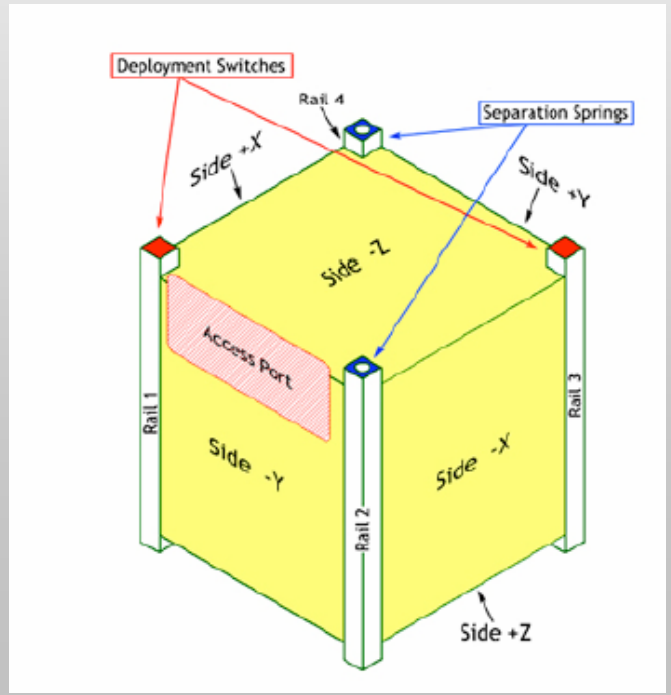


KUTESat-1
Pathfinder

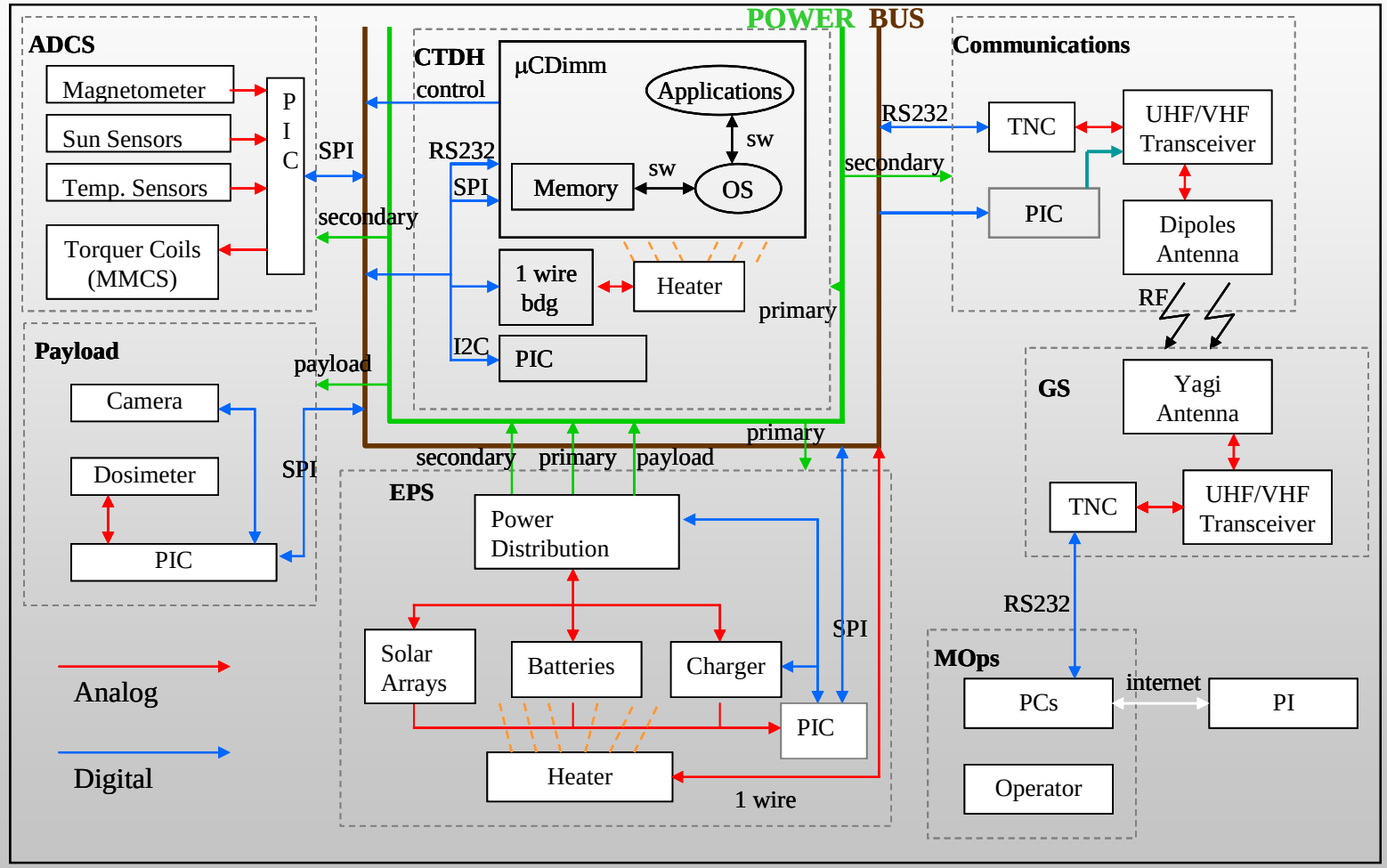


Pathfinder

- **CubeSat Standard**
  - **Picosatellites**
  - **Robert Twiggs,Stanford,2000**
  - **<1 kg, 10 cm cube**
  - **California State Polytechnic University**
  - **P-POD**



