# RAFT
# Radar Fence Transponder
# Phase III Safety Review  Jan 06


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MIDN 1/C Ben Orloff
MIDN 1/C Eric Kinzbrunner
MIDN 1/C JoEllen Rose
Midn 1/C Steven Schwarzer


# Key Milestones: Schedule

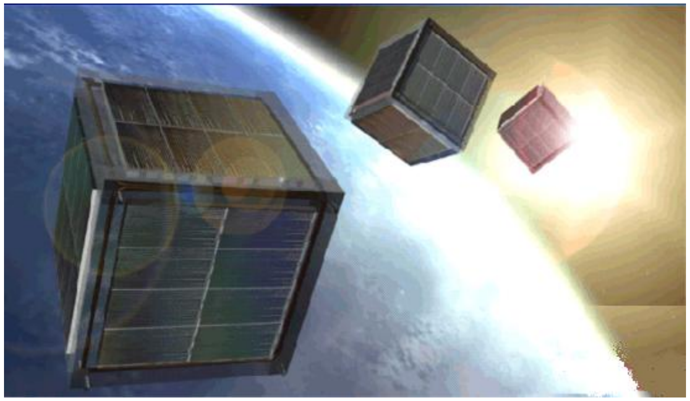
- Assumption: Launch NET May 2006

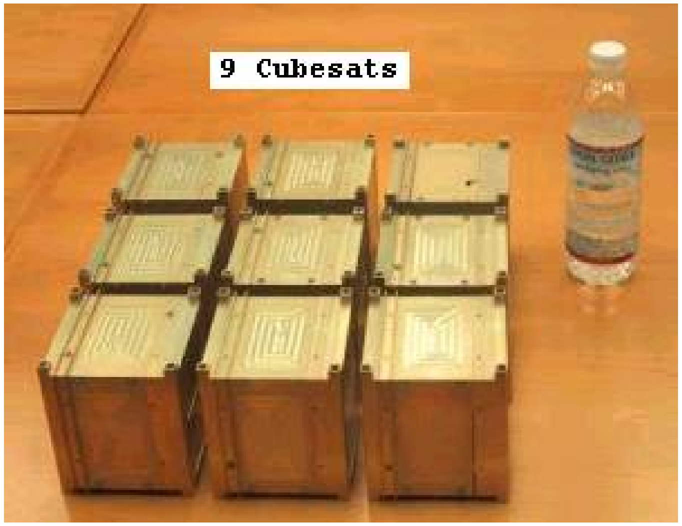
| | |
|---|---|
| ✓ RAFT Kickoff | Apr 04 |
| ✓ RAFT USNA SRR | Sep 04 |
| ✓ RAFT PDR | 19 Nov 04 |
| ✓ RAFT Phase 0/1 Safety | 16 Dec 04 |
| ➢ RAFT Phase 2 Safety | 10 Feb 05 |
| ◆ RAFT CDR | 23 Feb 05 |
| ◆ RAFT Flight Unit Testing | Jan 05 |
| ◆ RAFT Phase 3 Safety | Feb 06 |
| ◆ RAFT Delivery/Install | Apr 06 |
| ◆ RAFT Flight (STS-116) | Oct 06 |

# So Many CUBEsats

30 to 50 in Construction

How to Track them???






**AIAA/USU Small Sat Conference**

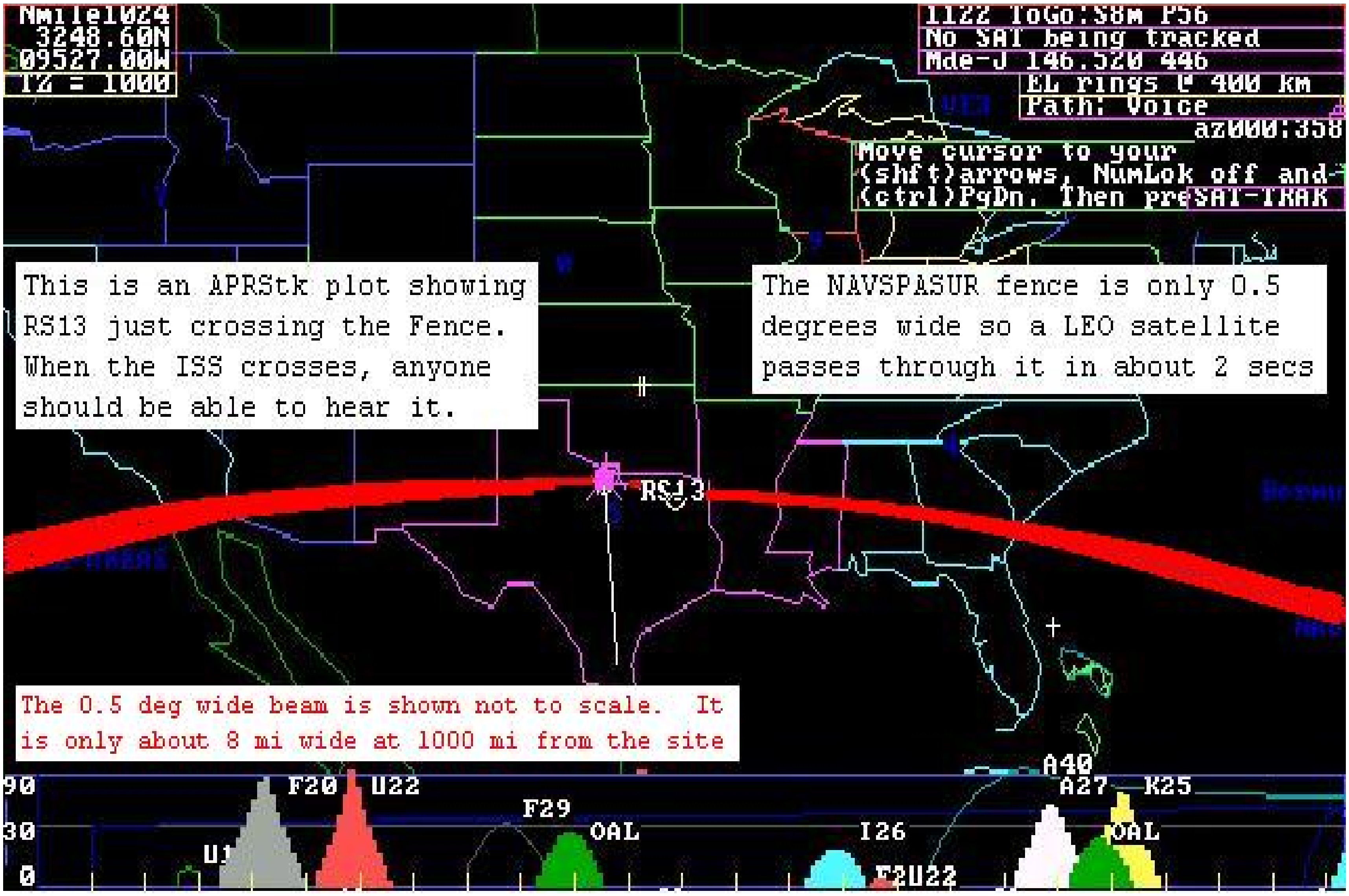
**30% of papers were for PICO, NANO and CUBEsats**

**All smaller than 10 cm**

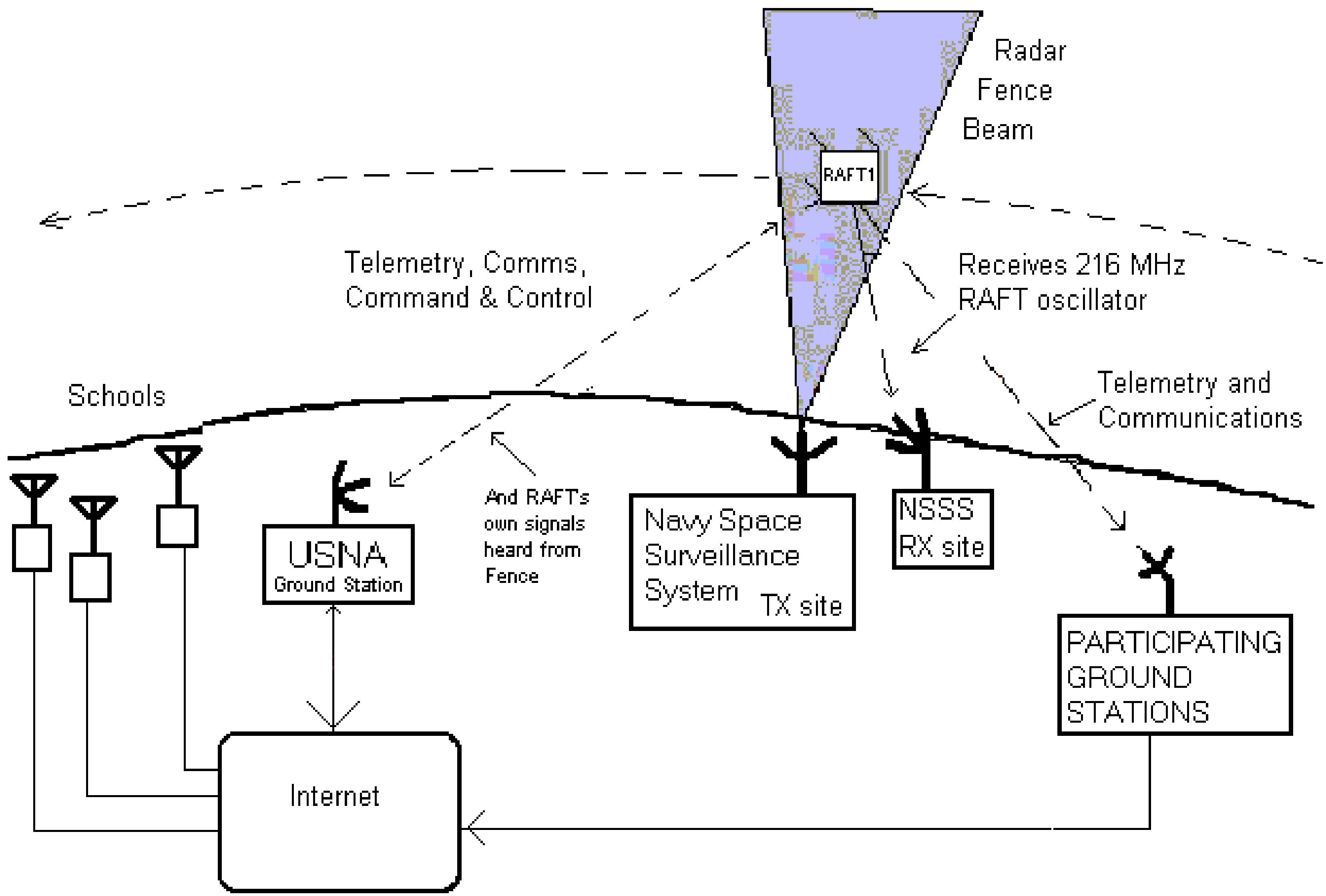
# Mission Statement

- To provide the Navy Space Surveillance (NSSS) radar fence with a means to determine the bounds of a constellation of PicoSats otherwise undetectable by the radar fence
- To enable NSSS to independently calibrate their transmit and receive beams using signals from RAFT.
- This must be accomplished with two PicoSats, one that will actively transmit and receive, and one with a passively augmented radar cross-section.
- Additionally, RAFT will provide experimental communications transponders for the Navy Military Affiliate Radio System, the United States Naval Academy's Yard Patrol crafts, and the Amateur Satellite Service.

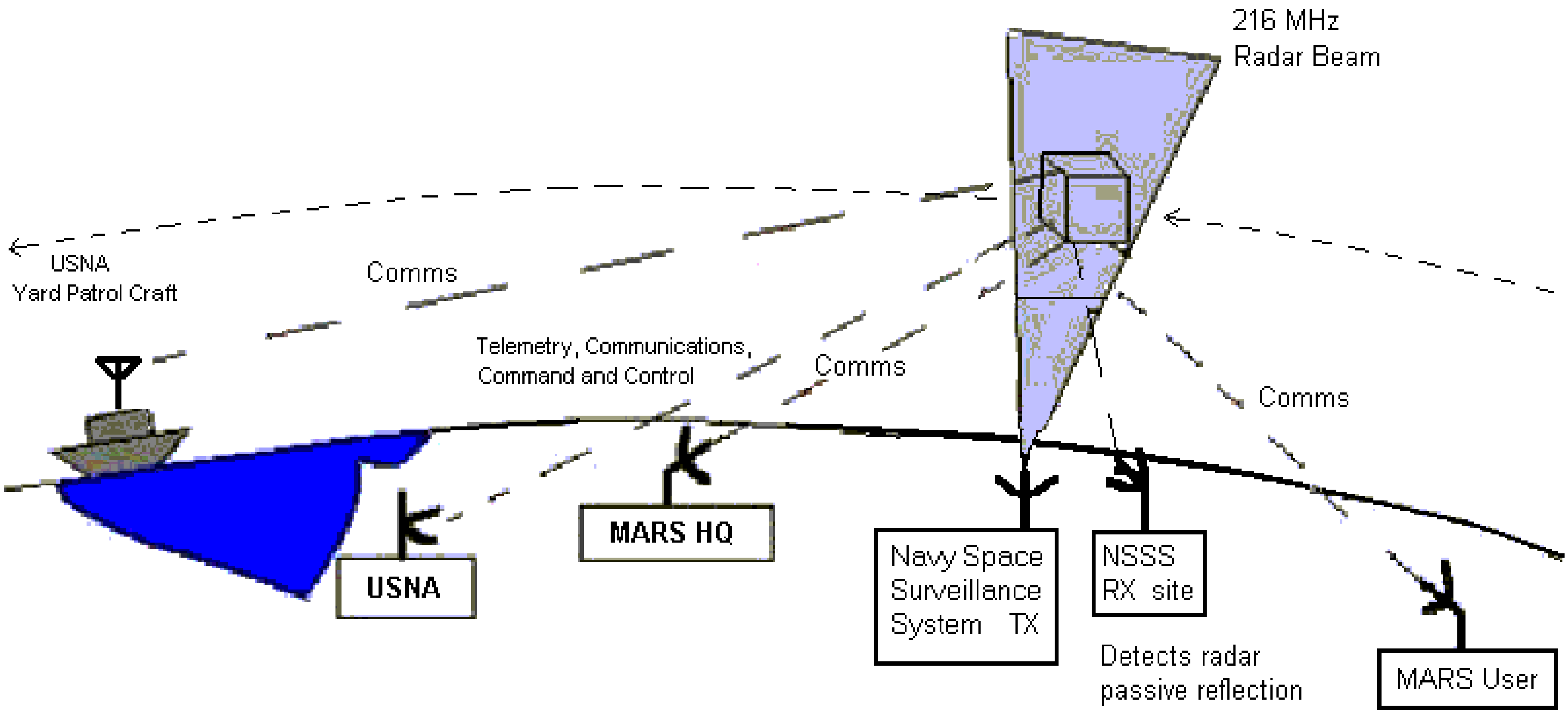
# NSSS Radar Fence



# RAFT1 Mission Architecture



# MARScom Mission Architecture



# Military Affiliate Radio System

The Mission of the MARS system is to:

- Provide auxiliary communications for military, federal and local disaster management officials

- Assist in effecting communications under emergency conditions.

- Handle morale and quasi-official communications traffic for members of the Armed Forces and authorized U.S. Government civilian personnel

- Provide routine operations in support of MARSGRAMS and … contacts between service personnel and their families back home

# Yard Patrol Craft Application

**The Yard Patrol Craft**

105' length
Crew of about 25
Quantity 20

**YP COMMS EQUIPMENT**

**Tactical UHF** (uplink)

**Harris HF Xcvr** (downlink)

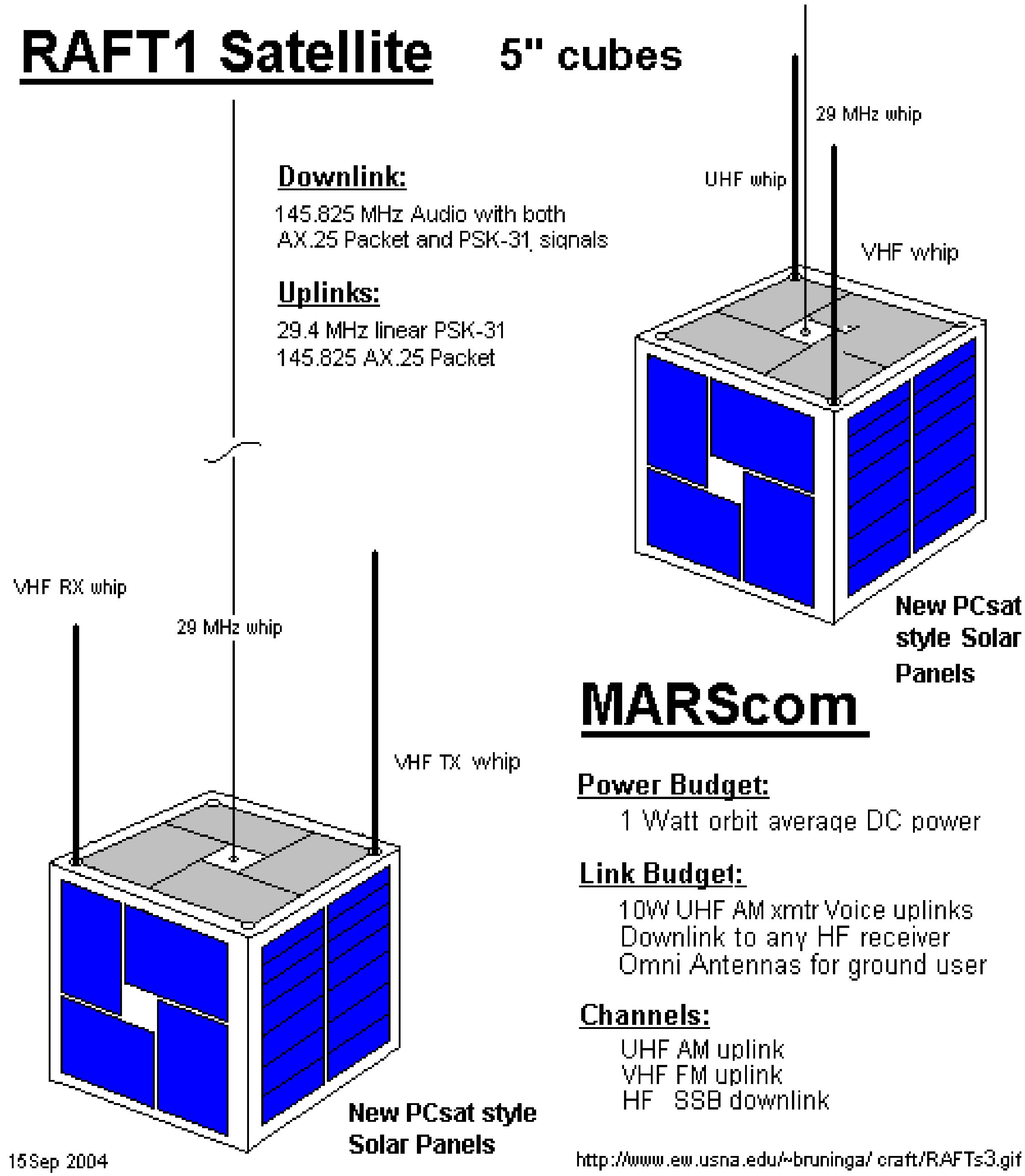
**Unique UHF AM Uplink and HF SSB downlink**

