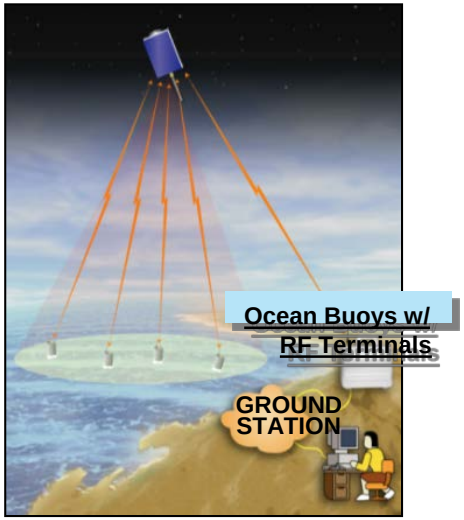
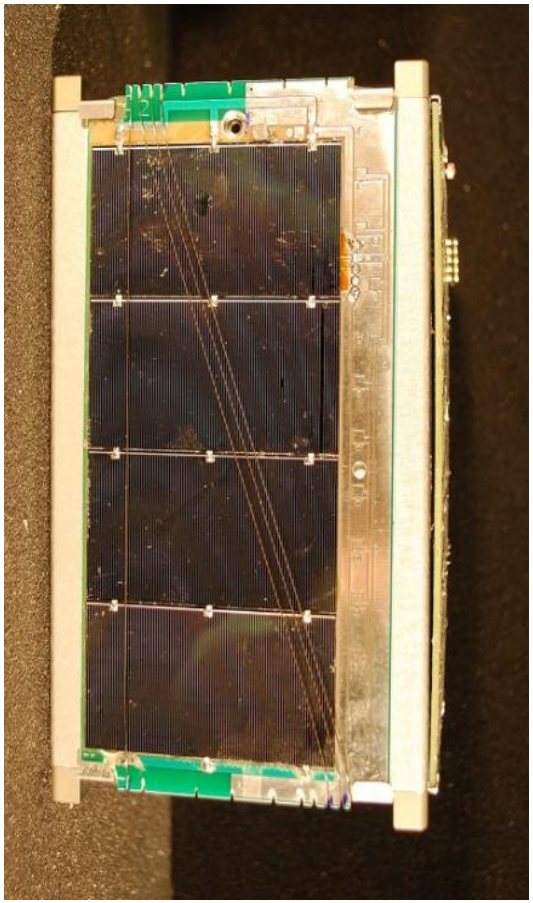
USNA Small Sat Successes: Very Lowcost Student Project Approach

Jun 2018 NASA Goddard



Bob Bruninga WB4APR
US Naval Academy Satellite Lab
bruninga@usna.edu



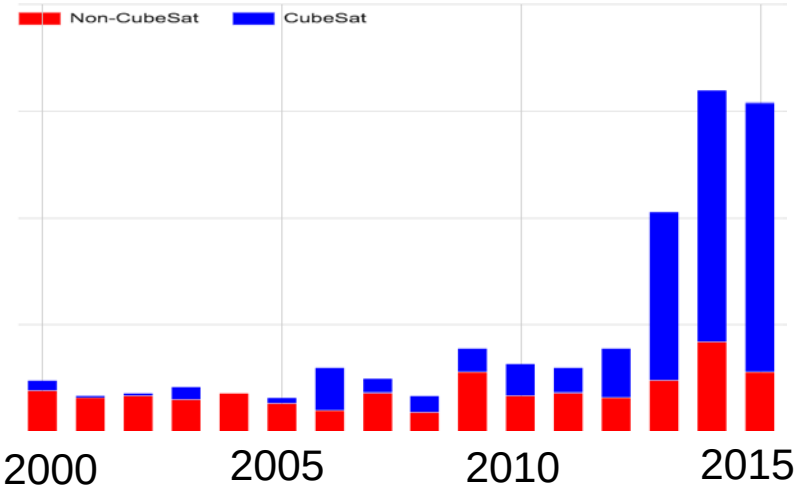
A satellite relay channel for Amateur Satellite User data anywhere on earth.

Mission

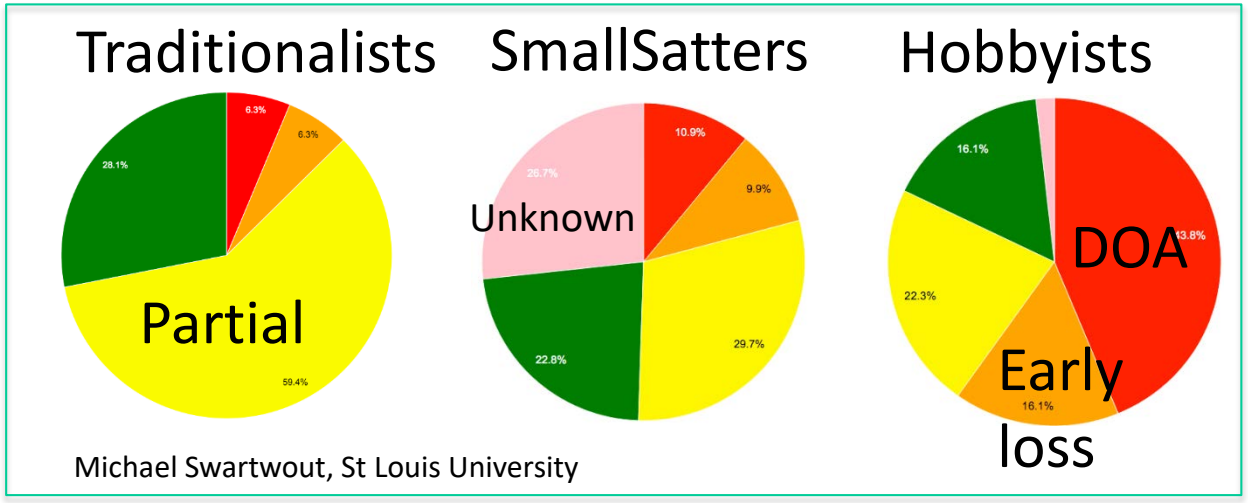
Success Statistcs

More & More Cubesats…

Offer all new capabilities…

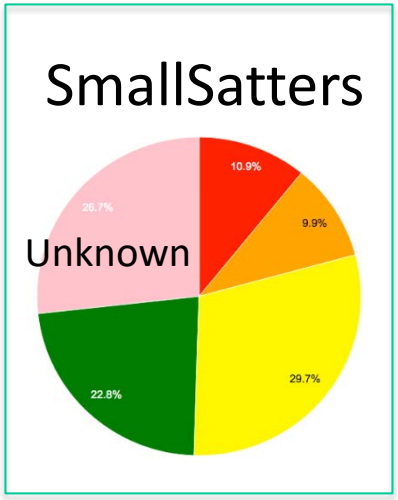


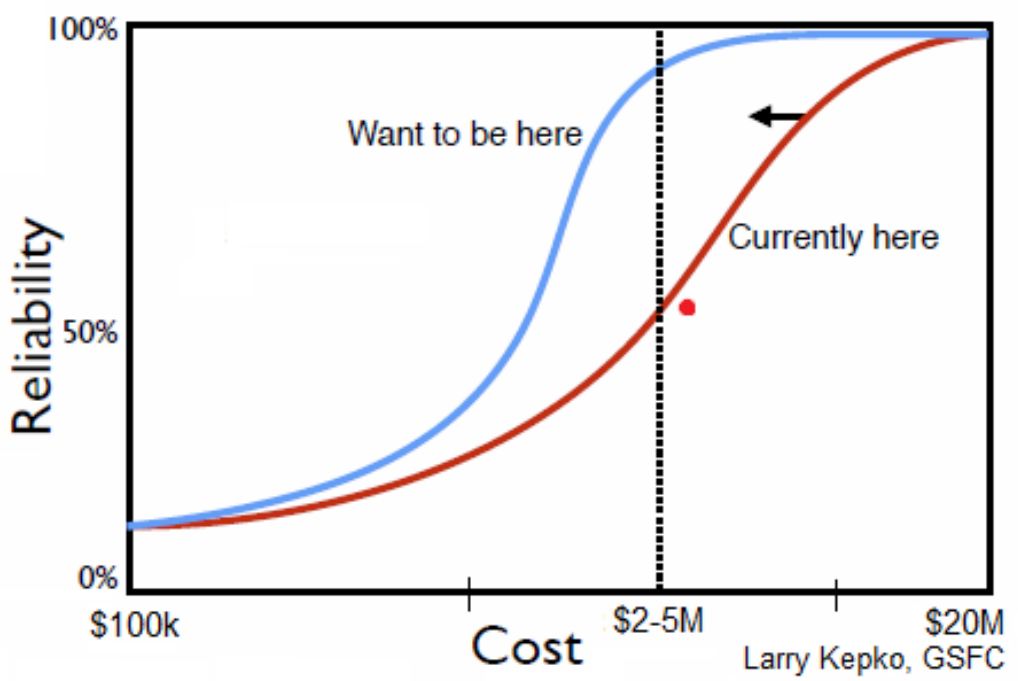
How are they Doing?



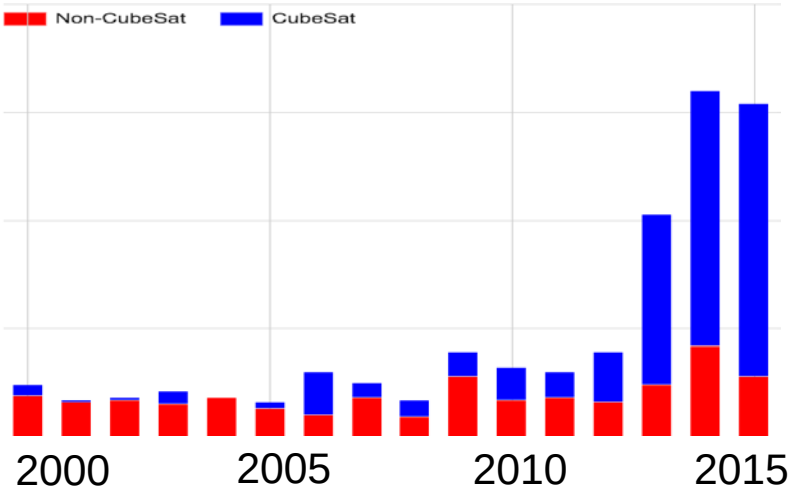
2015 data

How are they Doing?



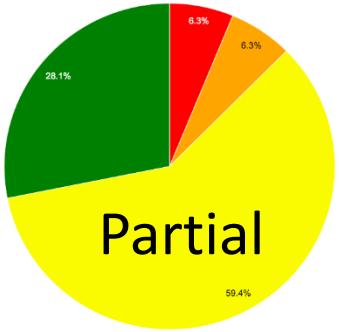


HFSAT (USNA-1603)

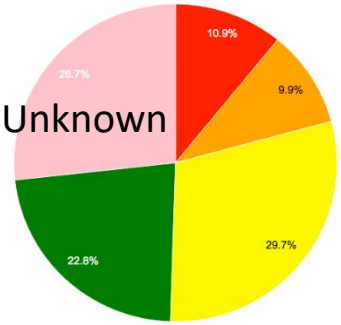


How are we Doing?

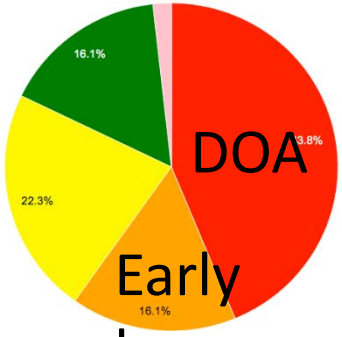
Traditionalists



SmallSatters



Hobbyists

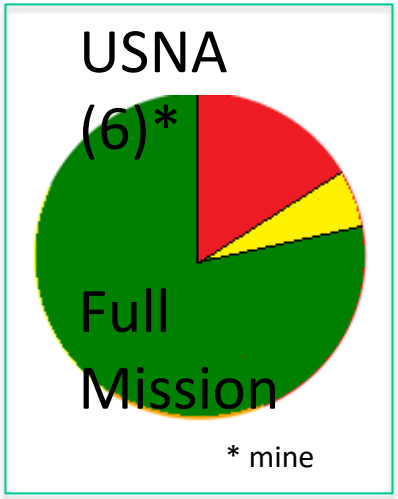


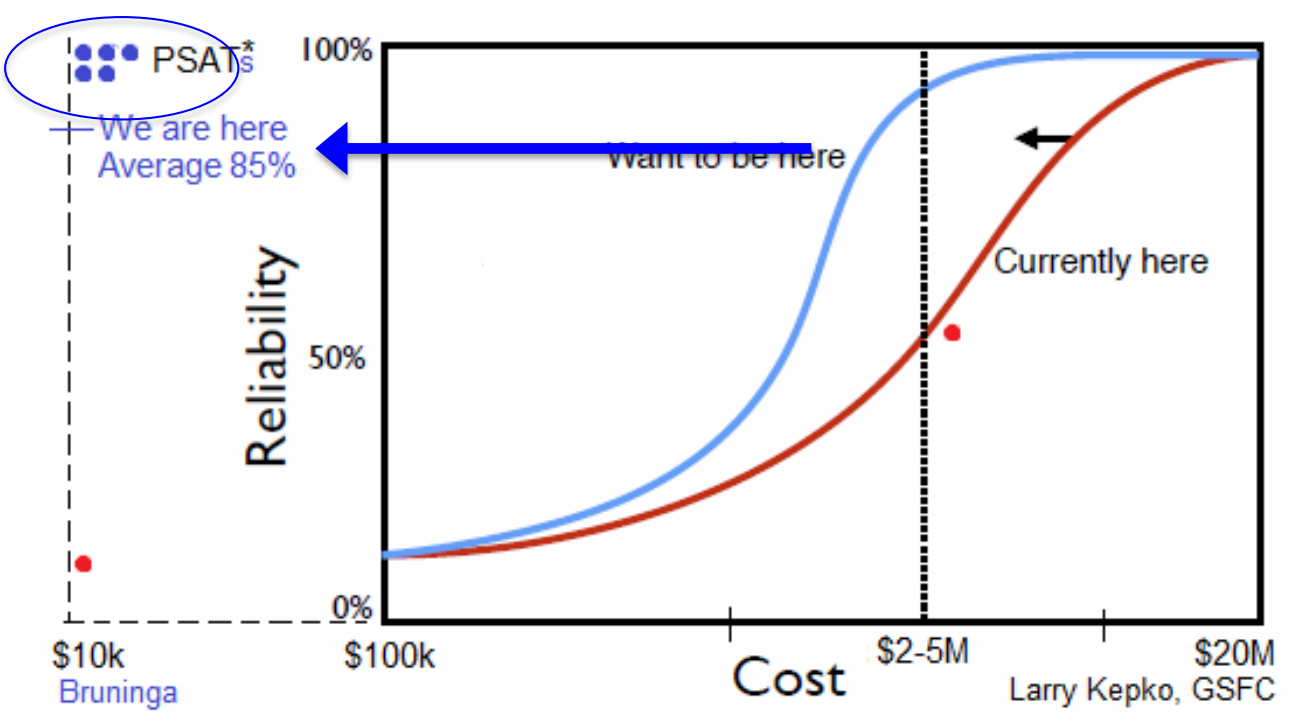
Michael Swartwout, St Louis University

USNA (6)*

* mine

How are we Doing?





Cubesat Remote Data & Comms Transponders

A satellite relay channel for Amateur Satelilte User data anywhere on earth.

Engineering Educational Objective:

One or two semester student engineering projects

Individual engineering responsibility

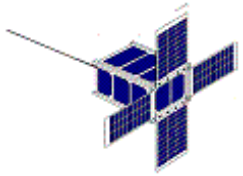
Low cost

Driven to completion

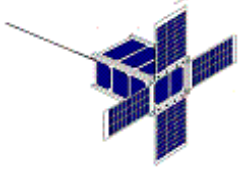
Where Failure (learning) is an option

Quicker Student involvement using a Ground Terminal Operational Missons

Ground Terminal Applications Focus (force tracking and text-messaging)



Supports Student Experimenters
School missions/movements
Theater area communications
and Emergency Response Comms



The Yard Patrol Craft

Education

Force

Multiplier!

APRS Global data network

Solution: Ground Terminal Applications Focus

Supports Student Experimenters world wide

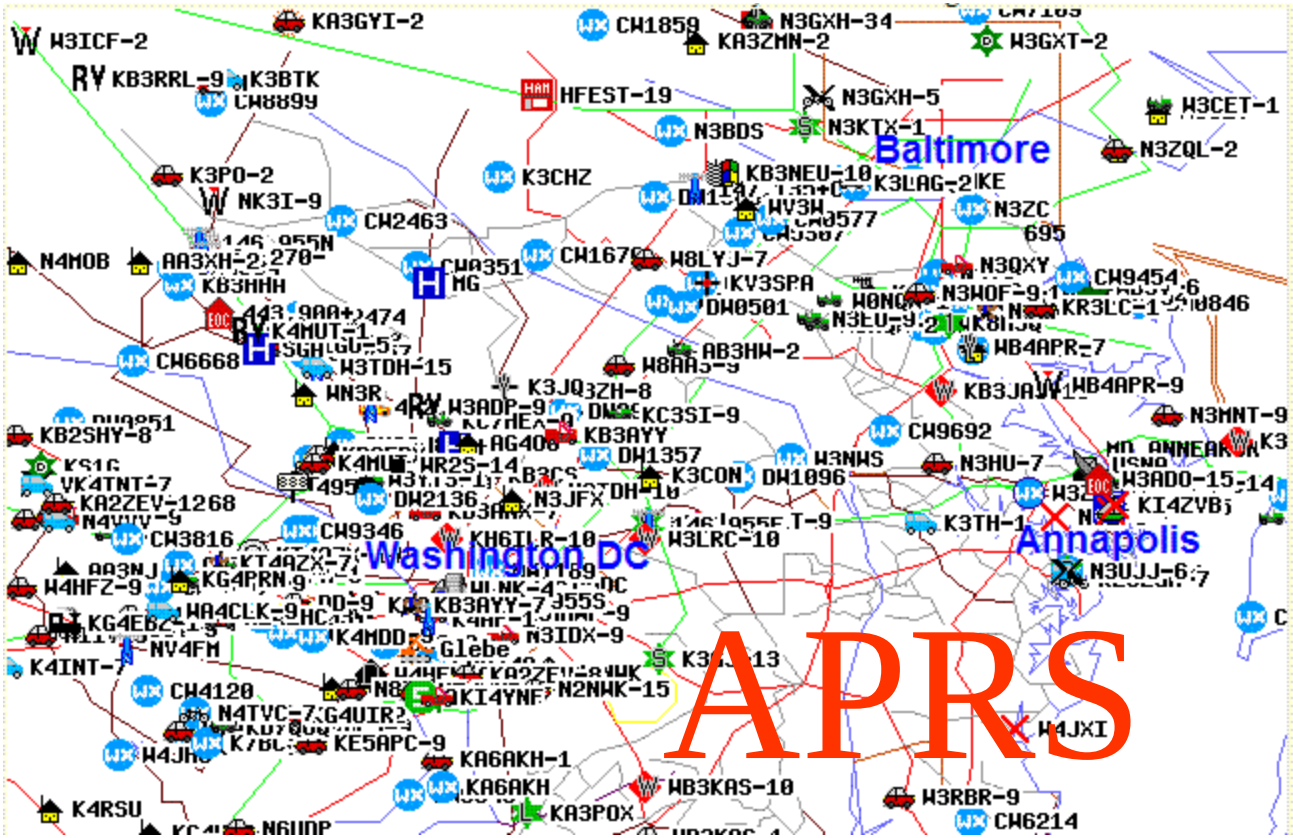
OR

OR

OR

Communications Mission Background

APRS is everywhere * (Remote Data Relay)



FOCUS:

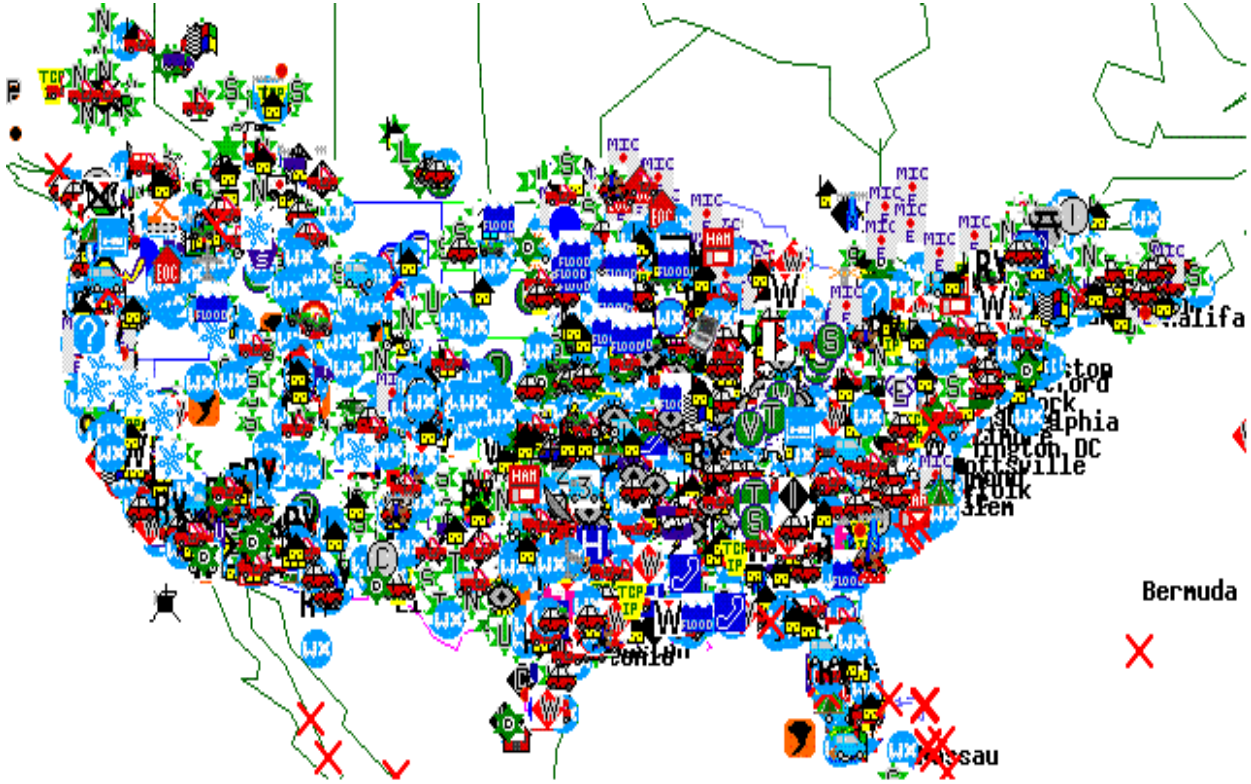
"Network Centric" & Remote Sensor Experiments

300 stations
In 35 miles

Find any station, Any map, Anywhere- http://aprs.fi

APRS Terrestrial Data Relay Network

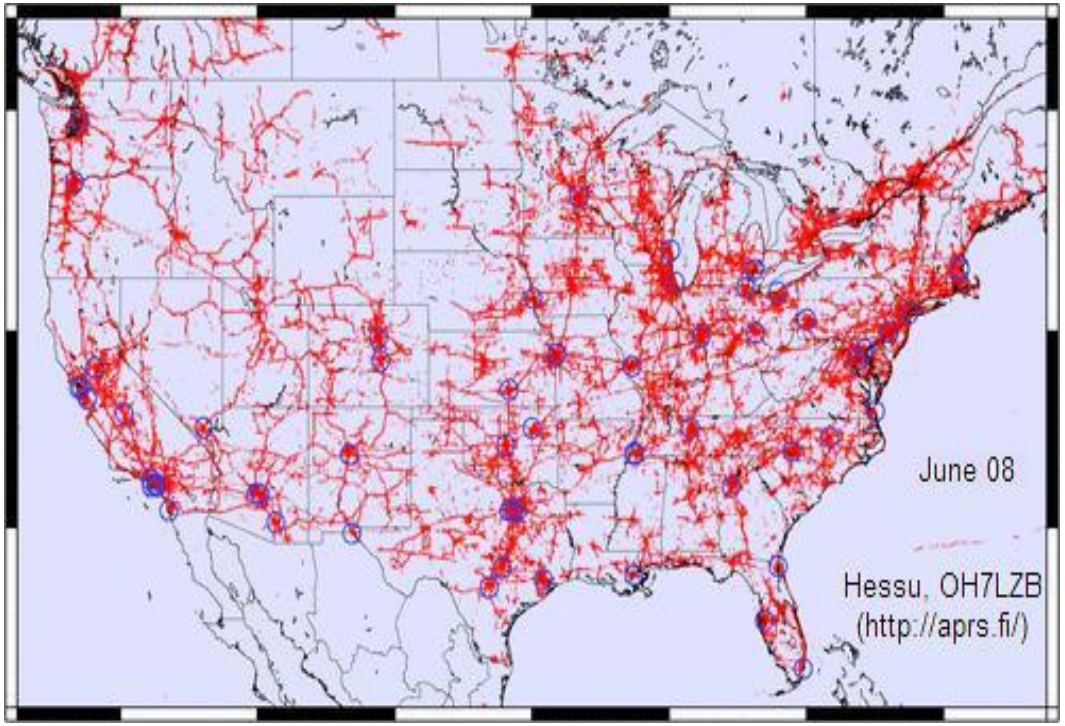
- Supports over 20,000+ terrestrial users and experimenters.