Original System

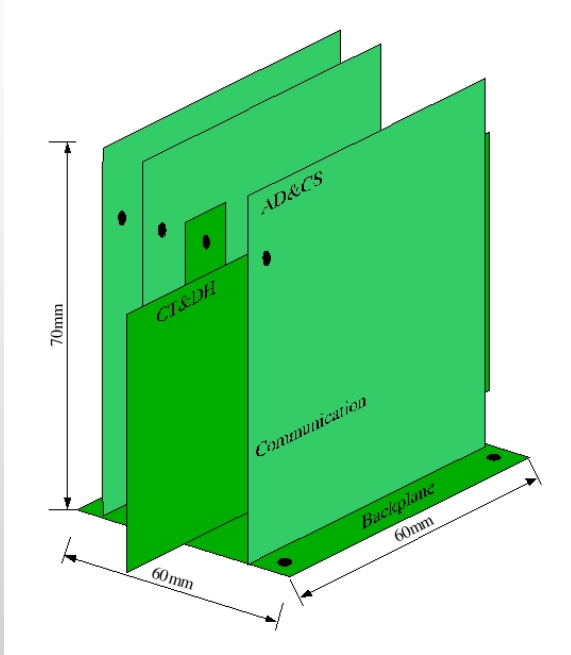


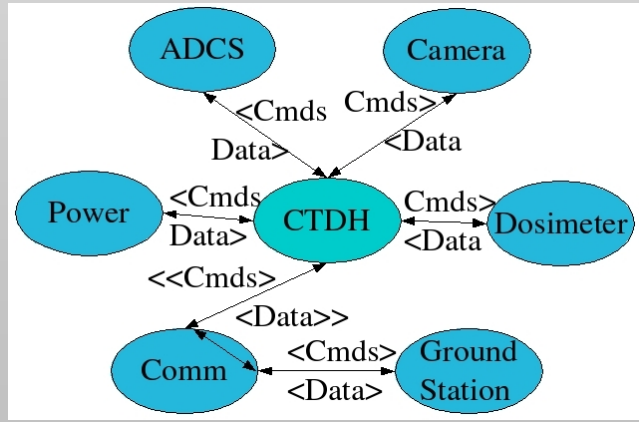
Original System

- CTDH
- Communication
  - HAM radio
- Attitude Determination and Control System (ADCS)
  - Magnetometer and Sun sensors
  - Torquer Coils
- Electrical Power system
  - Lithium batteries
  - GaAs Solar cells
  - Power distribution
- Payload
  - Dosimeter- Radfet
  - Camera- CMOS image sensor

Control Telemetry &Data Handling

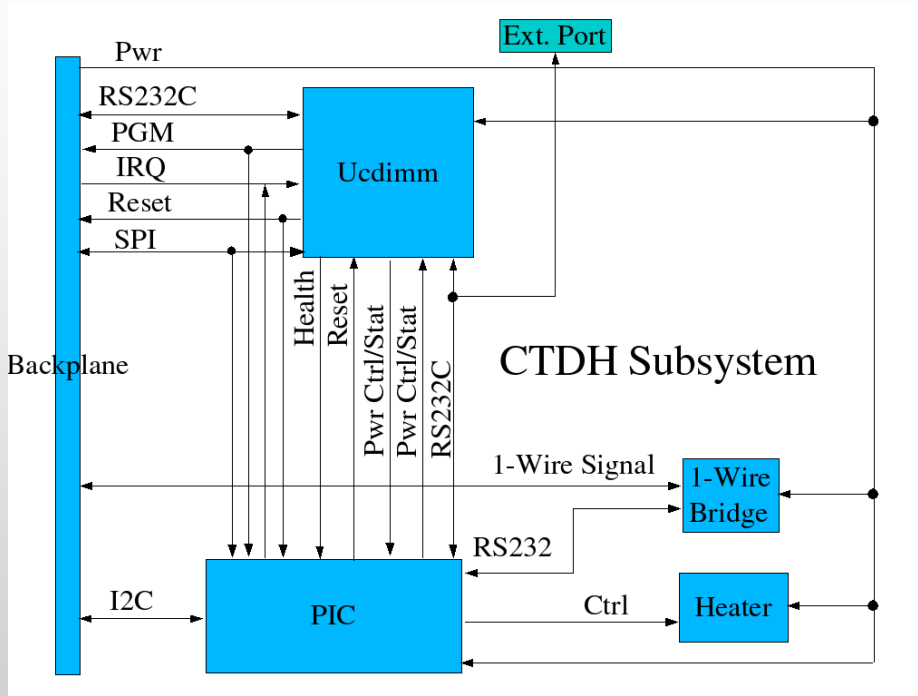
- **Communicate with Ground Station**
- **Backplane: Interface with other subsystems**
- **Instrument and Health data capture**
- **Control modes of operation**