# RAFT1 and MARScom

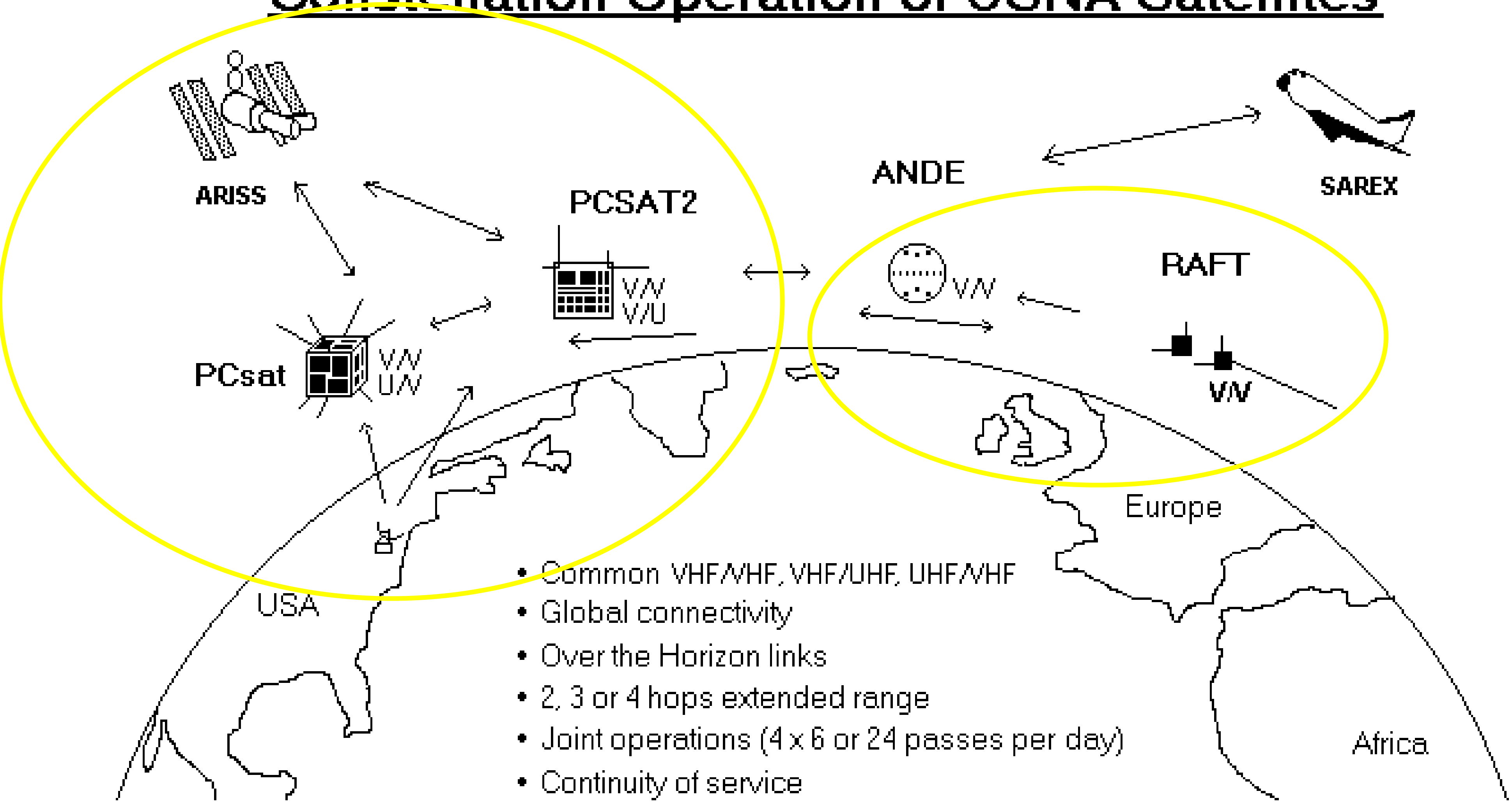
5” Cubes

3 Antennas Each

Identical Mechanical



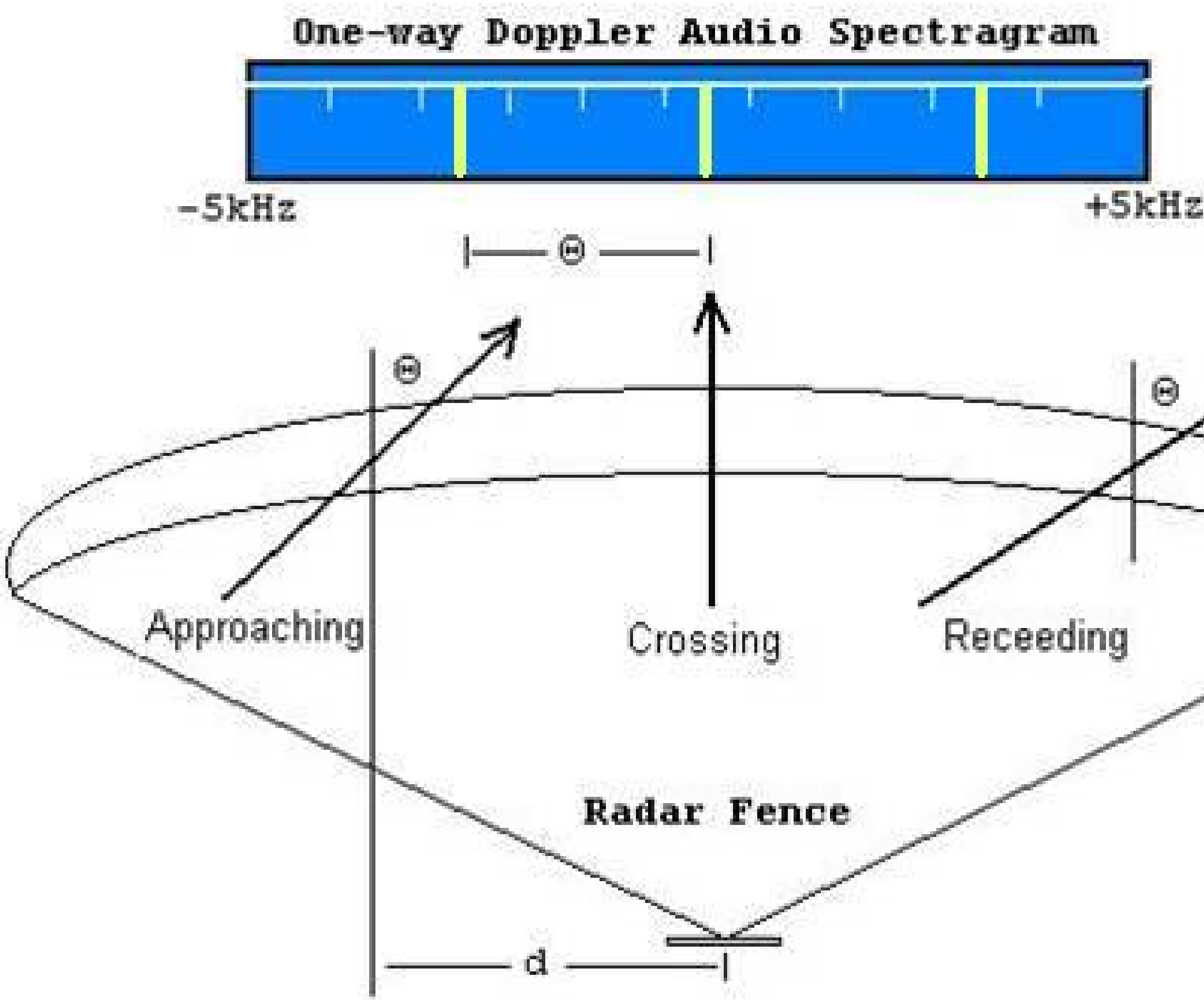
# Constellation Operation of USNA Satellites



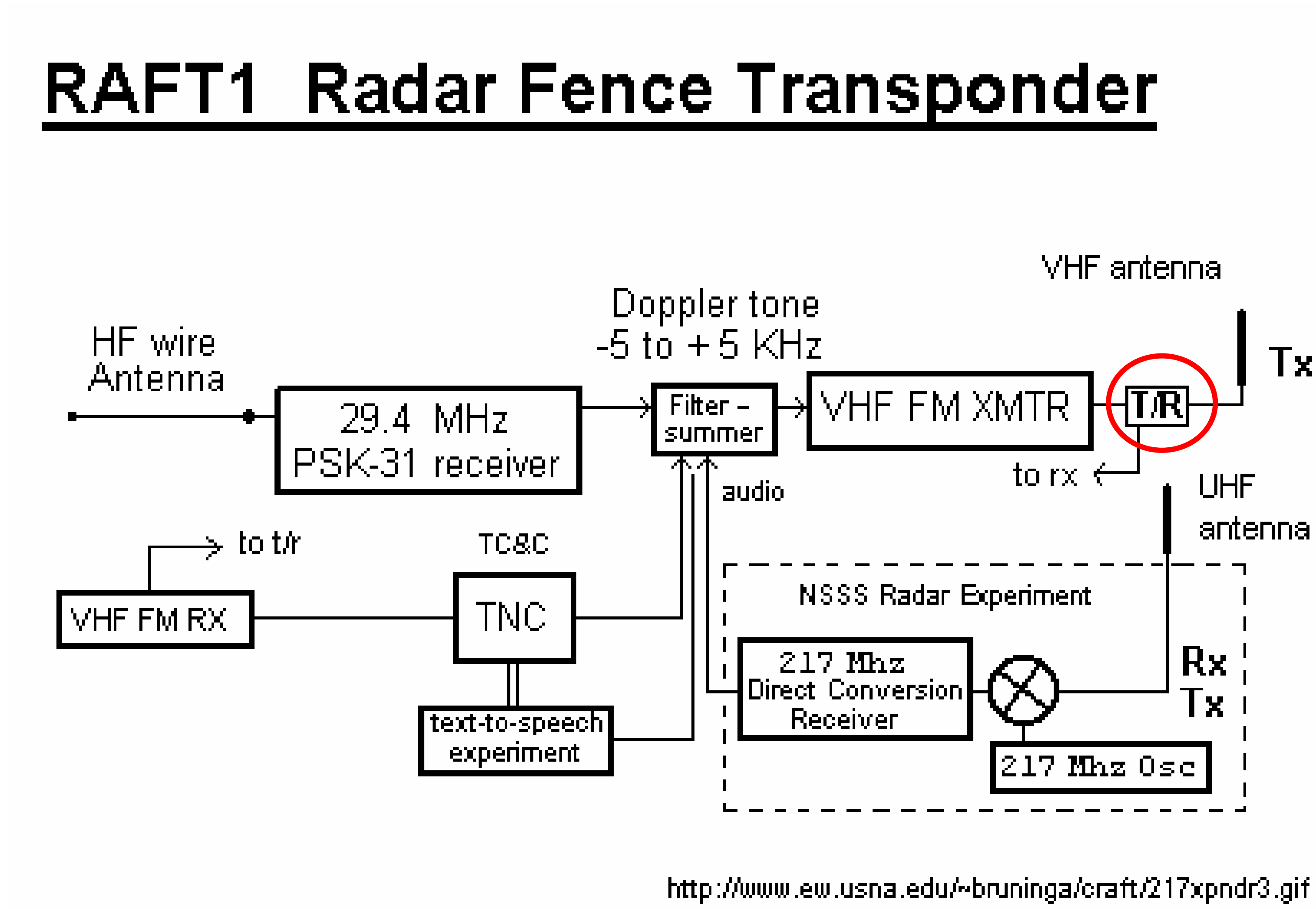

WB4APR

http://www.ew.usna.edu/~bruninga/craft /USNAsats.gif

# Pass Geometry

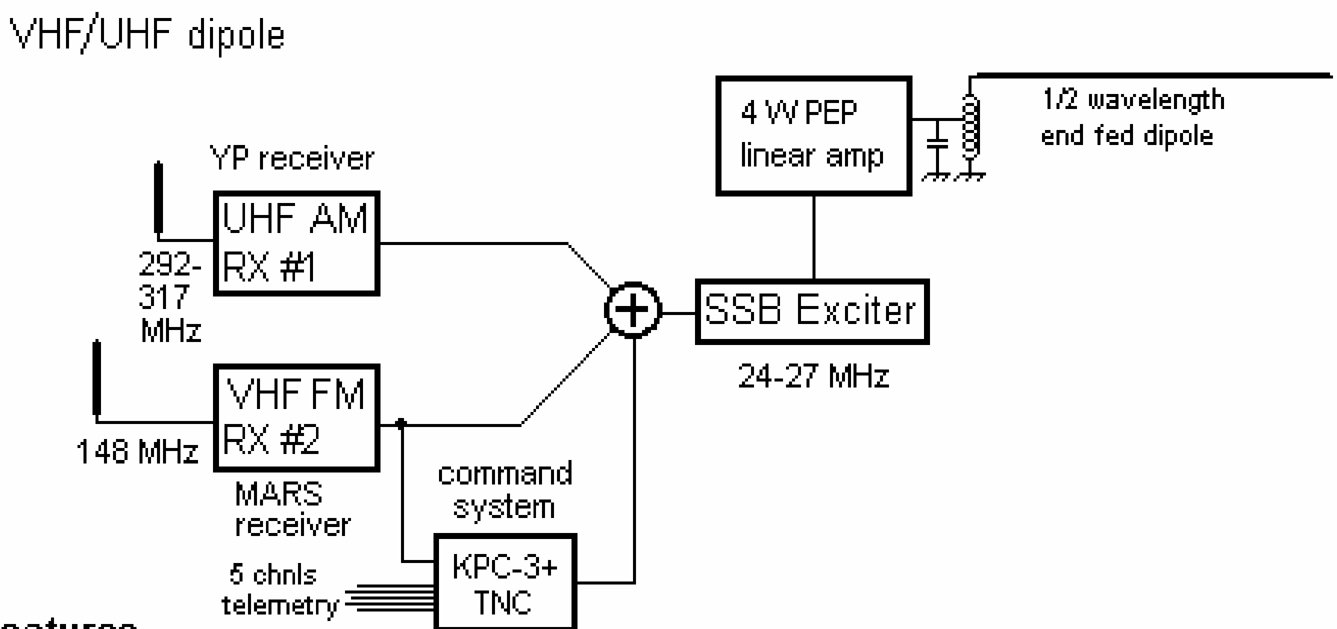


# Raft1 Block Diagram



# MARScom Block Diagram

## MARScom Voice Transponder

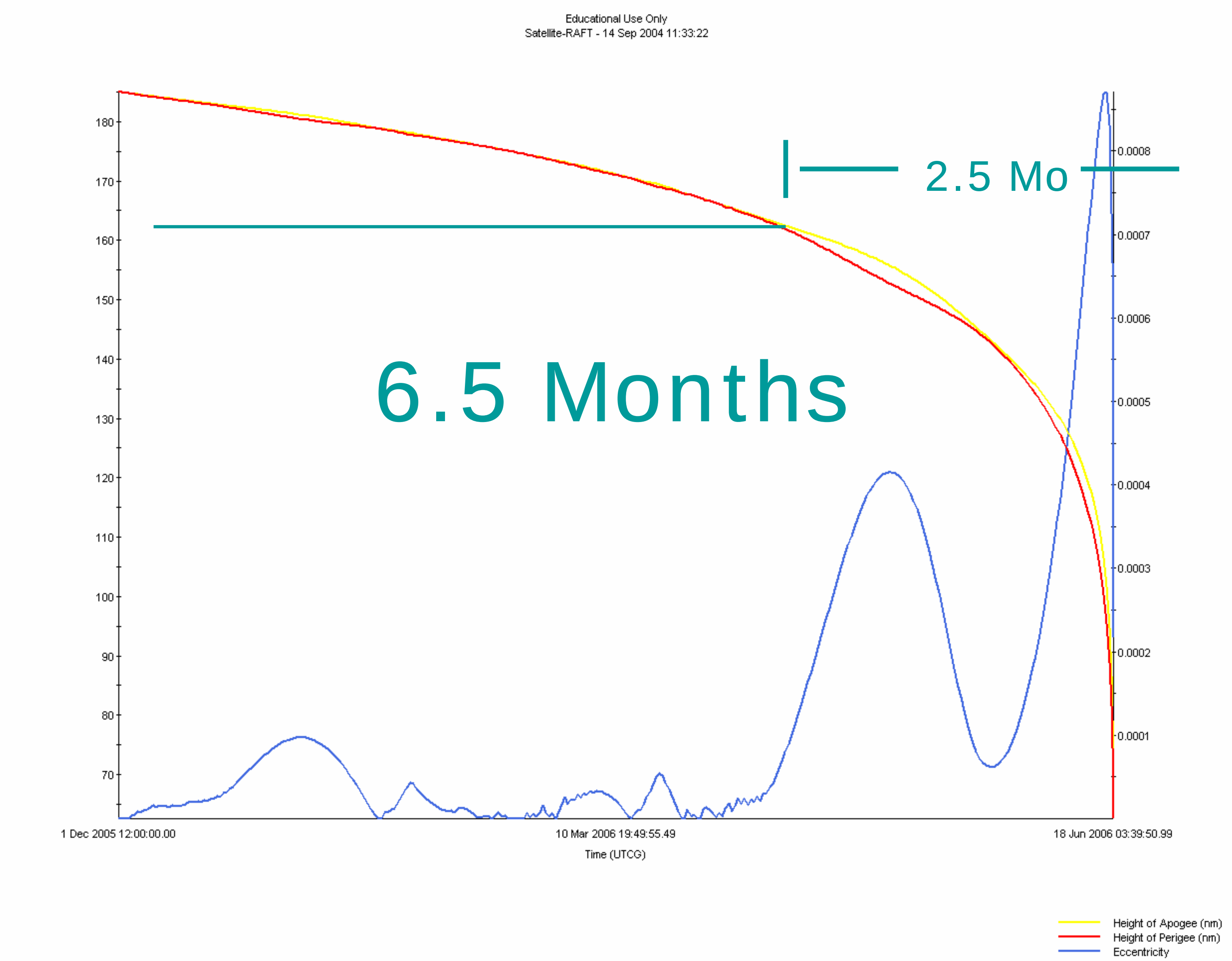



**Features**

- UHF AM receiver makes MARScom compatible with ALL older UHF transmitters
- Summed dual Uplinks allow near full-duplex voice between Netcontrol and User without AGC power sharing or carrier hetrodyne
- Command receiver allows control of all three modes

http://www.ew.usna.edu/~bruninga/mars/marsXponder2.gif

# RAFT Lifetime Estimate



# RAFT Deployment

Velocity of pair:

1.8 m/s

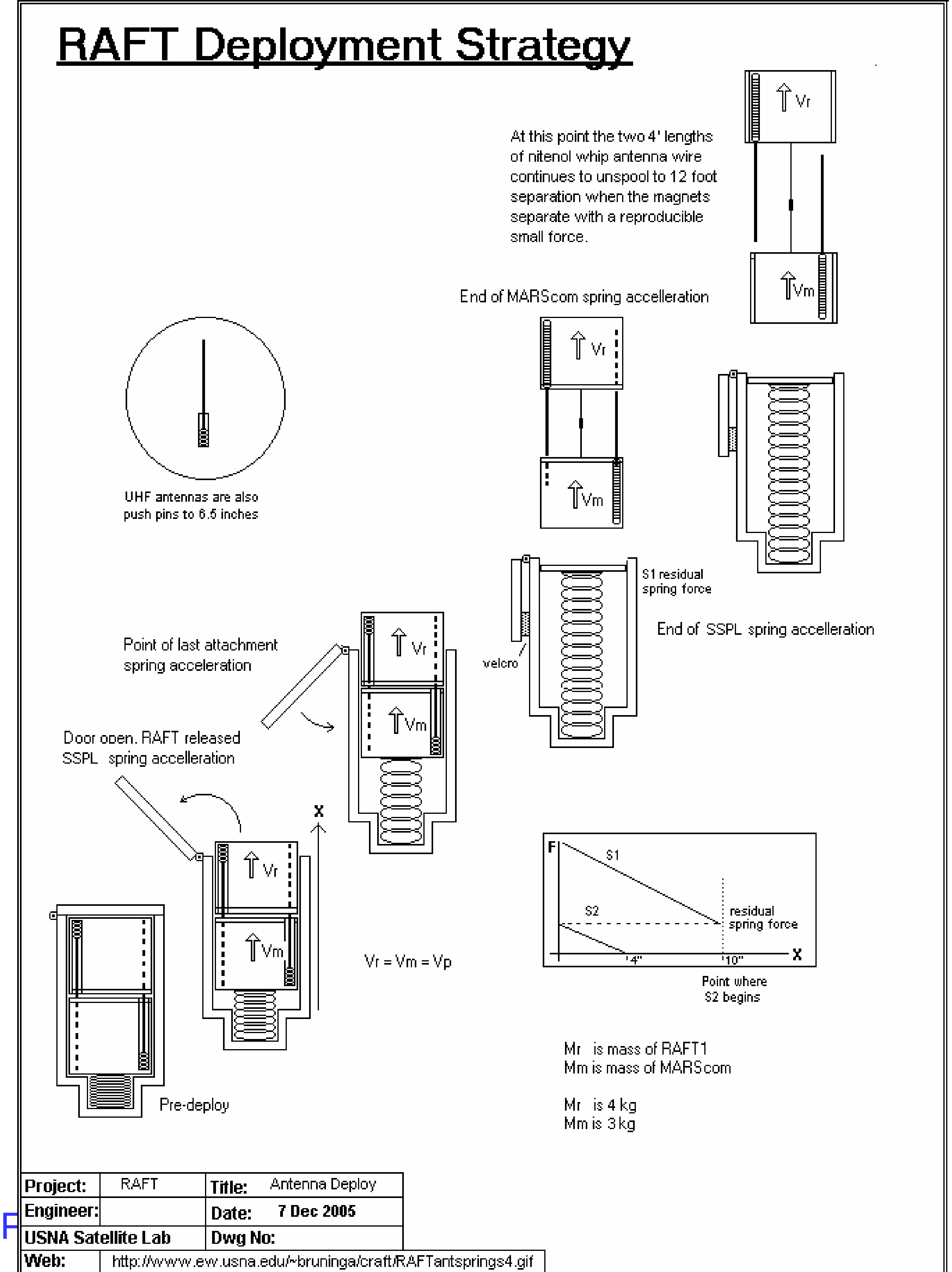
Velocity of RAFT:

2.6 m/s

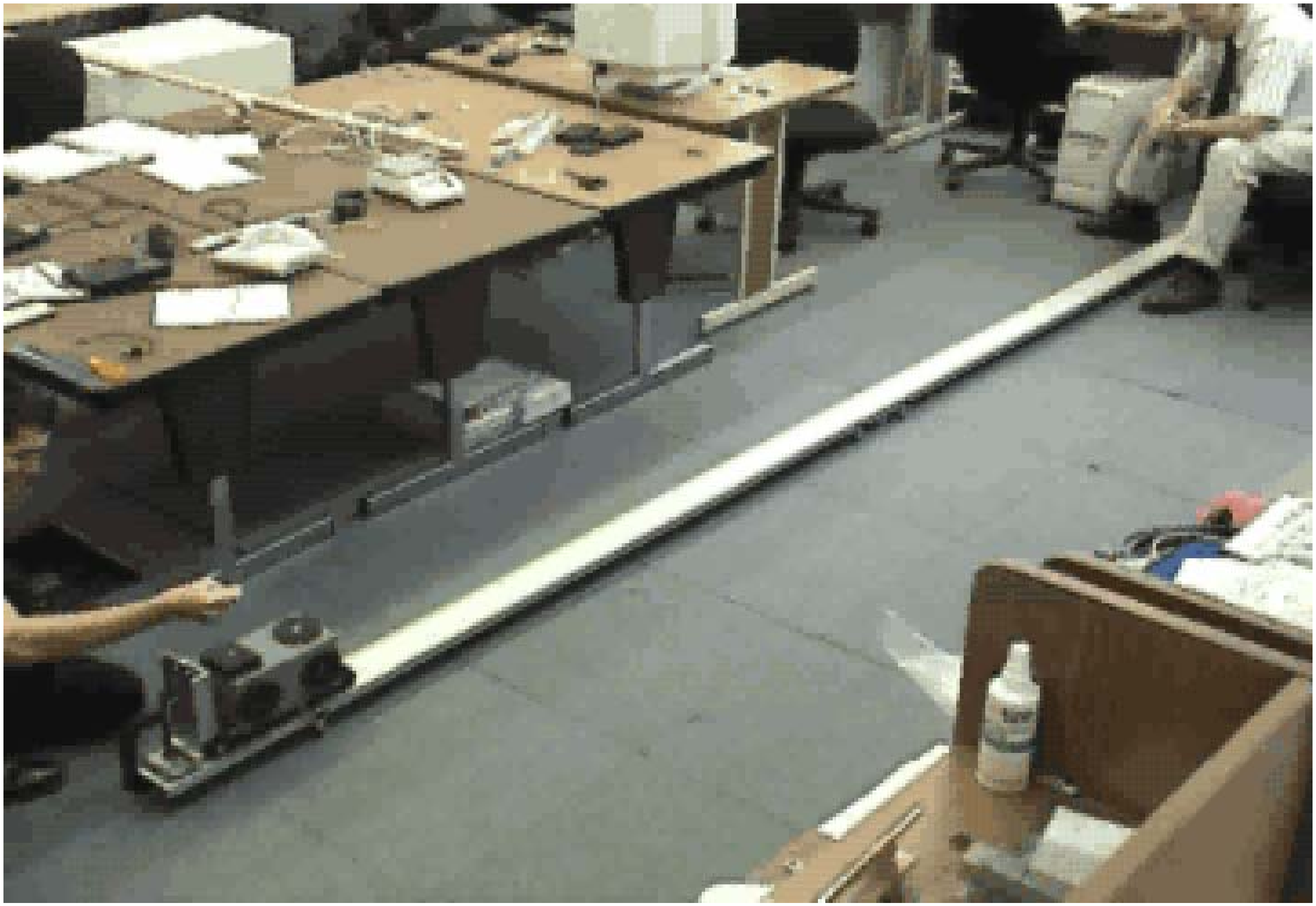
Velocity of MARScom:

1.2 m/s

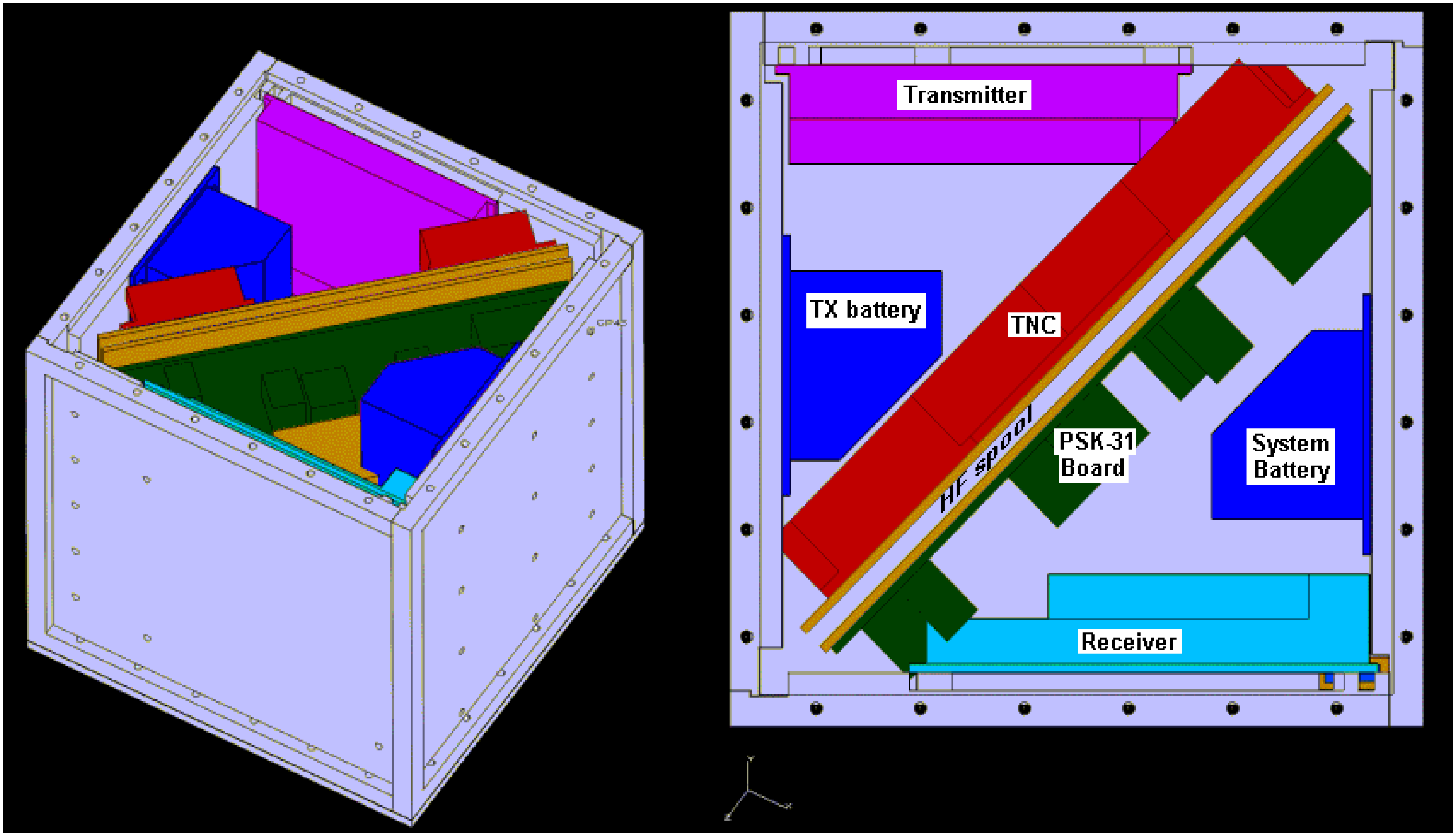
Was 1.5, 1.3 & 1.8



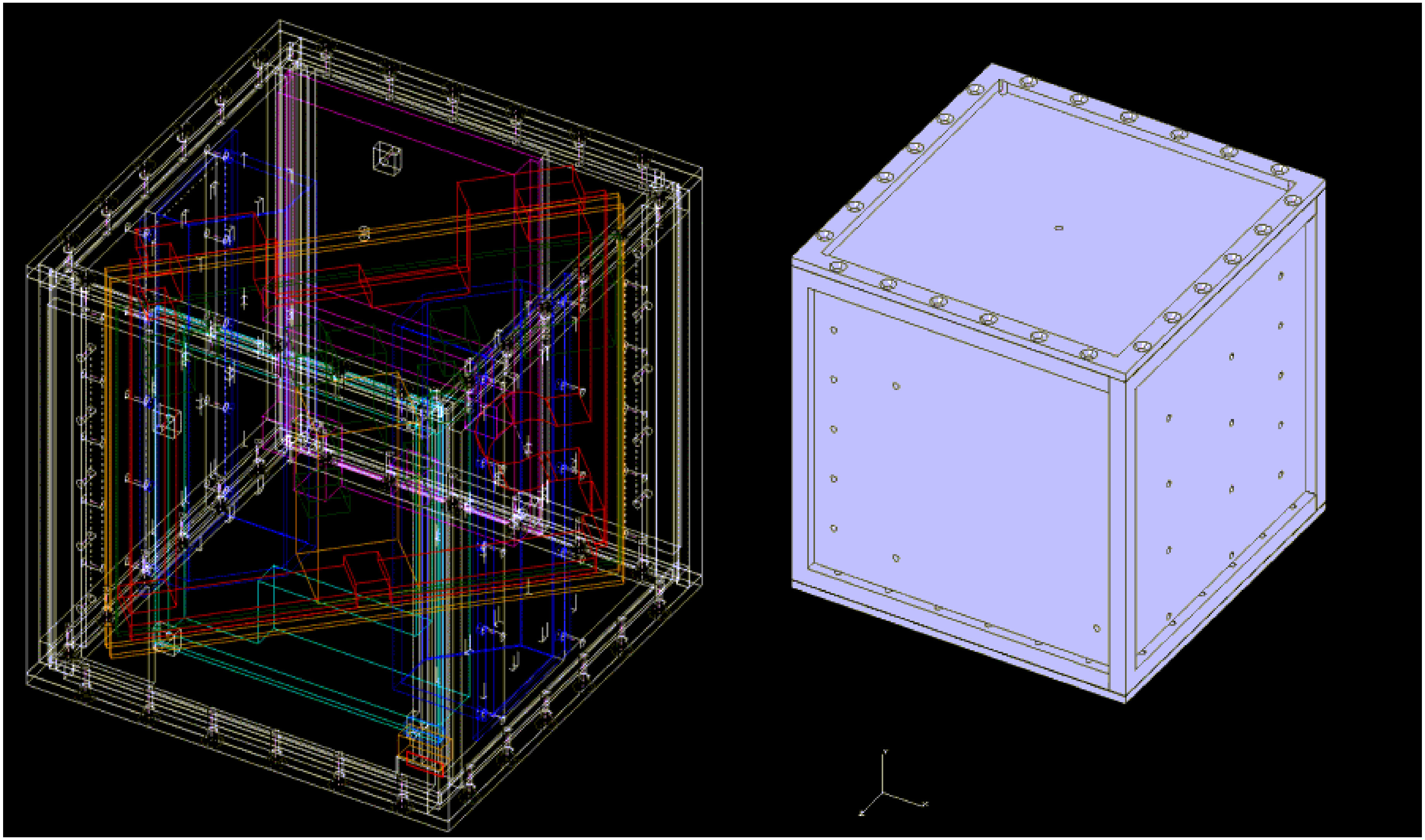
# Low Friction Track Separation Test



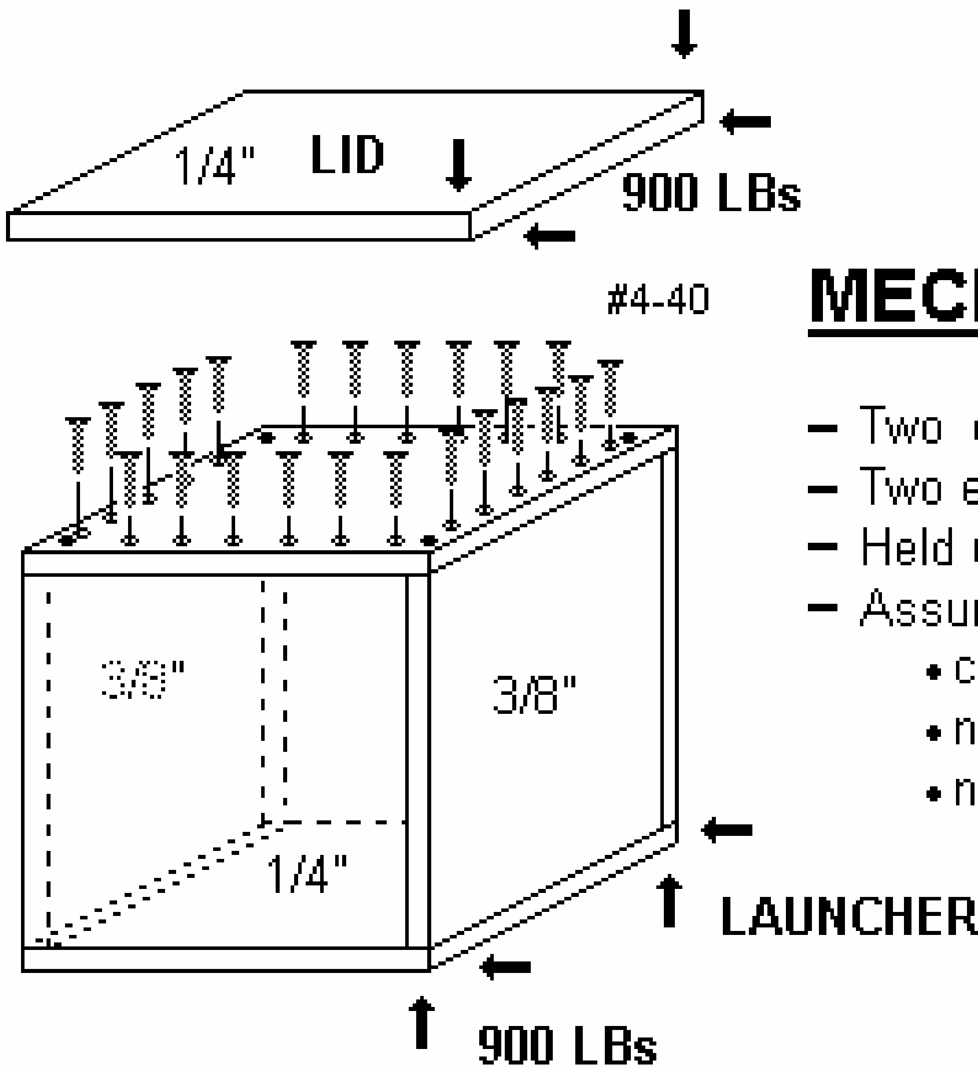
# Mechanical Design



# Using "IDEAS" CAD Modeling



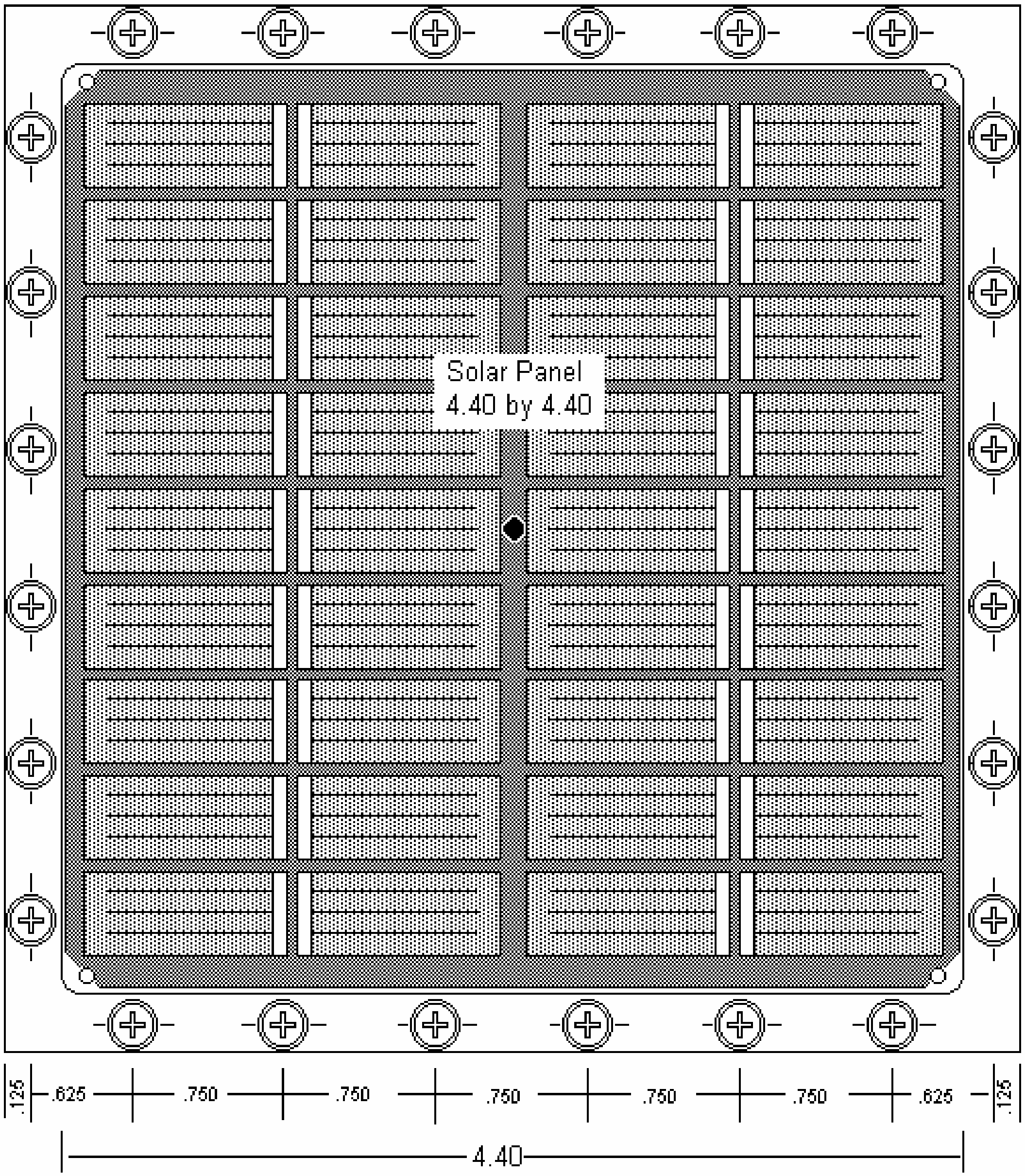
# Assembly Plan




## MECHANICAL & FASTENERS

- Two equal 3/8" sides (pocketed to 1/16")
- Two equal 1/4" Top/Bottoms (pocketed to 1/16")
- Held under 900 LBs peak compressive load
- Assures:
  - captive screws
  - no lateral fastener failure modes
  - no Launcher failure modes