- But stops at the shoreline and has huge holes in the wilderness

APRS Global data network

There are terrestrial network holes everywhere

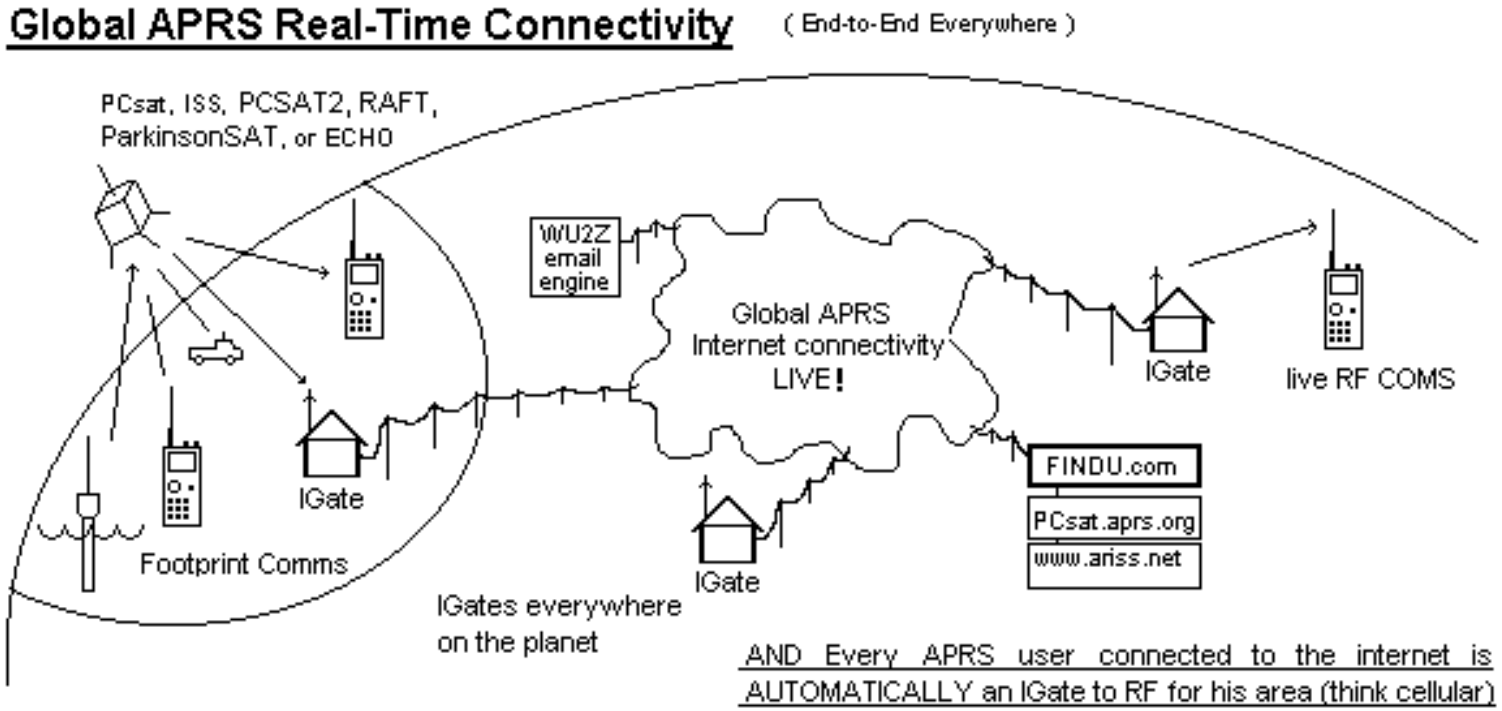


Just like cell coverage,

Maybe 70% of USA users are actually out of range of the terrestrial network in rural areas

Hence the need for a satellite relay as well…

APRS Space & Global Internet linked Data Network



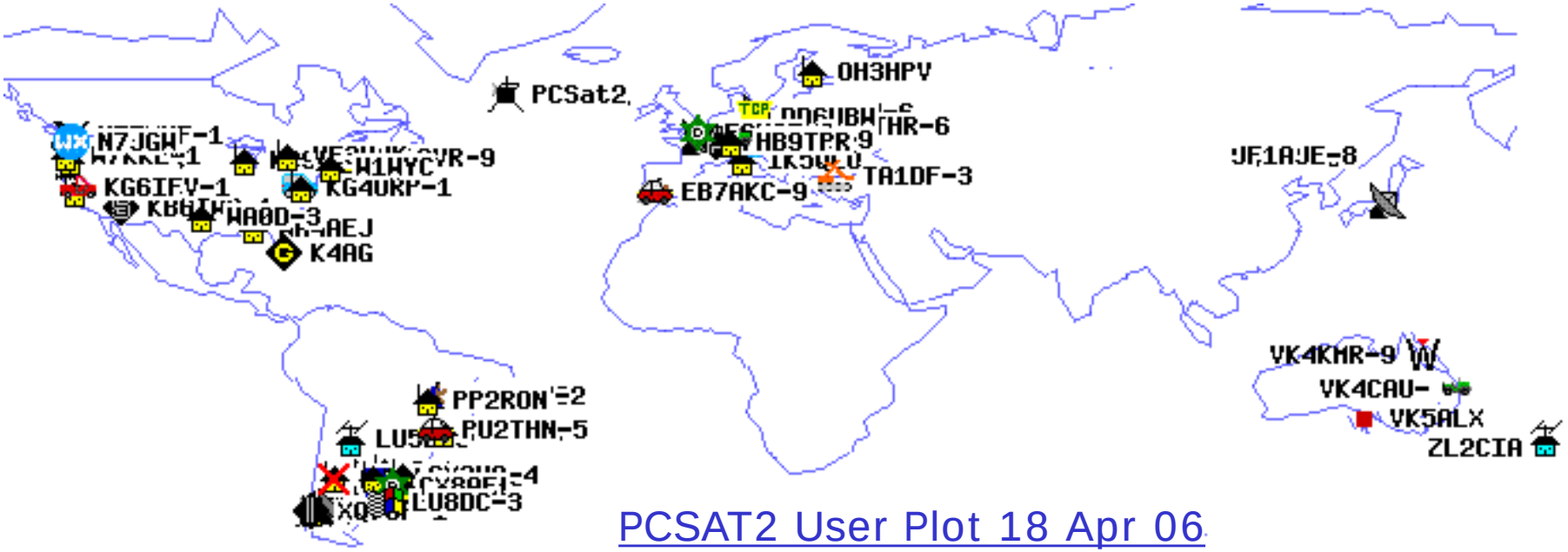
APRS Global Packet Radio Network

Internet Linked for live Communications

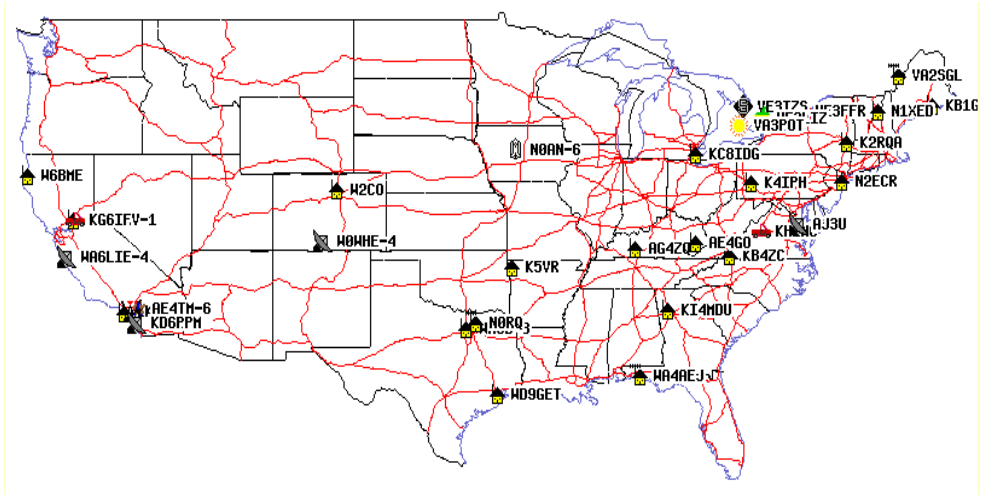
Automatic Packet Reporting System

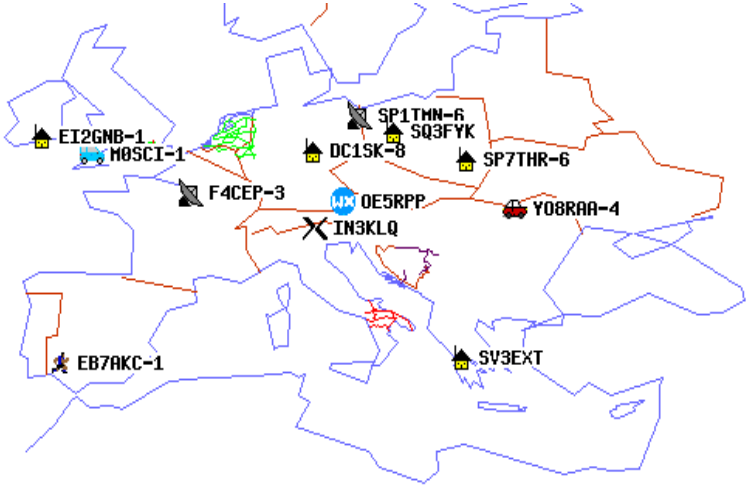
APRS Global data network

Satellite Users more sparse – Need to Track to Use



PCSAT2 User Plot 18 Apr 06





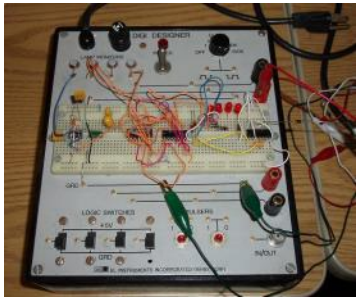
APRS Global data network

Remote Sensor Projects

Naval Academy Student Project

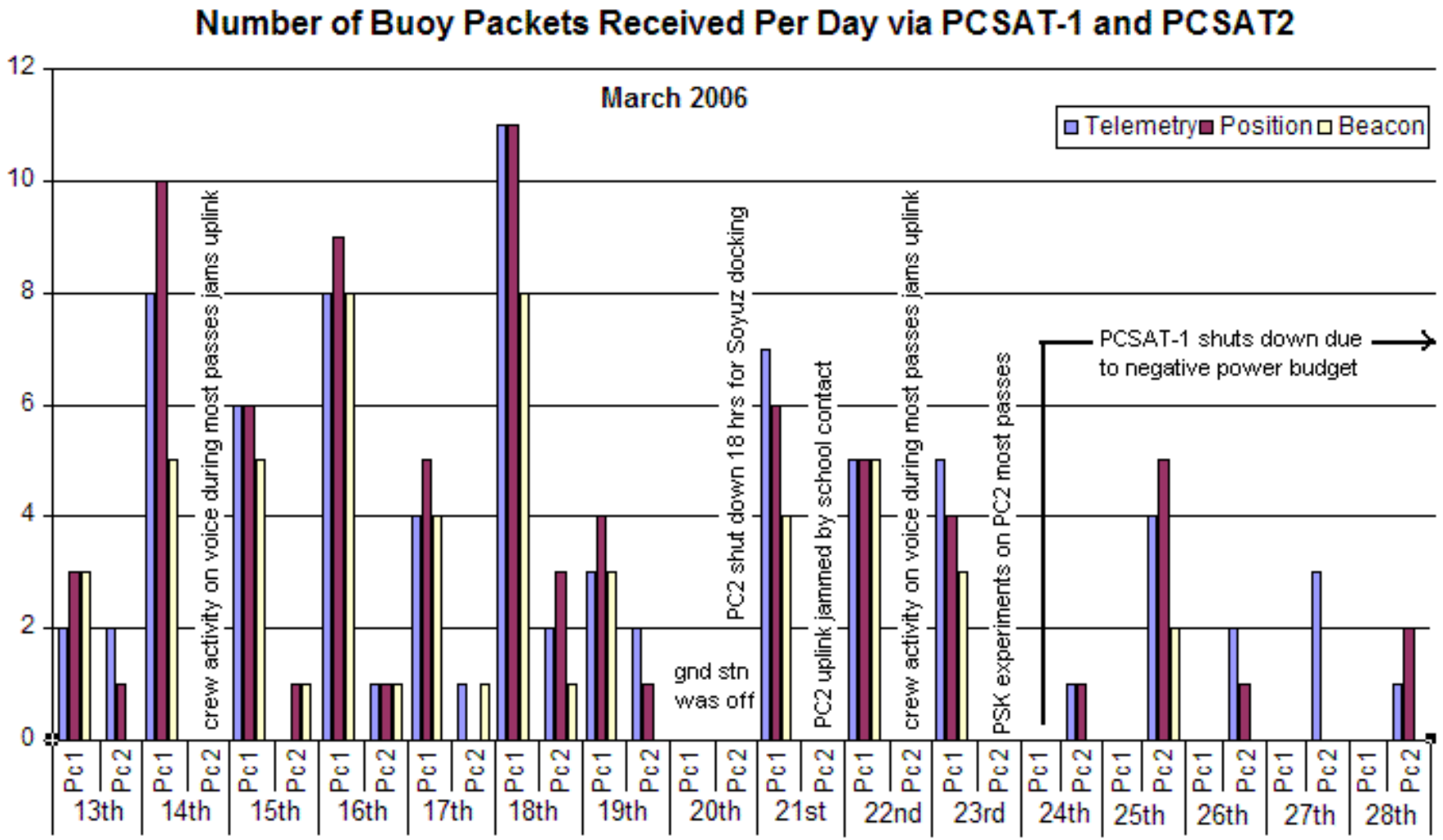
* If free-floating, do not disturb.
* If aground, move to deep water and advise bruninga@usna.edu
* If later than 30 Nov 2006, recover and advise above.

2006 15:1 reduction 2008



See Buoy Location and Telemetry at
http://www.ew.unsa.edu/~bruninga/buoy4.html

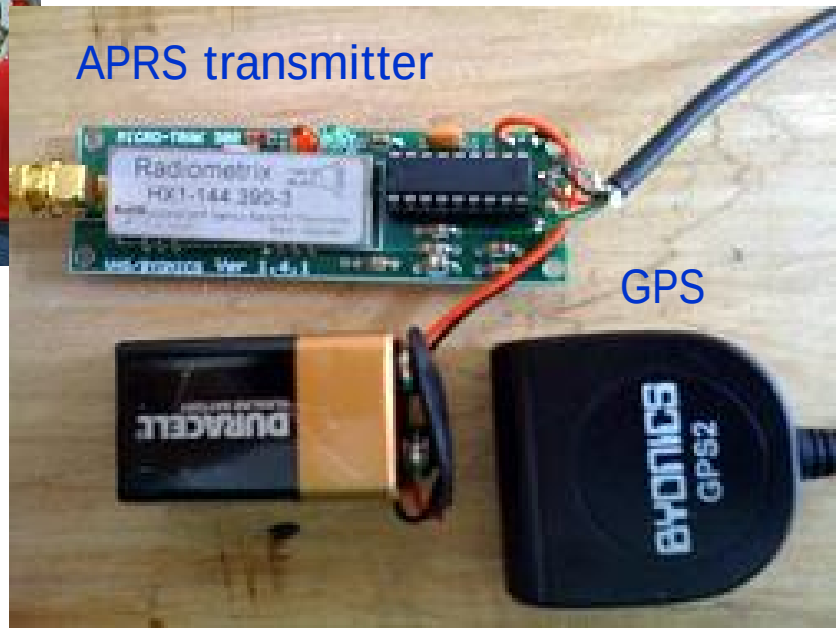
Remote Buoy Baseline Test – Success of 1 min Xmit rate



APRS Global data network

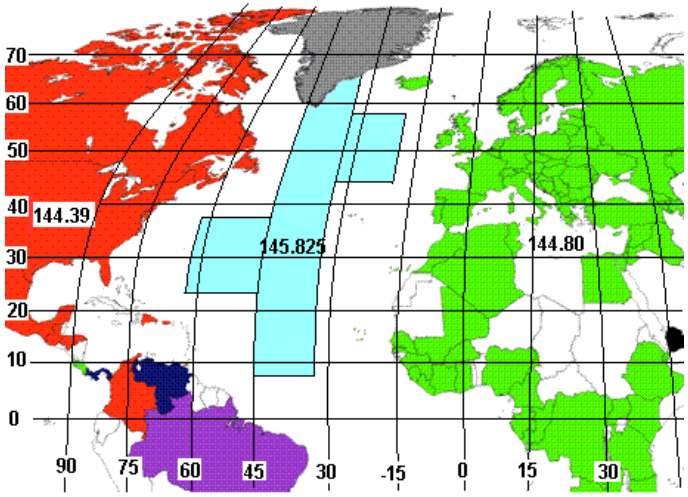
Example Remote Sensors using APRS Protocol

Very Simple



Why We Need Amateur Satellite Transponders

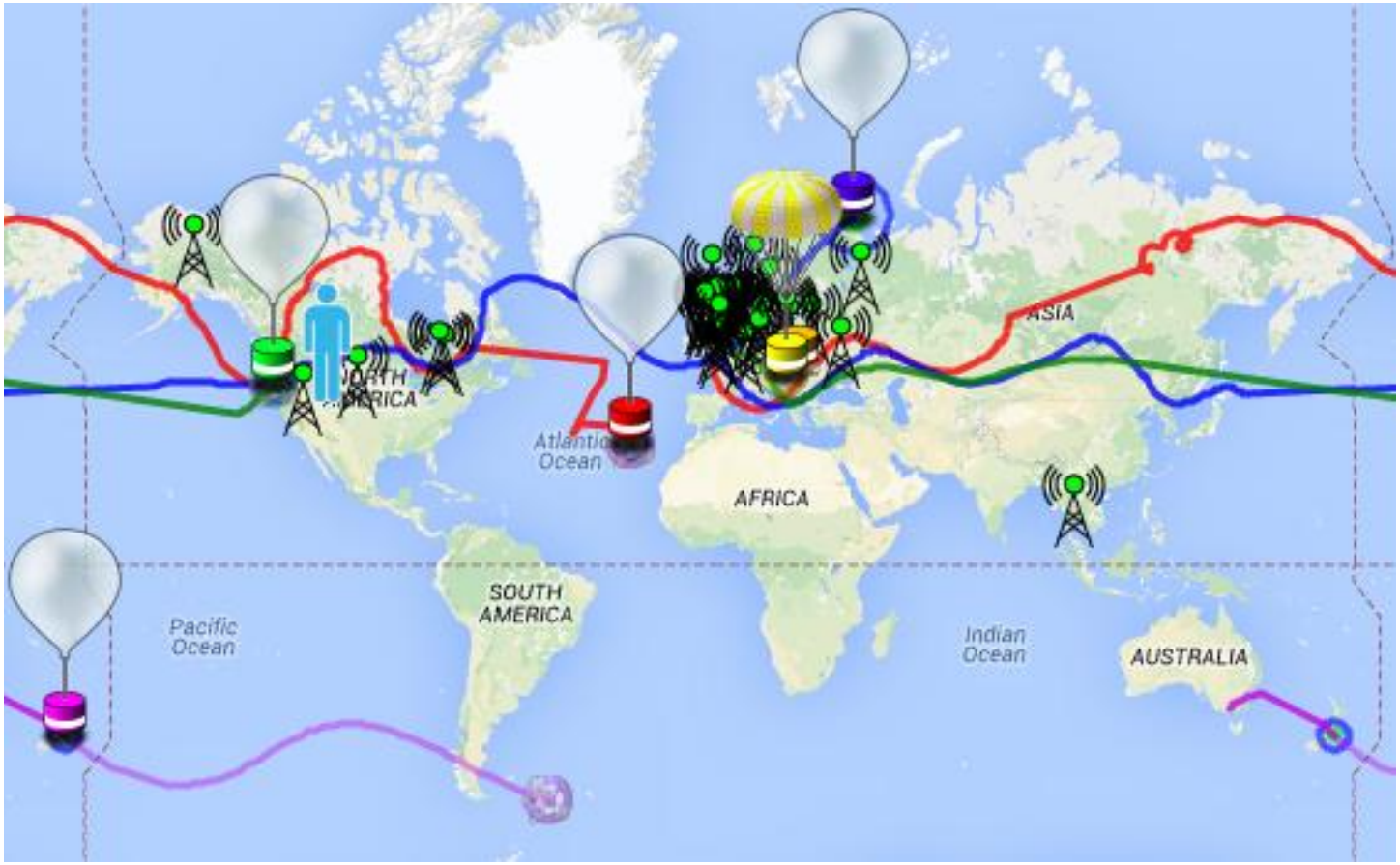
- Transatlantic APRS balloon launched and tracked through terrestrial network
- Lost comms over Atlantic Ocean
- It could have been picked up by our Psat/Pcsat transponder or the ISS



Possible APRS TransAtlantic Freq Plan

Global Wilderness Areas (90% of Earth)

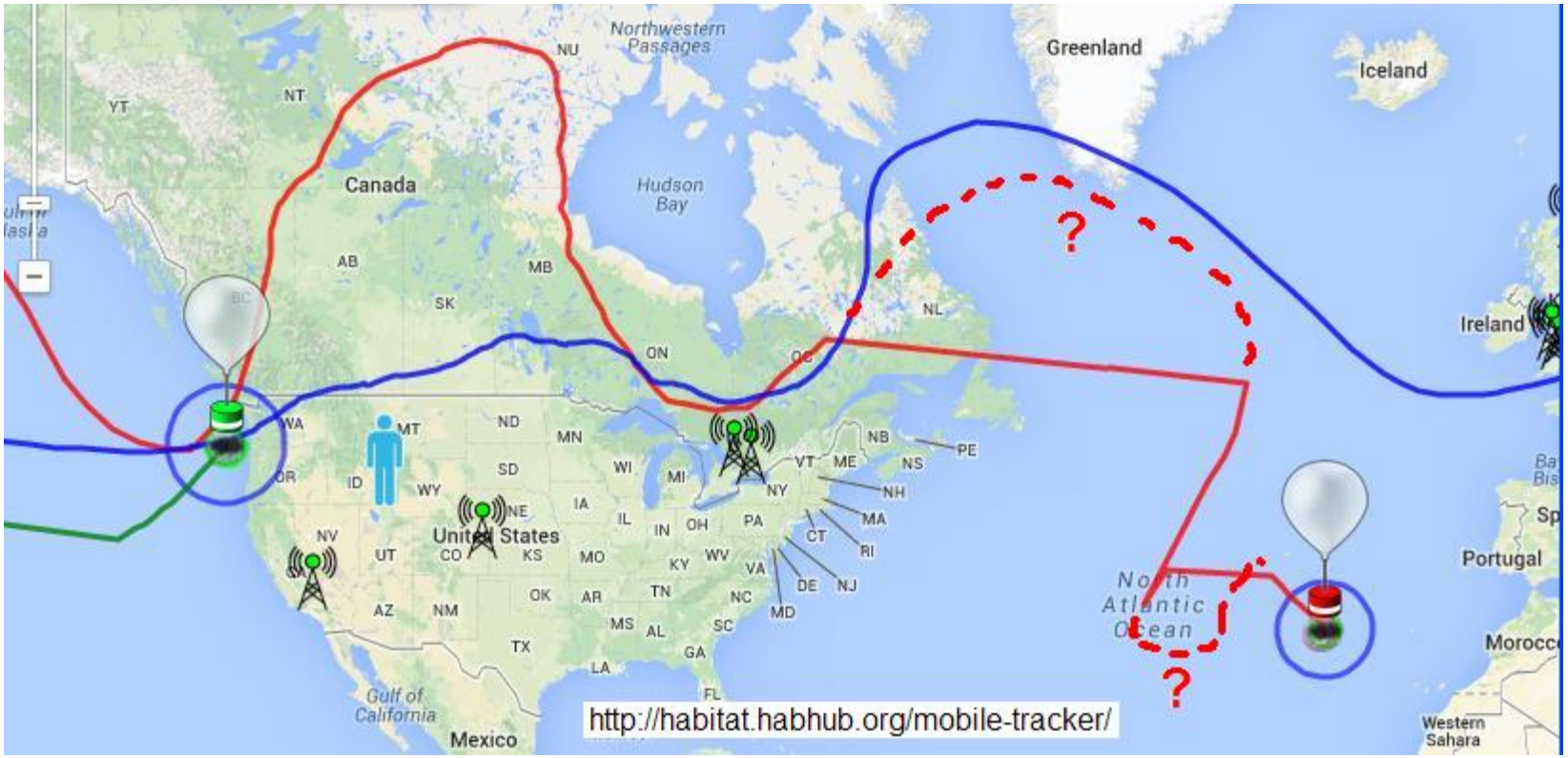
- Live Global APRS Balloon Tracking Web Page