CTDH design

- **Communication**
  - **SPI**
  - **I2C**
  - **RS-232**
  - **1-Wire**
- **Programming**
  - **In circuit serial programming (ICSP)**
  - **Enable Lines**

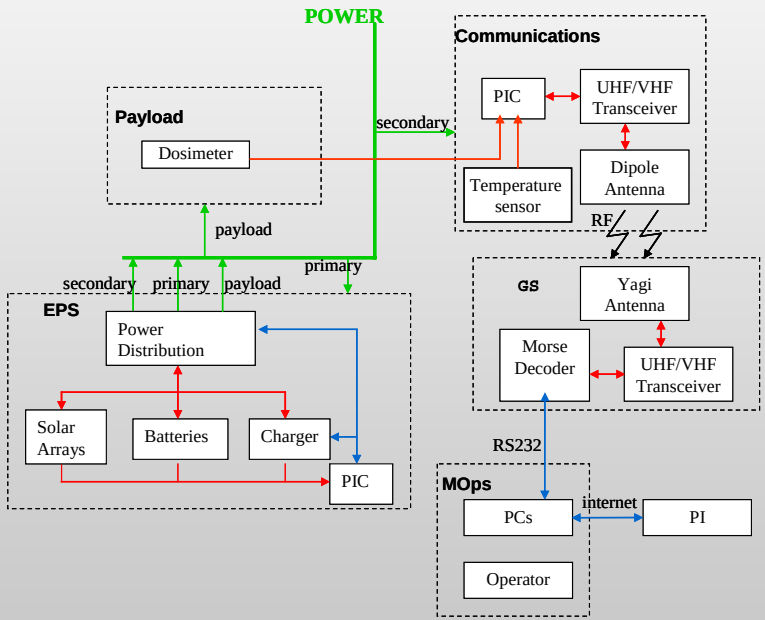


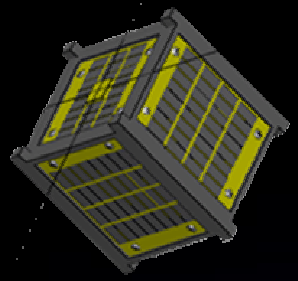
CTDH design

- **PIC monitor**
  - **Health**
  - **Single Event Upsets (SEU) and Latches (SEL)**
- **Radiation effects**
  - **SEU every 4436 days in stormy magnetic weather**

Final design

- **Issues with subsystem communication**
- **Payload and ADCS subsystems not mature**
- **EPS PIC**
  - **Antenna deployment**
  - **Power to subsystems**
  - **Simple power management**
- **Communication PIC**
  - **Telemetry**
  - **Morse Code**





Modular Platform

Need for Standards

- **Past lessons implemented**
- **Adopted by many**
- **Rapid development**
  - **DARPA –Falcon program**
  - **Operationally Responsive (ORS) – TacSat-1**
- **Space plug-n-play Avionics (SPA)**
- **… implementation 5 years**

Modularity

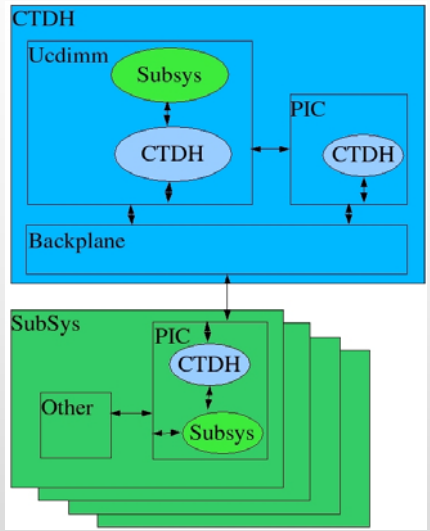
- **Pros**
  - **Improve system design.**
    - **Replace modules**
    - **Design modules independently**
  - **Reduced integration and testing time**
  - **Reduce non recurring engineering costs.**
    - **Transfer of intellectual knowledge**
  - **Multiple missions**
    - **Emphasis on payload design**
  - **Mass production**
- **Cons**
  - **Initial costs high**
  - **Designed for particular developer**
  - **Not compatible with Specialized missions**