# Solar Panel Design on 5 Sides




on PCB panel

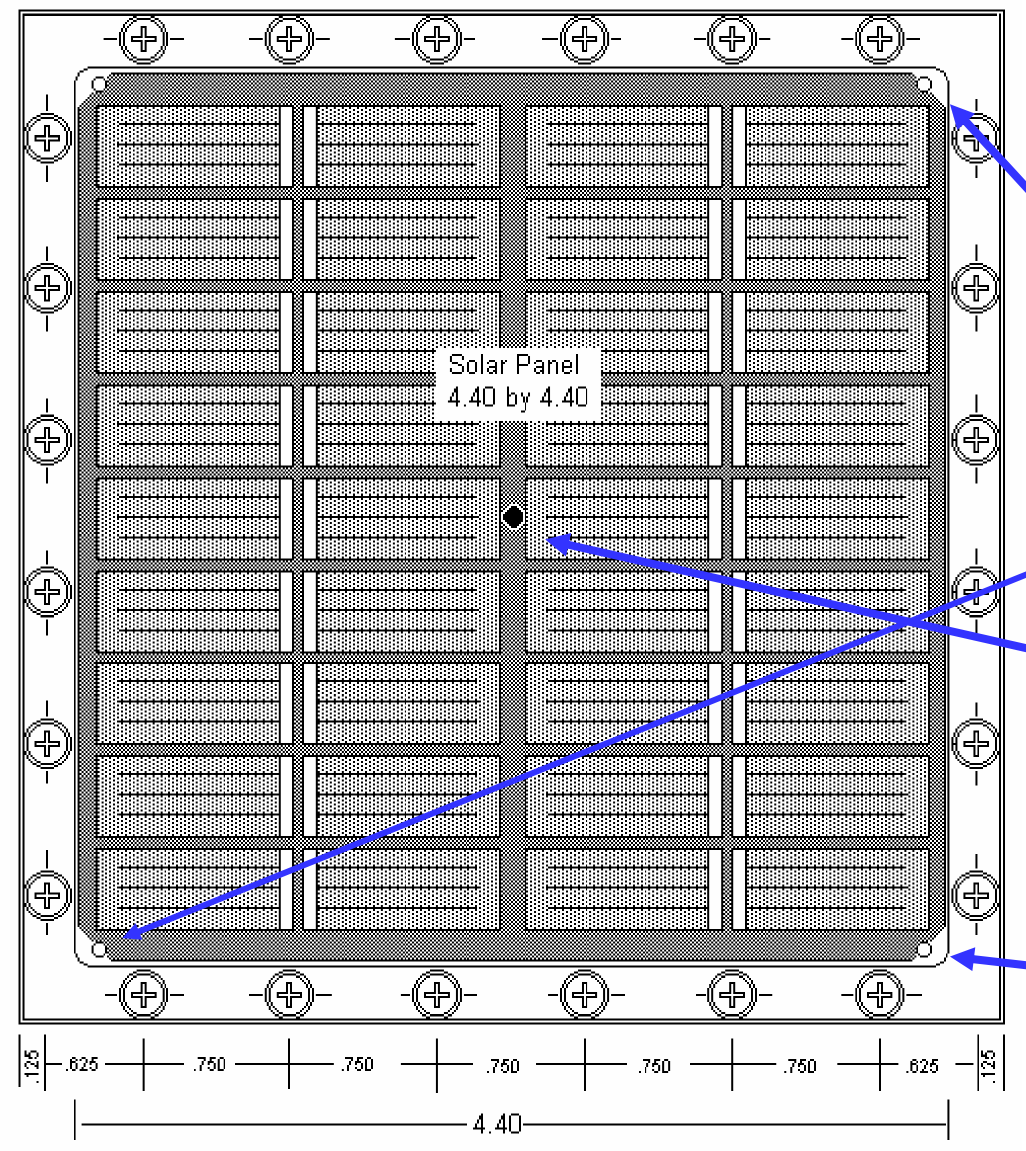
Covered with Clear Teflon Coating

1.5 Watt panel

Mechanically rugged for rain/hail/birds

PCsat Flight Heritage

# Multi-Function Top Panel



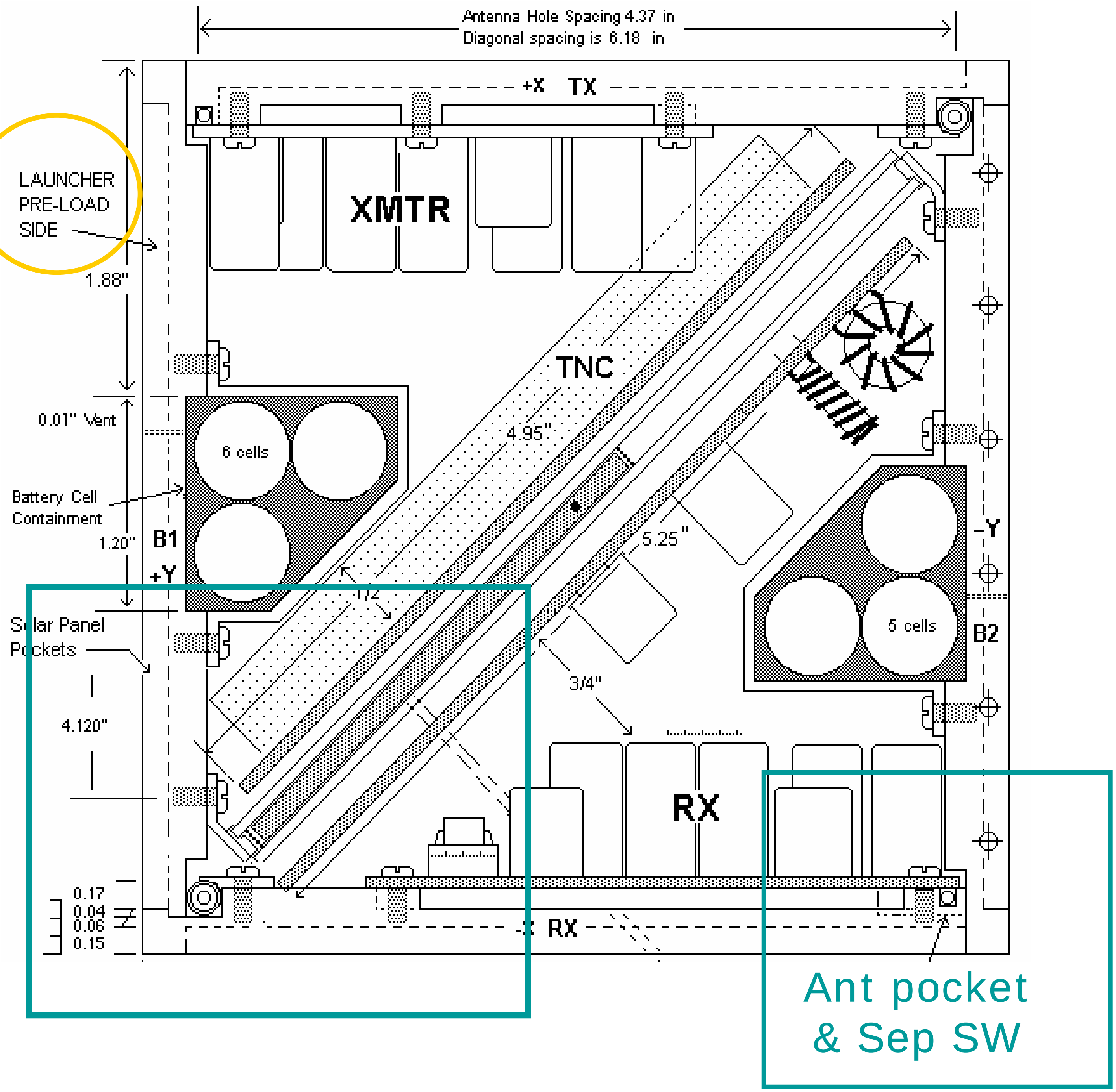

VHF Antenna holes

HF whip hole

Pockets for other satellite antennas and Sep Switch

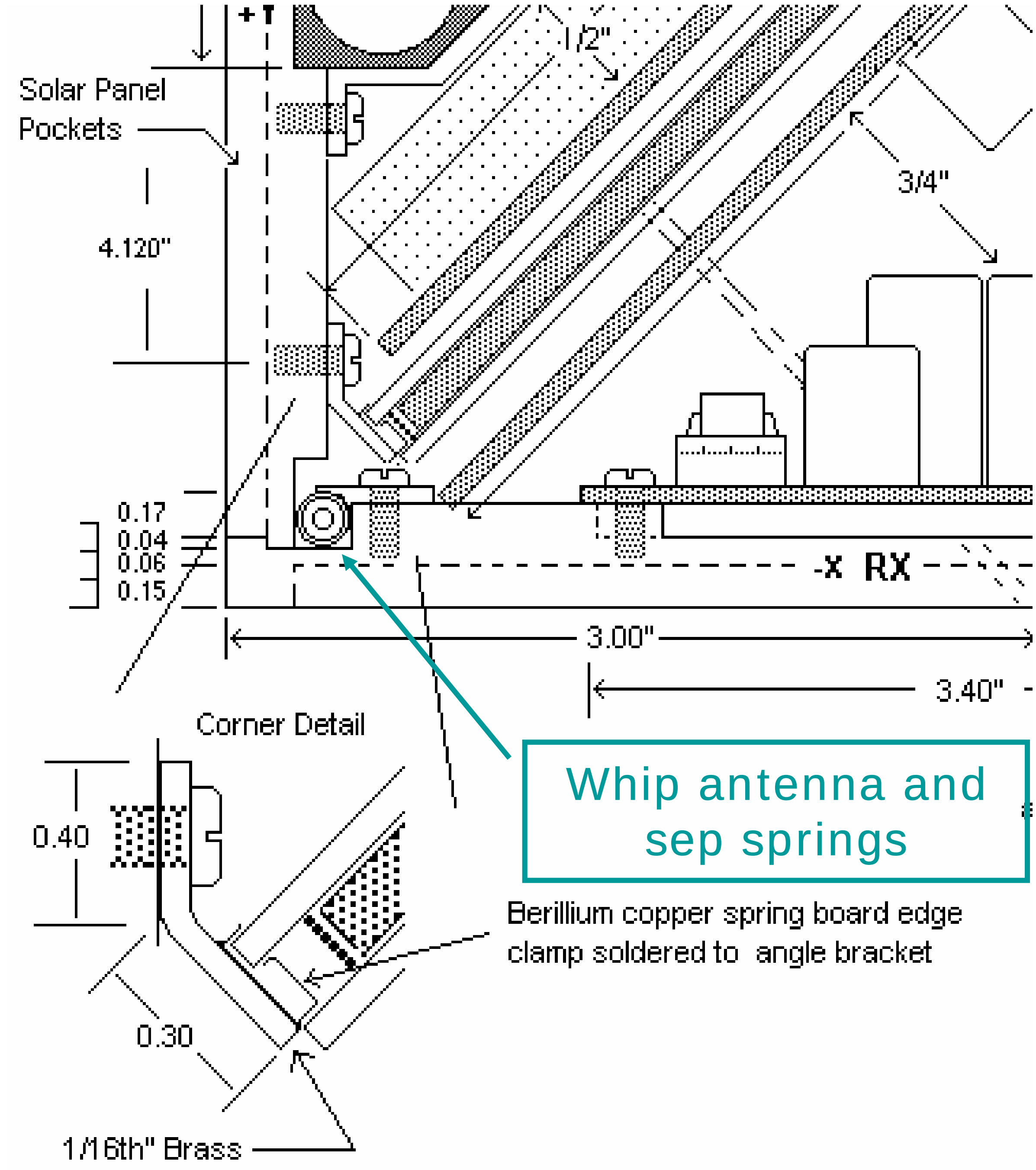
# RAFT1 Internal Diagram

# Top View



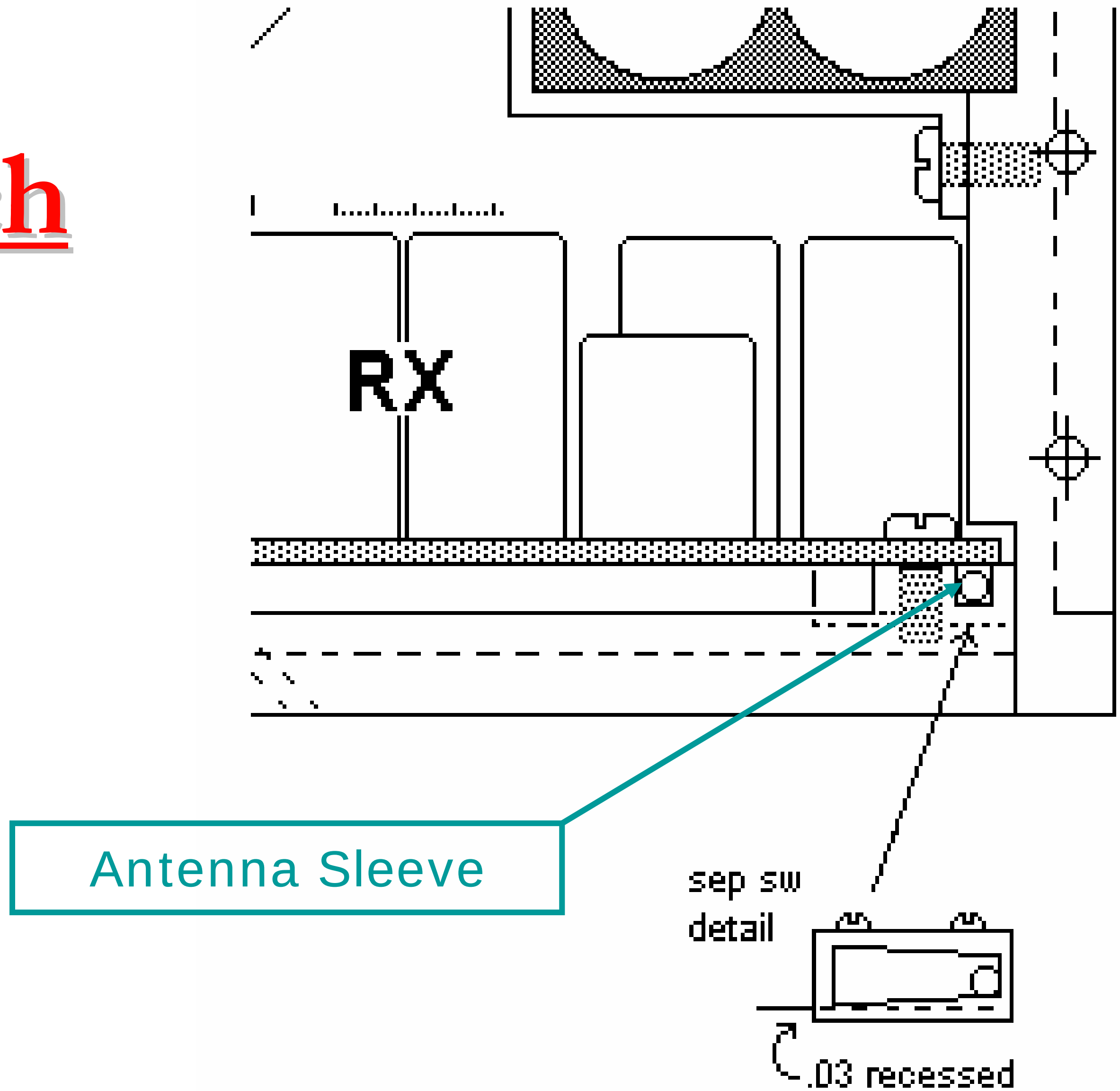
# RAFT Internal Diagram

# Corner Detail

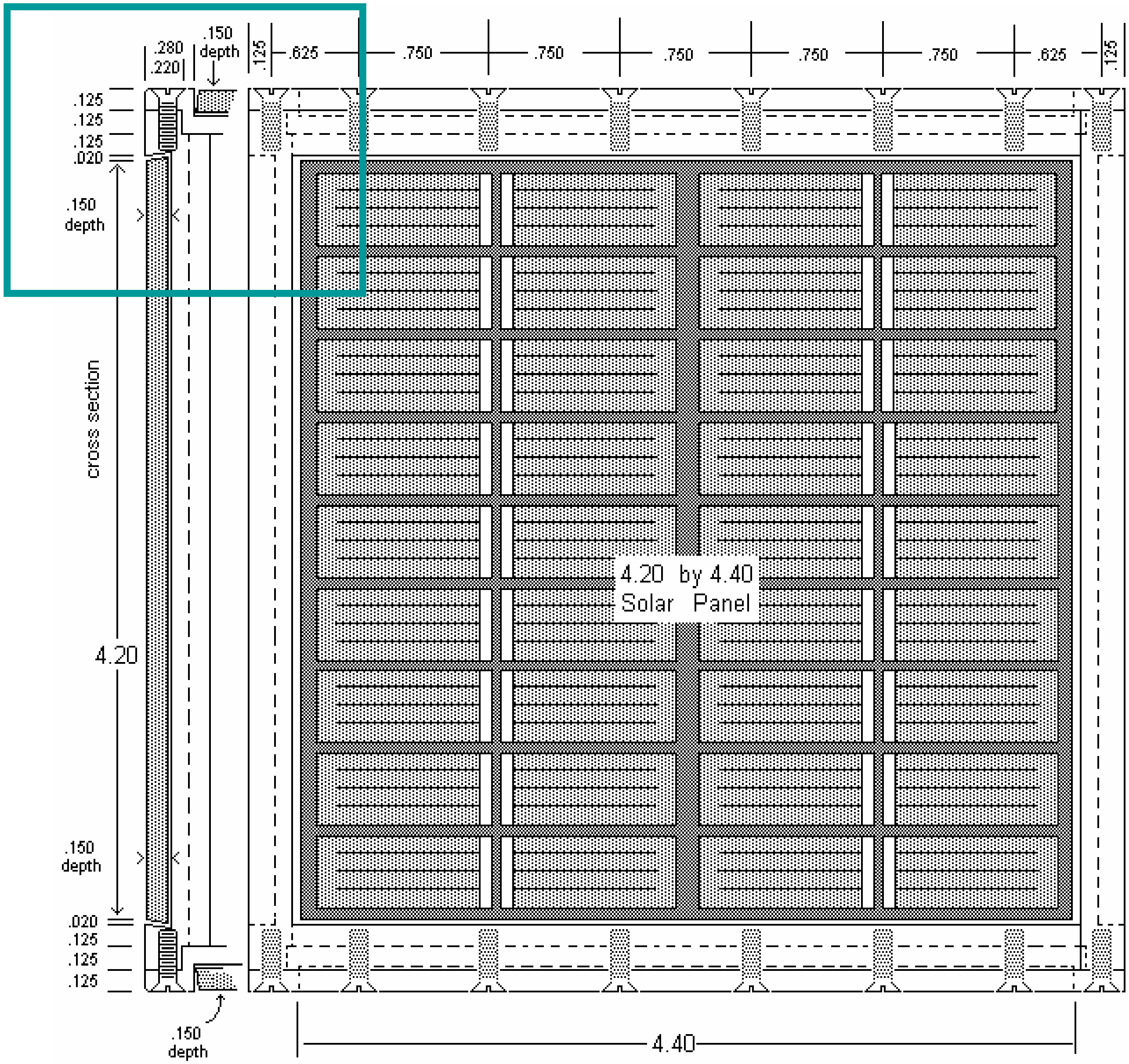


# RAFT SEP-Switch

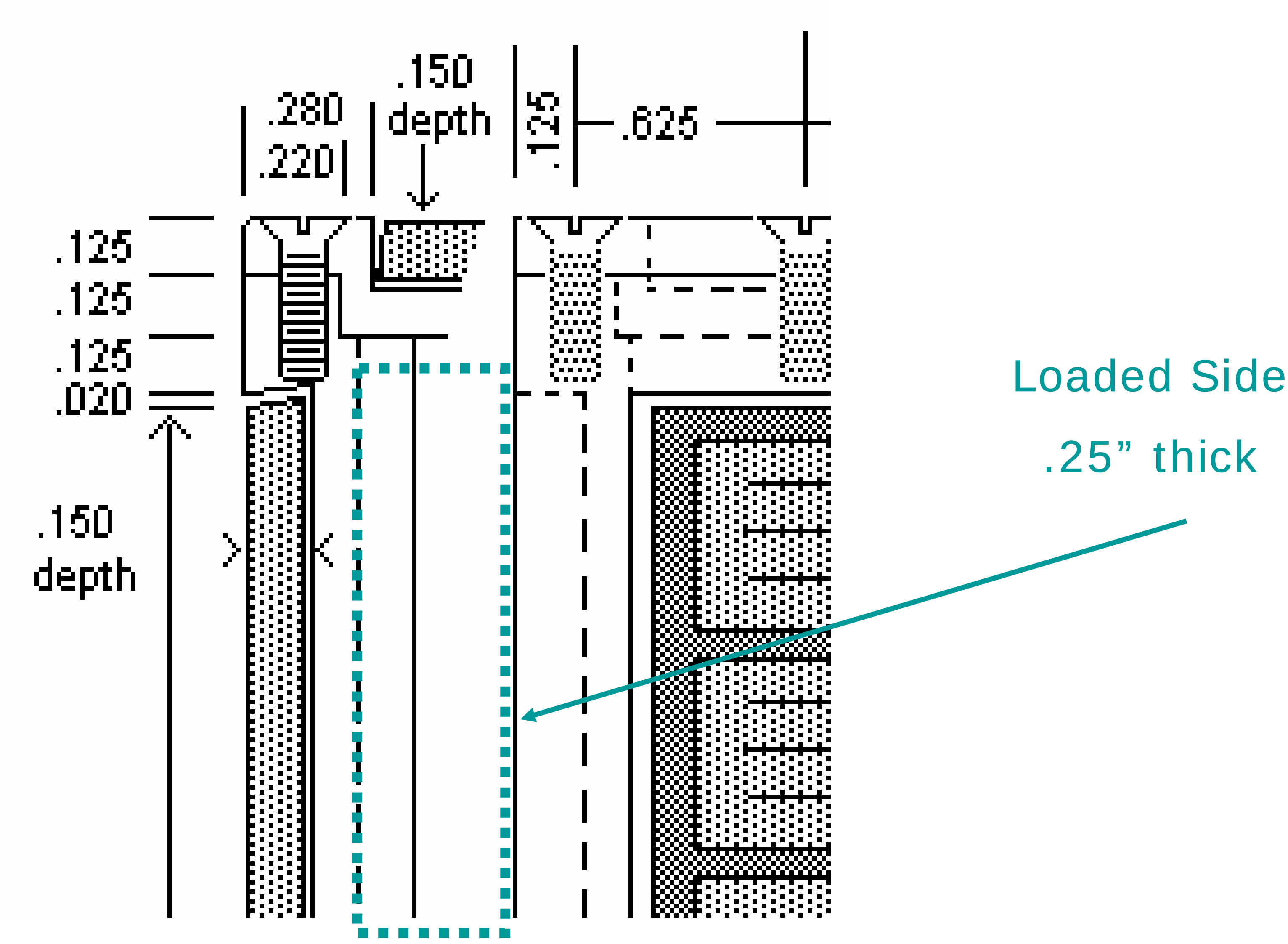
# Corner Detail



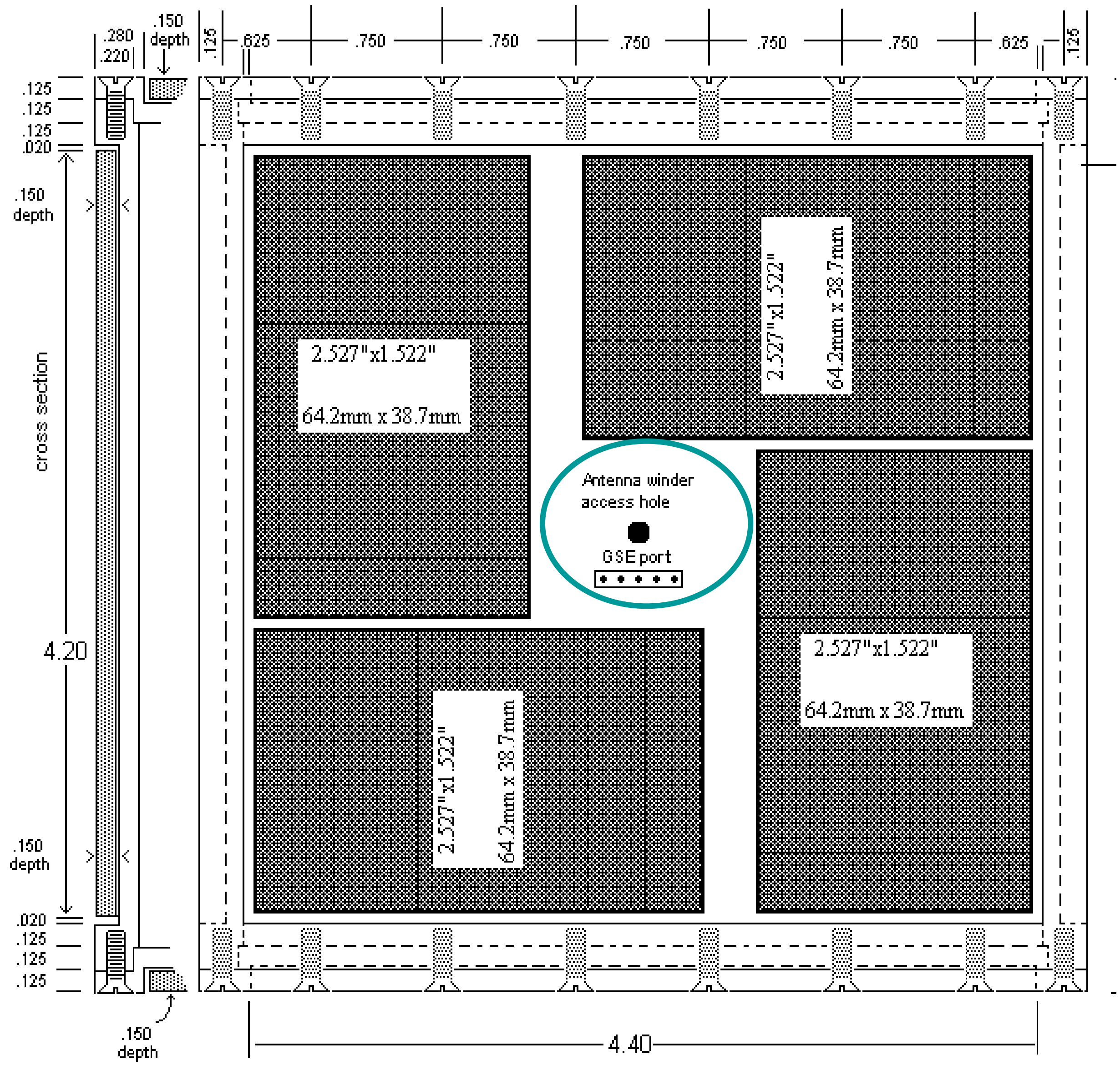
# Side Panel


.280
.220
.150
depth
.125
.625
.750
.750
.750
.750
.750
.625
.125
.125
.125
.125
.020
.150
depth
cross section
4.20
4.20 by 4.40
Solar Panel
.150
depth
.020
.125
.125
.125
.150
depth
4.40