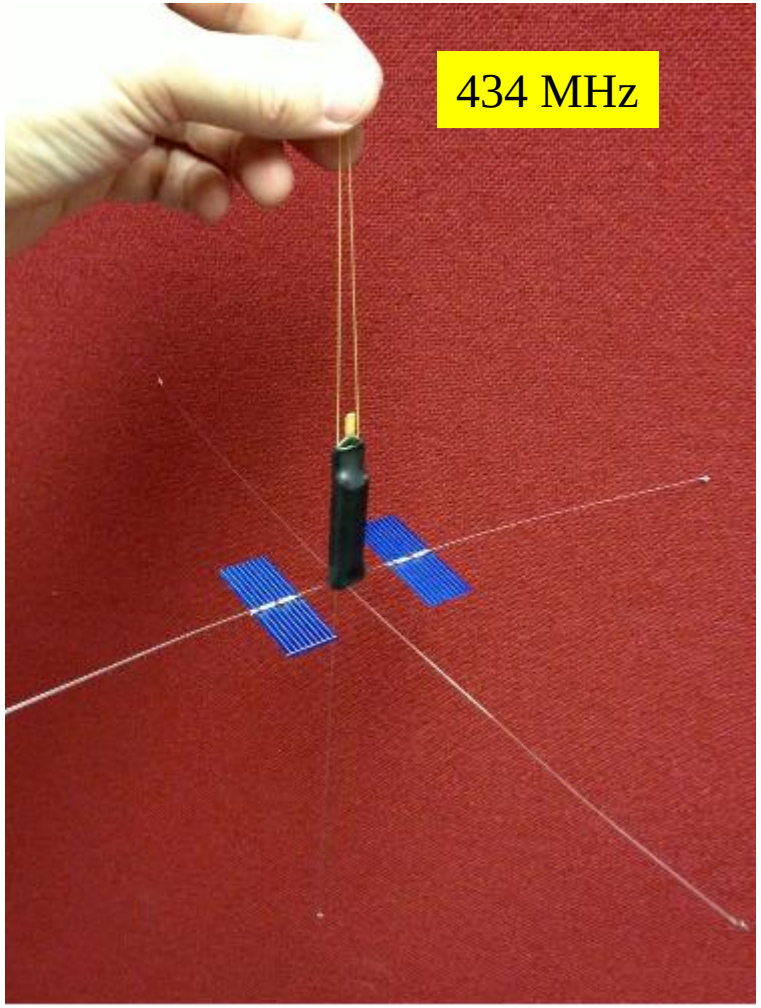
Global Wilderness Areas (90% of Earth)

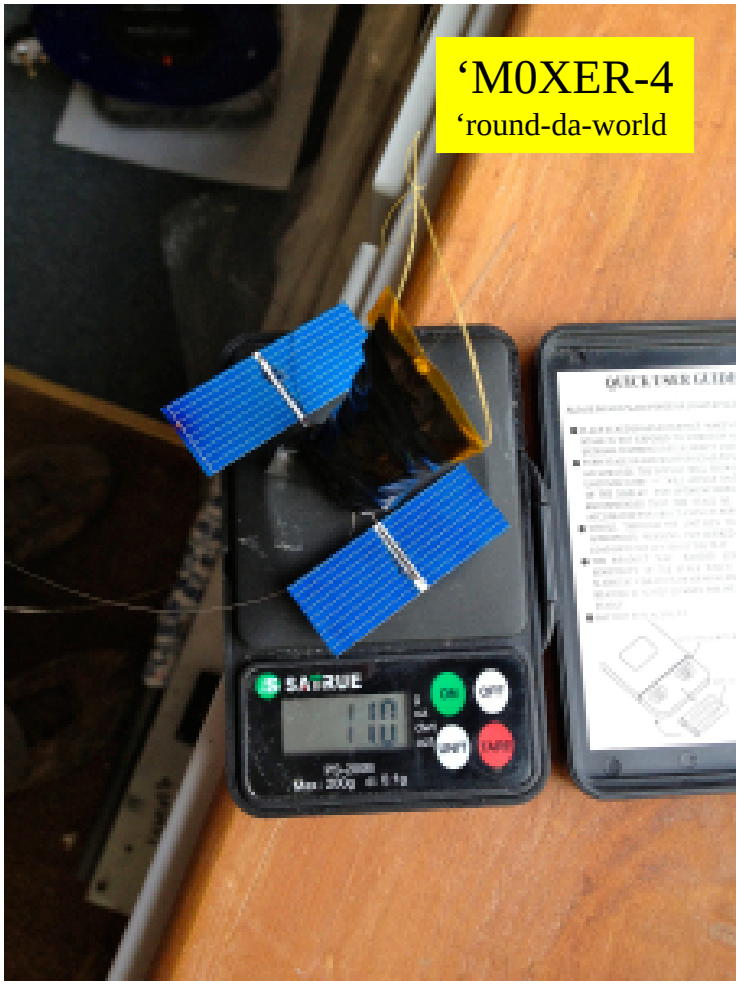
M0XER-3, 4 and 6

- Live Global APRS Balloon Tracking Web Page



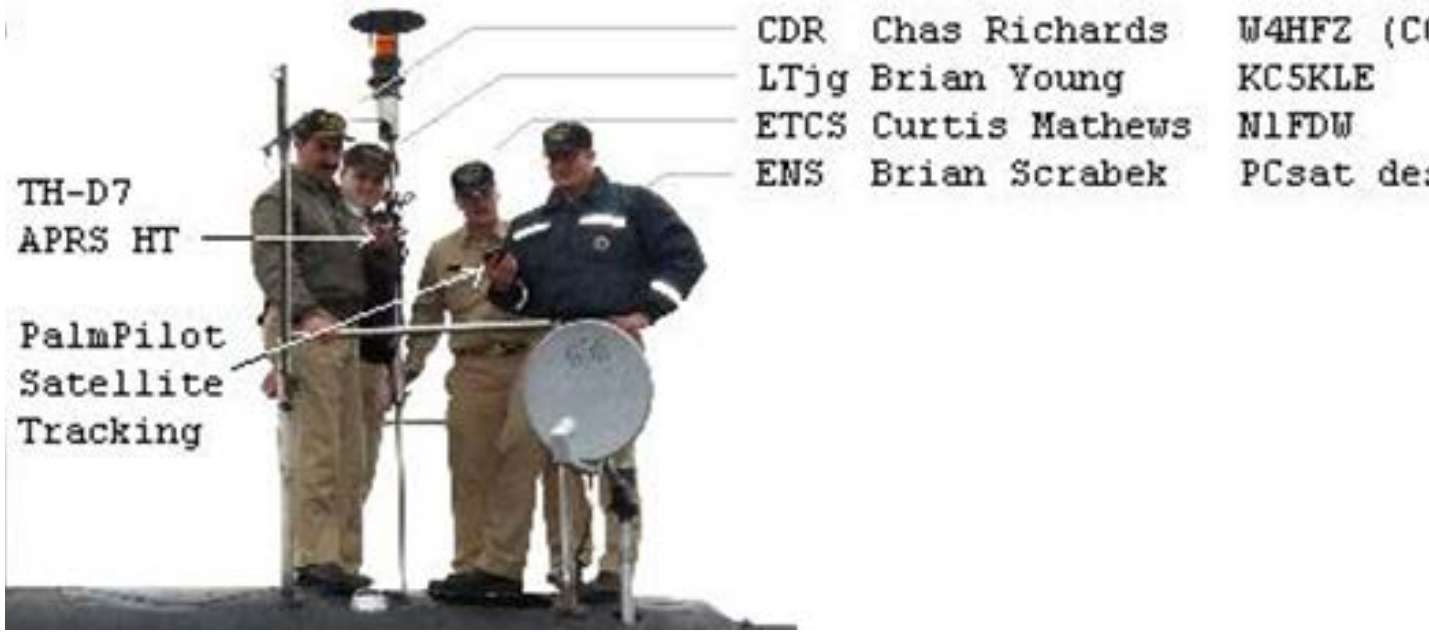
Tiny M0XER APRS (balloon data) payloads





Hand-Held Satcom via APRS & Psat

Ground Terminal is Walkie-Talkie, and Tablet



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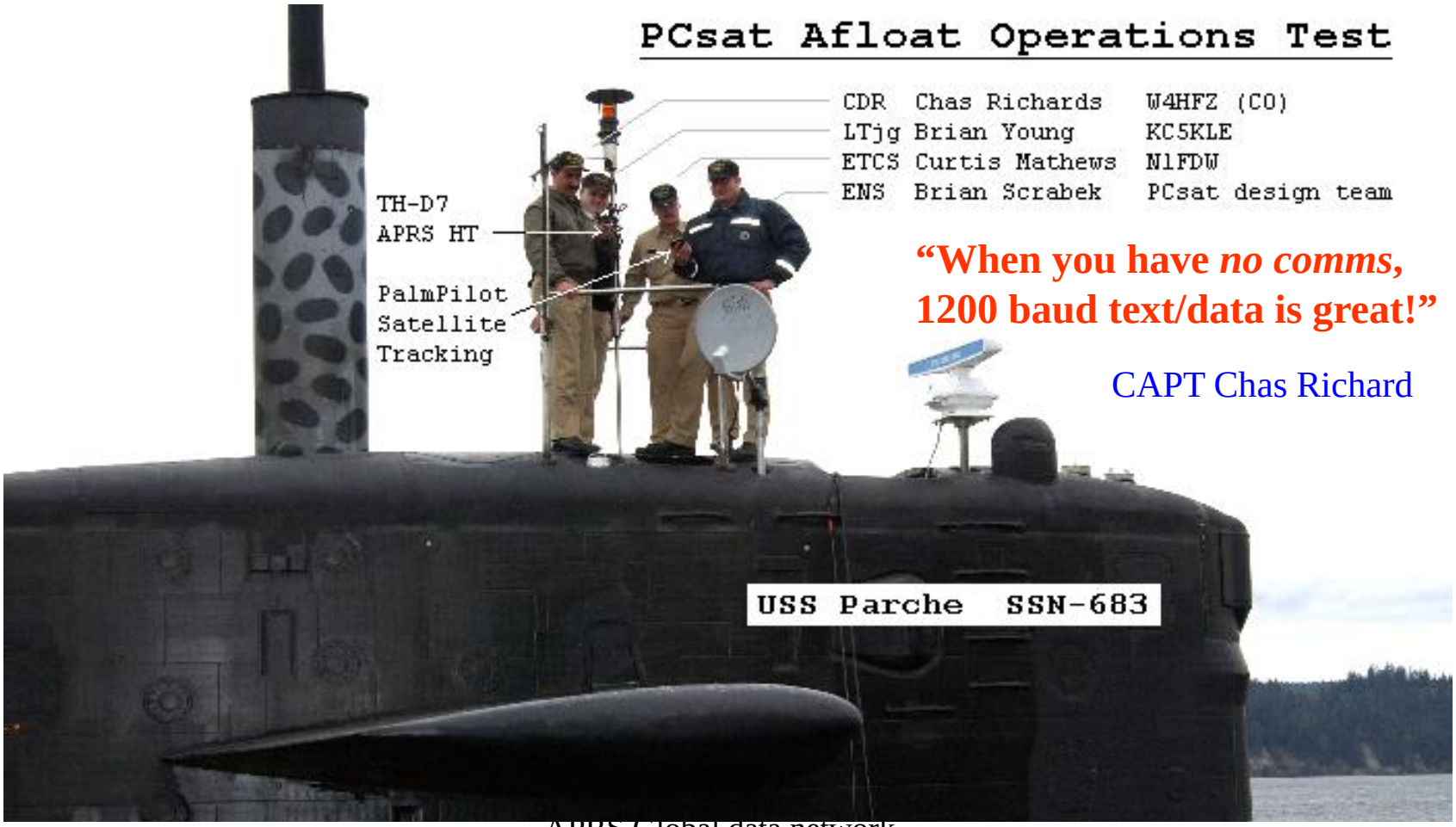
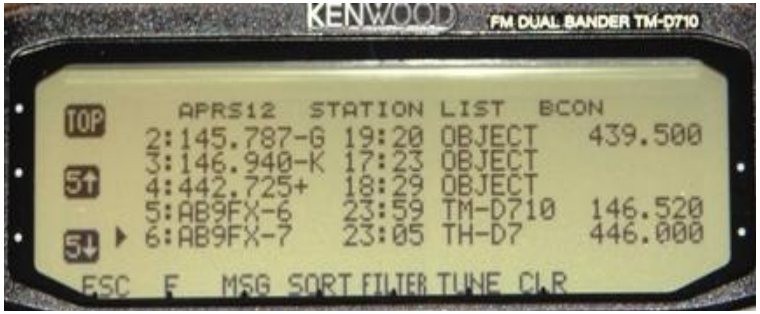


Ground Terminal Applications Focus

Tactical Situational Awareness and Text Messaging

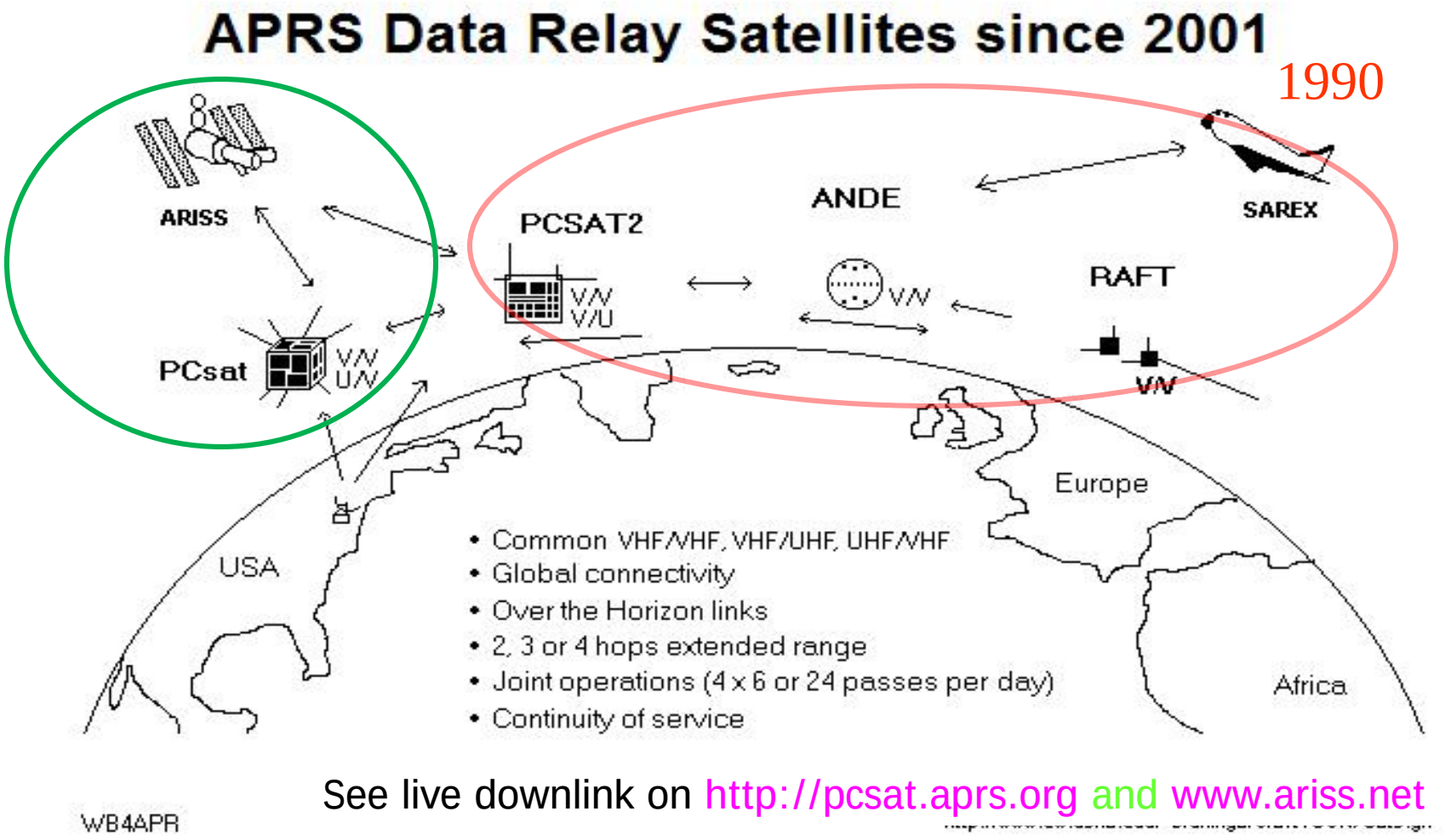
Last 100 stations!



Direction & Distance

Frequency and Tone

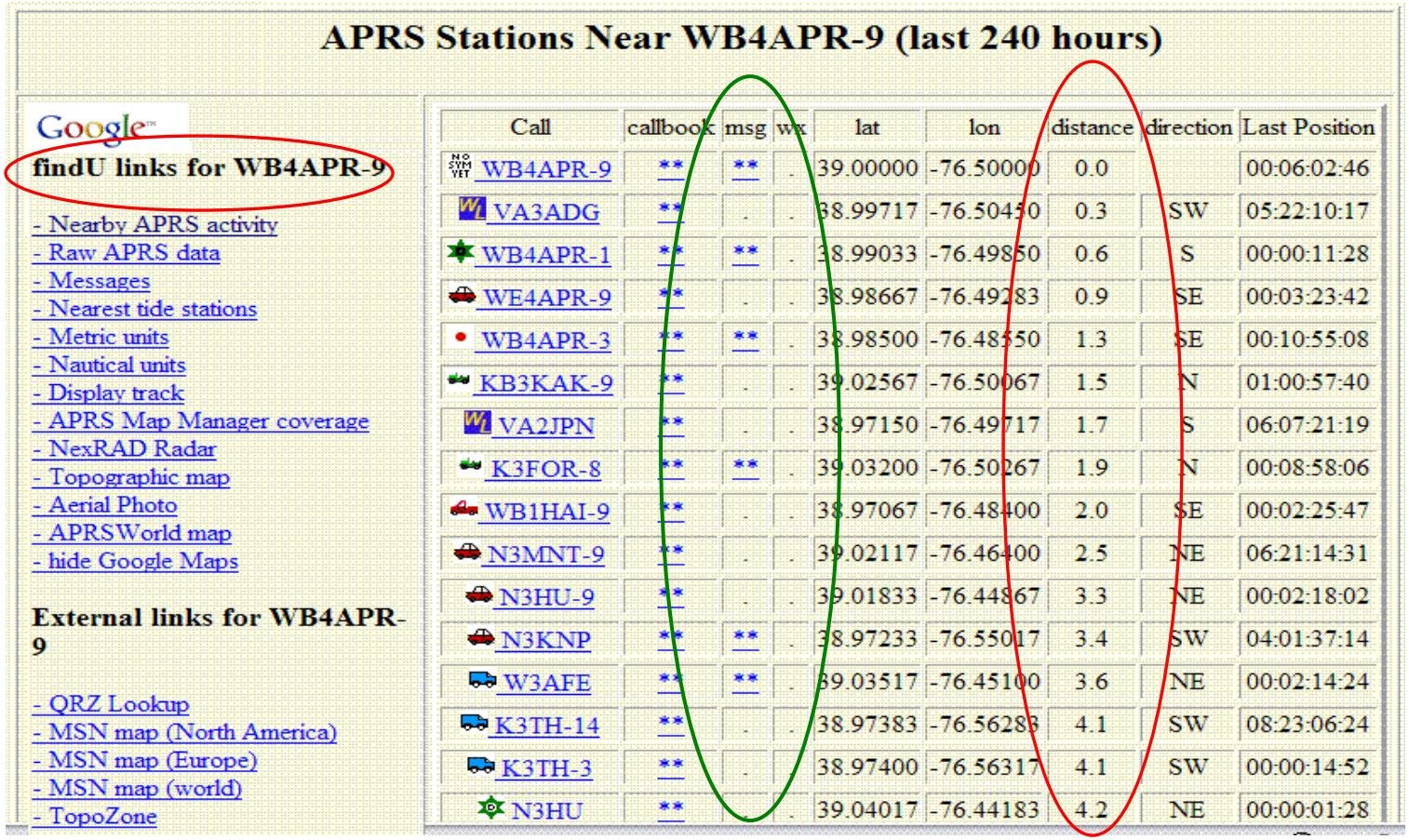
All on 145.825 MHz & Generc



See live downlink on http://pcsat.aprs.org and www.ariss.net

APRS Experiment Data Access (via internet)

http://map.findu.com/wb4apr* to see data on ANY experiment in the world



APRS Stations Near WB4APR-9 (last 240 hours)

Google

findU links for WB4APR-9

- Nearby APRS activity
- Raw APRS data
- Messages
- Nearest tide stations
- Metric units
- Nautical units
- Display track
- APRS Map Manager coverage
- NexRAD Radar
- Topographic map
- Aerial Photo
- APRSWorld map
- hide Google Maps

External links for WB4APR-9

- QRZ Lookup
- MSN map (North America)
- MSN map (Europe)
- MSN map (world)
- TopoZone

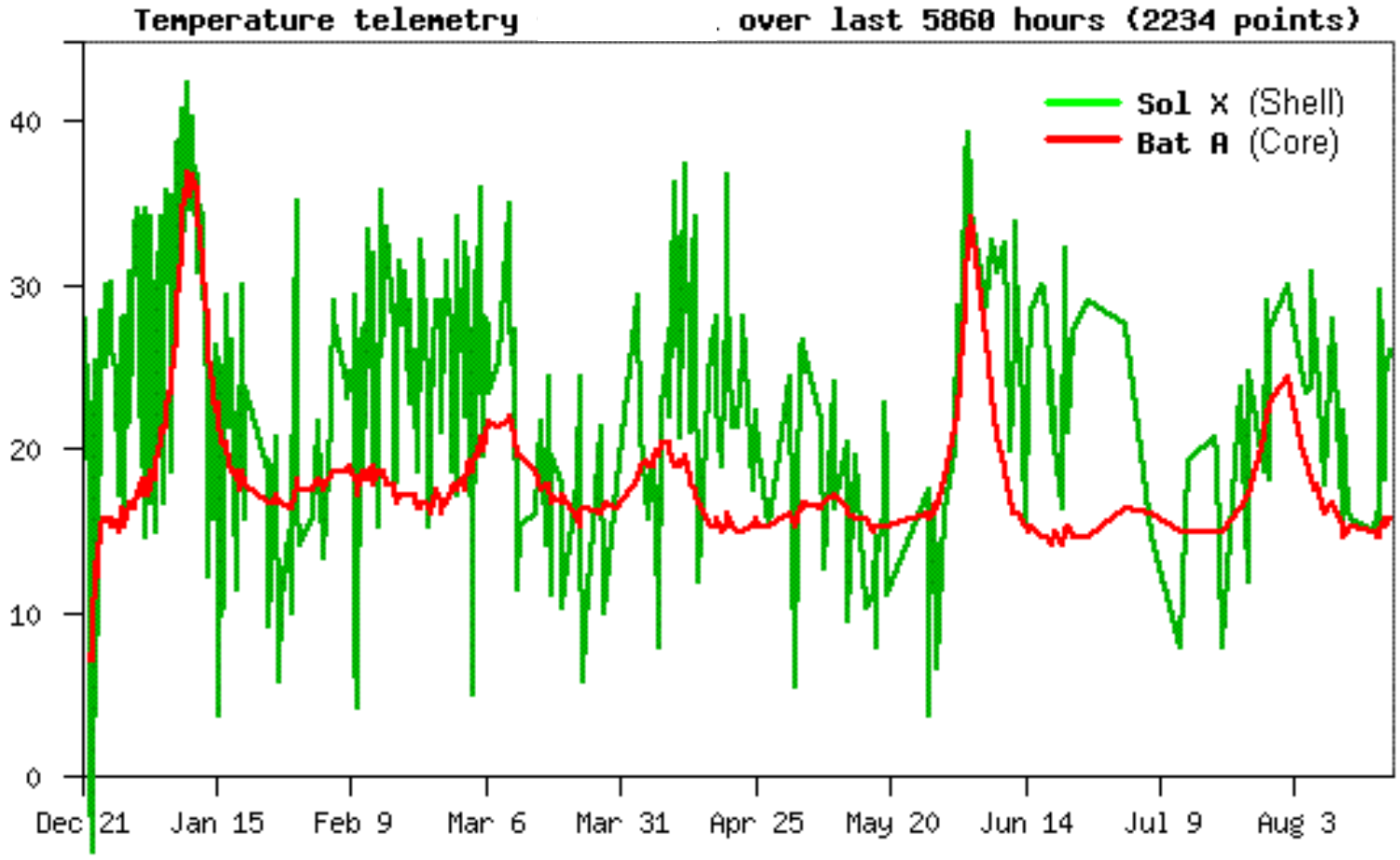
Call	callbook	msg	wx	lat	lon	distance	direction	Last Position
WB4APR-9	**	**	.	39.00000	-76.50000	0.0		00:06:02:46
VA3ADG	**	.	.	38.99717	-76.50450	0.3	SW	05:22:10:17
WB4APR-1	**	**	.	38.99033	-76.49850	0.6	S	00:00:11:28
WE4APR-9	**	.	.	38.98667	-76.49283	0.9	SE	00:03:23:42
WB4APR-3	**	**	.	38.98500	-76.48350	1.3	SE	00:10:55:08
KB3KAK-9	**	.	.	39.02567	-76.50067	1.5	N	01:00:57:40
VA2JPN	**	.	.	38.97150	-76.49717	1.7	S	06:07:21:19
K3FOR-8	**	**	.	39.03200	-76.50267	1.9	N	00:08:58:06
WB1HAI-9	**	.	.	38.97067	-76.48400	2.0	SE	00:02:25:47
N3MNT-9	**	.	.	39.02117	-76.46400	2.5	NE	06:21:14:31
N3HU-9	**	.	.	39.01833	-76.44867	3.3	NE	00:02:18:02
N3KNP	**	**	.	38.97233	-76.55017	3.4	SW	04:01:37:14
W3AFE	**	**	.	39.03517	-76.45100	3.6	NE	00:02:14:24
K3TH-14	**	.	.	38.97383	-76.56283	4.1	SW	08:23:06:24
K3TH-3	**	.	.	38.97400	-76.56317	4.1	SW	00:00:14:52
N3HU	**	.	.	39.04017	-76.44183	4.2	NE	00:00:01:28