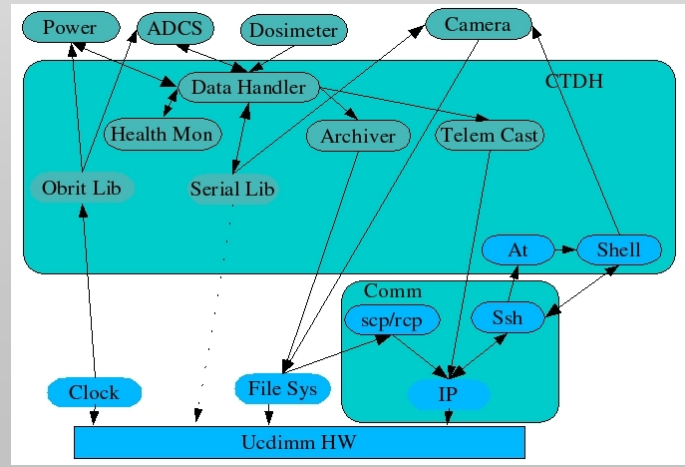
Small Satellite modular designs

- **SWARM**
  - **MIT**
  - **Bluetooth technology**
- **Aero Astro**
  - **Space Frame**
  - **SCOUT**
  - **SMARTBus™**
    - **Plug and Sense**
    - **Layered Software**
- **TEST**
  - **CubeSats**
  - **University of Illinois, University of Taylor**
  - **Standard communication interface- RS-422,I^2C**
  - **Interface module for each subsystem**

Proposed Platform - Software

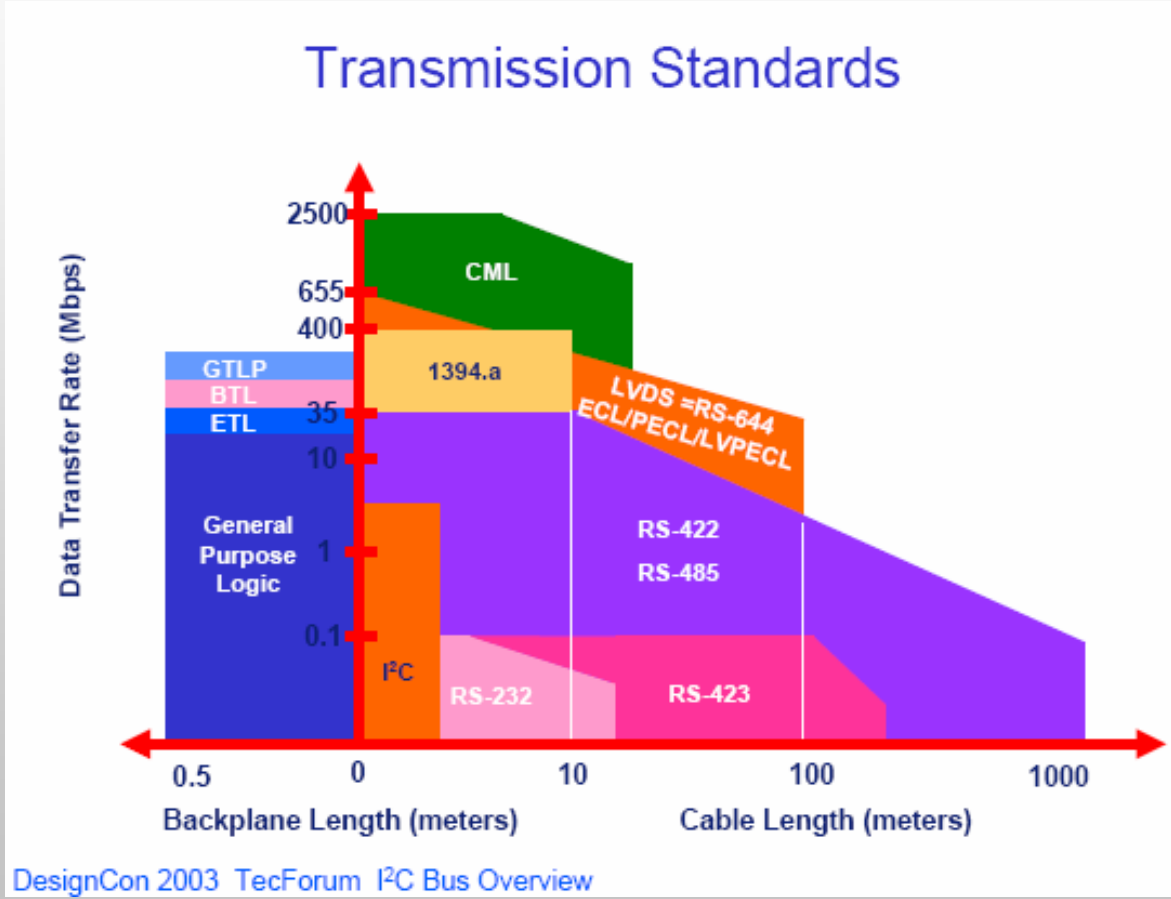
- **Software and logical interface**
  - **Controllers on each subsystem**
  - **Application software on main processor**
  - **Standard interfaces**
  - **Resource requests, provider and arbiter**
  - **Reprogramming**