# Side Panel Detail

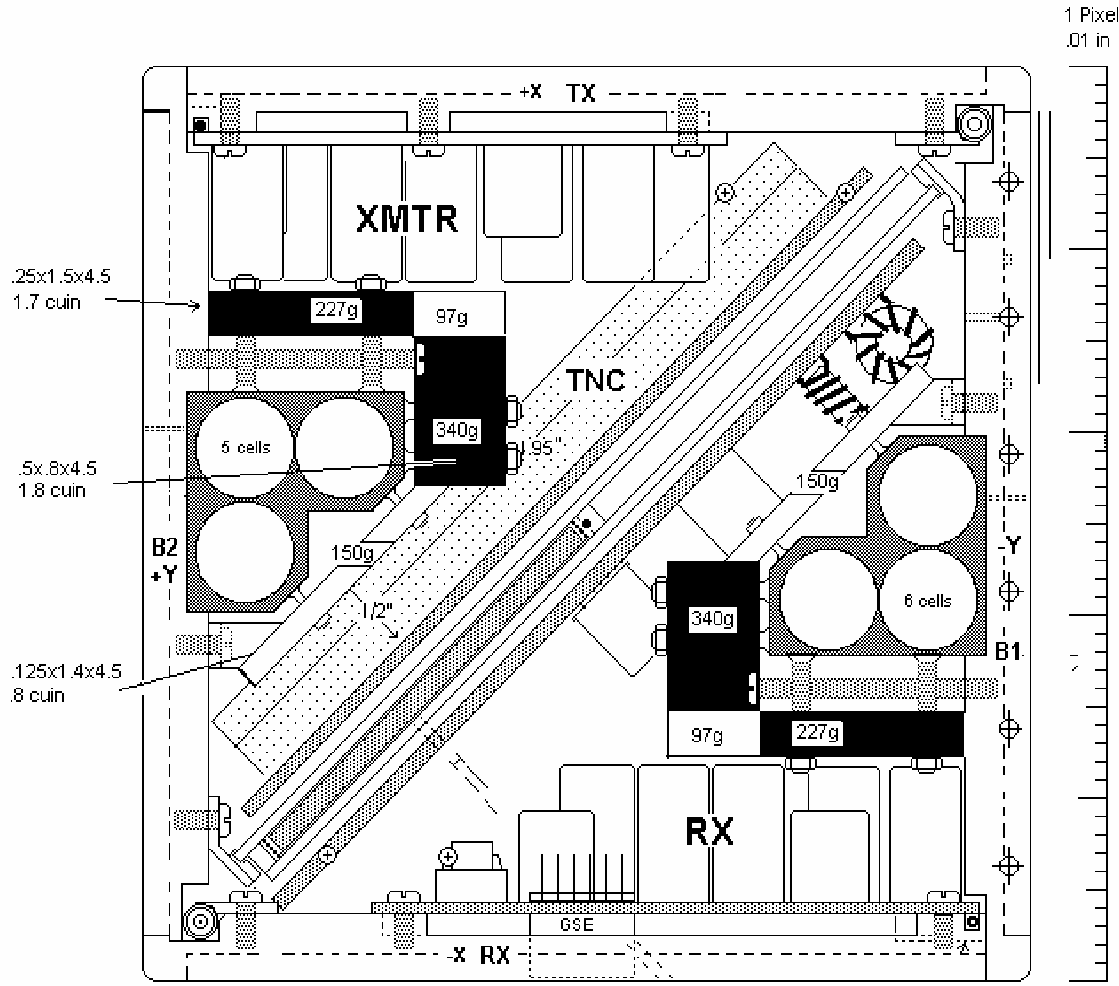


# Custom Side Panel
## for Antenna Crank and GSE Connector



# Ballast for RAFT1

## LEAD Ballast Plan




Total Possible: 325
325
340
340
150
150
------
1630 grams

RAFT Estimate 2901 g
Required Ballast 1100 g
Flight Goal 4000 g

Design: 227
227
340
340
1134

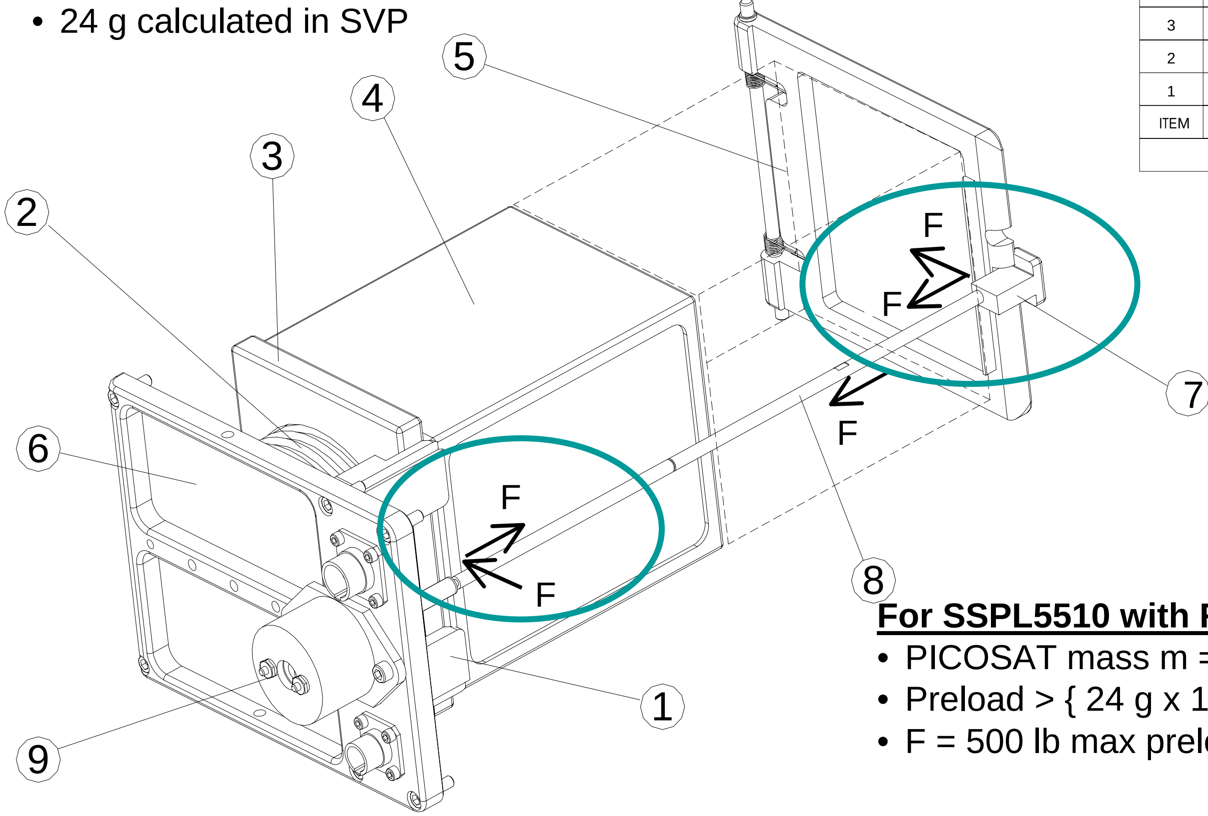
| | | | | | |
|---|---|---|---|---|---|
| | | **Project:** | RAFT | **Title:** | Ballast Plan |
| **Dwg No:** | | **Midn:** | Robeson | **Date:** | 30 Nov 2005 |
| **Web:** | www.ew.usna.edu/~bruninga/craft/RAFTballast.GIF | **USNA Satellite Lab** | | **Engineer:** | bruninga |

# SSPL4410 LAUNCHER: Preload and Launch Loads

**For SSPL4410 with MEPSI:**
- PICOSAT mass m = 1.6 kg = 3.5 lbs
- Preload > { 24 g x 3.5 lbs = 84 lbs }
- F = 125 lb max preload + 24 g x 3.5 lb ≈ 210 lbs
- 24 g calculated in SVP

| ITEM | QTY | DESCRIPTION |
|---|---|---|
| 9 | 1 | NEA DEVICE |
| 8 | 1 | LATCHROD |
| 7 | 1 | LATCH |
| 6 | 1 | BACK COVER |
| 5 | 1 | DOOR |
| 4 | 2 | PICOSAT |
| 3 | 1 | PUSHER |
| 2 | 1 | MAINSPRING |
| 1 | 2 | PRELOAD BLOCK |

PARTS LIST




**For SSPL5510 with RAFT:**
- PICOSAT mass m = 7 kg = 15.4 lbs
- Preload > { 24 g x 15.4 lbs = 370 lbs }
- F = 500 lb max preload + 24 g x 15.4 lb ≈ 870 lbs

* FRONT PICOSAT NOT SHOWN BUT IS IDENTICAL TO REAR PICOSAT AND REPRESENTED WITH HIDDEN LINES

***credit*:** THE AEROSPACE CORPORATION

# Side Panel Buckling Analysis

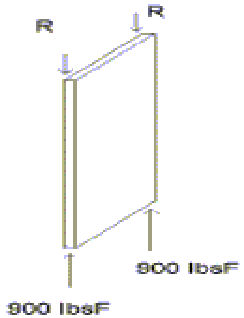
## Buckling Analysis for RAFT Side Panel

Step 1:
Define Constants, material is T6-6061 Aluminum

K = .4, non-dimensional coefficient for panel that is simply supported on 3 sides, and free on one
E = 10000 ksi, Young's Modulus

Step 2:
For this analysis, the wall was assumed to have a thickness equal to the average of all cross-sections

Determine average thickness, length and cross-sectional area




$$T = \frac{.1*1.75 + .225*2.25 + .25*.5}{4.5} = .1792"$$ , average thickness

L = 4.5" , length

A = .1792*4.5 = .8064 sq.in., cross-sectional area

Step 3:
Find critical stress for aluminum T6-6061 sheet, stress where buckling occurs

$$Fcr = K*E*\left(\frac{T}{L}\right)^2 = .4*10000000*\left(\frac{.1792}{5}\right)^2 = 5136.1\,psi$$ , critical stress

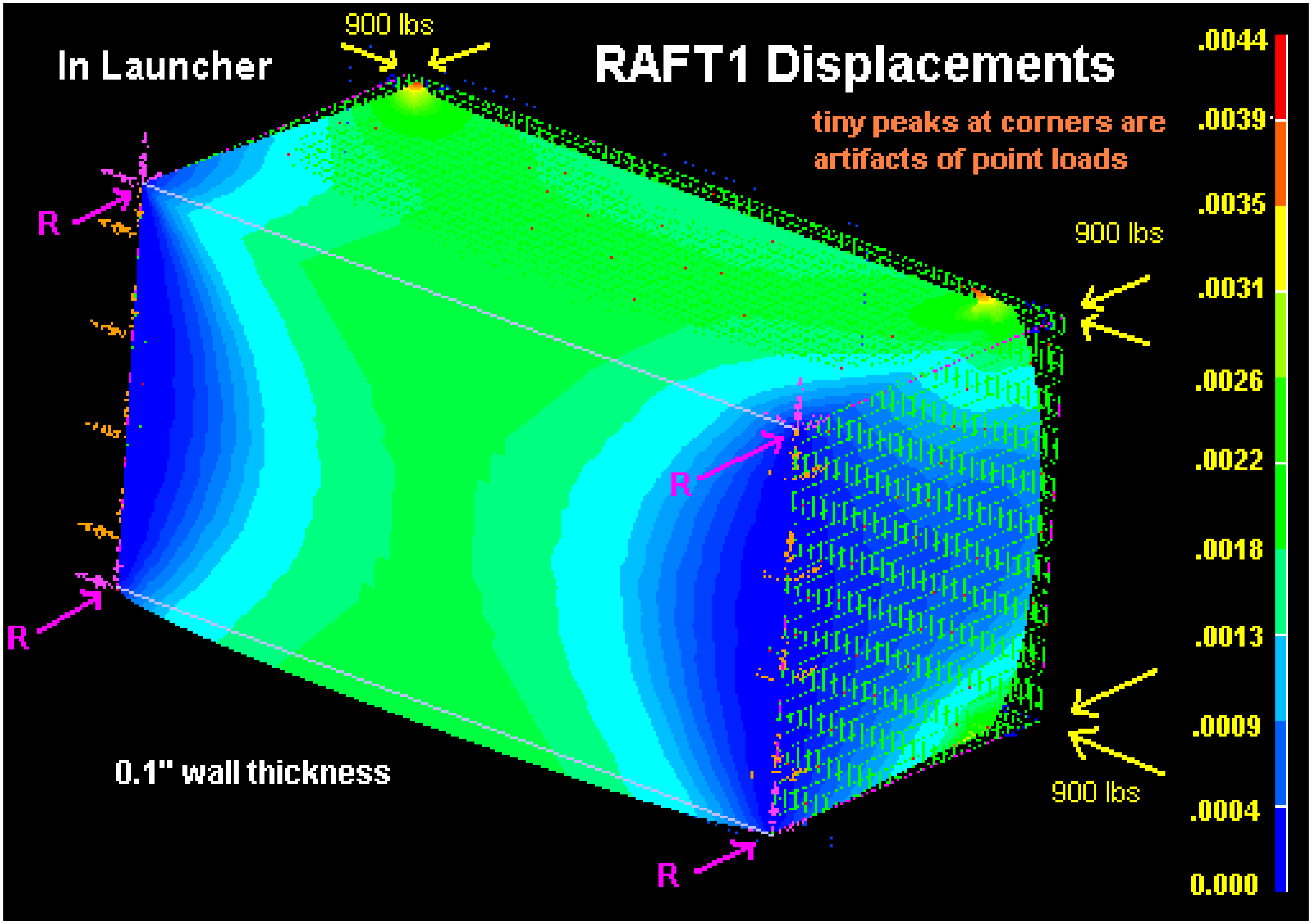
Step 4:
Find Critical Load

Pcr = Fcr * A = 5136.1 * .8064 = 4140.99 lb, critical load

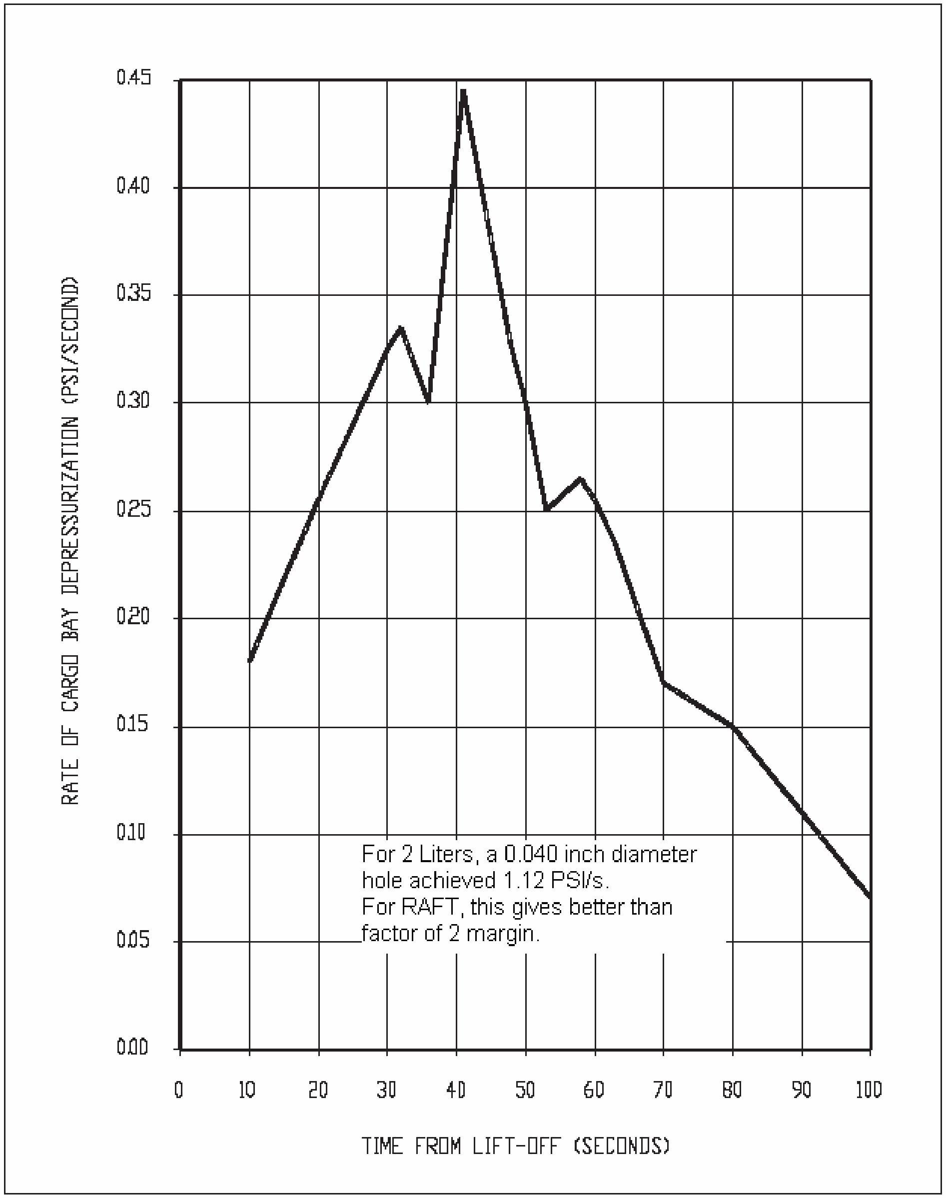
Step 5:
Compare to Load of 1800 lbsF (the sum of the two 900 lbsF dynamic loads)

4140.99/1800 = 2.3, Therefore there is a safety factor greater than 2.