* Click to see all stations on map

Based on the USNA Automatic Packet Reporting System

Findu.com Telemetry Plots

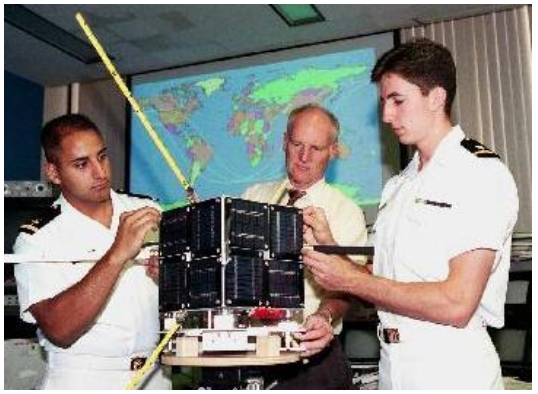
Live Example: www.aprs.org/wb4apr-15.html



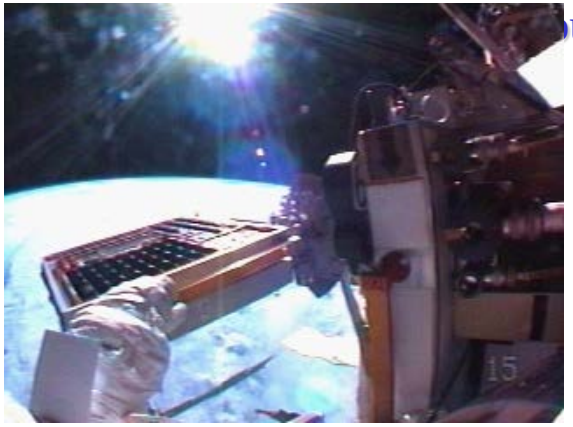
QuickLook: Global APRS Data Network

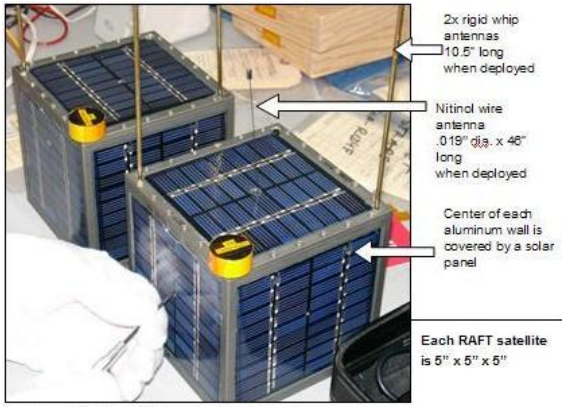
- aprs.fi - Every Packet on Earth
- ariss.net - Every packet via ISS
- pcsat.aprs.org – Every packet via USNA Sata

APRS in Space
Automatic Packet Reporting System



- 2001 PCSAT-1 Prototype Comm (semi-operational)
- 2006 PCSAT2 on ISS (returned after 1 year)
- 2007 ANDE de-orbited in 1 year
- 2008 RAFT de-orbited in 5 months
- 2007 Present ISS semi-operational due crew settings
- 2014 CAPE II AX.25 U of Louisiana (Nick Pugh)
- 2015 PSAT APRS and PSK31

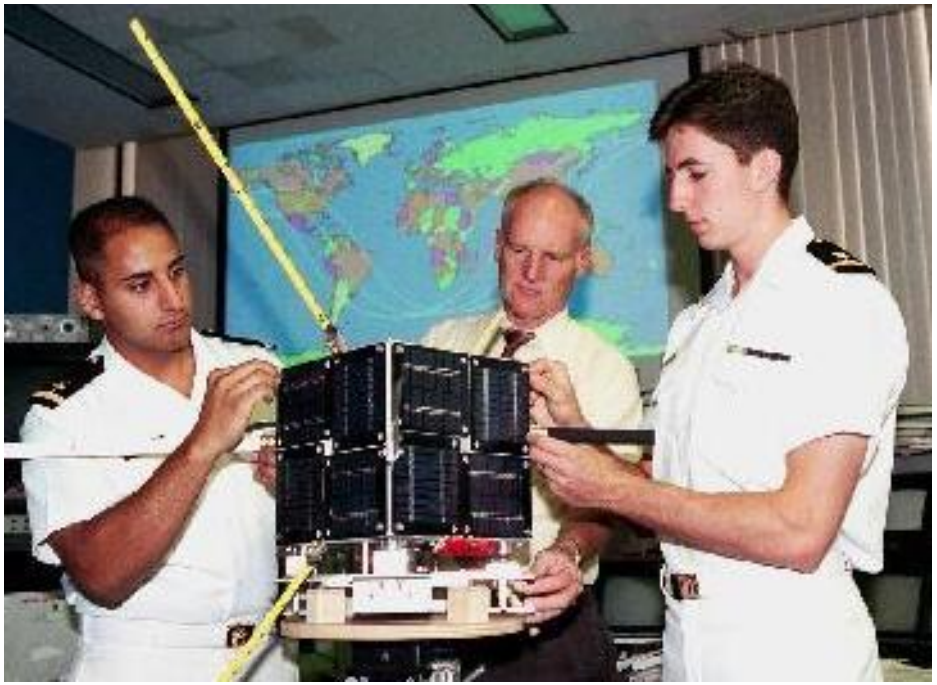




APRS space frequency is published as 145.825

See live downlink on http://pcsat.aprs.org and www.ariss.net

APRS in Space
PCSAT – 2001 to Present



Swarthout: "Oldest semi-operatonal Student built satellite in space"

Eng-model at Udgar-Hazy Smthsonian

Established the APRS space frequency as 145.825

Feature: Radiometric spin at 0.6 RPM

See live downlink on http://pcsat.aprs.org and www.ariss.net

APRS in Space
ANDE Satellite (free ride)

Free ride, but…

- No external solar cells
- No external Antennas

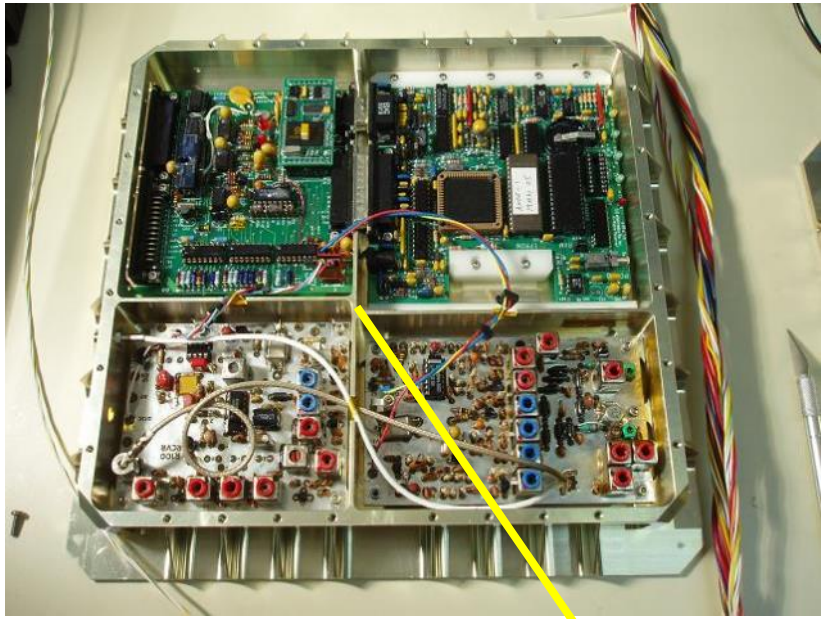
Filled it with 4 trays
112 D-cell Lithiums

Insulated 2 halves for
A VHF antenna

Operated full 1 year mission

See live downlink on http://pcsat.aprs.org and www.ariss.net

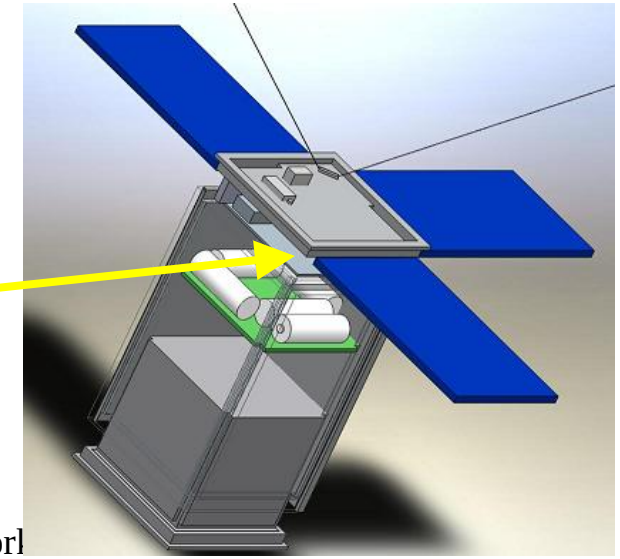
Huge reduction from transponders on PCSAT's 1,2, ANDE and RAFT missions



Earlier reductions to 5" cubesat on RAFT (2006)

4:1

Now reduced 18:1 in volume/mass for 4" cubesat 2009



AX.25 A single 3” COMM card 145.825 MHz

Mission: Remote Data Relay, Data Exfiltration, Remote Sensor Relay

Benefit: Support Space Education on the ground through space applications and student experimental access

Hardware: VHF simplex data Xsponder 145.825 MHz

Size/Mass: < 10 cu.in (1 PCB 3.4” square), <0.1kg

Power: < 1W orbit average, 5 volts.

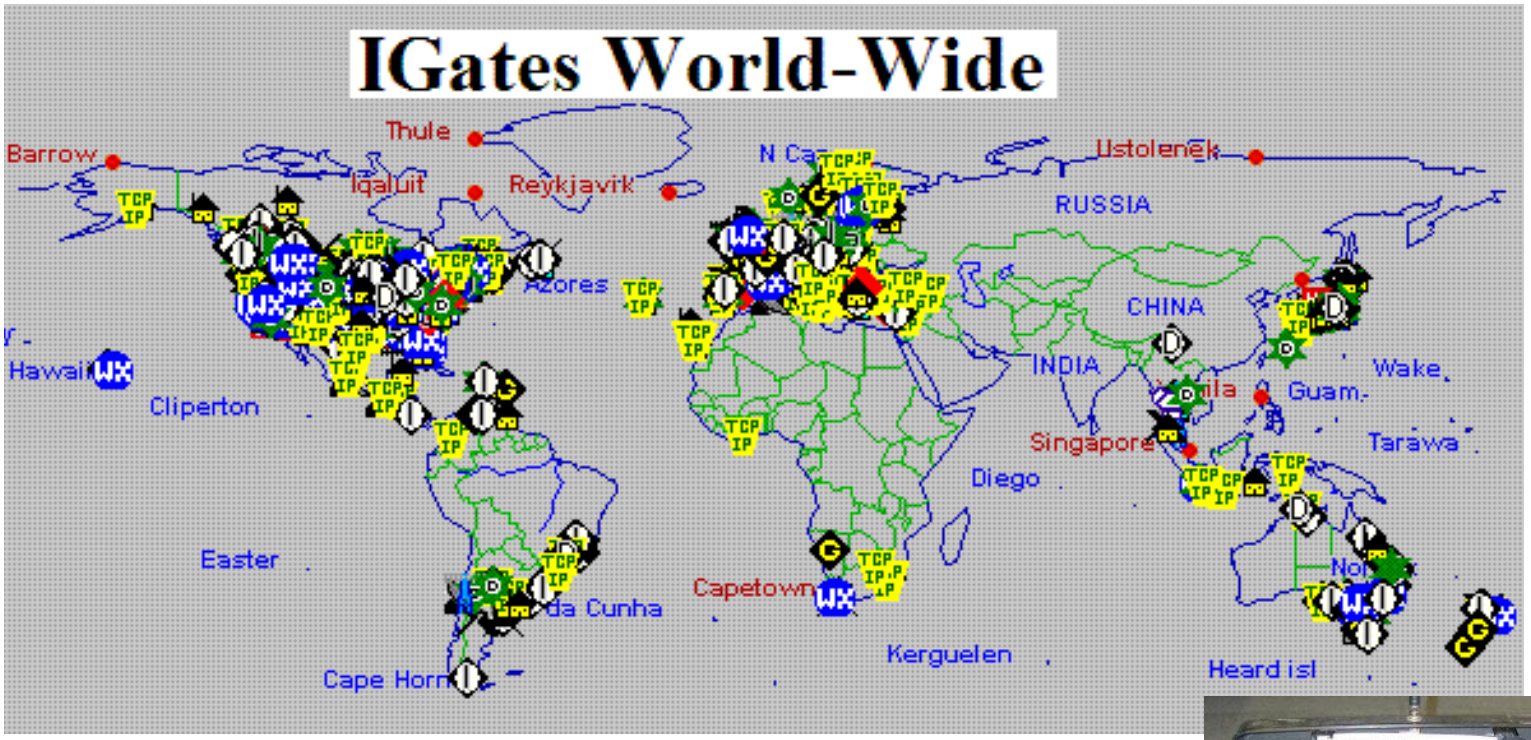
Integration Requirement: Simply, on/off (or *)

Structure Impact: Needs 19” thin wire whip antenna (1 cu.in)

Benefit to Spacecraft: High visibilty to worldwide educational institutions, fosters collaboration, orders of magnitude greater student experimental access to space systems (ground segment). * Independent back-up telemetry command/ control channel, RS232 serial data, 16 on/off discretes, backdoor reset capability. Worldwide Telemetry Beacon access via global station network.

APRS Global data network

Psat APRS Network Architecture



Global Volunteer Ground Station Network

Internet Linked for live Telemetry

APRS Global data network

Global Volunteer Groundstations

feed live downlink into Internet

APRS iGate

APRS IGate
with Raspberry Pi
and DVB-T stick

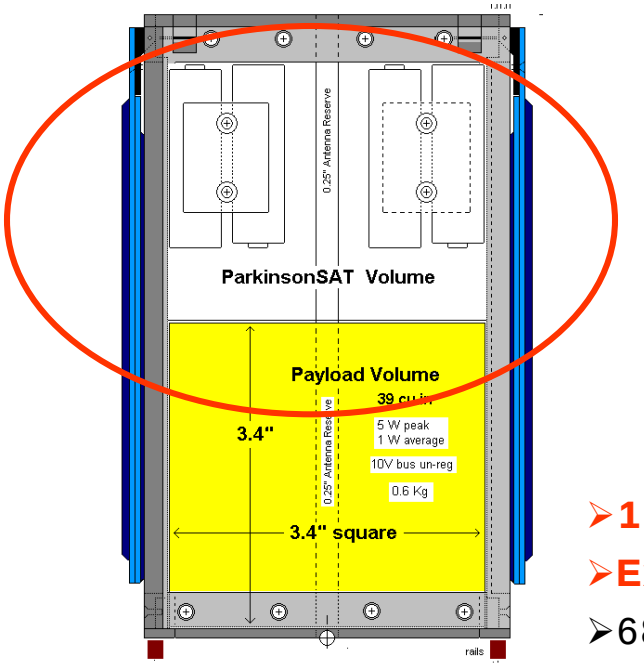
DK3WN

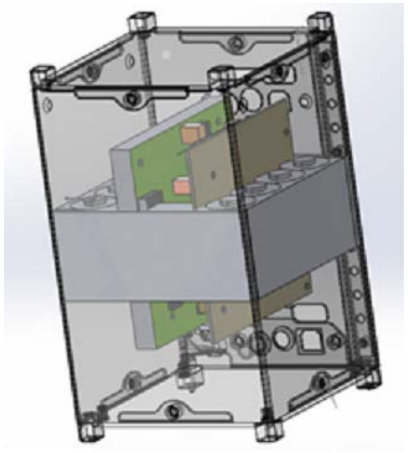
http://www.kubonweb.de/?p=130
http://www.mstewart.net/super8/aprs/RASP/index.htm
http://n5dux.com/ham/raspberrypi/igate.php
http://www.radio.cc/post/aprs-igate-with-raspberr-pi-setup

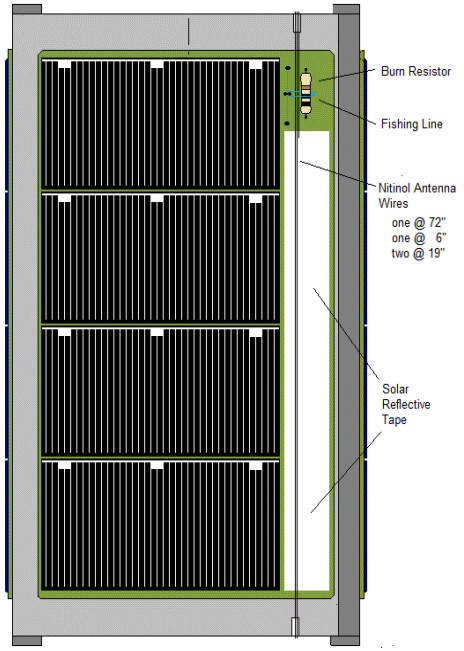
Raspberry PI iGate APRX with soundmodem
https://www.youtube.com/watch?v=MtUnuJn_70o

Psat Transponder May 2015

75% Payload Space Available! (only 50% shown here)



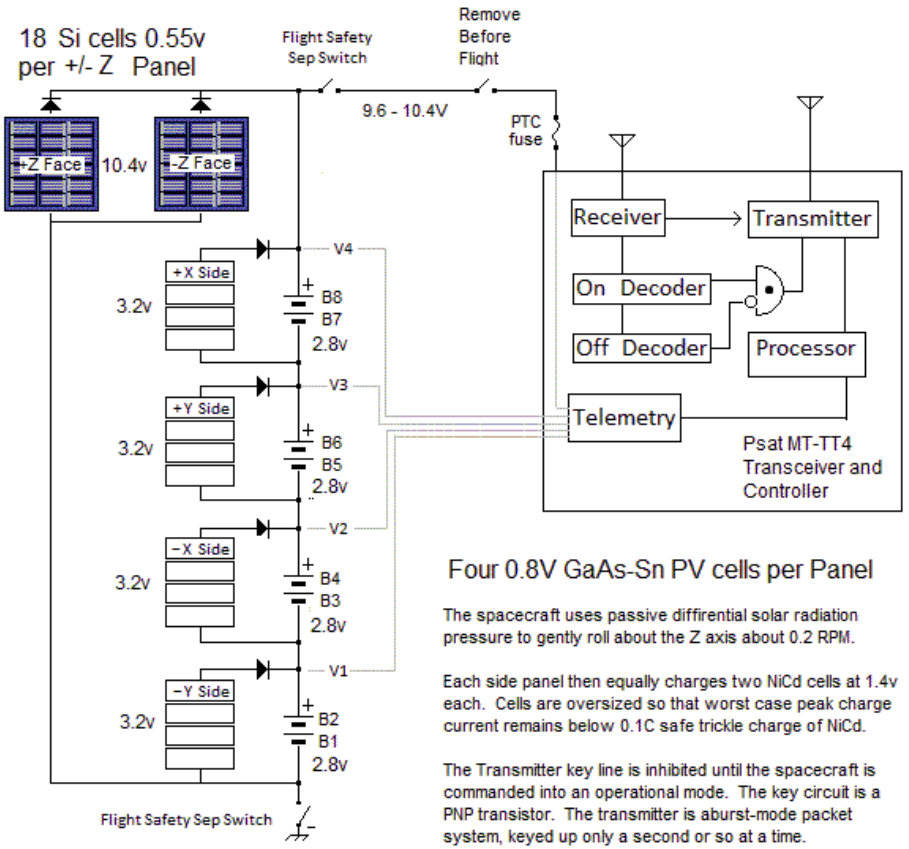




- **18 cu.in for Transponder**
- **External 19” whip antenna**
- 68 cu.in for Aux Payload (SPMS?)
- Aux payload gets 4” external panel
- Aug payload gets .5 kg – self contained
- 1 to 3W average power for aux payload

PSAT Unique Parallel-charge EPS Design

- Uses 2 NiCd cells per low-cost silicon solar panel = 1000-to-1 cost savings



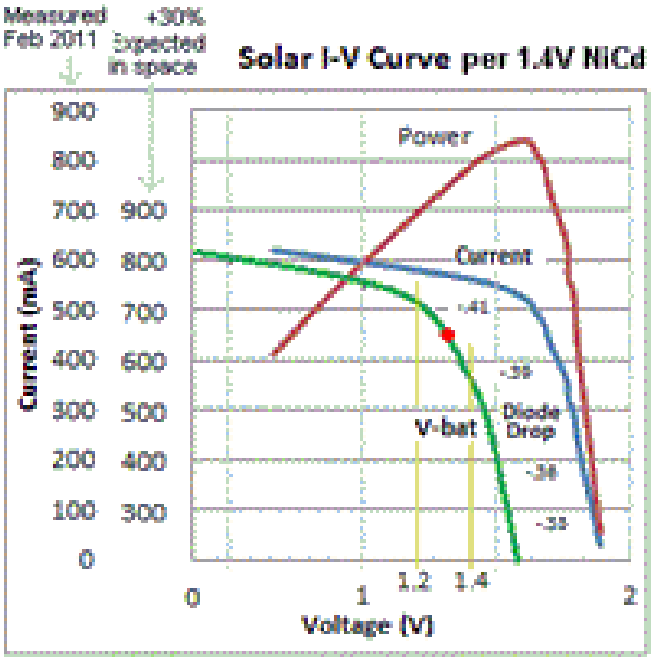
Four 0.8V GaAs-Sn PV cells per Panel

The spacecraft uses passive diffirential solar radiation pressure to gently roll about the Z axis about 0.2 RPM.

Each side panel then equally charges two NiCd cells at 1.4v each. Cells are oversized so that worst case peak charge current remains below 0.1C safe trickle charge of NiCd.

The Transmitter key line is inhibited until the spacecraft is commanded into an operational mode. The key circuit is a PNP transistor. The transmitter is aburst-mode packet system, keyed up only a second or so at a time.

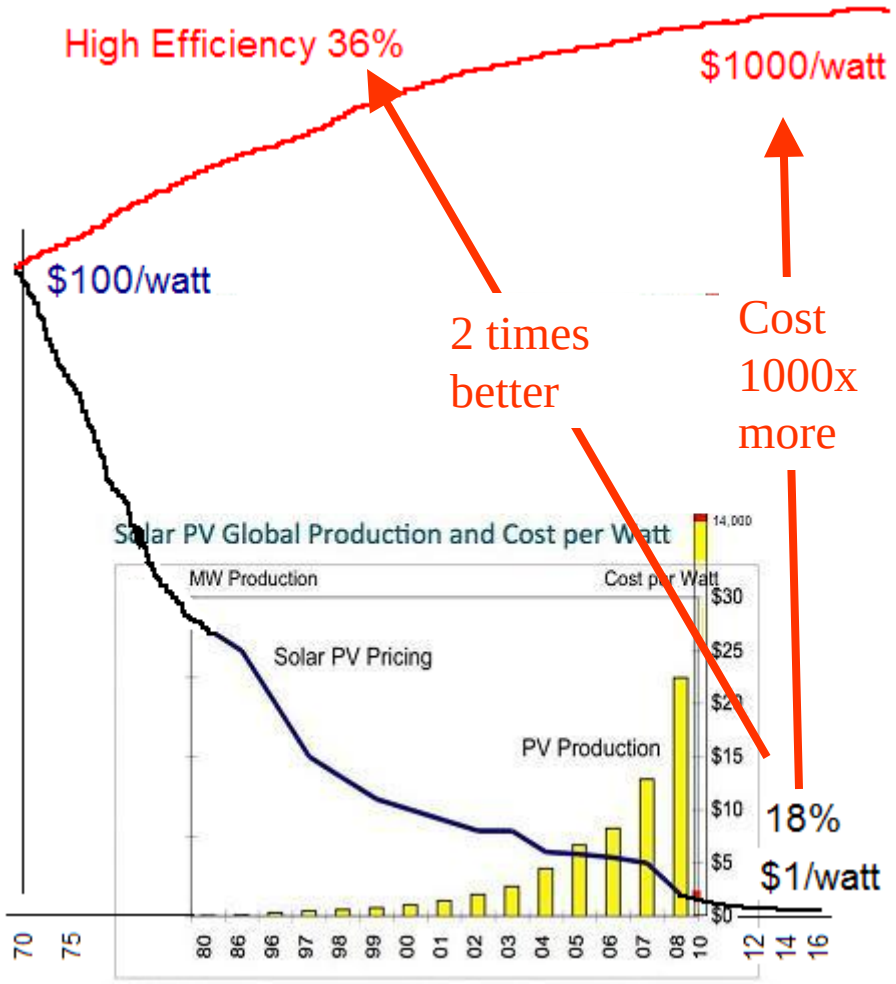
Passive Battery Charge Regulation



Peak Power 650 mA and 1.3V = 0.85W

No BCR: match IV w NiCds

Silcon Solar is 1000 times lower cost

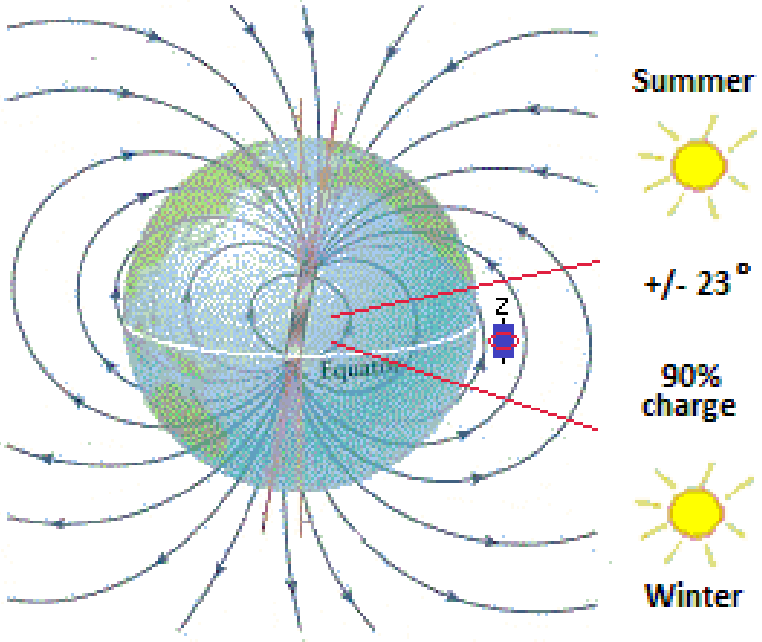


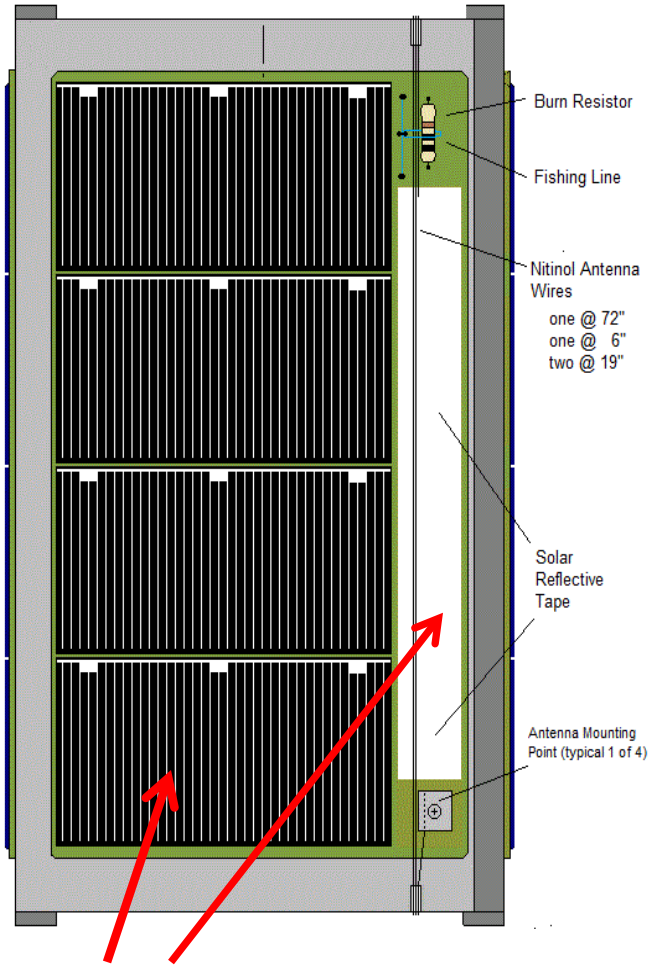
High efficiency prices ONLY go up since the space industry will pay anything for each additional 1 percent.