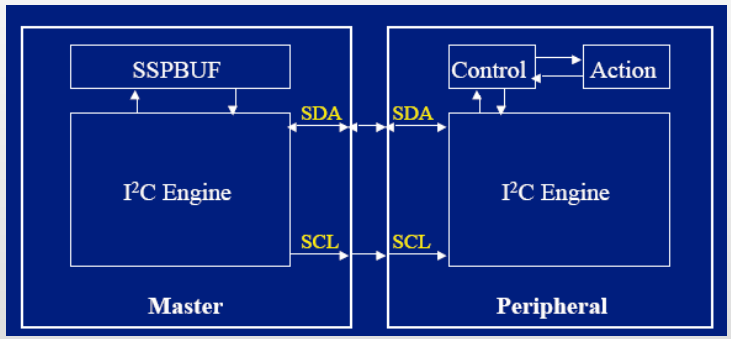
Proposed Platform -Electrical

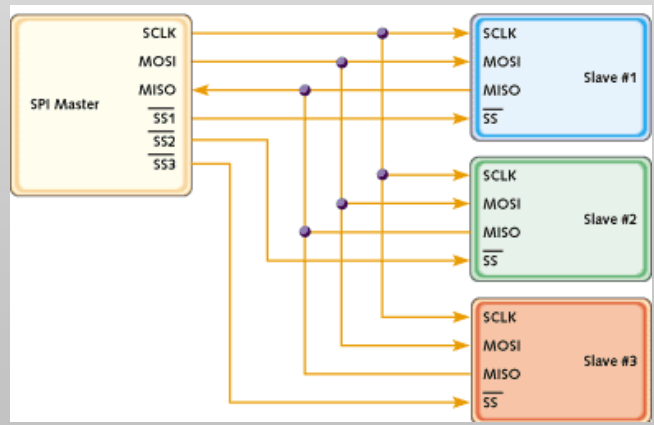
- **Communication bus**



Proposed Platform -Electrical

- **Communication bus cont..**
  - **I2C**
    - **Phillips**
    - **2 wire- Data and Clock**
    - **Single or Multiple Masters**
    - **Addressable slaves- 128 or 1024**
    - **100 kbps, 400 kbps , 3.4 Mbps**
  - **SPI**
    - **Motorola**
    - **3 wires- Data In, Data Out, Clock and x- number of slaves**
    - **Single Master ***
    - **> 1 Mbps**





Proposed Platform -Electrical

- **Communication bus cont..**
  - **RS-232**
    - **Common Standard**
    - **Asynchronous- Tx and Rx**
    - **Standard 19.2 kbps, but 115.2 kbps possible**
    - **Peer to Peer ***
  - **Final choice**
    - **RS-232:Control and Health Status**
    - **SPI: Legacy**
    - **I2C: Secondary bus, Video and Image collection**

Proposed Platform -Electrical

- **Power distribution**
  - **Common voltage levels**
  - **Division of power**
- **Control**
  - **Interrupt**
  - **Reset**
  - **Programming**
    - **FPGA's**
    - **PIC's**

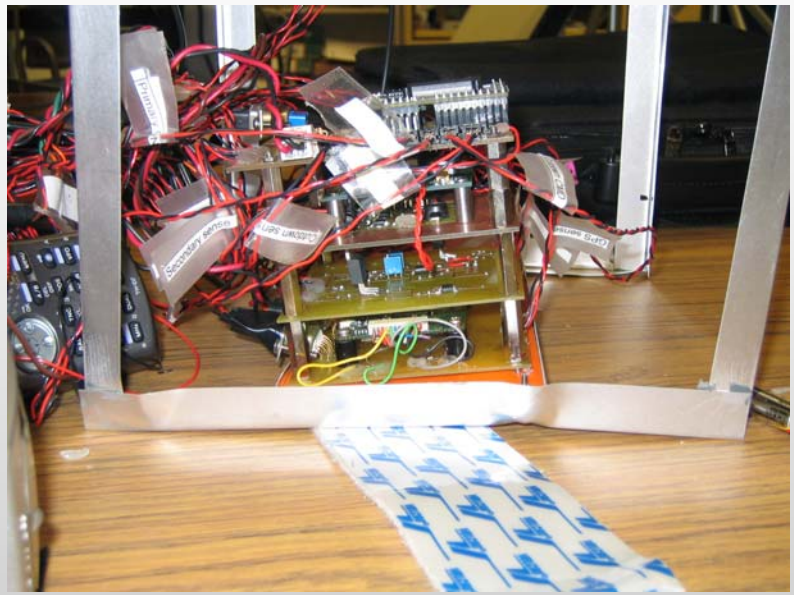
Proposed Platform -Electrical

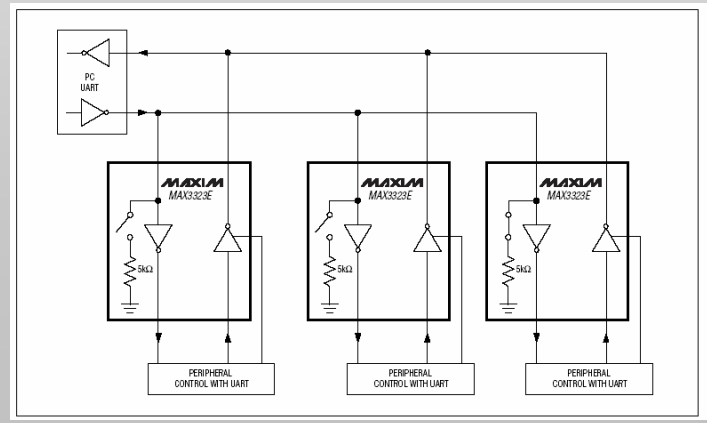
- **Final design**
- **Separate analog and digital grounds**
- **5 subsystems**