# Structure Displacements



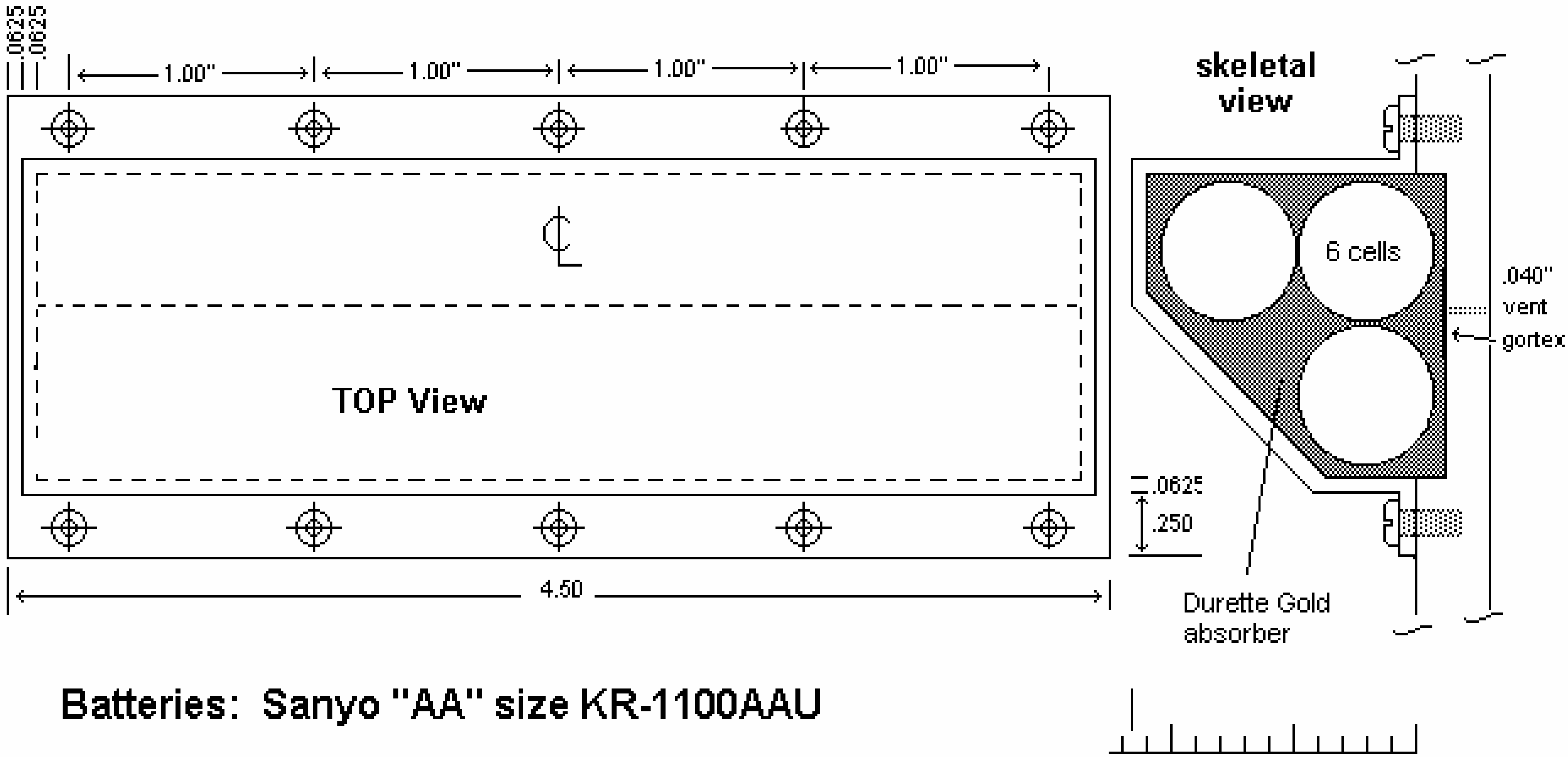
# Depressurization Rate




.040 hole

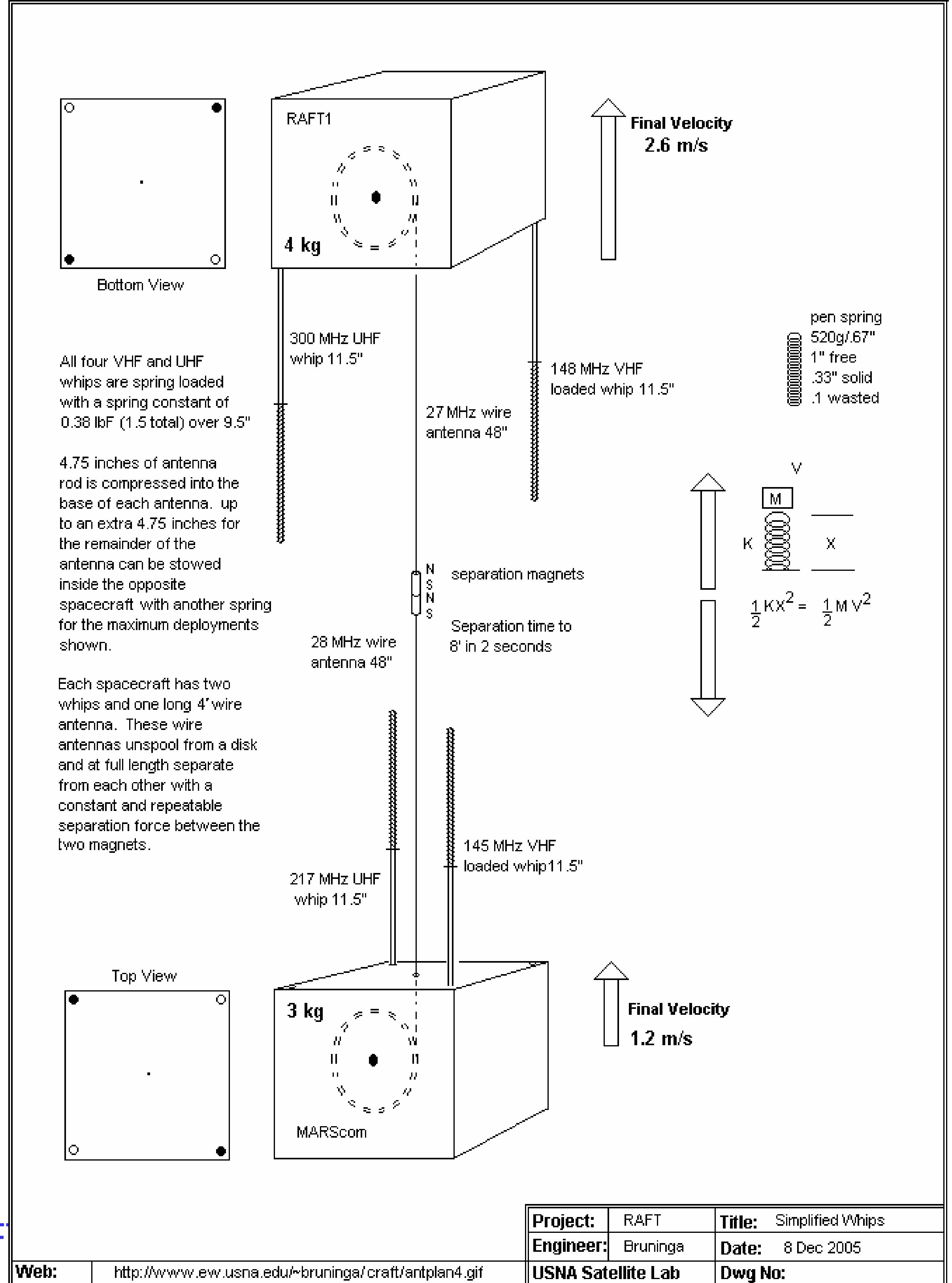
Gives 2:1 margin for depressurization

# Battery Box

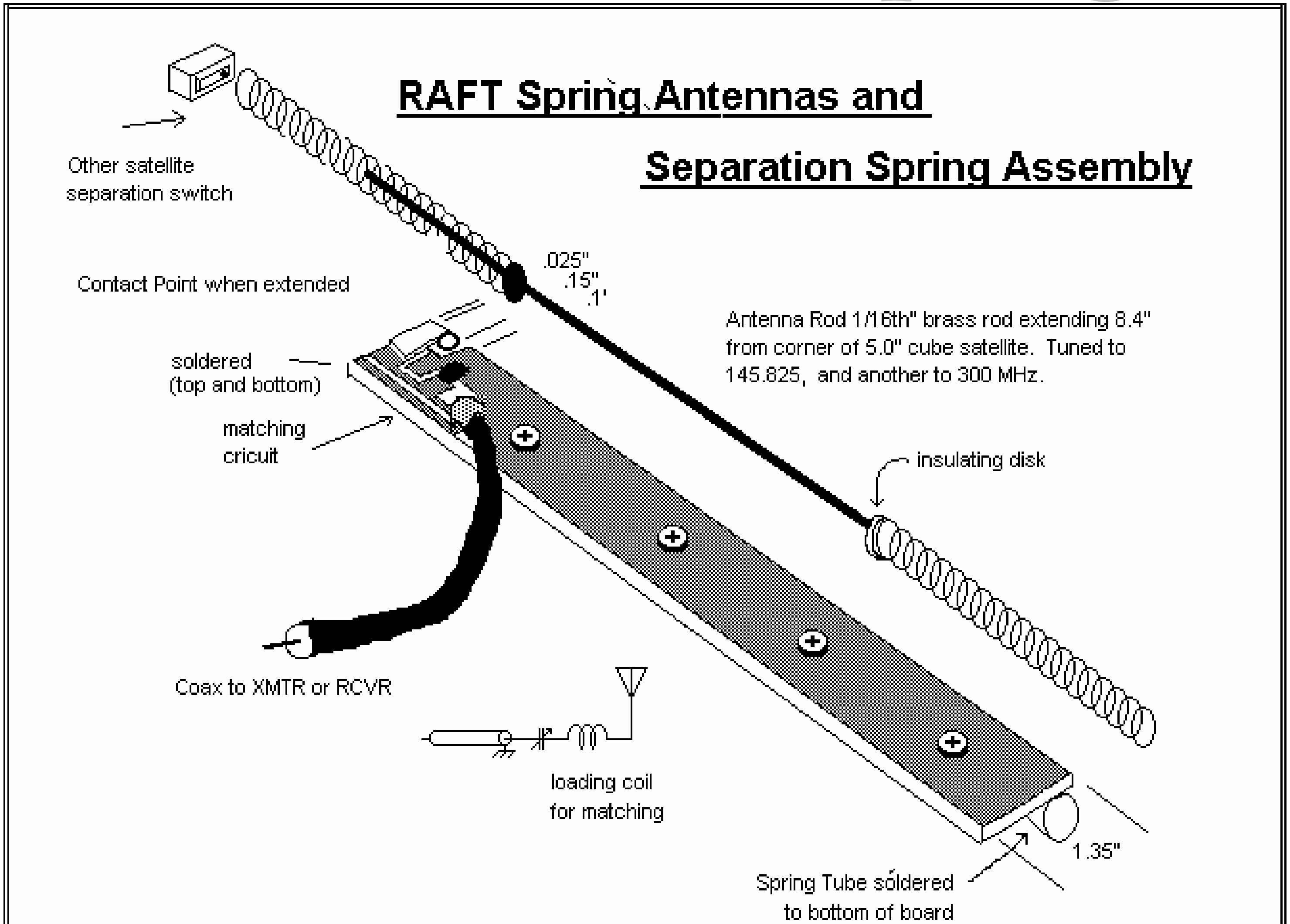



Batteries: Sanyo "AA" size KR-1100AAU

# RAFT Antenna Separation Mechanisms



# RAFT Antenna Springs




| | | | |
|---|---|---|---|
| **Project:** | RAFT | **Title:** | ANT Assy |
| **Engineer:** | Bruninga | **Date:** | 10 Nov 2005 |
| **USNA Satellite Lab** | | **Dwg No:** | |
| **Web:** | http://www.ew.usna.edu/~bruninga/craft/RAFTantASSY4.gif | | |

# Antenna Buckling Analysis

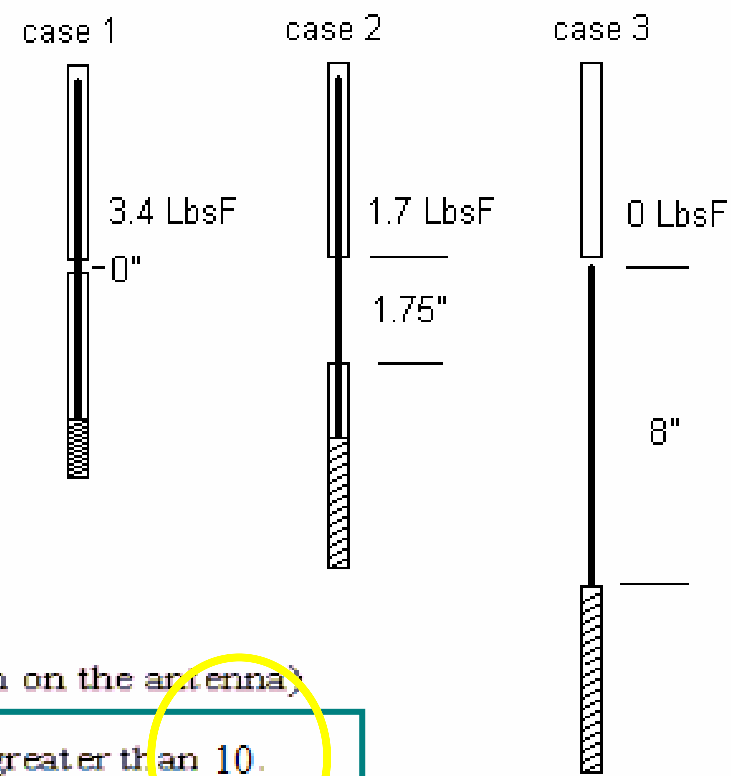
Step 1:
Define Constants, material is Brass Alloy 360 Free-machining

E = 14100 ksi, Young's Modulus

Step 2:
For this analysis, the antenna was calculated with 1.75" in length. This is because at the outset the antenna rod will not buckle since it will be encased by the tubing. Therefore, it was determined that the worse case scenario for buckling would be when the antenna is exposed 1.75". The maximum force seen is 3.4 lbs, which is more than will be seen at the point that 1.75" of antenna is exposed since the force will taper off.

L = 1.75", length

d = 1/16", diameter




Step 3:
Find moment of inertia of rod

$$I = \frac{\pi * d^4}{64} = \frac{\pi * \left(\frac{1}{16}\right)^4}{64} = 7.5\text{E-}7\ in^4$$

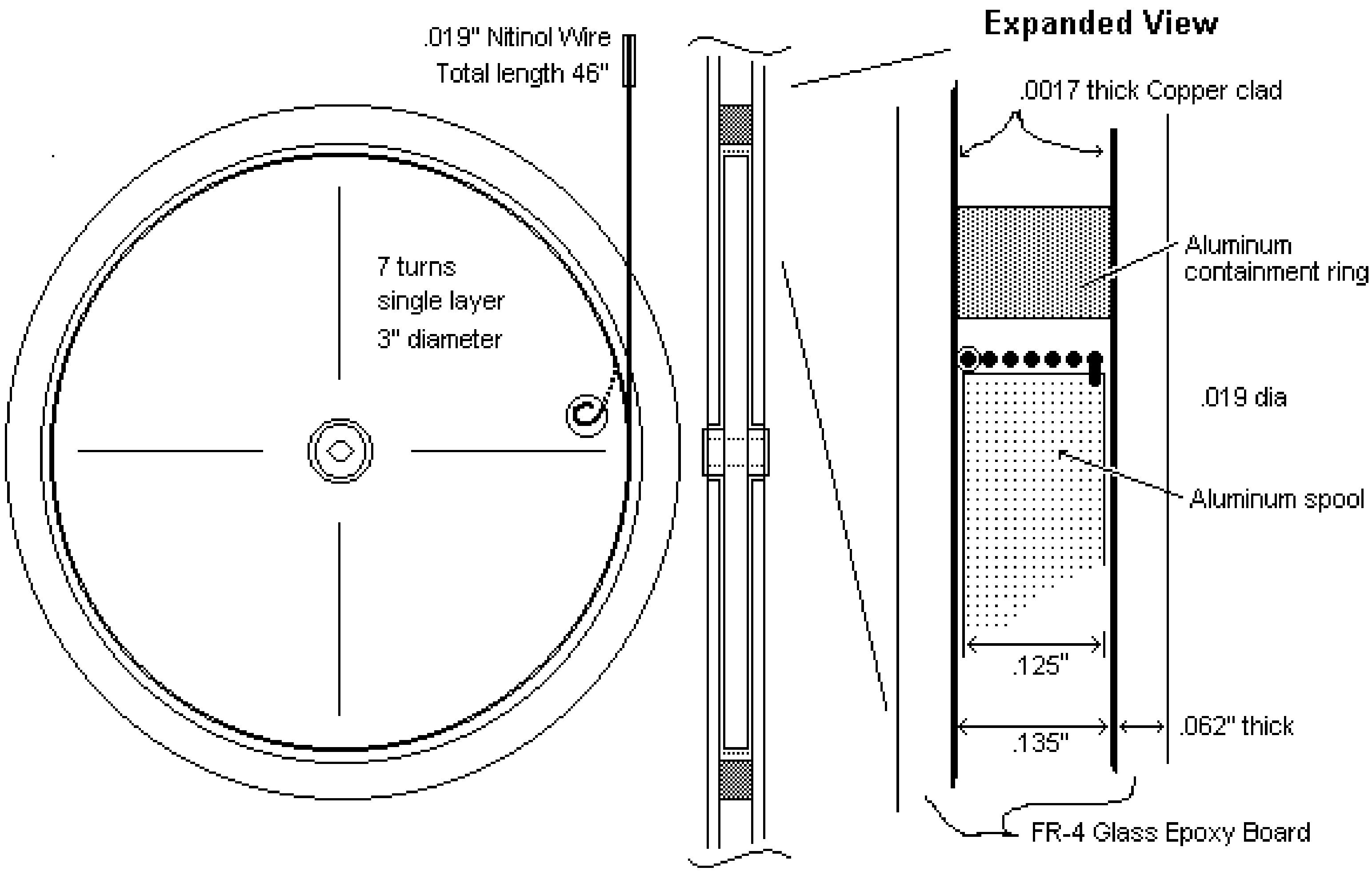
Step 4:
Find Critical Load

$$F_{cr} = \frac{EI\pi^2}{L^2} = \frac{14100000 * 7.5\text{E-}7 * \pi^2}{1.75^2} = 34.08\ lbsf$$

Step 5:
Compare to Load of 3.4 lbsf (the maximum load seen on the antenna)

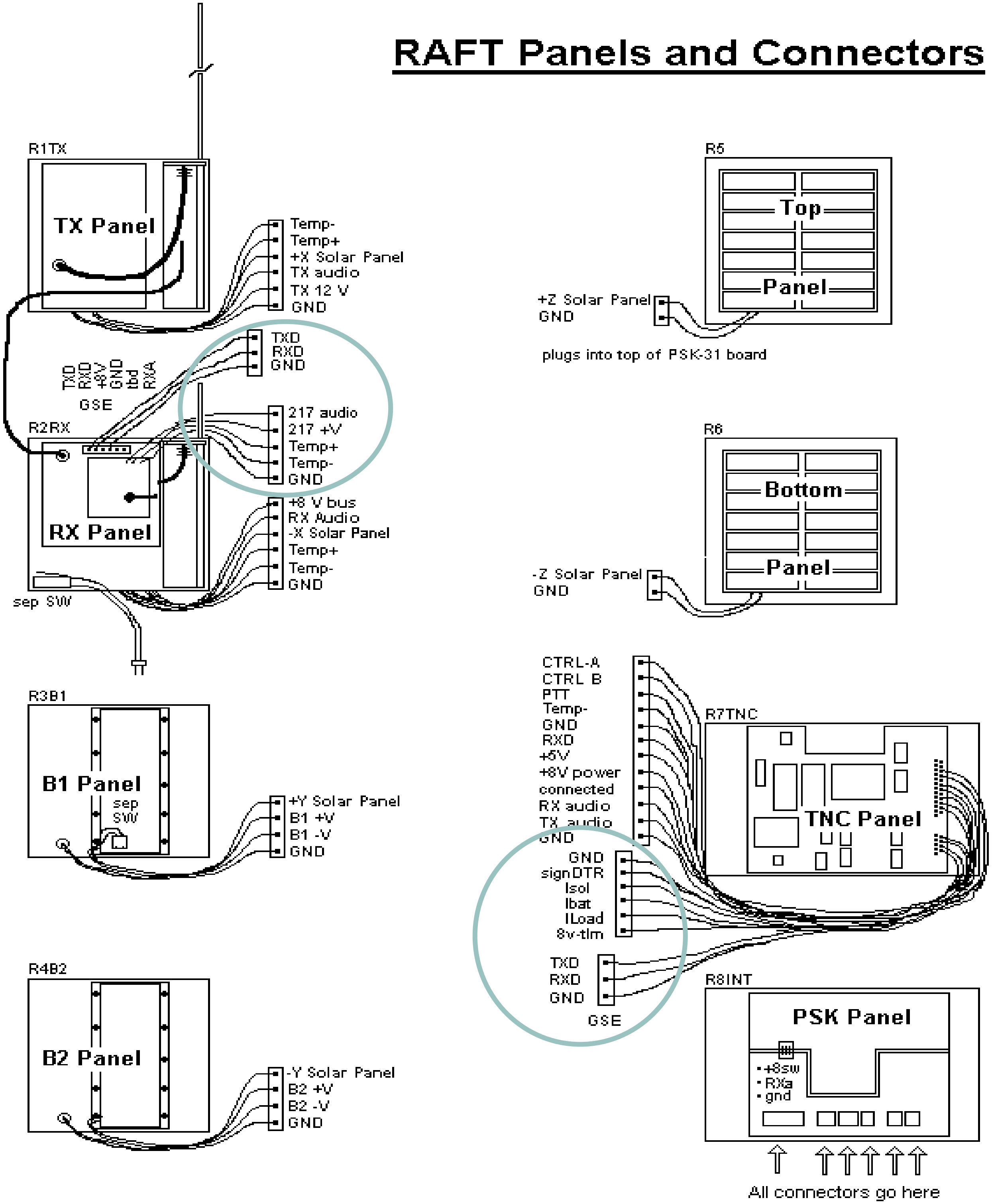
34.08 / 3.4 = 10.02, Therefore there is a safety factor greater than 10.