Home panel prices only go **down** since homeowners will not buy anything but the cheapest

Unique Power Attitude – Z coil ADCS

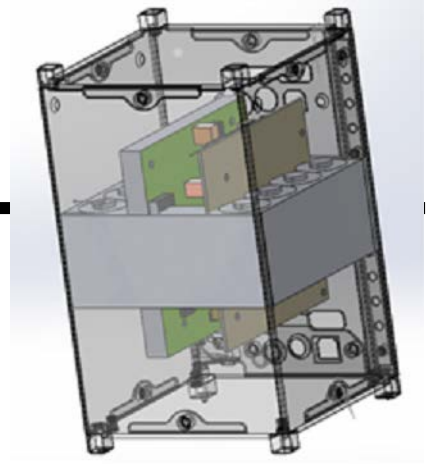
- Uses only one Z coil for attitude Control
  - Fires only within +/- 20 deg of Equator
  - Solar Panel angle better than 95% power
  - Higher reliability
  - Passive Spin maintenance

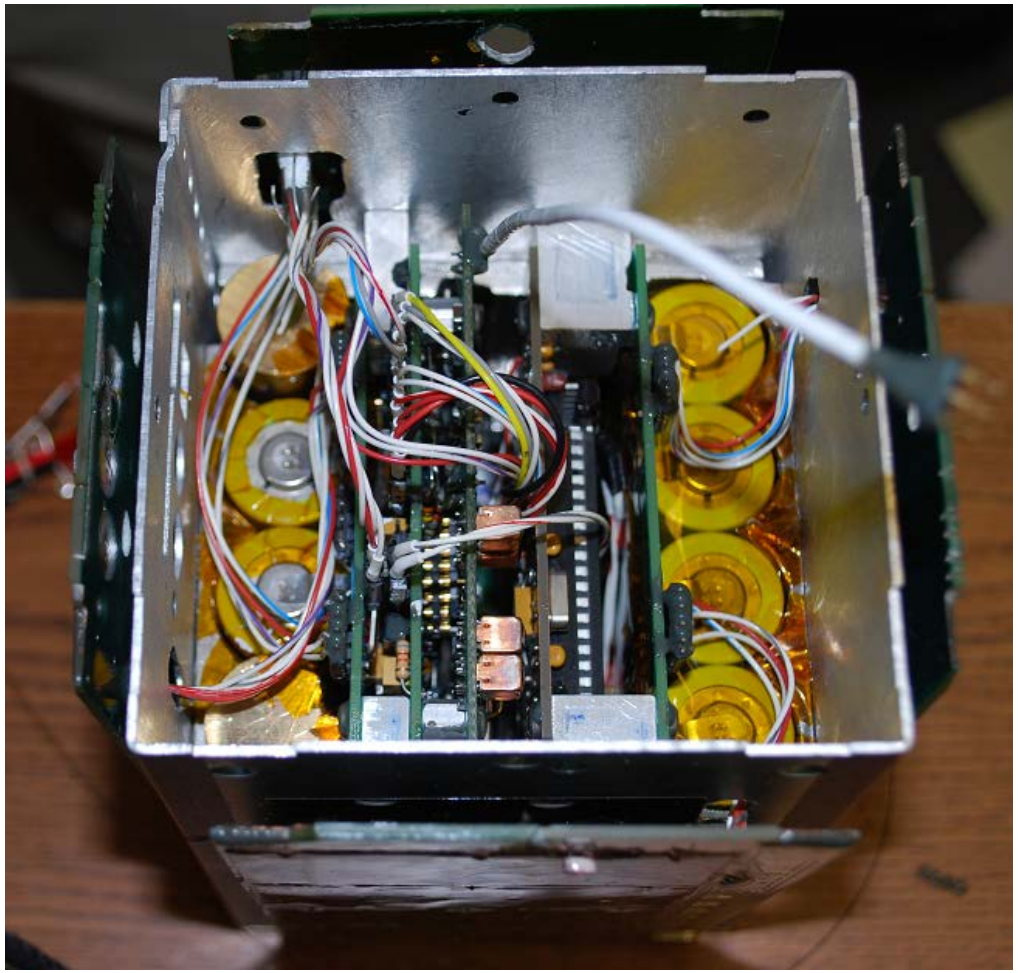




Differential Radiation Spin

PSAT's mass is centered in Z



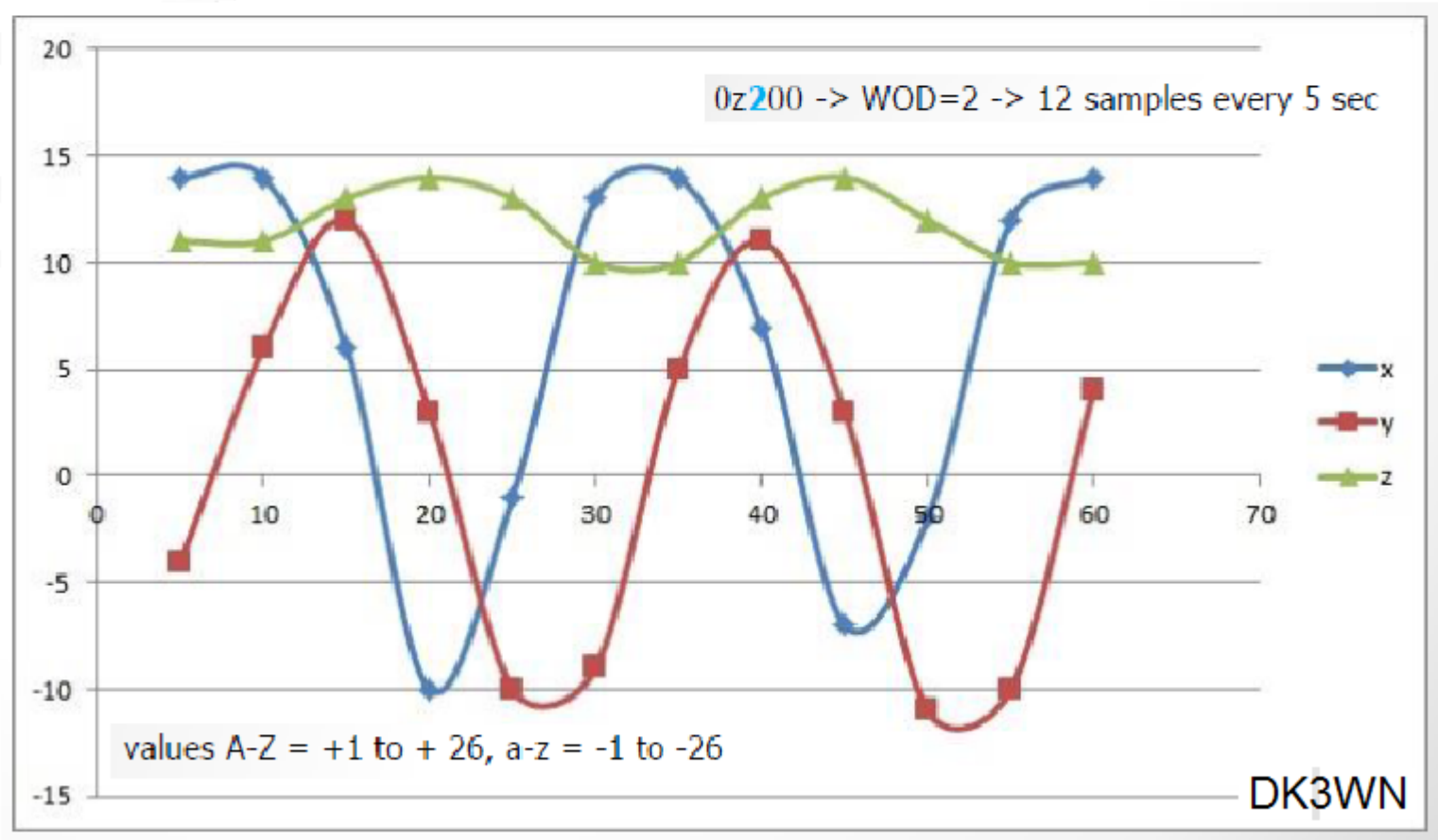


- For Maximum MOI about Z
- Batteries to outside for MOI & Shielding
- Stainless steel belt around everything

PSAT BS2 CPU telemetry – spin analysis

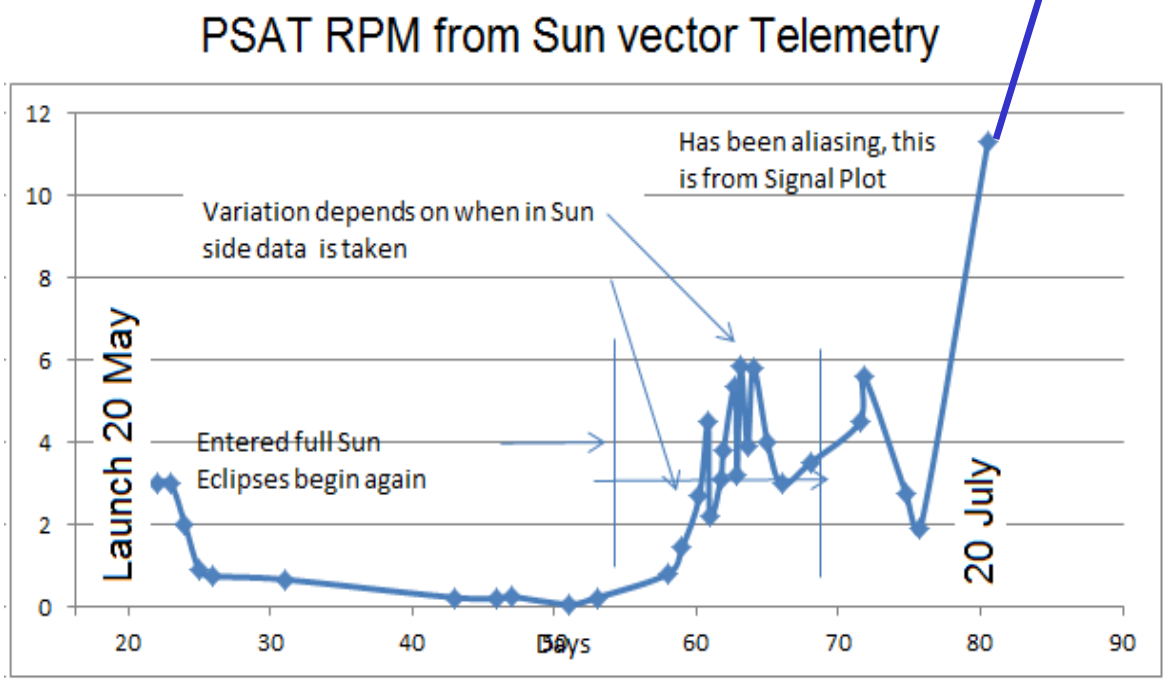
S#033814,0z290,qhDqhEqhFqhHqhIqhIpiJpiKpiLphLphMphM

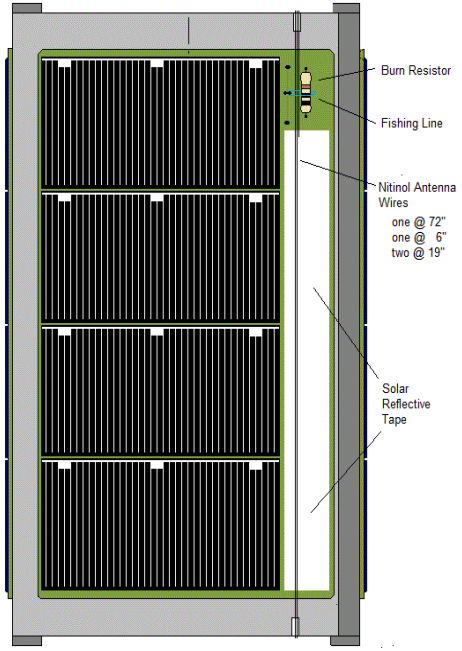
sun vector triplets `xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz xyz`



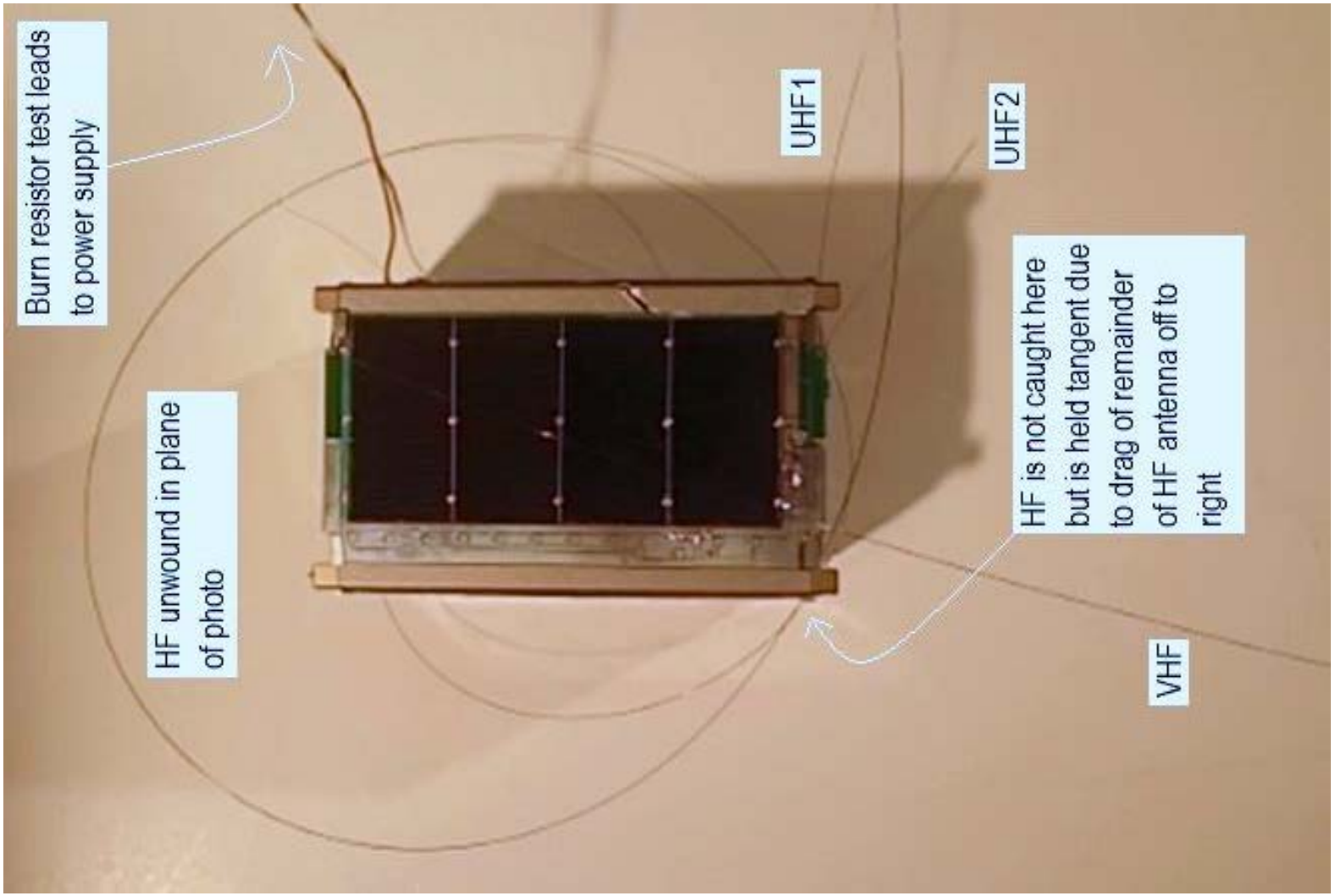
1 Aug is 27 RPM!

- When we find the time we are really looking forward to understanding our Solar Radiative Spin system.

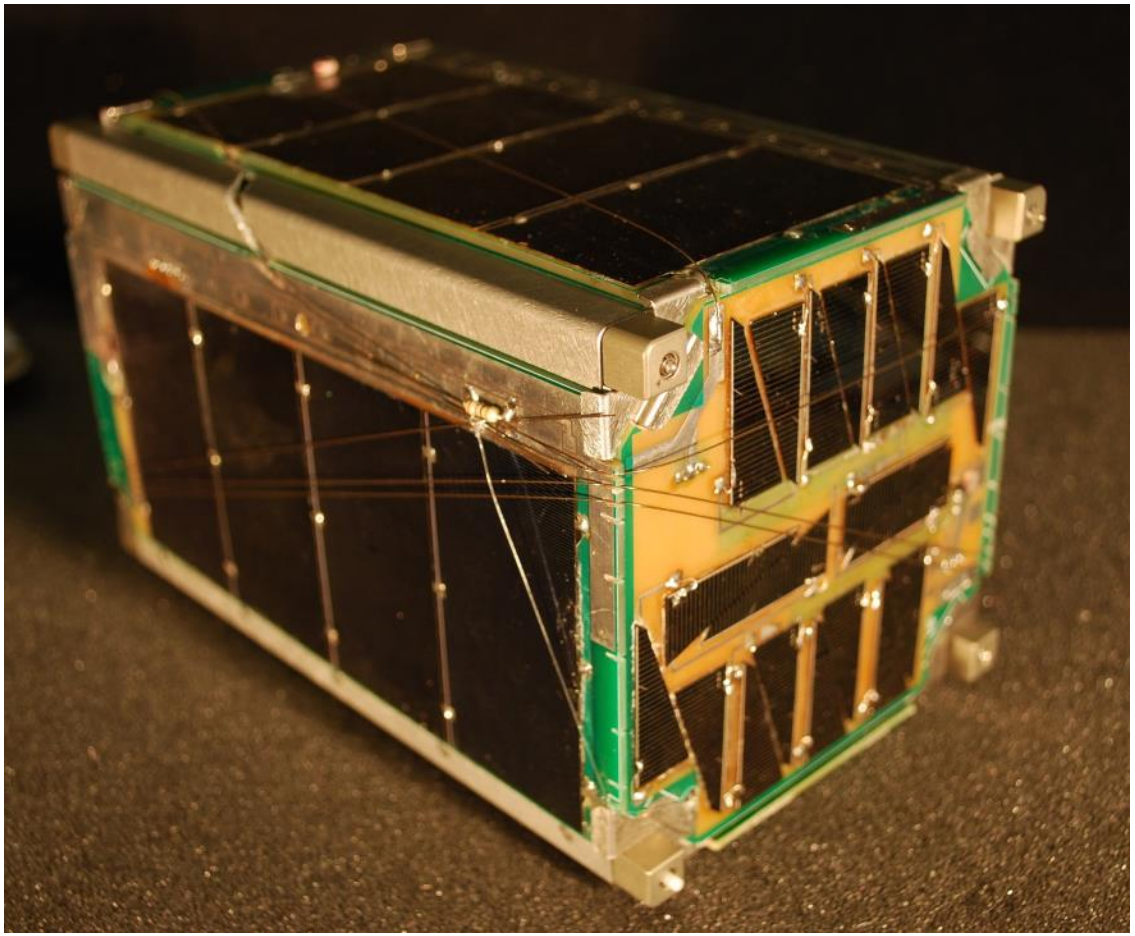




PSAT Nitinol Wire Whip Antennas



Wrapping Antennas to one Burn Resistor



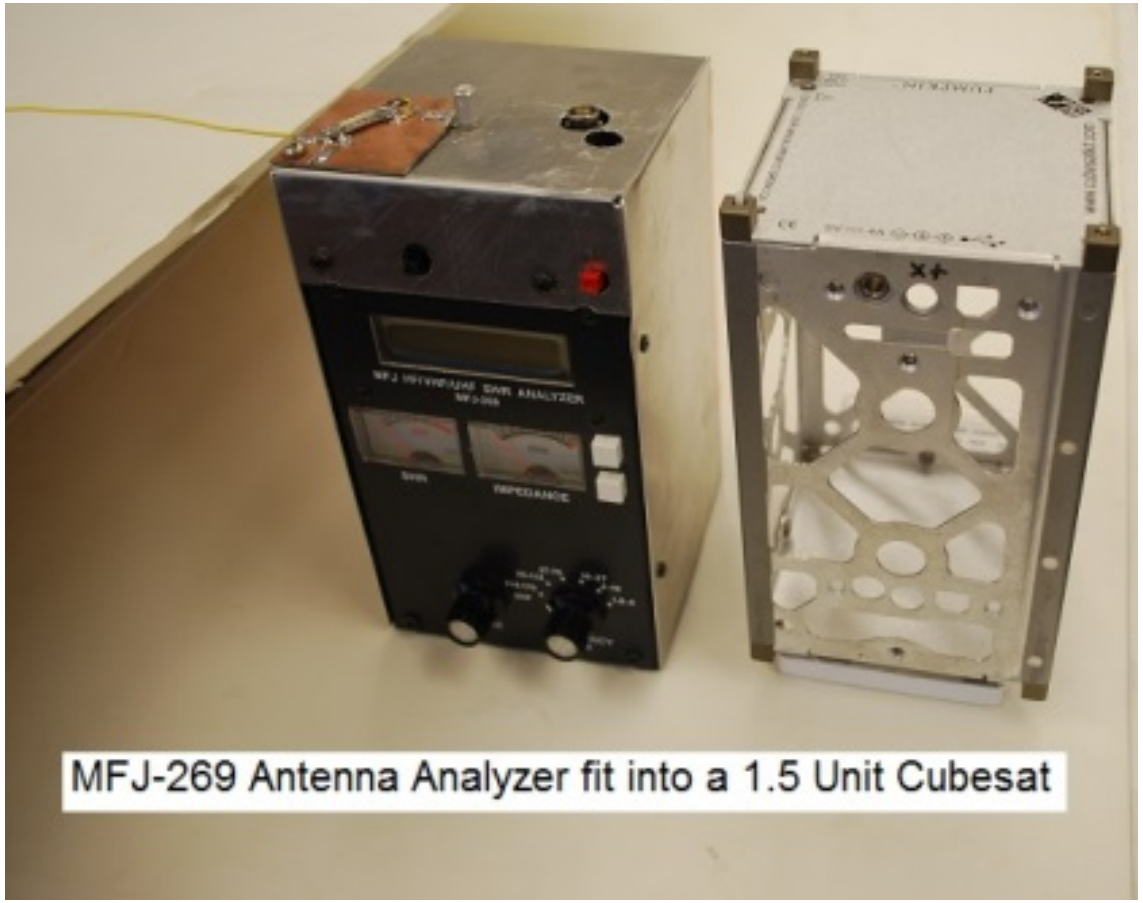
2 Orthogonal UHF whips

One VHF whip

One 6’ HF whip

3rd Enable Switch

Tuning Antennas on a 7” Spacecraft

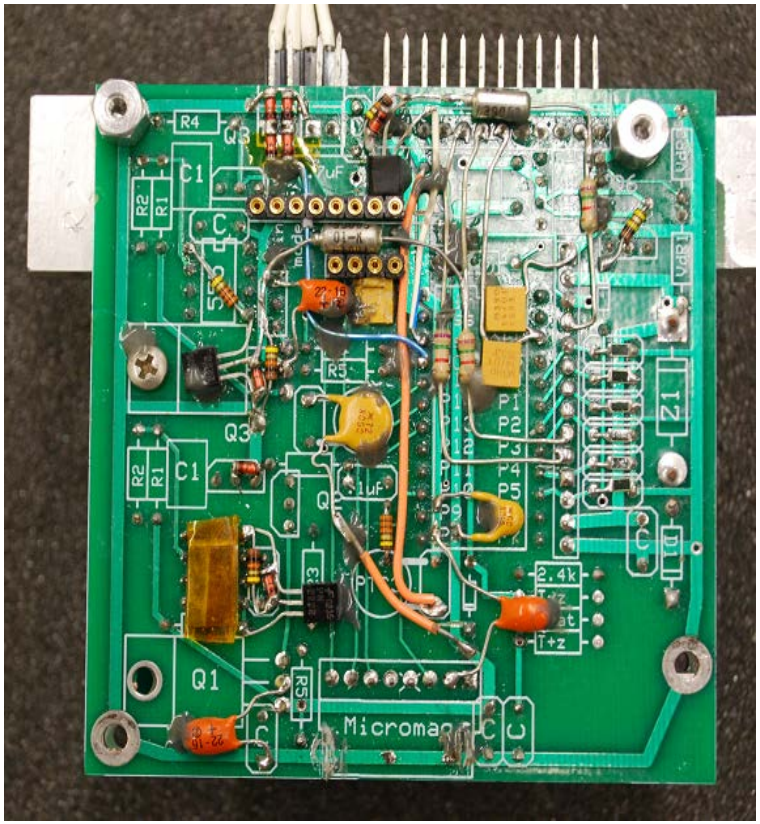


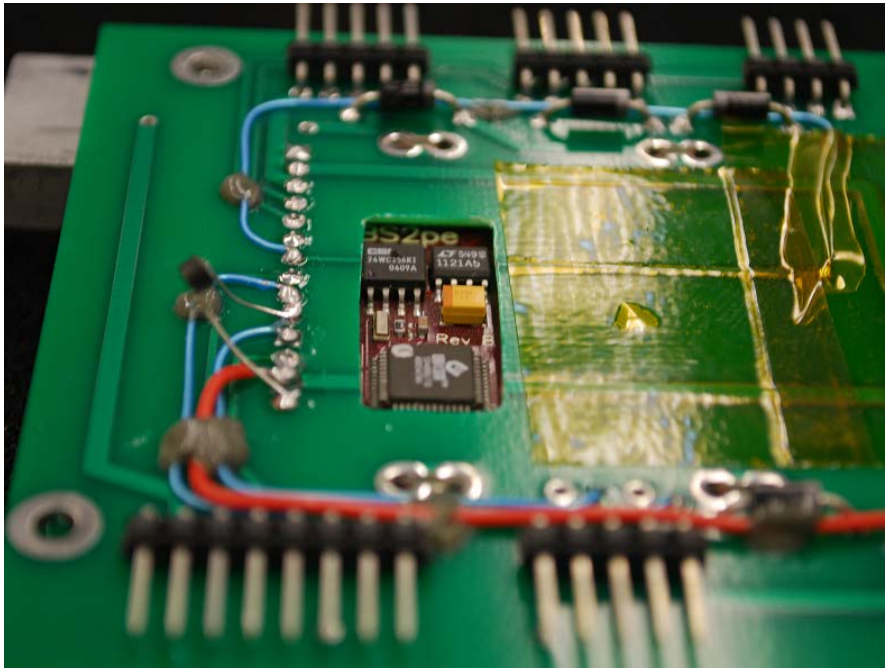
Imagine turning a 6’ HF whip on a 7” spacecraft Ground plane!