Signal group	Type	Number of lines	Signal group	Type	Number of lines
Communications	RS-232 Tx	1	**Power**	Secondary 28 V	2
	RS-232 Rx	1		Payload 3.3 V	2
	RS-232 enable	5		Payload 5 V	2
	I2c Data	1		Payload 12 V	3
	I2c Clock	1		Payload 28 V	10
	SPI Data out	1		Analog ground	20
	SPI Data In	1	**Control**	Interrupt	5
	SPI clock	1		Reset	5
	SPI enable	5		Programming Data/TDI	1
Power	Primary 3.3 V	2		Programming Clock/TCK	1
	Primary 5 V	2		TMS	1
	Primary 12 V	2		TDO	1
	Secondary 3.3 V	2		Programming enable	5
	Secondary 5 V	3		Digital ground	5
	Secondary 12 V	3	**Total**		**94**

HABS-Mk3

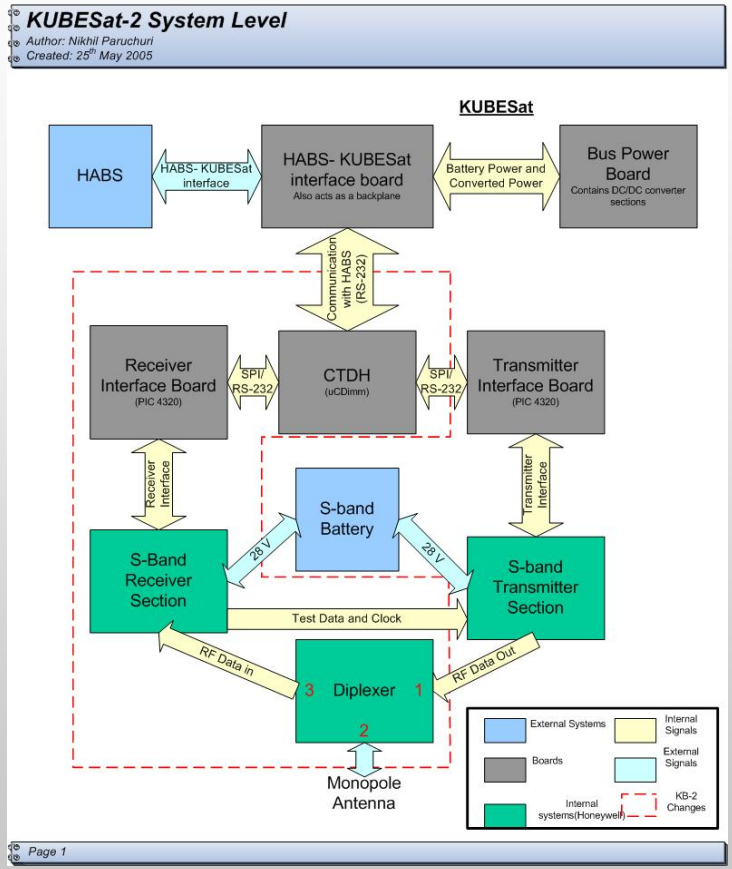
- **Necessity**
  - **Reduce weight**
  - **Robust**
  - **Reduce time of assembly**
- **Changes made**
  - **Backplane implemented**
  - **Multiplex RS-232**
- **Results**
  - **1 lb reduction**
  - **Assembly time reduced to 2 hours**
  - **3 flights**