# Long-Wire Antenna

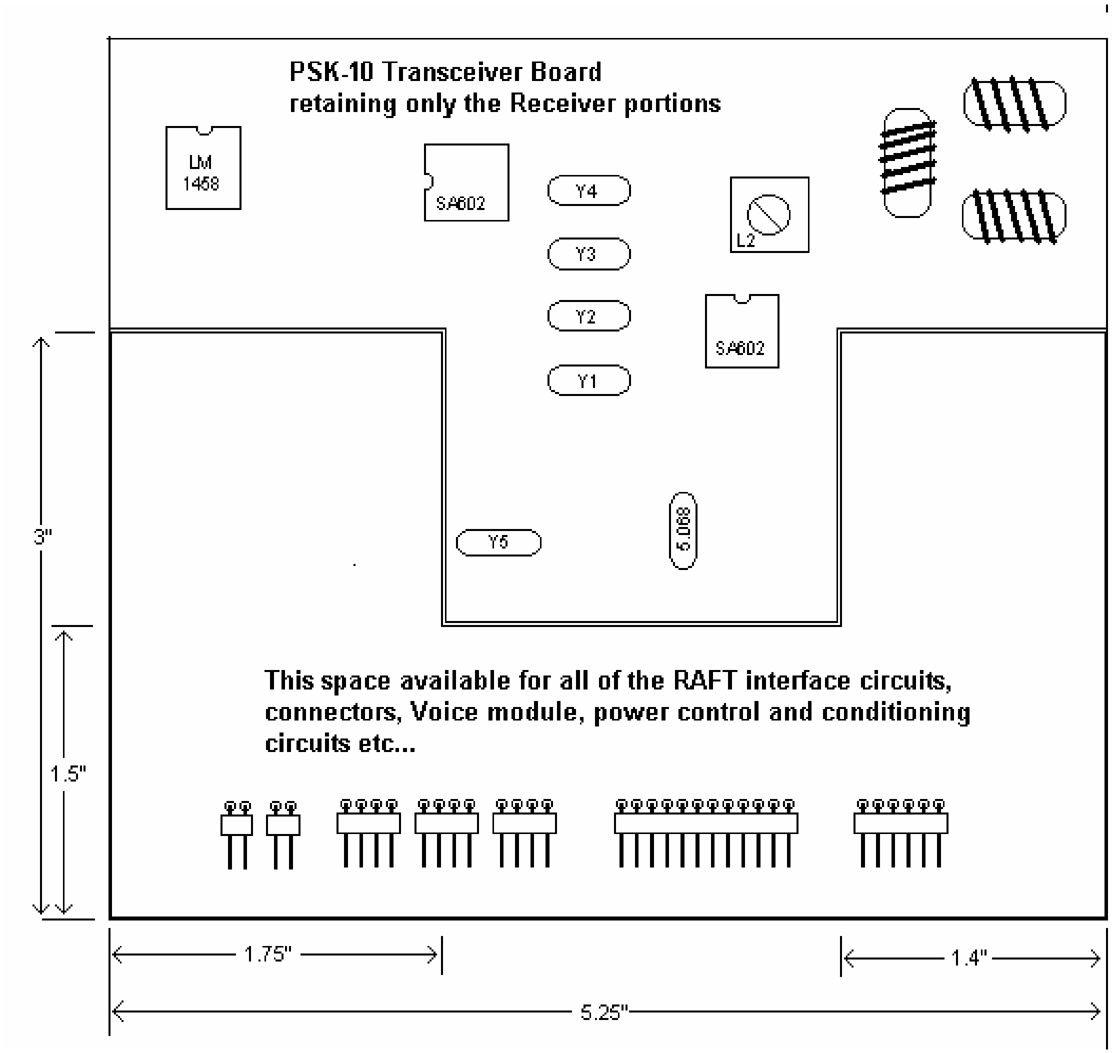


# RAFT1 Panels and Connectors

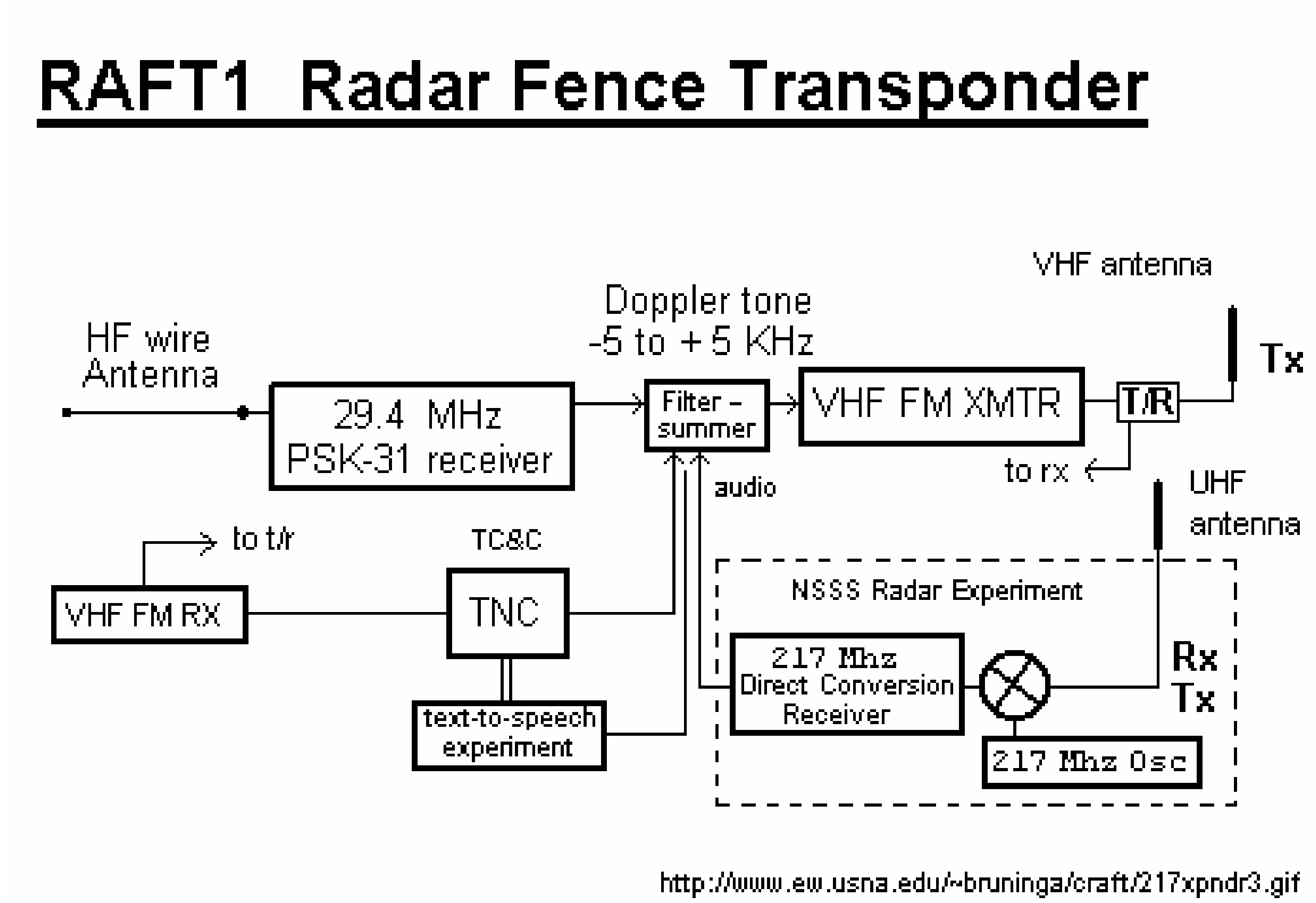
## RAFT Panels and Connectors



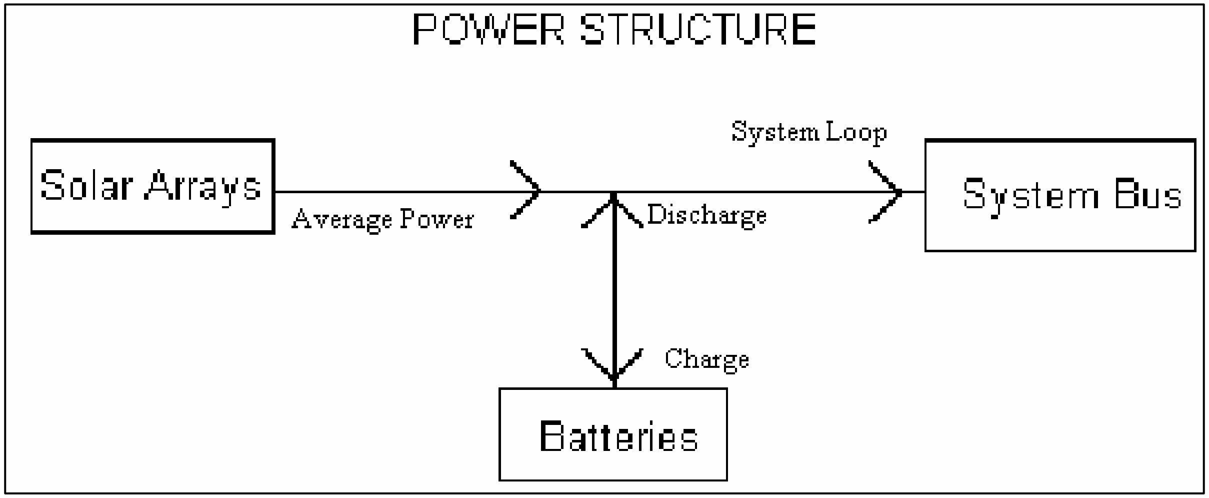
# Interface Board

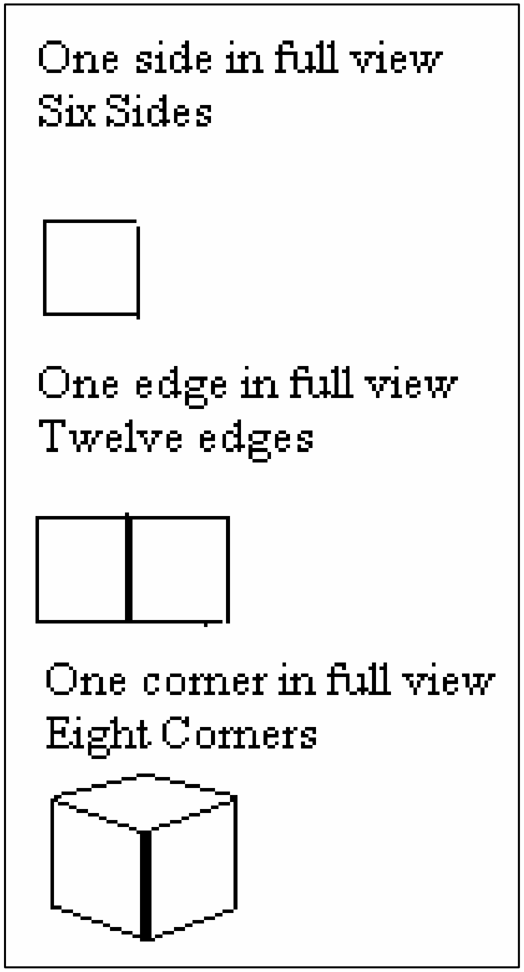


# Raft1 Electronics Systems



# EPS and Solar Power Budget




Computing average solar power for a cube satellite taking weighted average of all 26 possible orientations.

This analysis is for an ISS orbit with a maximum eclipse of 39% with a 25% efficient solar cell.

# Solar Power Budget

| | |
|---|---|
| $SC_{eff}$=Solar Cell Efficiency | $X_e$=Eclipse path efficiency |
| $I_d$=Elements of Inherent Degradation | L=BusLoad |
| a=Sun Angle | $P_{BOL}=SC_{eff}*I_d*SolarConstant$ |
| n=number of exposed cells | $P=P_{BOL}*\sin(a)$ |
| A=area of one cell | $P_{totalavg}=P_{avg}1+Pavg2+P_{avg}3$ |
| t=exposure multiple | $P_{total}=P*n*A$ |
| $t_{total}$=total number of exposures | $x=t/t_{total}$ |
| $T_d$=Time in Daylight | $P_{avg}=P_{total}*x$ |
| $T_e$=Time in Eclipse | $L=(P_{totalavg}*X_e*X_d*T_d)/(T_e*X_d+T_d*X_e)$ |
| $X_d$=Daylight path efficiency | |

| | | | |
|---|---|---|---|
| $SC_{eff}$ (%) | 25 | 25 | 25 |
| $I_d$ | 0.77 | 0.77 | 0.77 |
| SolarConstant | 1367 | 1367 | 1367 |
| $P_{BOL}$ (W/m$^2$) | 263.15 | 263.15 | 263.15 |
| a (deg) | 90 | 45 | 33 |
| P (W/m$^2$) | 263.15 | 186.07 | 143.32 |
| n | 4 | 8 | 12 |
| A (m$^2$) | 0.0028 | 0.0028 | 0.0028 |
| $P_{total}$ (W) | 2.95 | 4.17 | 4.82 |
| t | 6 | 12 | 8 |
| $t_{total}$ | 26 | 26 | 26 |
| x | 1/4 | 1/2 | 1/3 |
| $P_{avg}$ (W) | 0.6801 | 1.9237 | 1.4817 |

| | |
|---|---|
| $P_{totalavg}$ (W) | 2.08 |
| $T_d$ | 0.61 |
| $T_e$ | 0.39 |
| $X_e$ | 0.65 |
| $X_d$ | 0.85 |
| L (W) | 0.96 |

**Conclusion**: The PCsat panels per side of the satellite and a 39% eclipse time, an average available bus load of 0.96 watts will be available to the spacecraft.

# RAFT1 Required Power Budget

| | Current (mA) | Normal | Avrg (mA) | PSK-31 | Avrg (mA) | STBY | Avrg (mA) |
|---|---|---|---|---|---|---|---|
| VHF FM TX | 500.00 | 2% | 10.00 | 10% | 50.00 | 1% | 5.00 |
| UHF FM RX | 30.00 | 100% | 30.00 | 100% | 30.00 | 100% | 30.00 |
| TNC | 15.00 | 100% | 15.00 | 100% | 15.00 | 100% | 15.00 |
| Down Converter | 50.00 | 0% | 0.00 | 10% | 0.05 | 0% | 0.00 |
| 29 MHz RX | 50.00 | 0% | 0.00 | 10% | 0.05 | 0% | 0.00 |
| 20% Reserve | 9.00 | | 9.00 | | 9.00 | | 9.00 |
| Avrg (mA) | | | 64.00 | | 104.10 | | 59.00 |

| | Normal Use | PSK-31 | STBY | Available |
|---|---|---|---|---|
| Avrg(mA) | 64.00 | 104.10 | 59.00 | 114.2857 |
| System (Volts) | 8.40 | 8.40 | 8.40 | 8.4 |
| Avrg (Watts) | 0.5376 | 0.87444 | 0.4956 | 0.96 |

Whole Orbit Average

10% Depth of Discharge

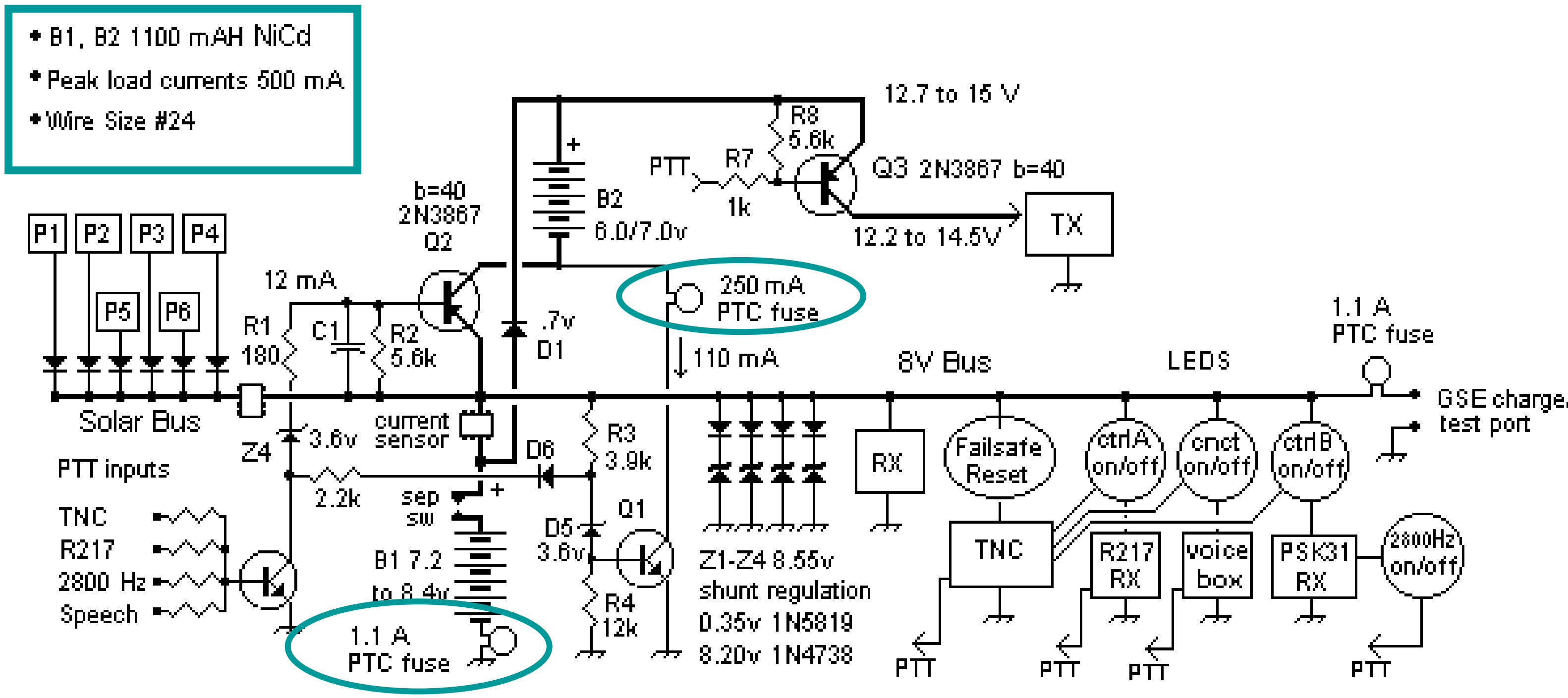
# MARScom Required Power Budget

| | Current (mA) | Normal | Current (mA) | YPSATCOM | Current (mA) |
|---|---|---|---|---|---|
| VHF FM RX | 30.00 | 100% | 30.00 | 100% | 30.00 |
| UHF AM RX | 30.00 | 0% | 0.00 | 100% | 30.00 |
| SSB Exciter | 50.00 | 8.34% | 4.17 | 8.34% | 4.17 |
| 1W Linear PA | 100.00 | 8.34% | 8.34 | 8.34% | 8.34 |
| Decoder | 10.00 | 100% | 10.00 | 100% | 10.00 |
| 20% Reserve | 8.00 | | 8.00 | | 8.00 |
| Avrg (mA) | | | 60.51 | | 90.51 |

| | Normal Use | YPSATCOM | Avalible |
|---|---|---|---|
| Avrg (mA) | 60.51 | 90.51 | 114.2857143 |
| System (Volts) | 8.40 | 8.40 | 8.4 |
| Avrg (Watts) | 0.51 | 0.76 | 0.96 |

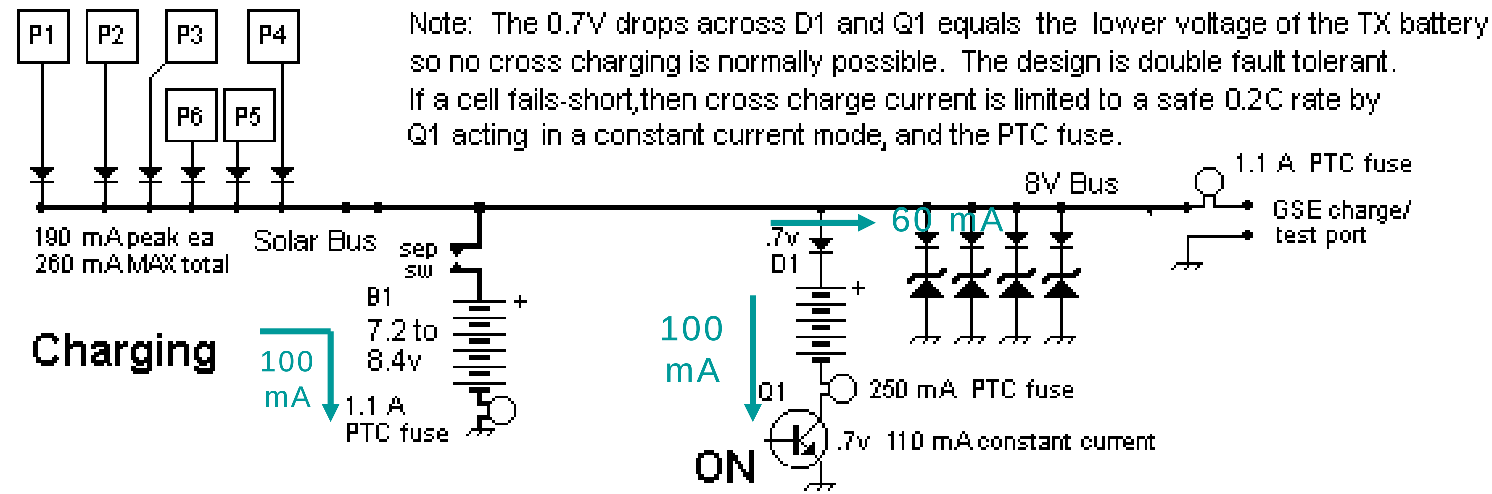
# Power System

## RAFT 8/12V Power System

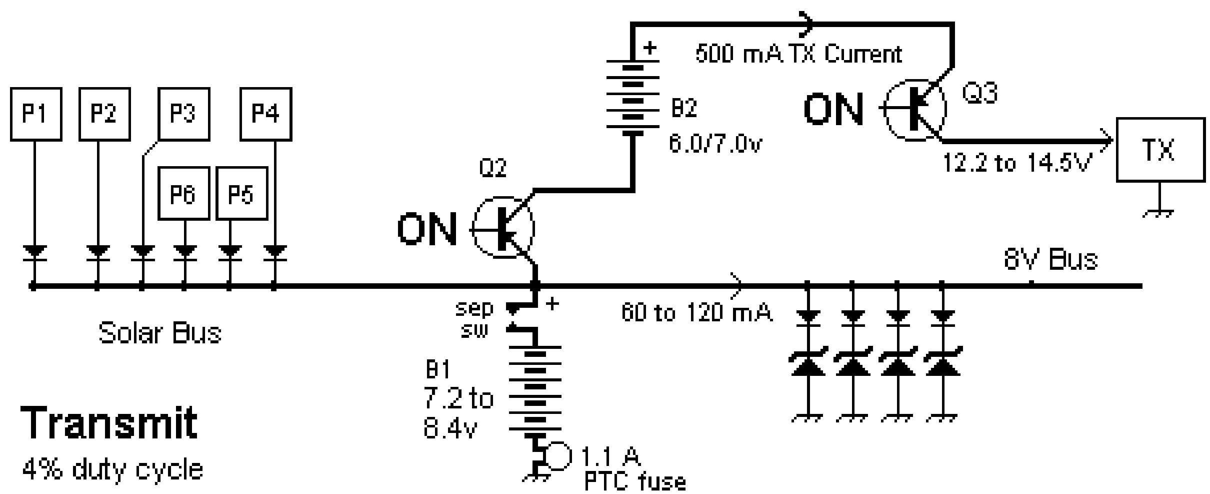



- Battery B1 is 6 cells NiCd feeding 7.2-8.4 unregulated bus to the TNC and Receiver.
- Solar panels provide 260 mA at 8.5 volts. About 110 mA peak is available to charge B1 and B2 via D1 and Q1.
- Q1 is biased to 110 mA trickle charge rate via R3/D5 during charging. When PTT goes low, D6 pulls Q1 OFF via R4.
- Excess solar power above 8.55V is shunted via Z1-Z4 leaving about 25 mA to each string
- For TX, Z4/R1 and R7 turn ON Q2 and Q3 connecting B1/B2 in series to provide 12 to 14.2 volts to the XMTR.
- The R1-C1 time constant and Zener Z4 assures that both Q1 and Q2 will not be on at the same time.
- Charging efficiency is 91% of normal, discharge efficiency is 98% of normal.

# Simplified Power System

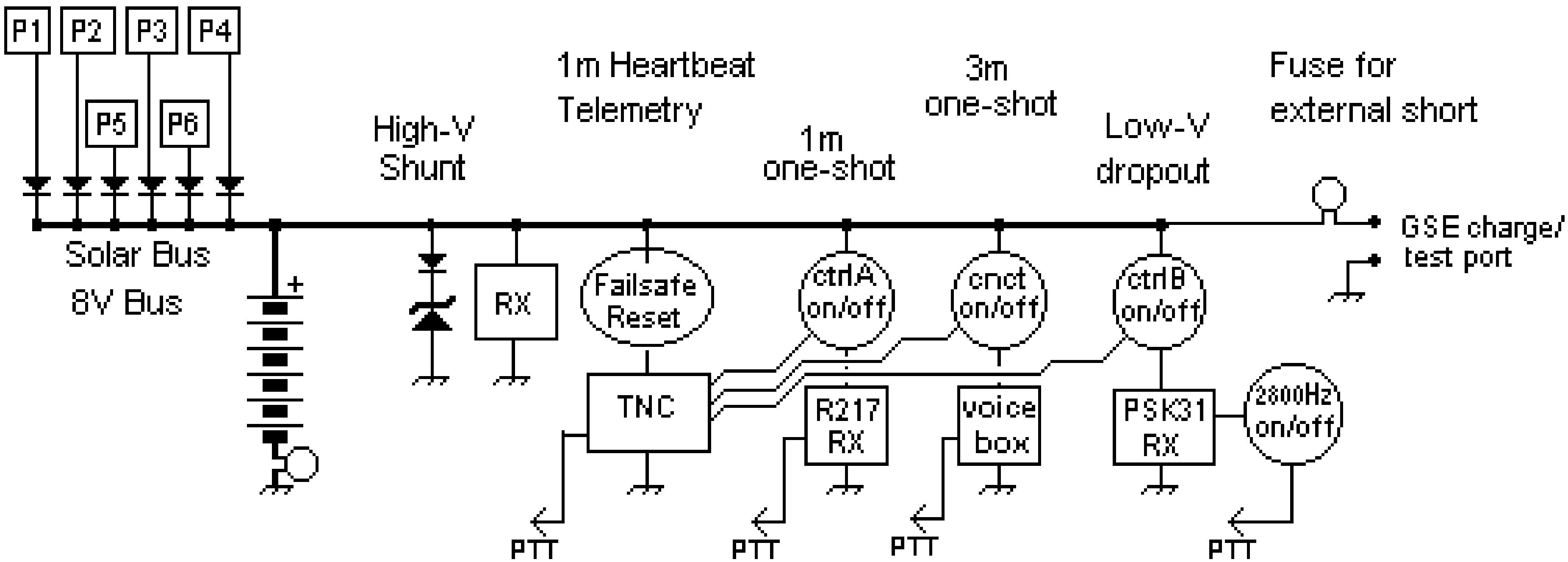


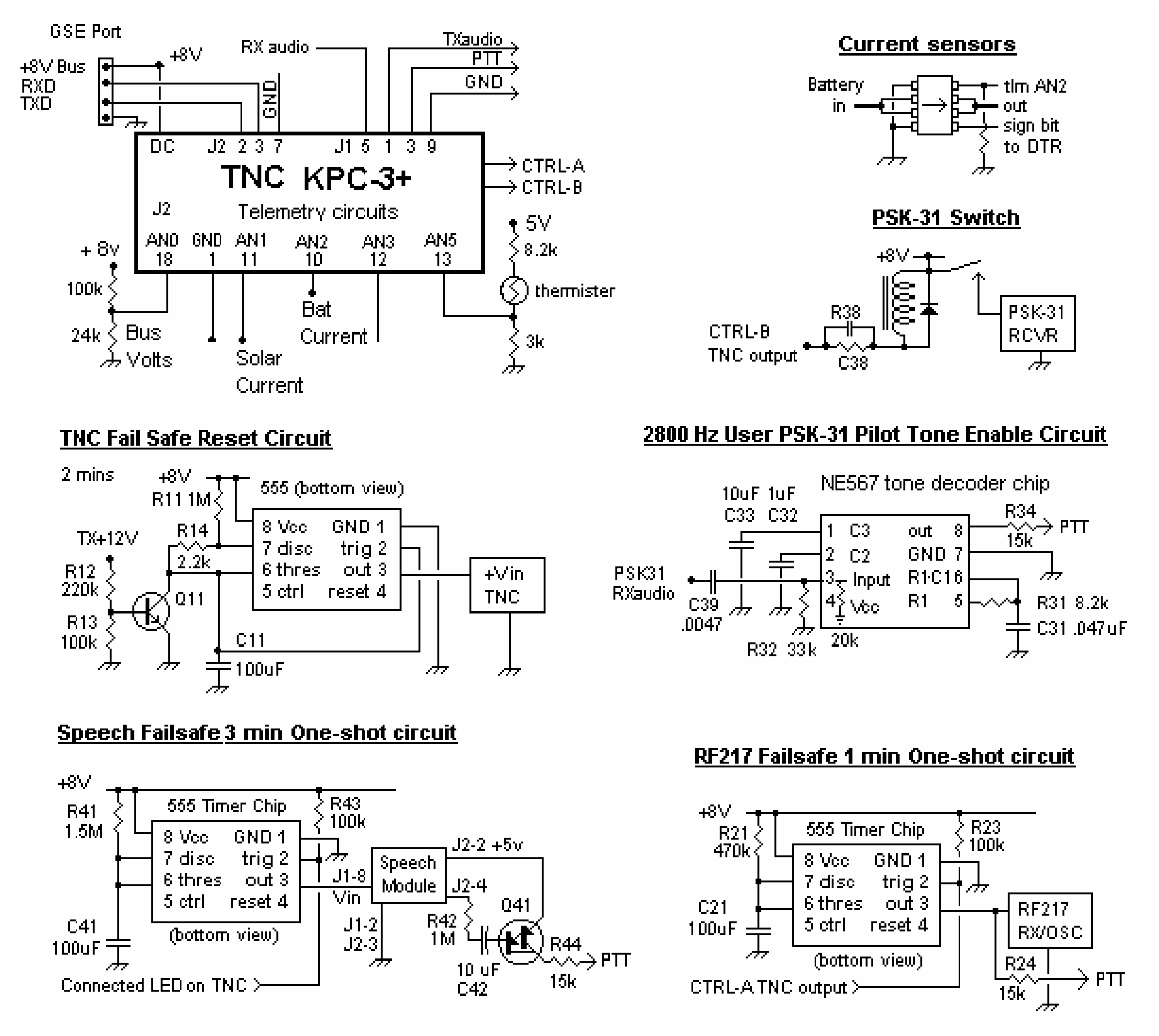

See Charge Safety Document: http://www.ew.usna.edu/~bruninga/craft/RAFTchargeSafety.txt