Any instrument connection detunes SWR to infinity

So, Put Analyzer inside!

How not to Make a Satellite

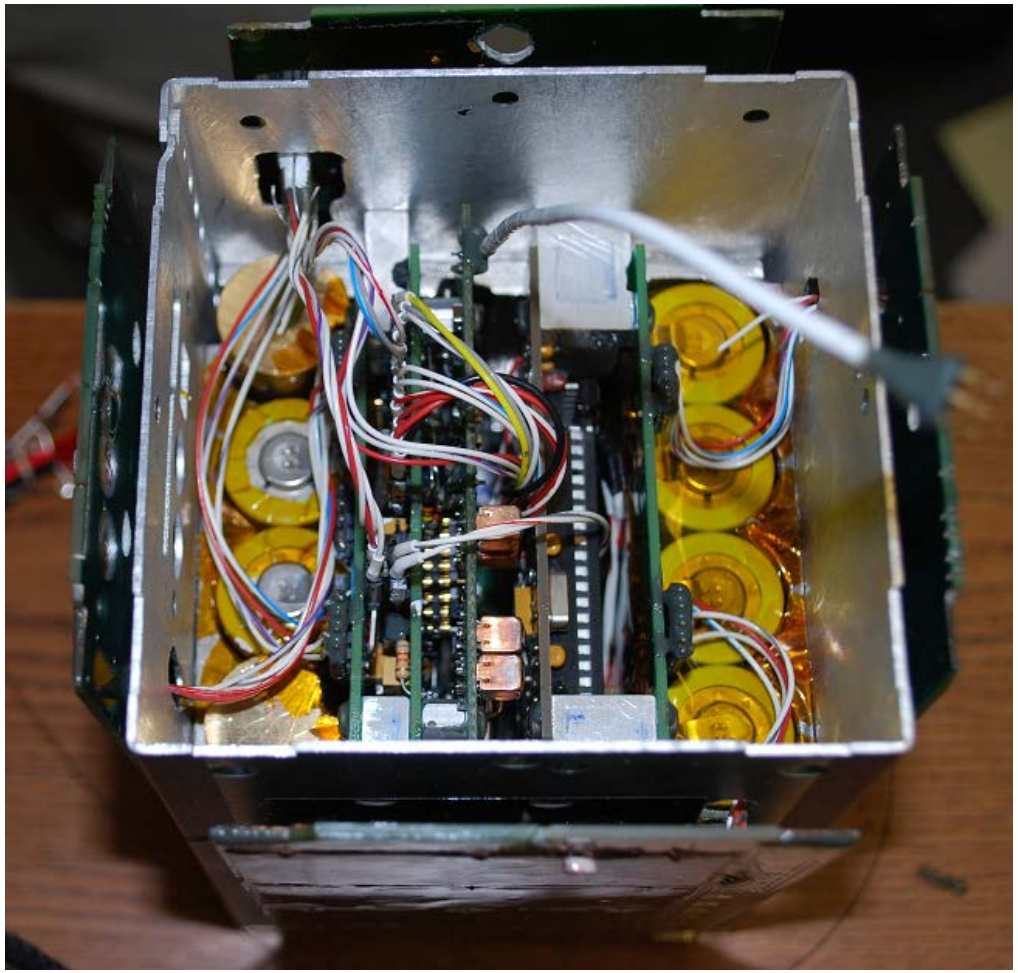




Make sure it fits

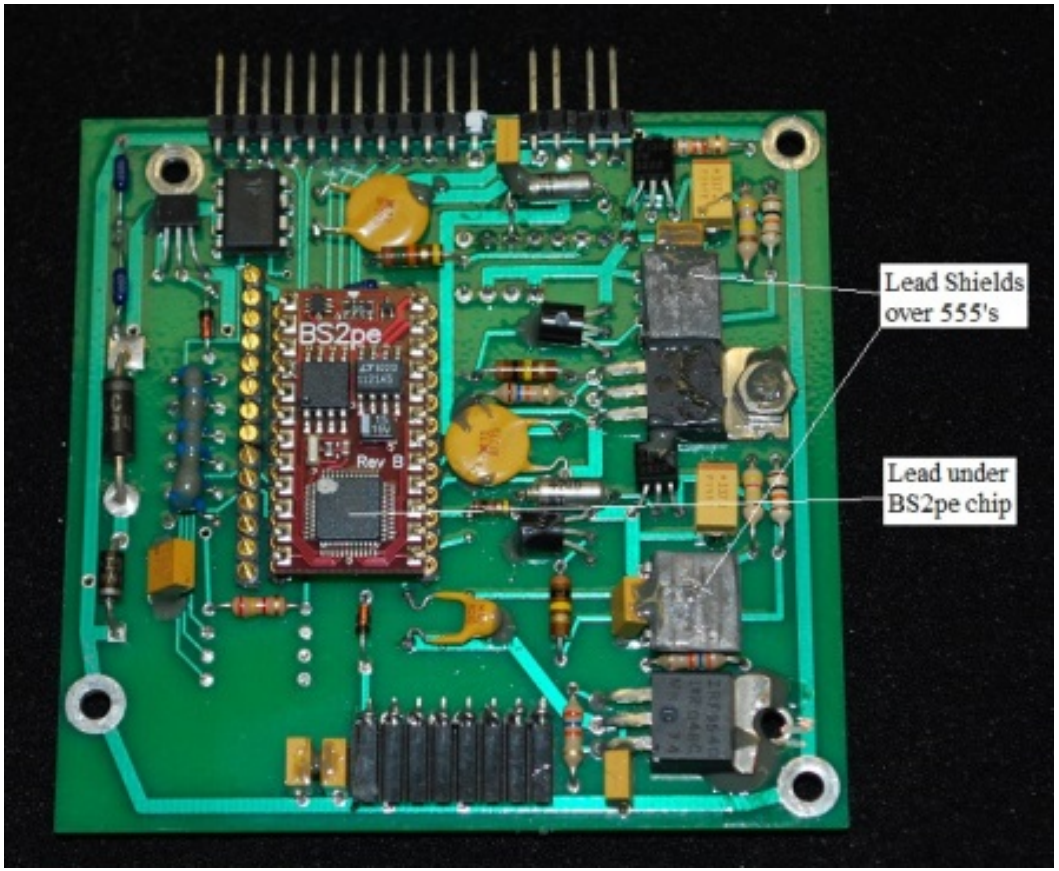
Stop adding neat features…

The boards stack across and zero clearance



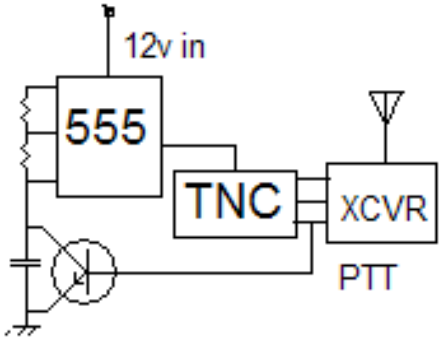
- For Maximum MOI about Z

Multiple CPU Reset Paths



Multiple Resets:

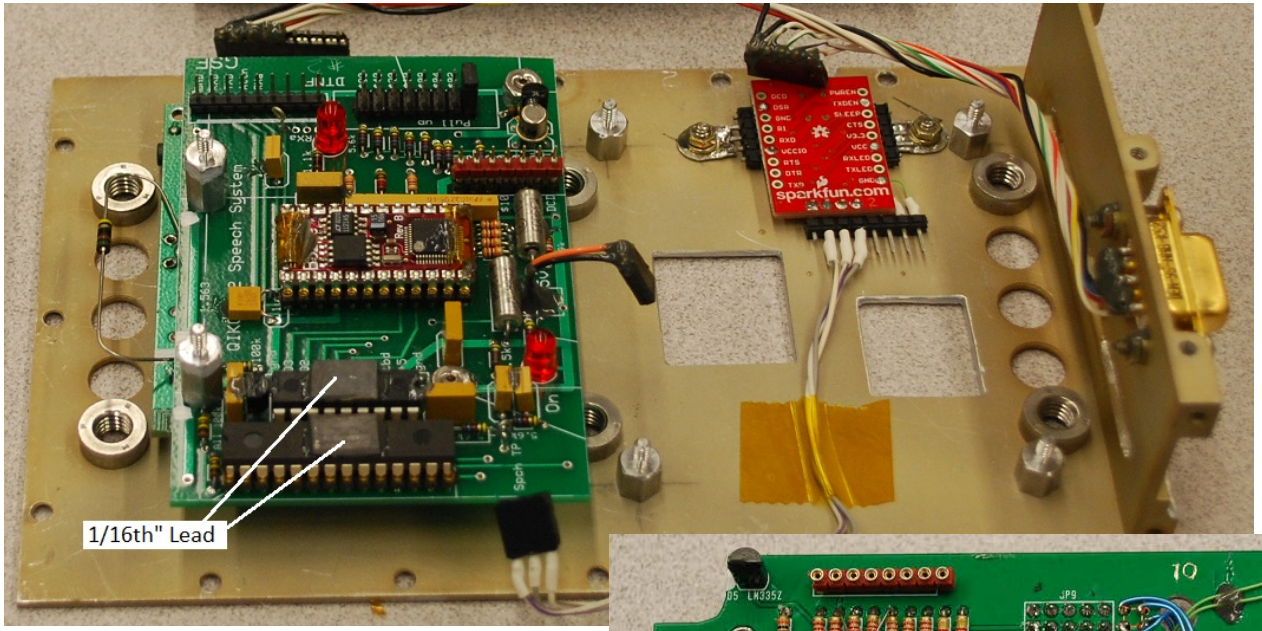
- 555 Watchdog



- Command bit
- 5 day timeout
- Second RX
- Touchtone

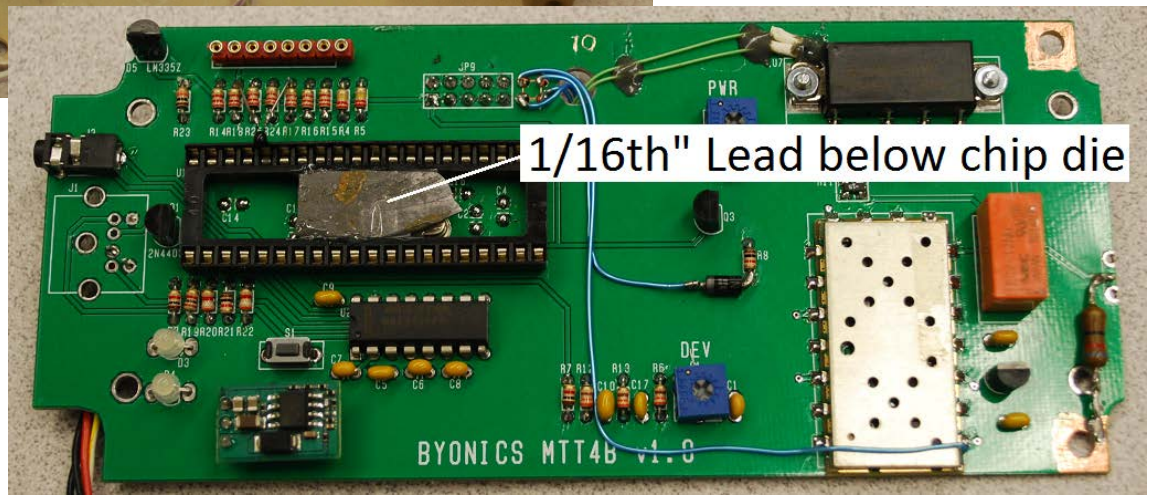
Lead shields over CPU, RAM and other critical dies

Chip Radiation Shielding



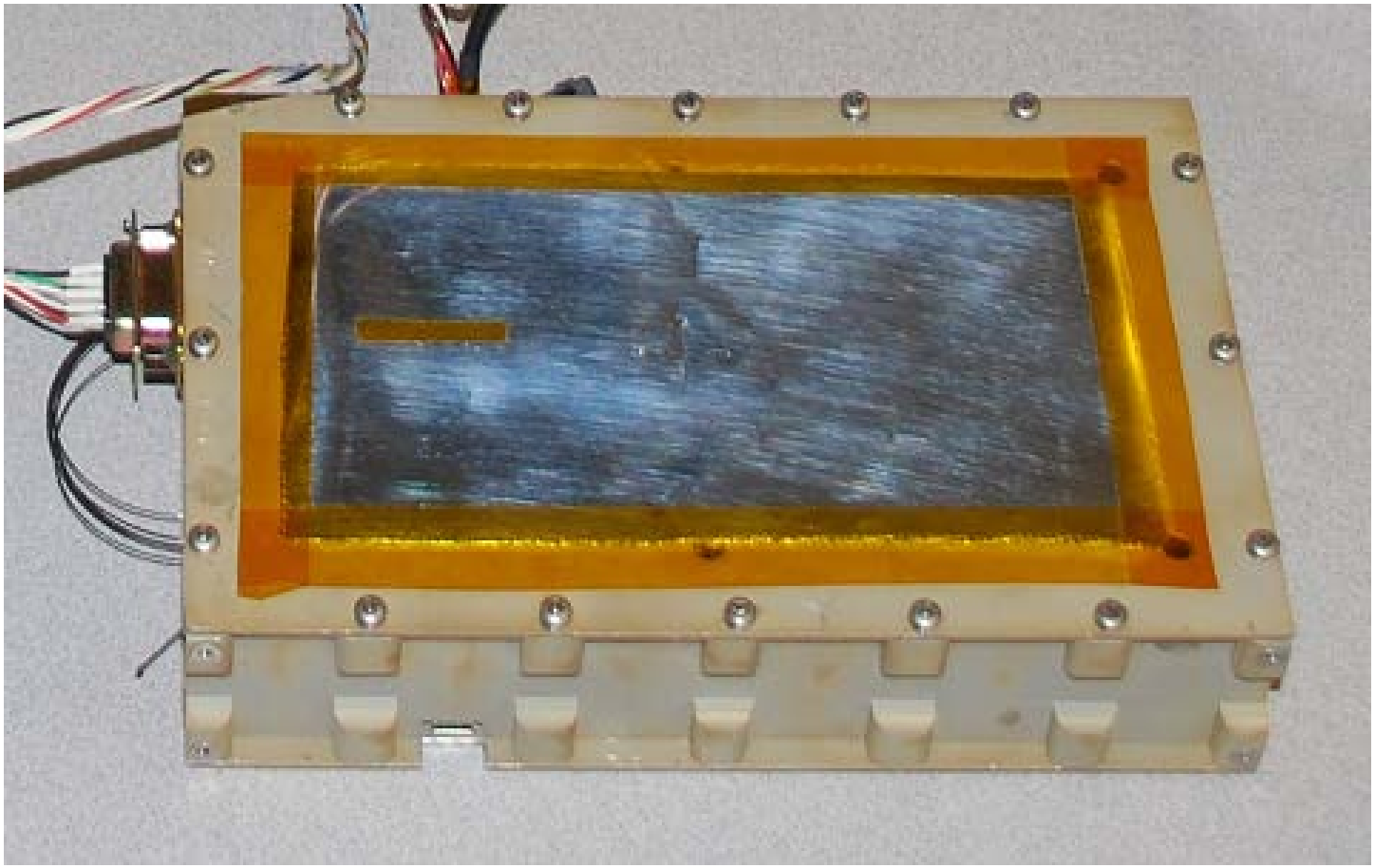
Radiation Shielding (Lead vs Tantalum)

Top and bottom of CPUs, RAMS And EEPROMS



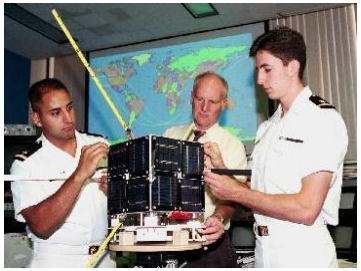
QIKCOM-1,2 Touchtone/Voce APRS satellite Xponder

145.825 downlink

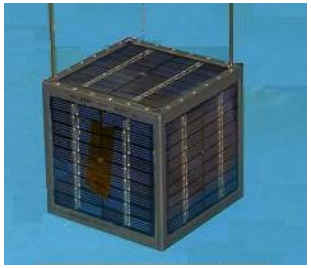


My USNA Satellites

Naval Academy – Education of the Future Space Cadre

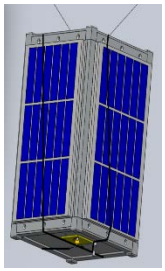


PCSAT (2001)

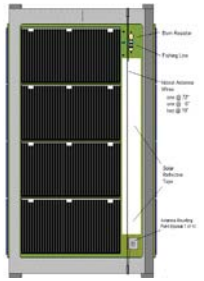


RAFT(2006)

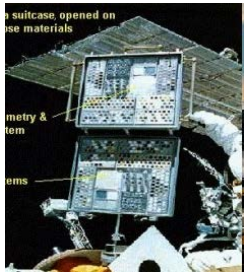
ARISS on ISS(2007)



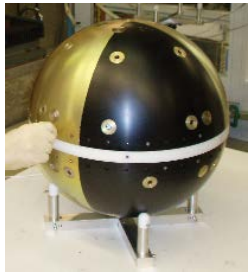
PSAT(2015)



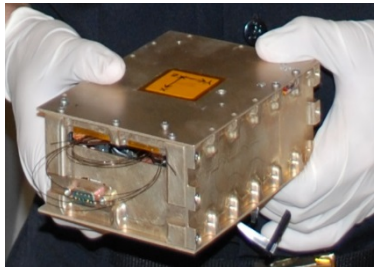
PSAT-2(2017)



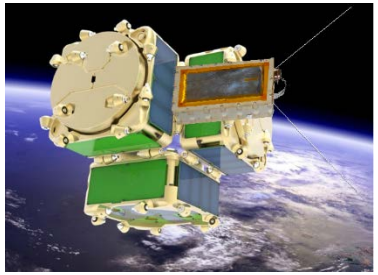
PCSAT2(2006)



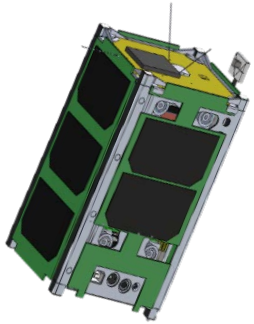
ANDE(2006)



QIKCOM-1 on ISS



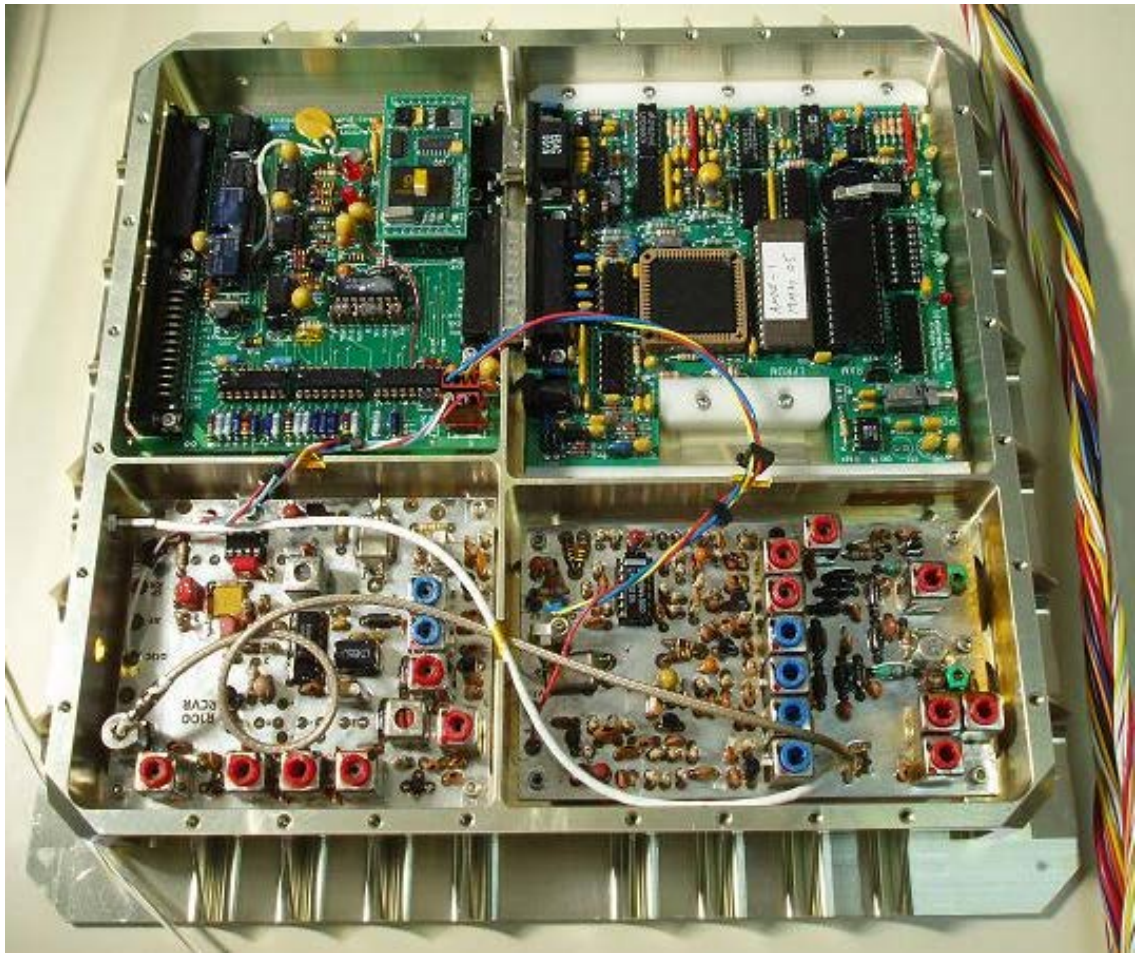
QIKCOM-2 (Aug 2016)



BRICSAT-2 (2017)

Key: Alive, De-orbited, Host , Manifest,

Relabilty Features



Oldest Student Sat in Space (2001-2018)

- 1980's RF circuits
- Physical caps/coils
- Tuning cores
- XTAL controlled Freq

- One CPU - Modem
- AX.25 Packet Radio
- Commercial HAM
- Hundreds /thousands
- Setups in Eprom

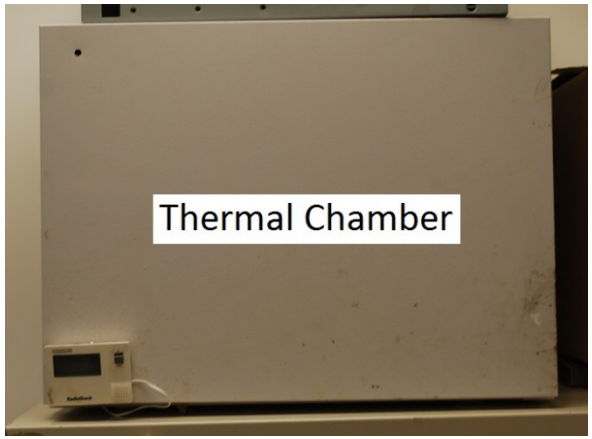
- Chips in sockets

Never leave a bakeout unattended

Never leave flight hardware unattended….