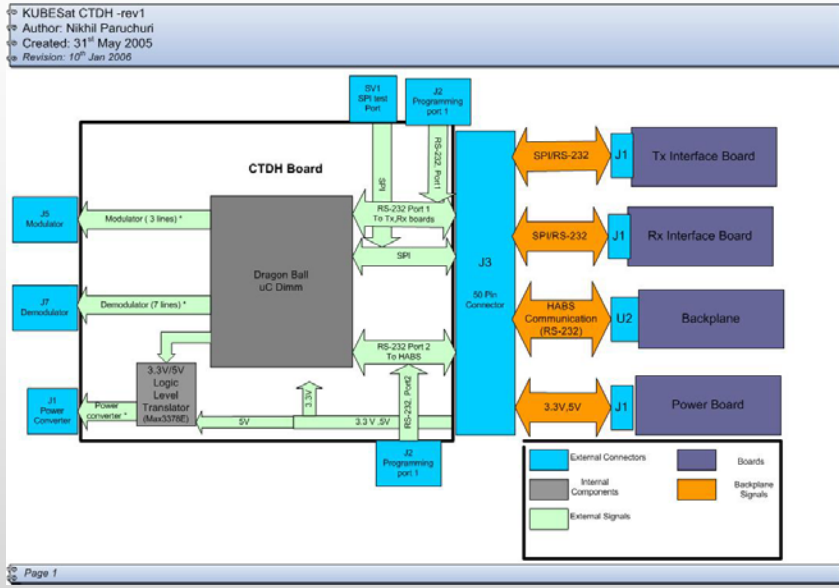
KUBESat-2

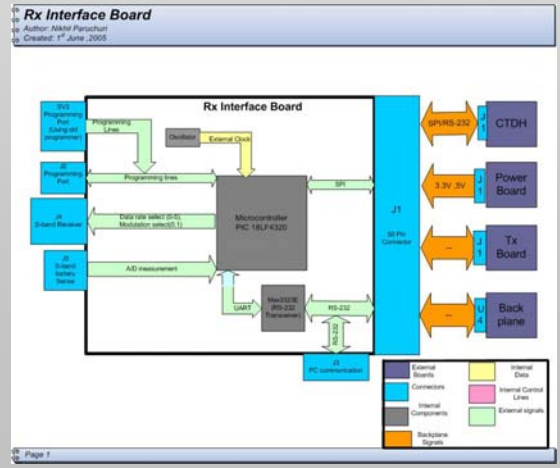
- S-band transceiver
- Ground Station control
- HABS interface
  - Power
  - Communication
  - Analog lines
  - Control

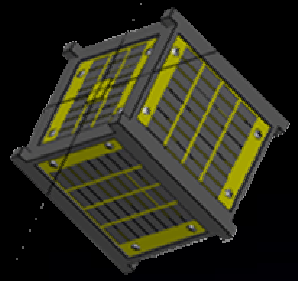


KUBESat-2 system design

- **CTDH**
  - **Communication with HABS**
  - **Control of subsystems**
  - **Redundant communication buses**
- **Rx and Tx interface boards**







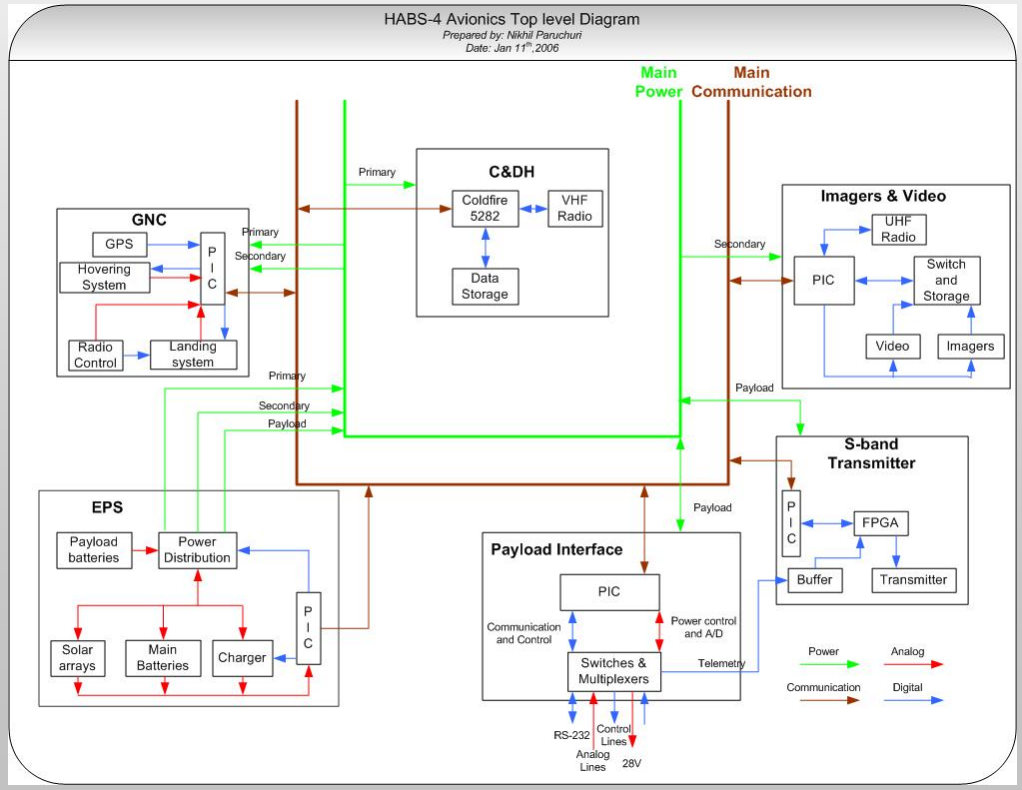
Future Work

Future work

- **Testing of KUBESat-2 software**
- **HABS-Mk4**
  - **Hovering**
  - **Controlled landing**
  - **Standard payload interface**
  - **S-band transmitter**
  - **Video**
  - **Mass production**