Especially in a “found” thermal chamber with cord cut off…

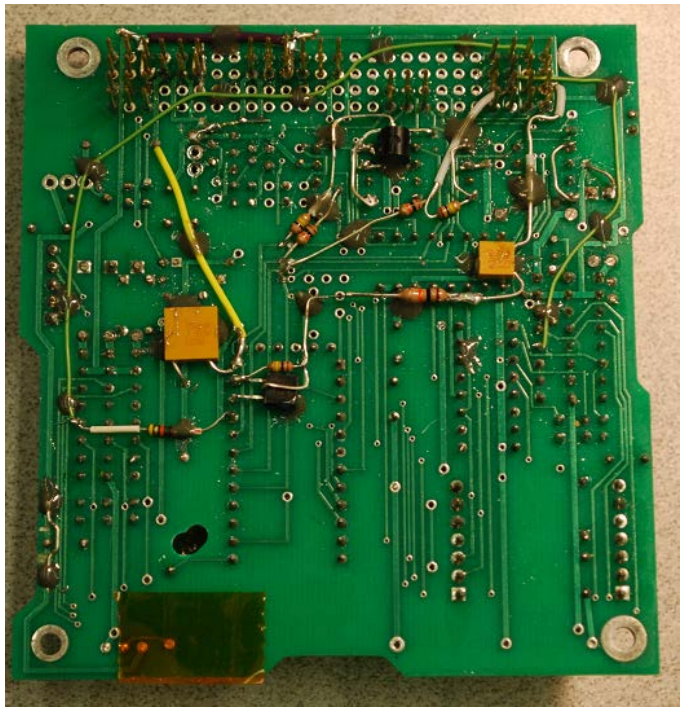
Fail-safe Heating Chamber



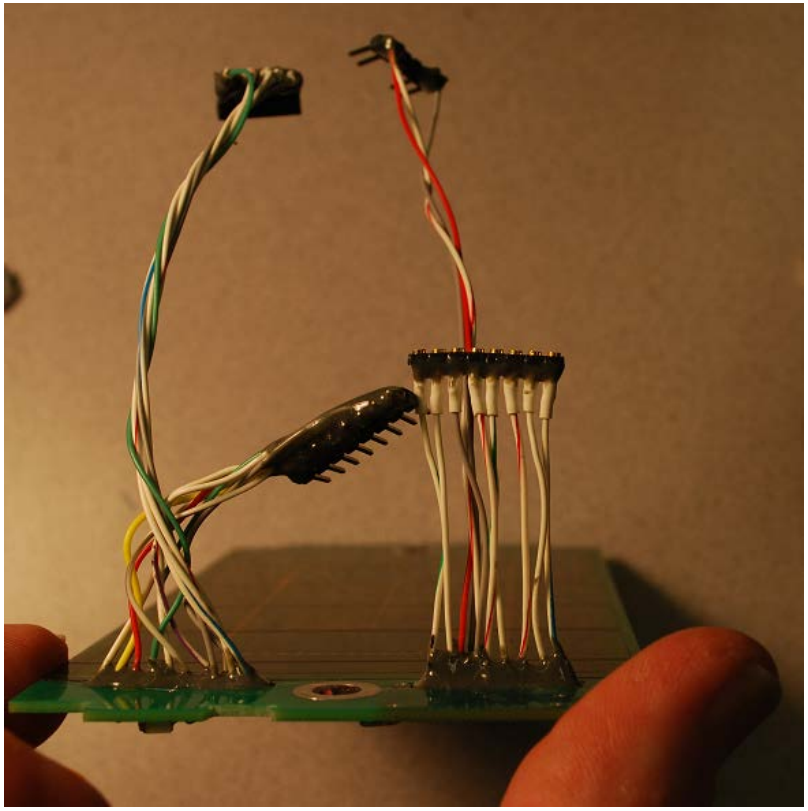
Fail-safe
Thermal
Chamber

Just screw in best combo of bulbs to achieve desired temp

Low-cost Approaches



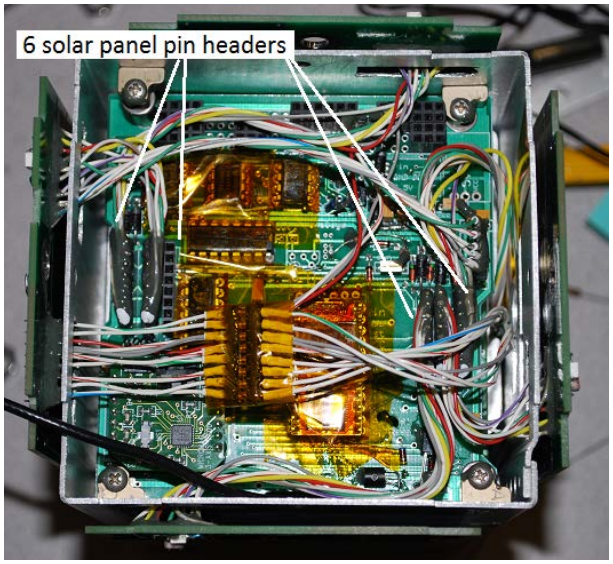
Always find
something to
Improve or tweak

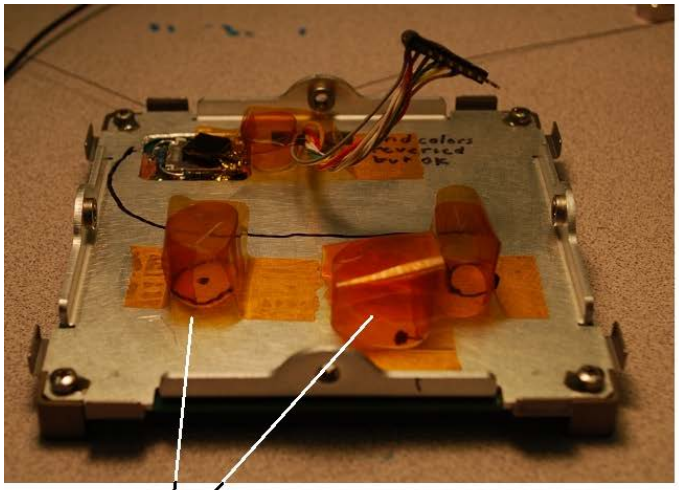


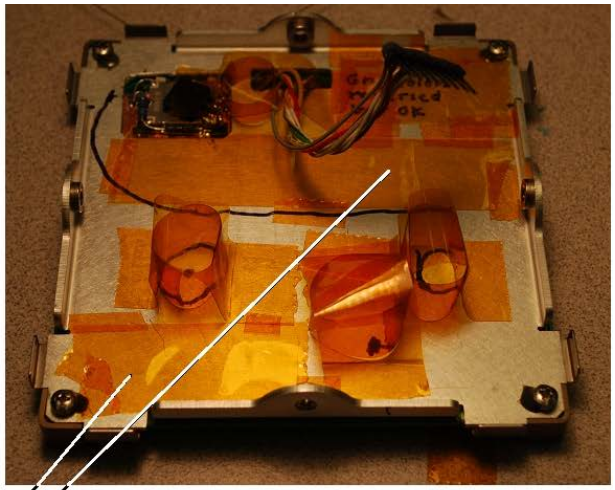
All connectors are just
0.1” Pin headers
(Solar panel w GSE)

Low-cost Approaches

Final
Top Panel
Assembly



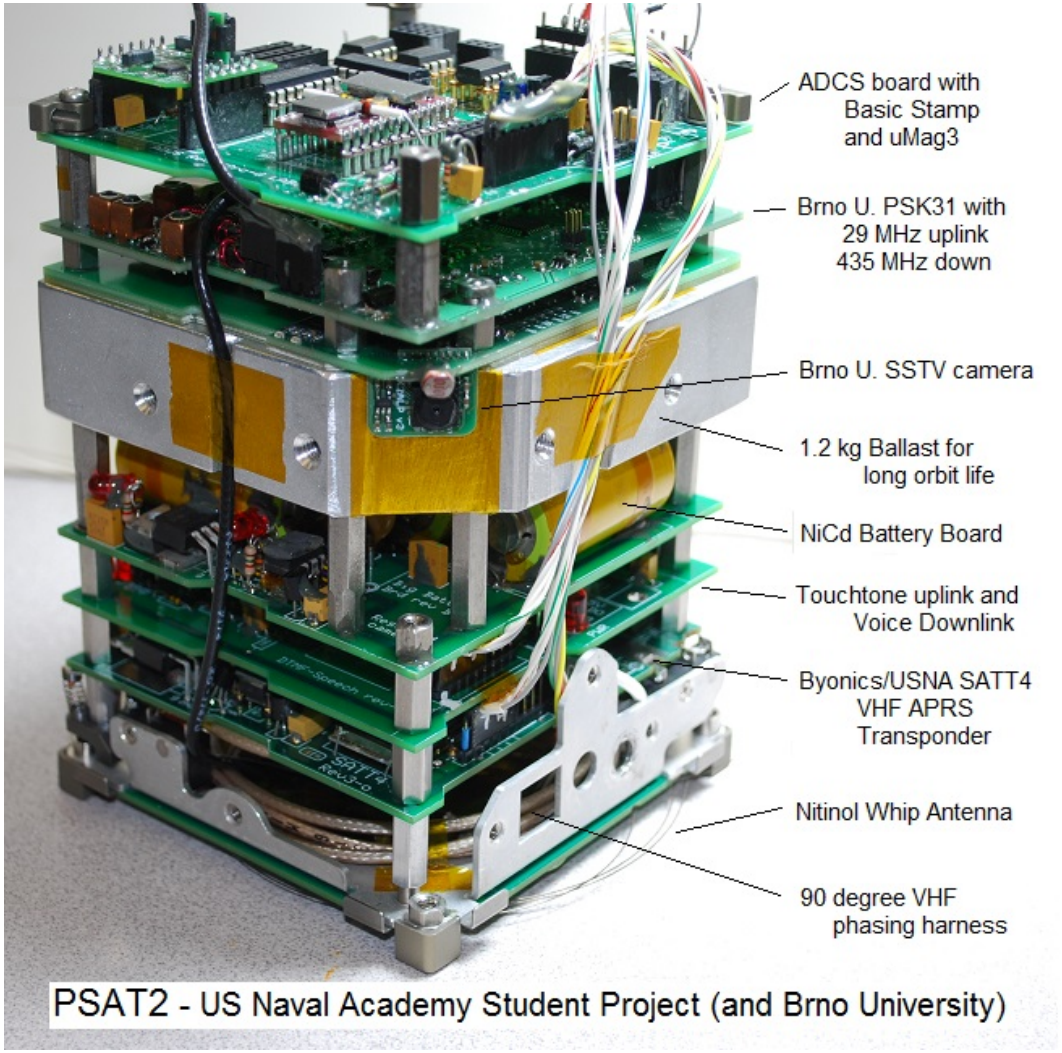




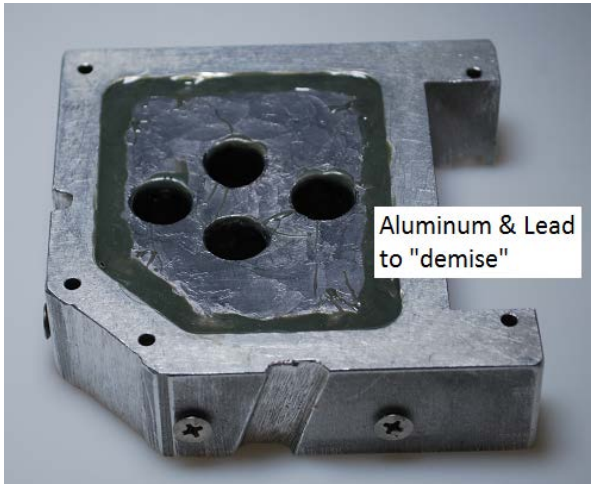
Tape Compressors to hold things on top of the stack in place.

Tape "catchers" sticky side up, to catch any debris that might still be inside.

Ballistic life Extension

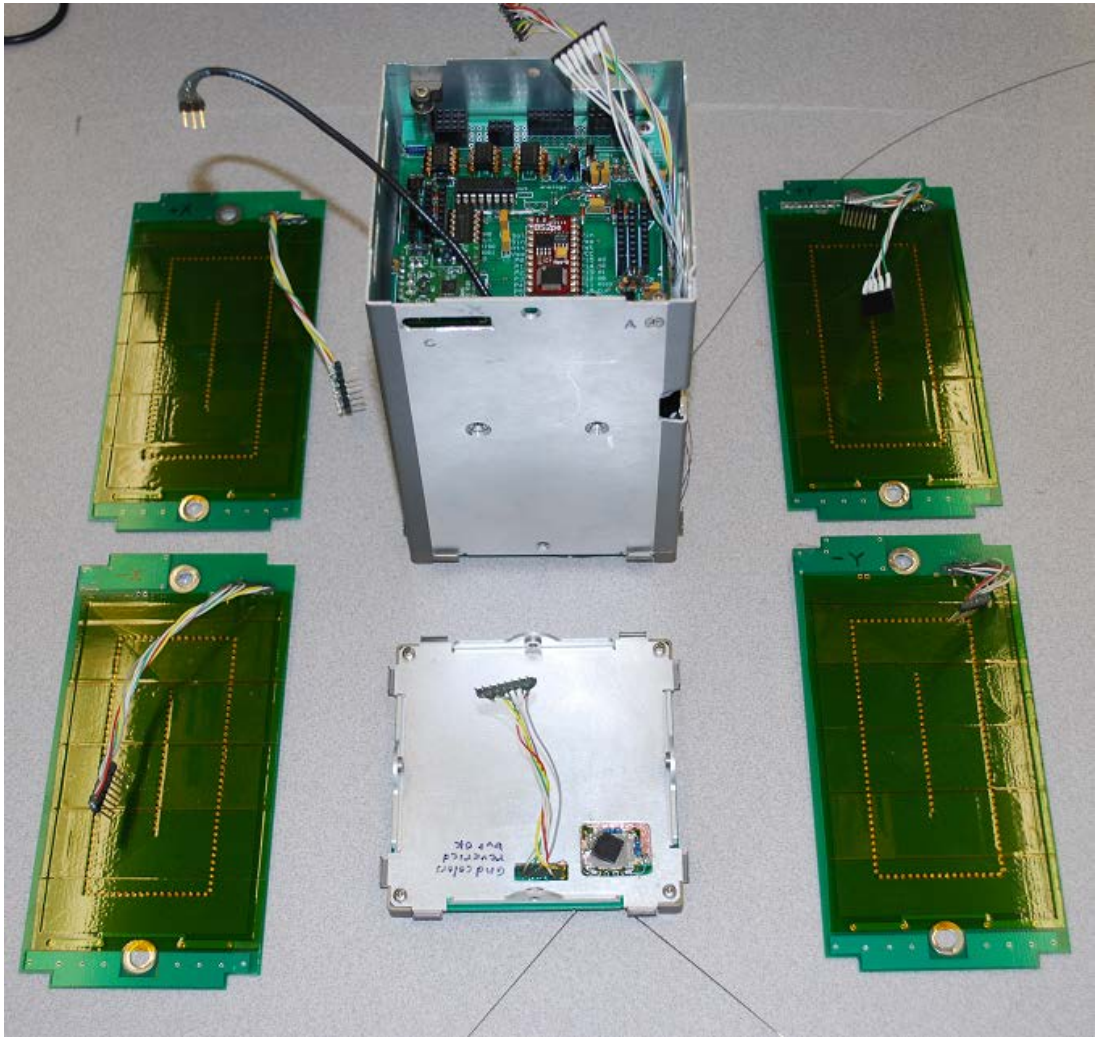


PSAT2 Stack



1.2 kg Ballast for long life

Solar Panel PCB Functions

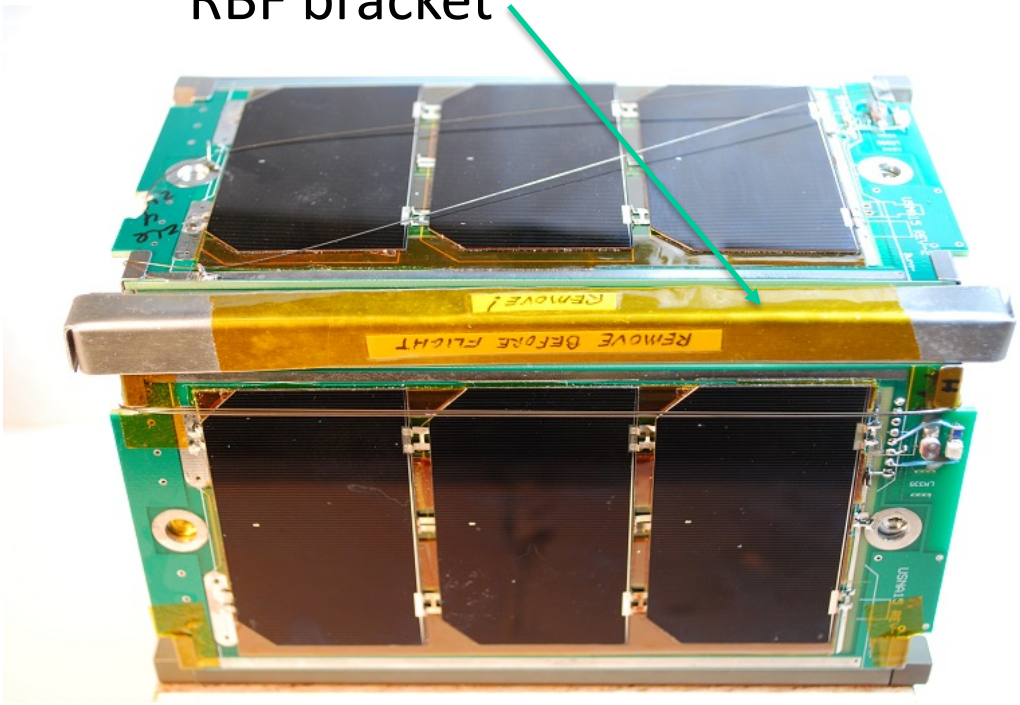


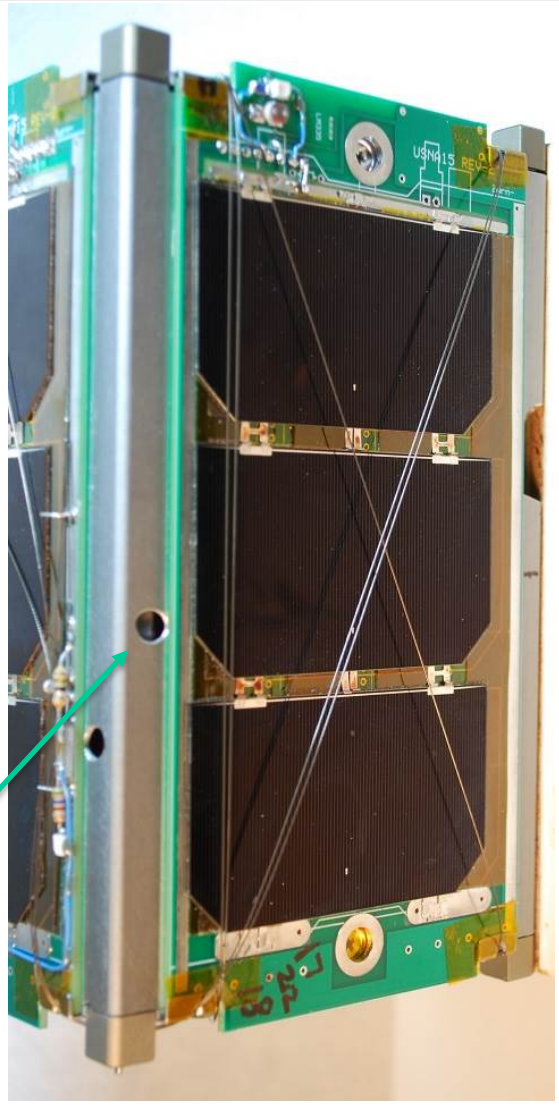
Solar Panels:

- 7.5 Volt UTJ Cells per side
- Torque Coils 2/panel, 4/axis
- Temp. and Sun Sense / side
- Antennas on top / bottom
- Cross polarized for Omni
- Pin-header connections
- Camera view port corner

Low-cost Features

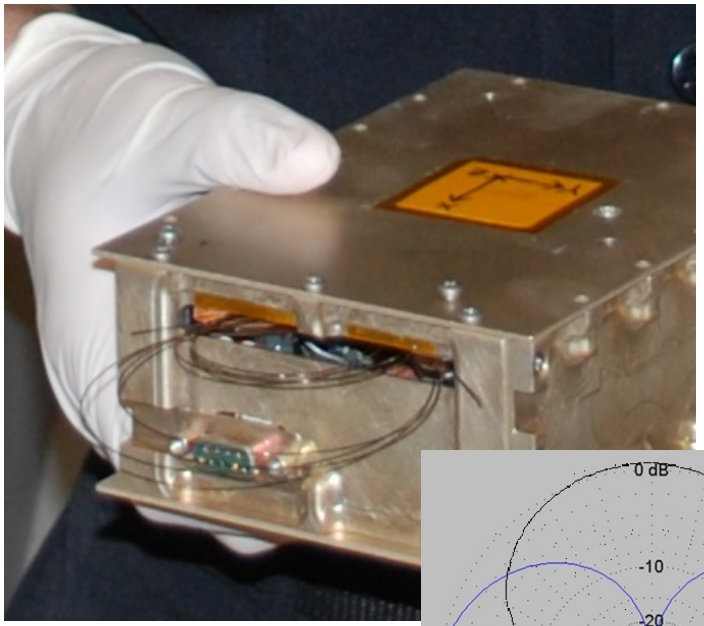
RBF bracket

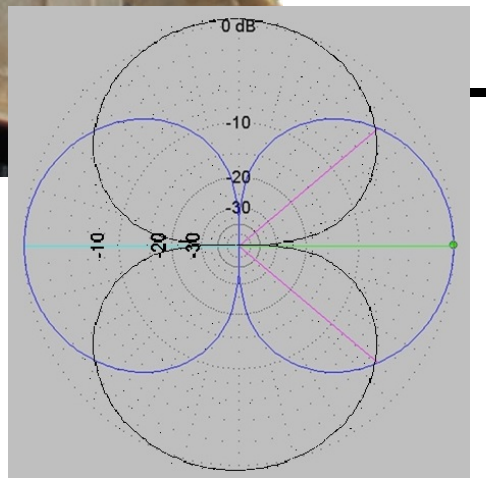


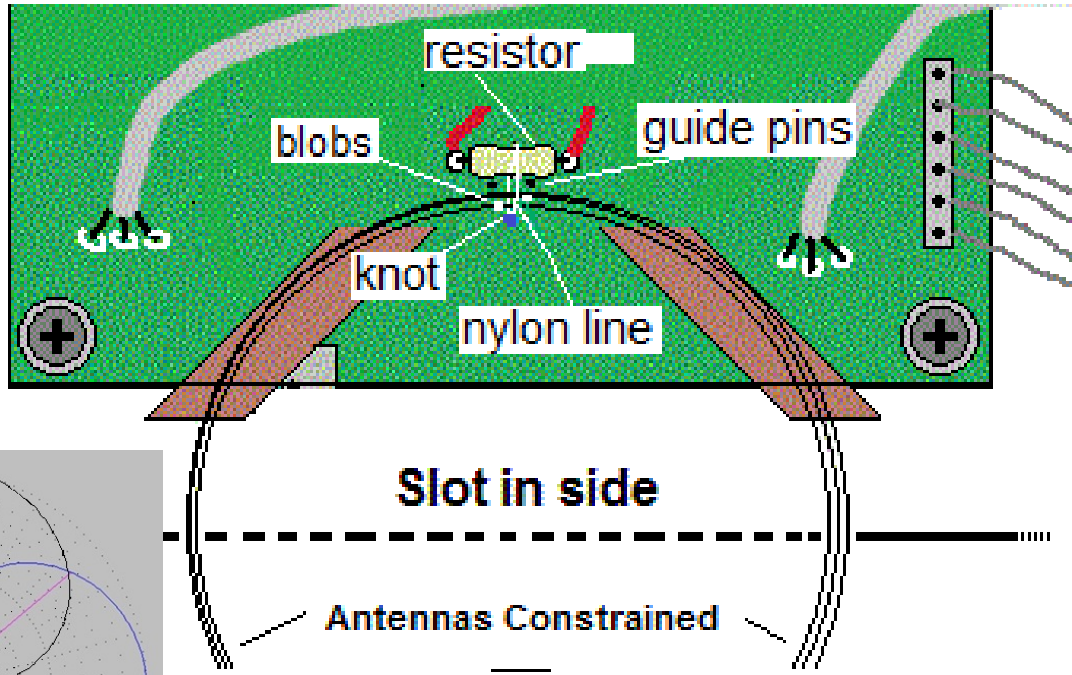


Troubleshooting LED view ports

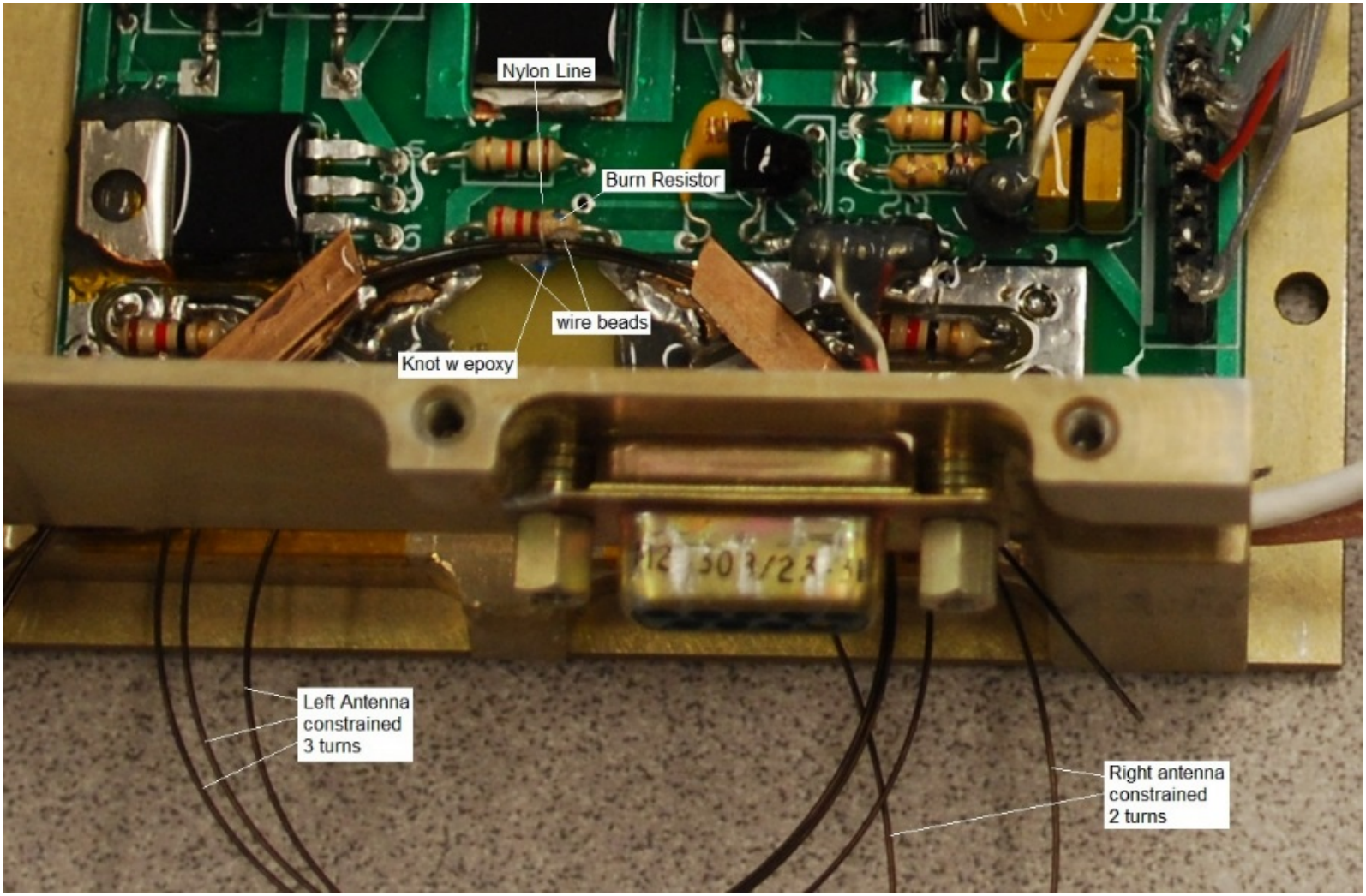
Nitinol Wire Whip Antenna Deployment







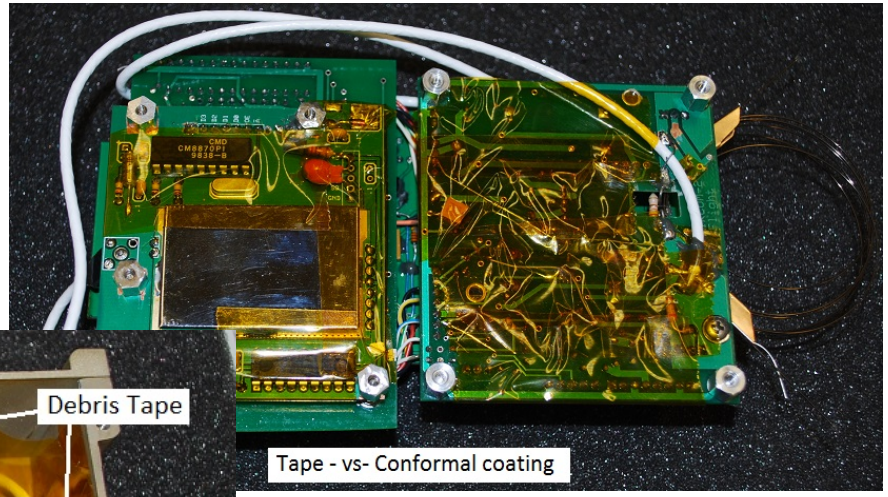
Nitinol Wire Whip Antenna Deployment



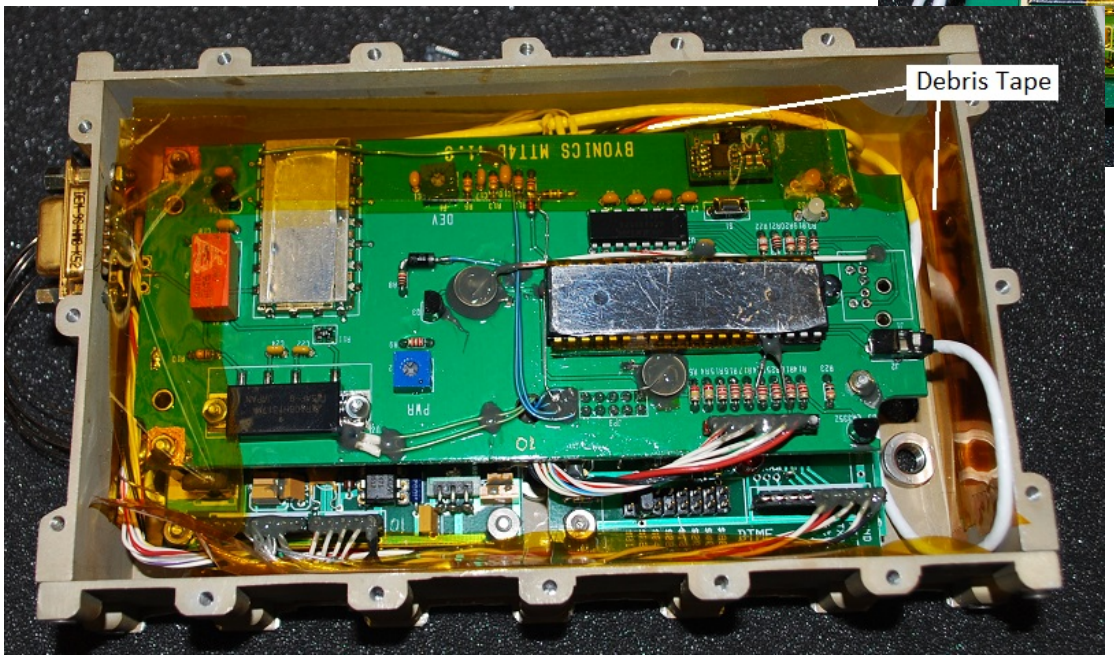
Low-cost Features

Conformal Coating

(just cover with tape)



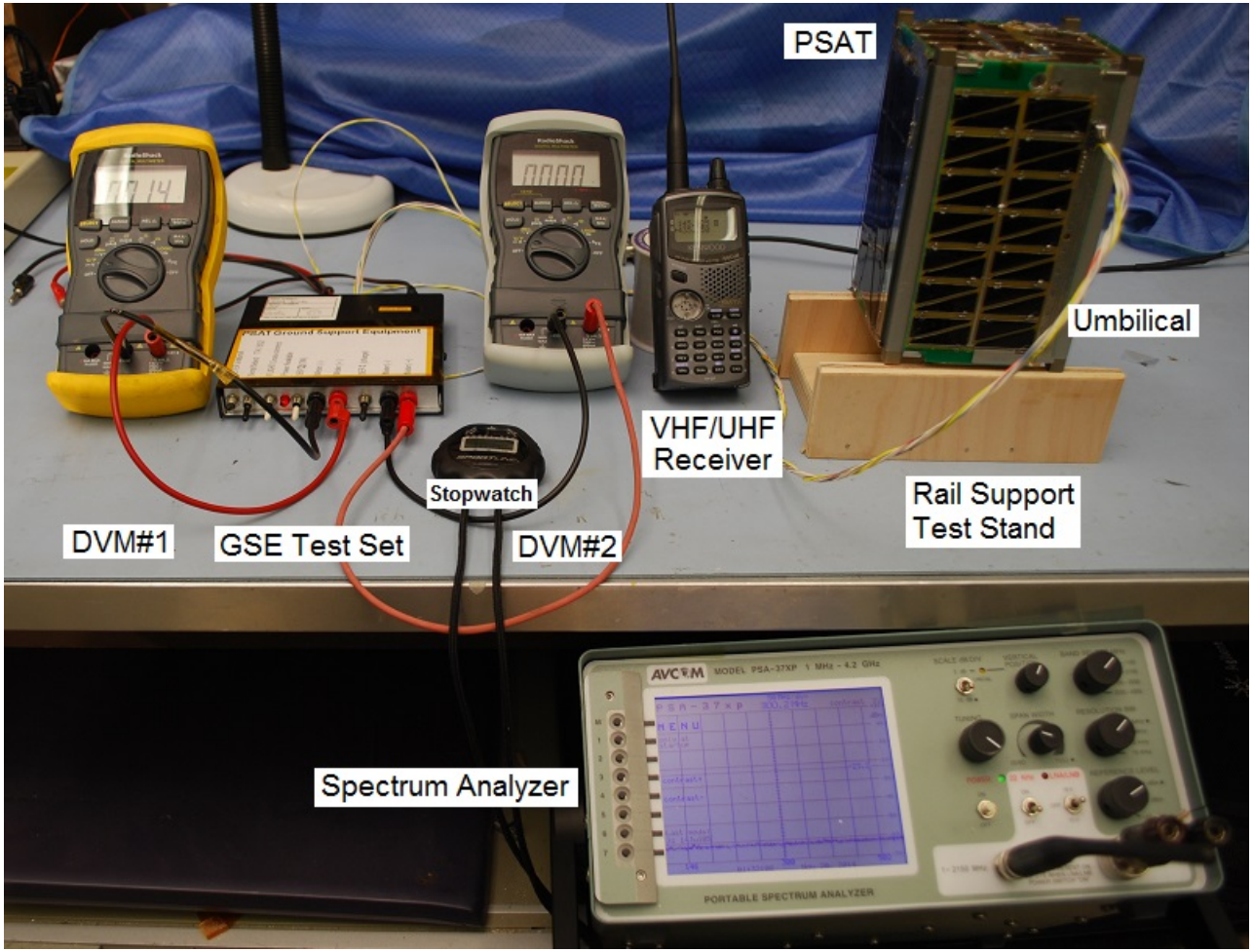
Tape - vs- Conformal coating



Debris catching

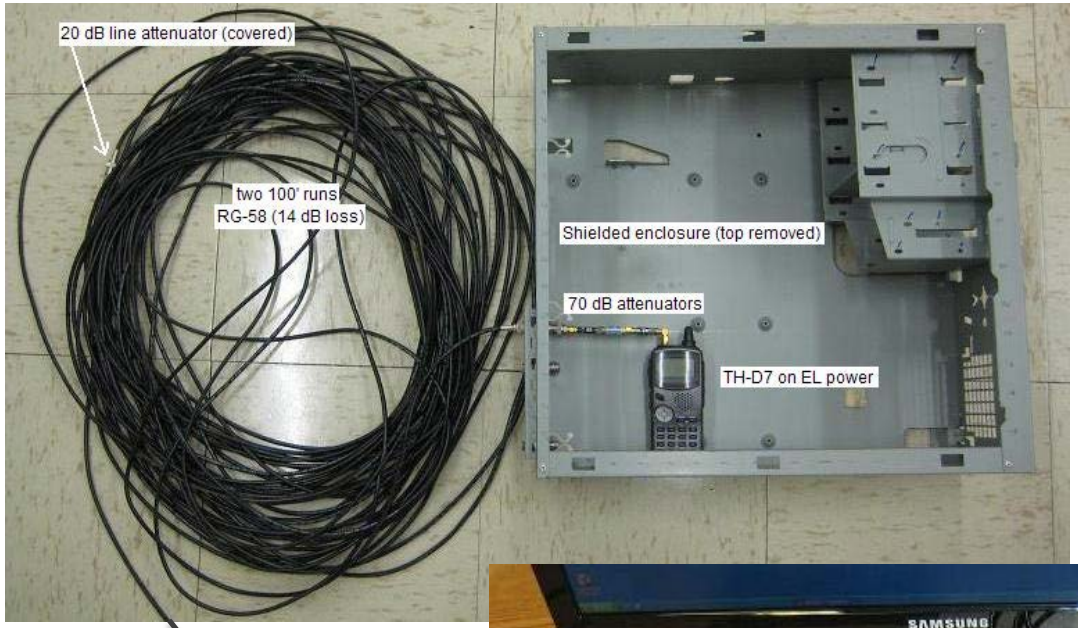
(Double sided tape)

Integration Testing with simple Test Equipment / Gnd Stn



Measuring Moments of Inertia

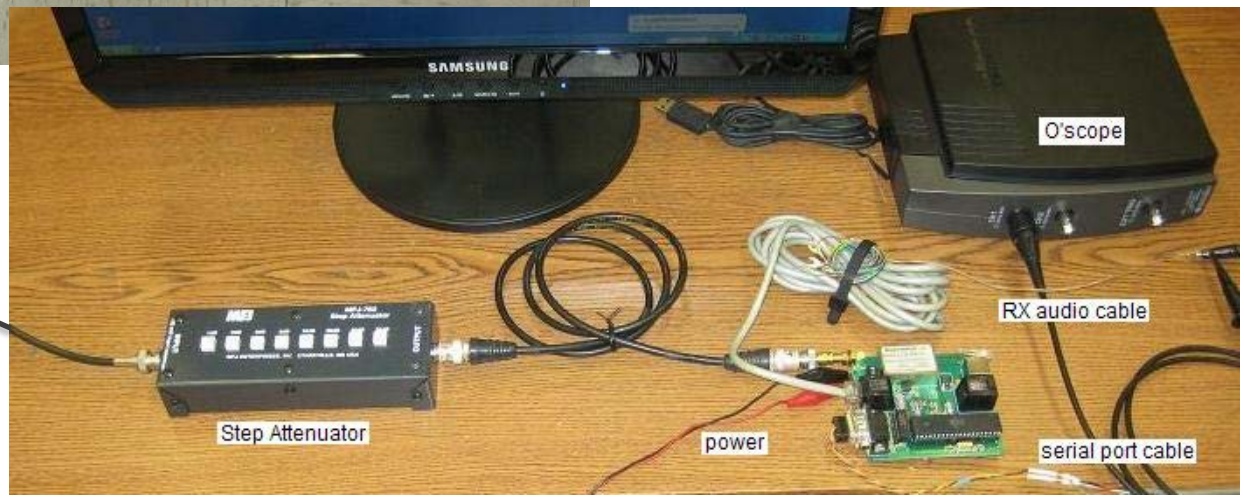
Real World RF Testing



"Bench top Testing"

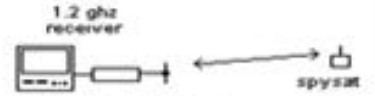
=

200' Room-to-Room
And around corner

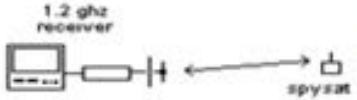


Distributed
100 dB
Attenuation

Real World RF Testing (end-to-end)



Basic link with fundamental dipole antenna but very susceptible to multipath fades and cancellations.

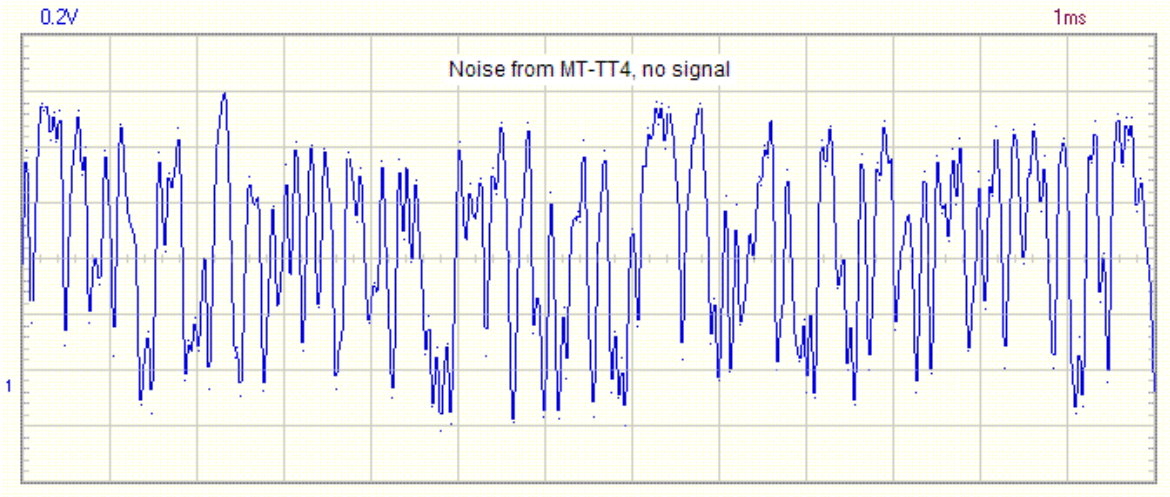


Adding a reflector off the back of the dipole gives 3 dB gain and possibly better viewing by eliminating half of the multi-path reflections.

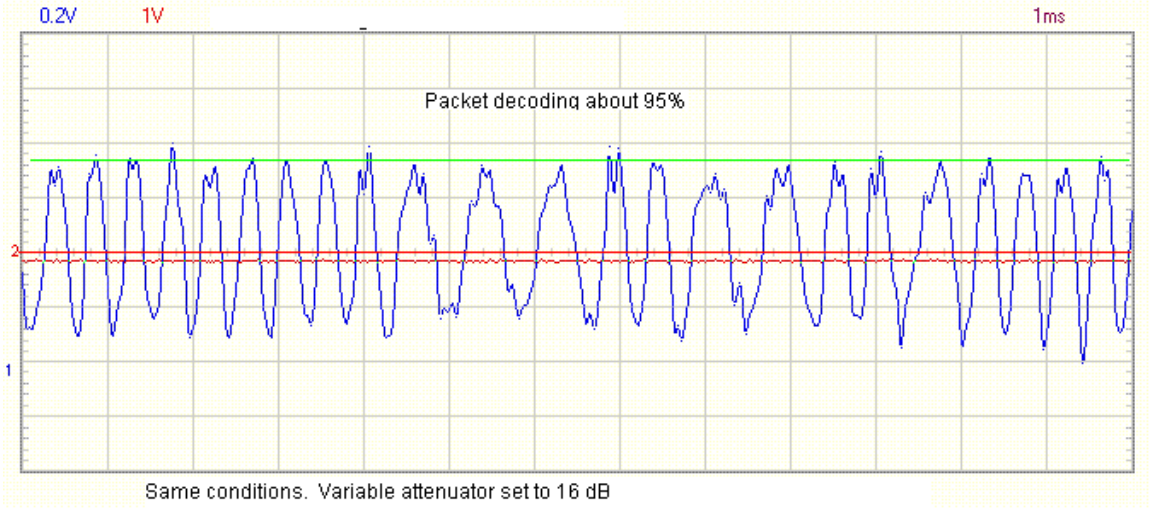
RF path of 1 mile test and 60 dB attn.

Same as 1000 mile LEO path

Real World RF Quality Testing



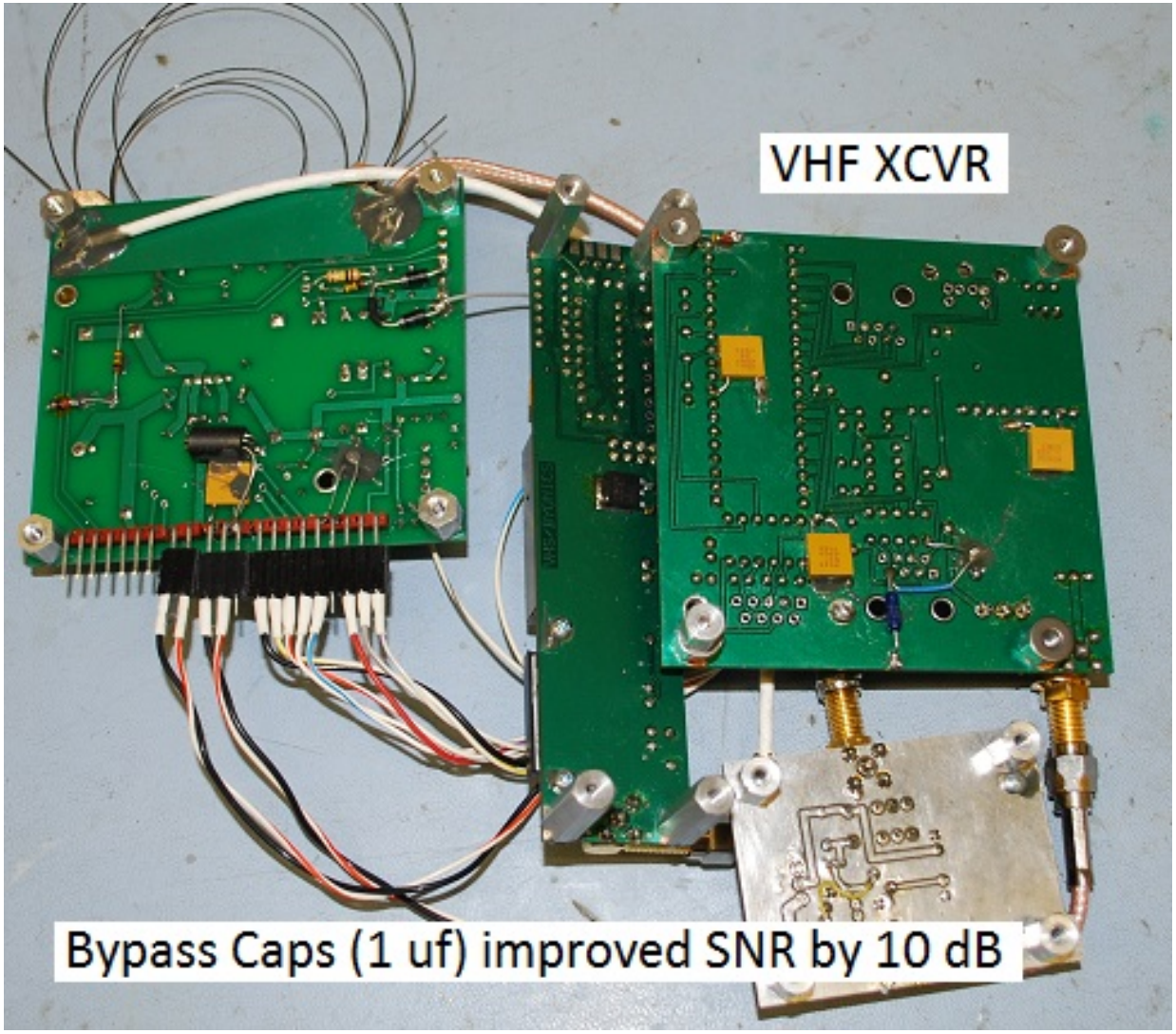
16 dB S/N
95% decode



Does it look right?

Does it sound right?

EMI Noise Mitigation



Cheap Ideas/Features Summary (1 of 2)

C&DH:

- Multiple backup Reset capability
- 555 Watchdog timer power cycle-resets
- 5-day lack of contact power cycle
- CPU Chip shielding
- Differential bit Controls (~~,00,11 OFF) (10,01 ONs)

EPS:

- Cheap solar (50% performance at 0.1% of cost)
- Parallel-charge, Series-use battery
- NiCd’s for absolute robustness and minmum risk
- Solar Radiative spin for thermal balance
- No BCR – Passive match of IV curve to NiCd
- Maximize mass for maximum orbit life

Cheap Ideas/Feature Summary (2 of 2)

Comms: (COTS and wide ham radio usage)

- VHF 9 dB link advantage over UHF, 16dB/Sband
- Very simple wire whip antennas and 1 resistor release
- Real-world RF link testing
- Bypass caps for EMI mitigation
- Antenna Tuning internal to spaceframe
- Common comms Protocol
- Worldwide RX-only internet linked ground network

Hardware:

- Simple pin-headers for all connections (flexibility)
- 2 layer - through-hole parts for simple design/testing
- Kapton tape for protection from metallic debris
- Kapton tape for debris trapping
- Simple string MOI measurements
- Soldering, no crimping
- No clean room till final Assembly
- ESD simplicity lax (50 yrs experience)