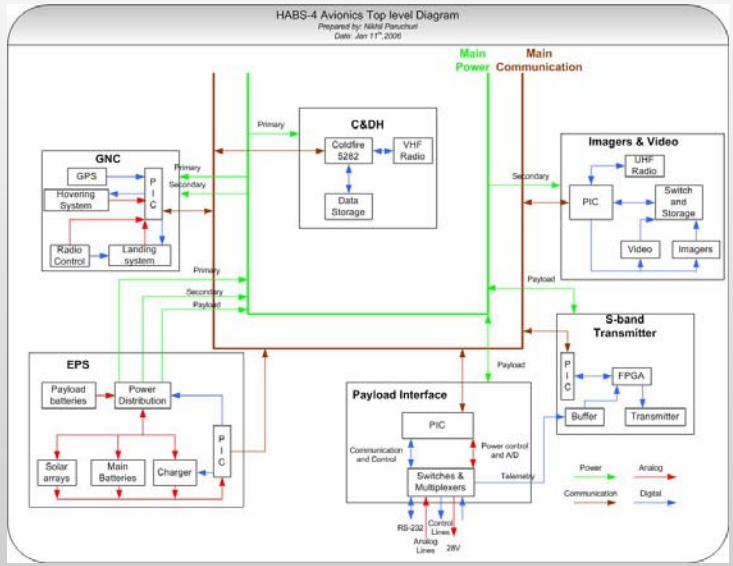
HABS-Mk4, proposal

- **Future Satellites considered.**
- **Control and Data Handling (C&DH)**
  - **Top priority communication**
  - **Legacy processor- Coldfire**



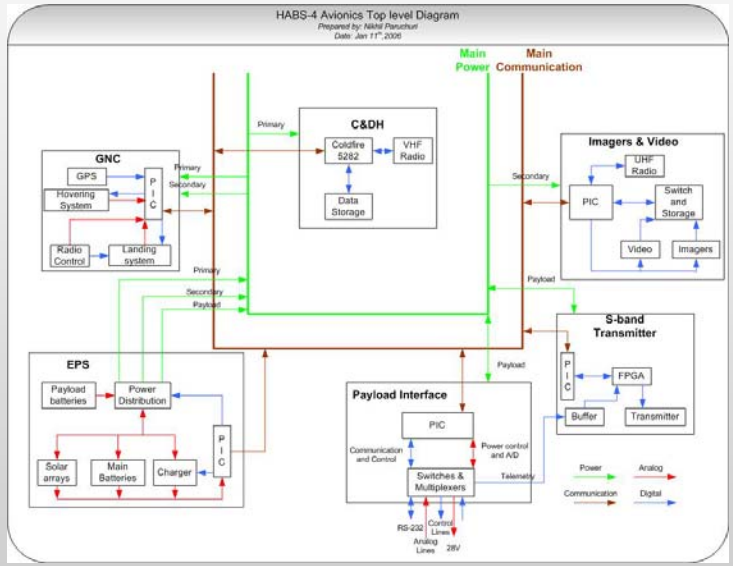
HABS-Mk4, Avionics

- **Guidance and Navigation Control (GNC)**
  - **GPS**
    - **DGPS**
  - **Hovering**
    - **Pressure valve**
    - **Ballast control**
  - **Landing**
    - **Spherachute**
    - **Radio Control**



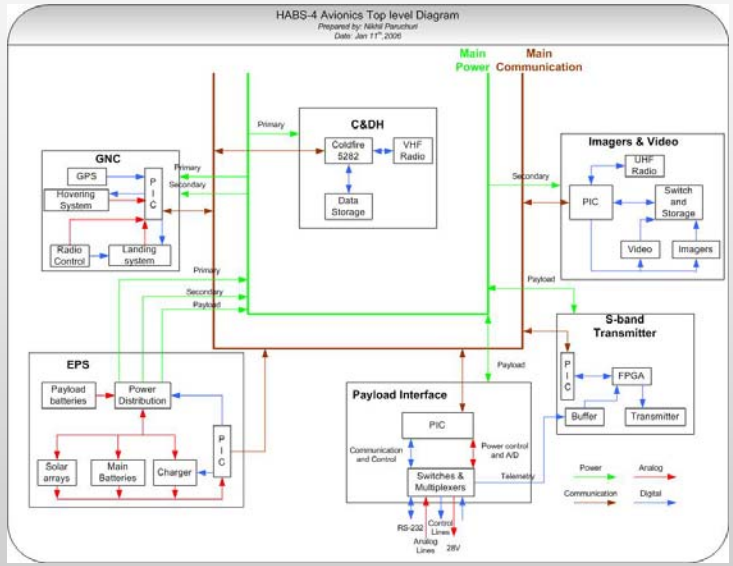
HABS-Mk4, Avionics

- **Electrical and Power subsystem**
  - **Main power source**
    - **Rechargeable batteries**
    - **Solar cells**
  - **Payload power source**
    - **Adopted based on payload**
- **Images and Video**
  - **UHF link**
  - **Landing control**



HABS-Mk4,Payload interface

- **S-band transmitter**
  - **Payload data buffer and transmit**
  - **FPGA**
- **Multiple payloads**
  - **RS-232 control**
  - **28 V standard power bus**
  - **Analog and Control lines**
  - **Route telemetry to S-band transmitter**



Conclusions

- **Phase-1 systems implemented and tested**
- **Modular platform developed from Phase-1 lessons**
- **HABS-Mk3 & KUBESat-2 , limited implementation**
- **HABS-Mk4 base for future satellite designs**
- **Smart software, layering**

Thank you !!

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Honeywell

KU The University of Kansas