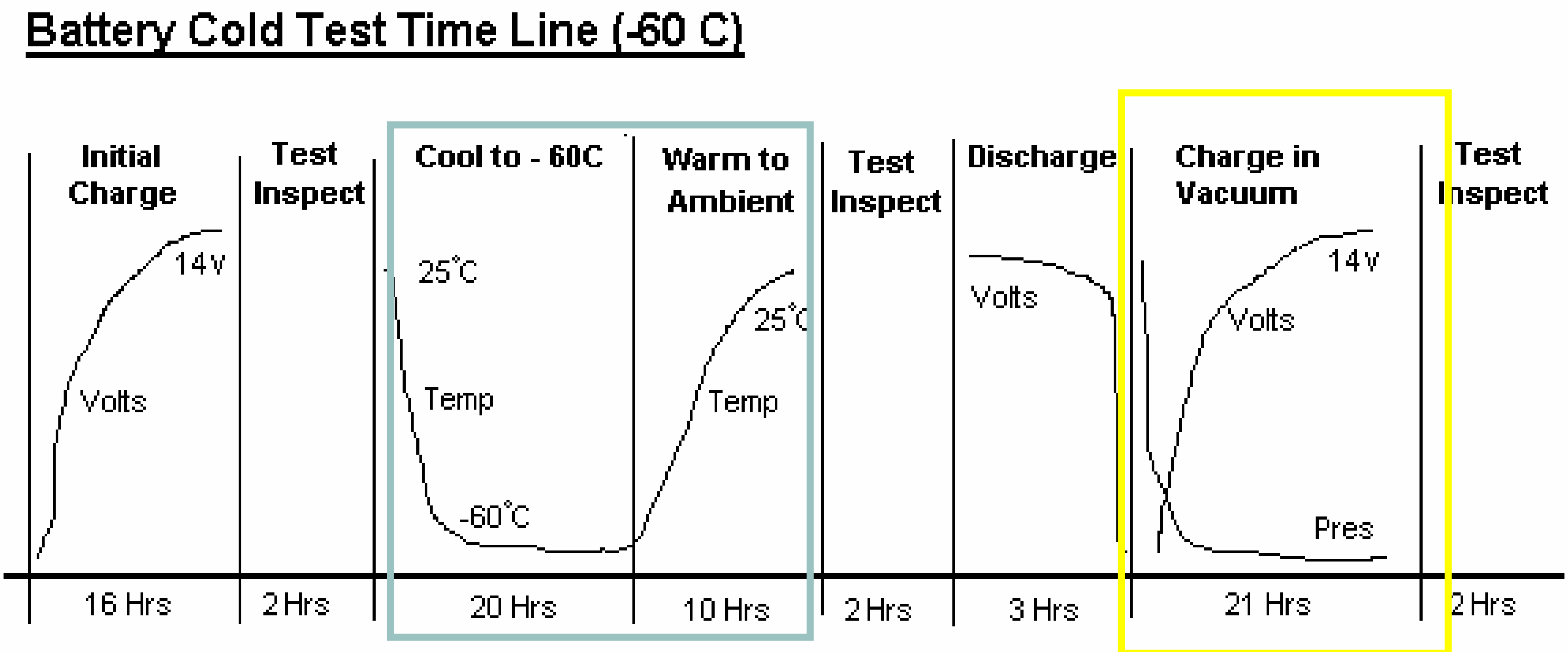
# Operations Safety Features

All Transmitter circuits time-out to OFF



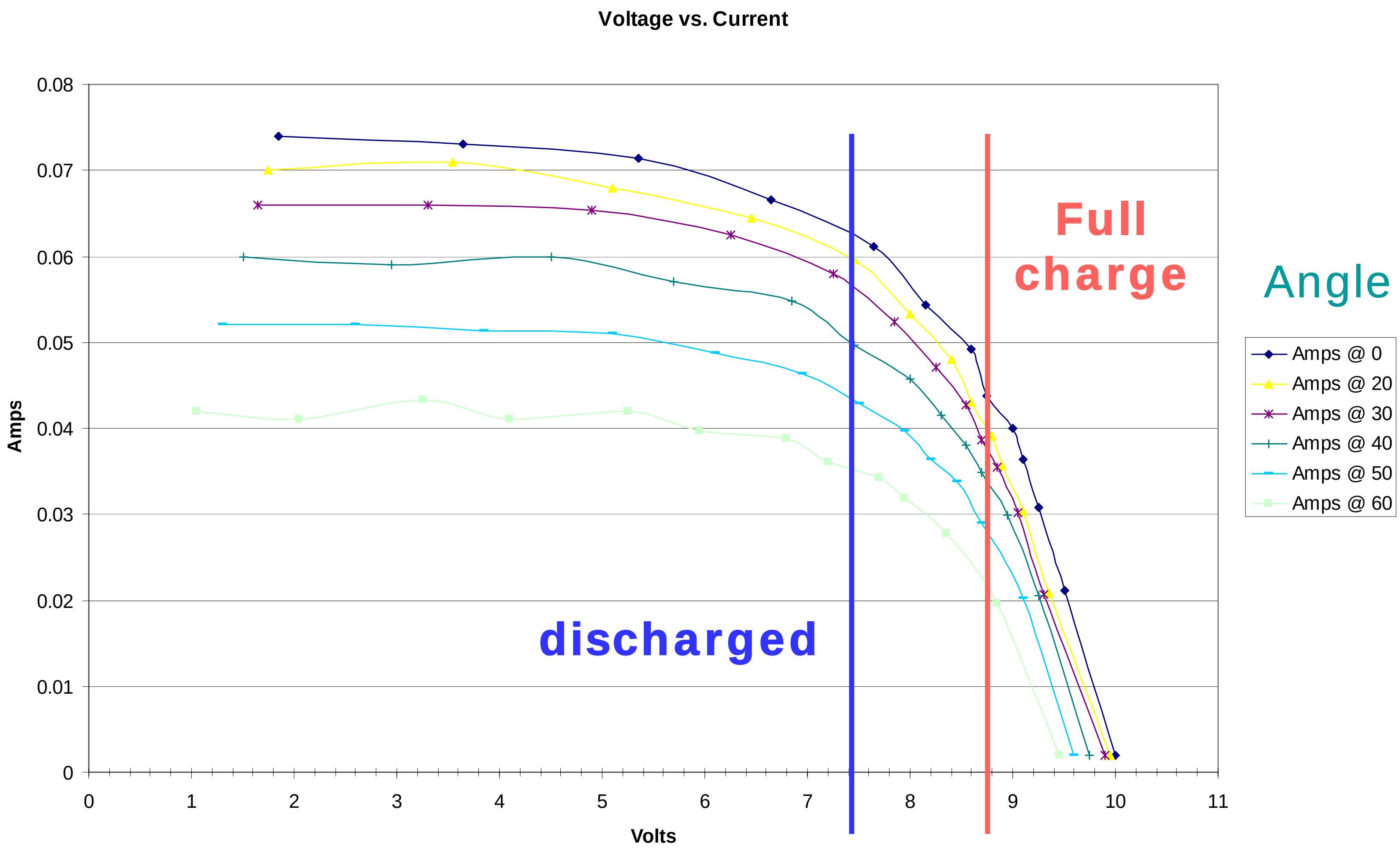

GSE Port
+8V Bus
RXD
TXD
+8V
RX audio
GND
TXaudio
PTT
GND
DC J2 2 3 7 J1 5 1 3 9
TNC KPC-3+
J2
Telemetry circuits
AN0 18
GND 1
AN1 11
AN2 10
AN3 12
AN5 13
CTRL-A
CTRL-B
5V
8.2k
thermister
3k
+ 8v
100k
24k
Bus Volts
Solar Current
Bat Current
Current sensors
Battery in
tlm AN2
out
sign bit to DTR
PSK-31 Switch
+8V
R38
CTRL-B TNC output
C38
PSK-31 RCVR
TNC Fail Safe Reset Circuit
2 mins
+8V
R11 1M
555 (bottom view)
TX+12V
R14
2.2k
R12 220k
R13 100k
Q11
8 Vcc GND 1
7 disc trig 2
6 thres out 3
5 ctrl reset 4
C11
100uF
+Vin TNC
2800 Hz User PSK-31 Pilot Tone Enable Circuit
NE567 tone decoder chip
10uF 1uF
C33 C32
PSK31 RXaudio
C39 .0047
R32 33k
20k
1 C3 out 8
2 C2 GND 7
3 Input R1C16
4 Vcc R1 5
R34 15k
PTT
R31 8.2k
C31 .047uF
Speech Failsafe 3 min One-shot circuit
+8V
R41 1.5M
555 Timer Chip
R43 100k
8 Vcc GND 1
7 disc trig 2
6 thres out 3
5 ctrl reset 4
(bottom view)
C41 100uF
Connected LED on TNC
J1-8 Vin
Speech Module
J2-2 +5v
J2-4
J1-2 J2-3
R42 1M
Q41
R44
PTT
10 uF C42
15k
RF217 Failsafe 1 min One-shot circuit
+8V
R21 470k
555 Timer Chip
R23 100k
8 Vcc GND 1
7 disc trig 2
6 thres out 3
5 ctrl reset 4
(bottom view)
C21 100uF
RF217 RX/OSC
R24 15k
PTT
CTRL-A TNC output

# Battery Tests




- No mass change, no leakage
- Worst case 10% loss of capacity
- Design Capacity has a 4 to 20 overdesign factor

# PCsat Solar Panel I-V Curve



# Frequency Coordination

- RAFT1 ITU Request Form submitted.
  - TX: 145.825 MHz, 2 Watt, 20 KHz B/W FM
  - RX: 28.120 – 28.124 MHz PSK-31 Receiver
  - RX: 145.825 MHz AX.25 FM
  - 216.98 MHz NSSS transponder
- MARScom DD 1494 submitted.
  - 148.375-148.975 MHz VHF cmd/user uplink
  - 24-29 MHz Downlink
  - 300 MHz UHF YP Craft Uplink Whip
    - Resonate at 216.98 MHz

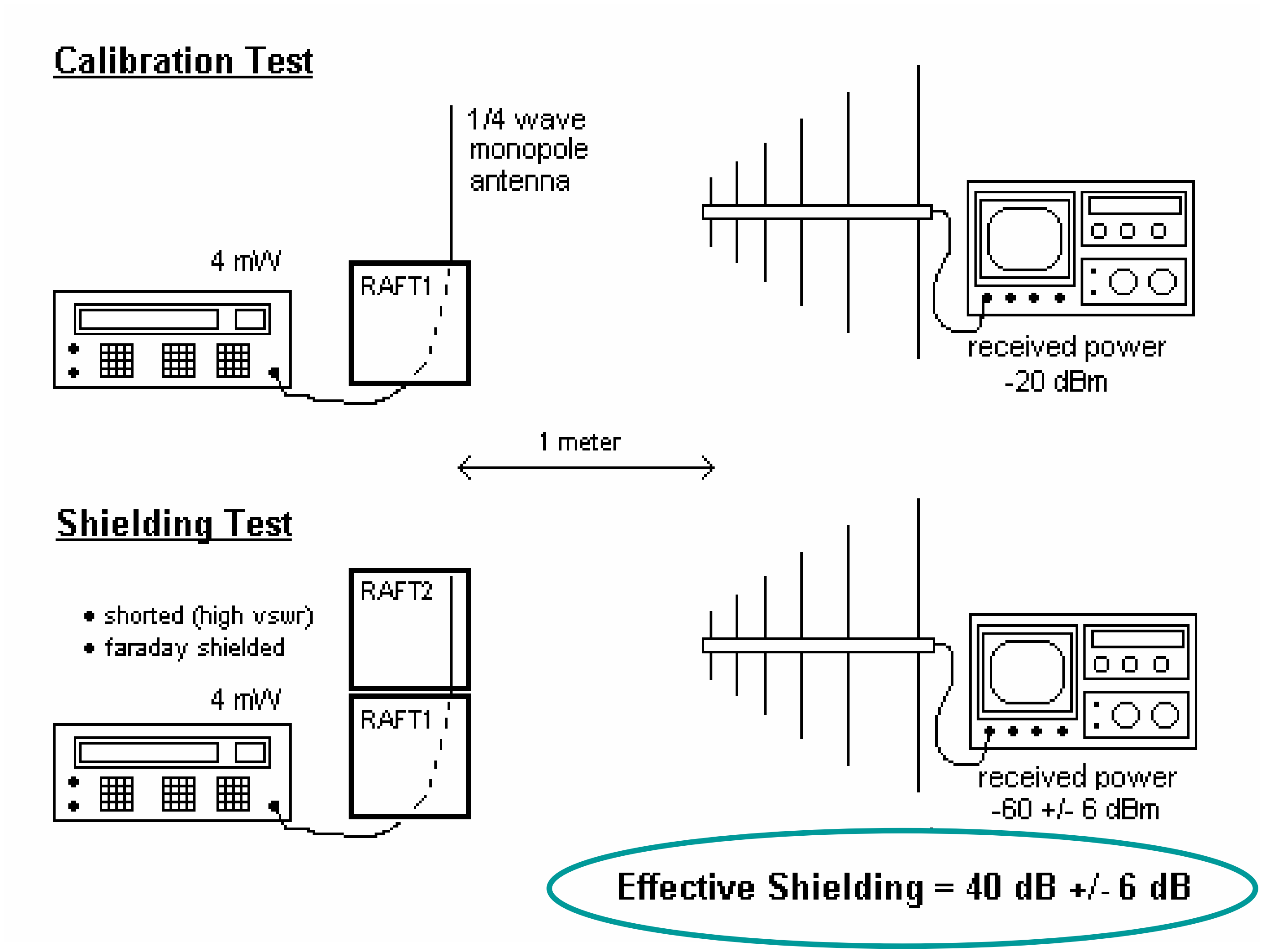
# Radiation Hazard = None

Antennas Compressed, Shorted, Shielded and Sep-SW OFF

Deployed and Active

11 V/m

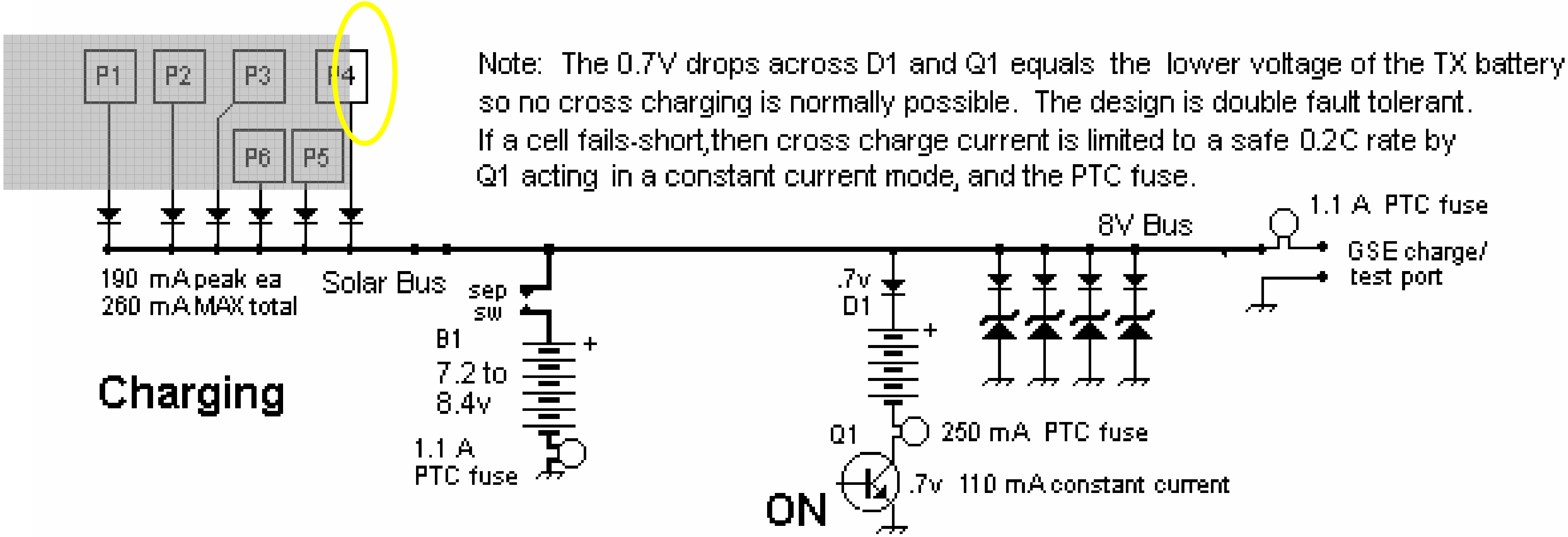
Pre-Separation
0.11 V/m



# Questions?

# Backup Slides

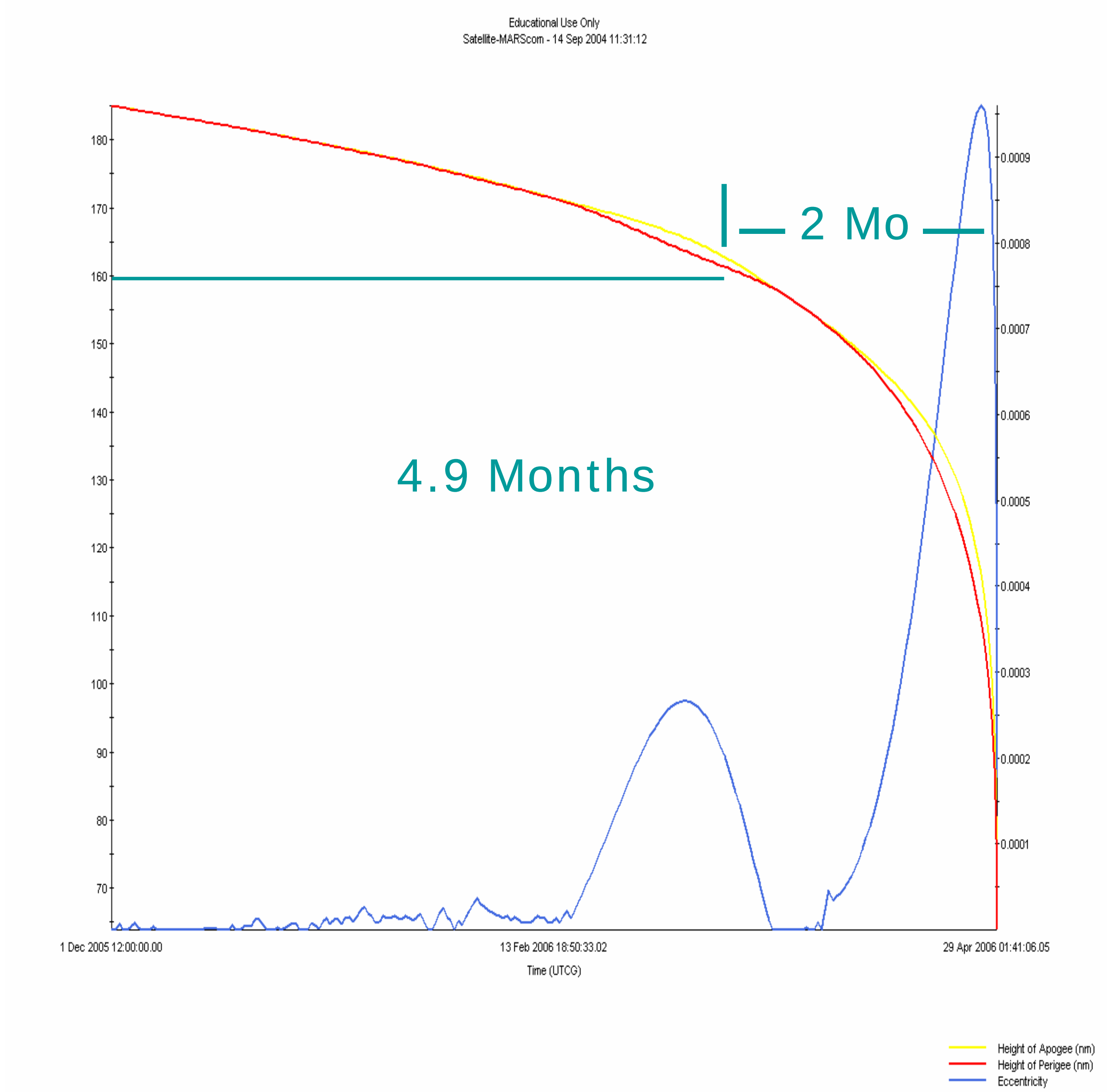
# Inadvertant Currents in Full Sun Exposure



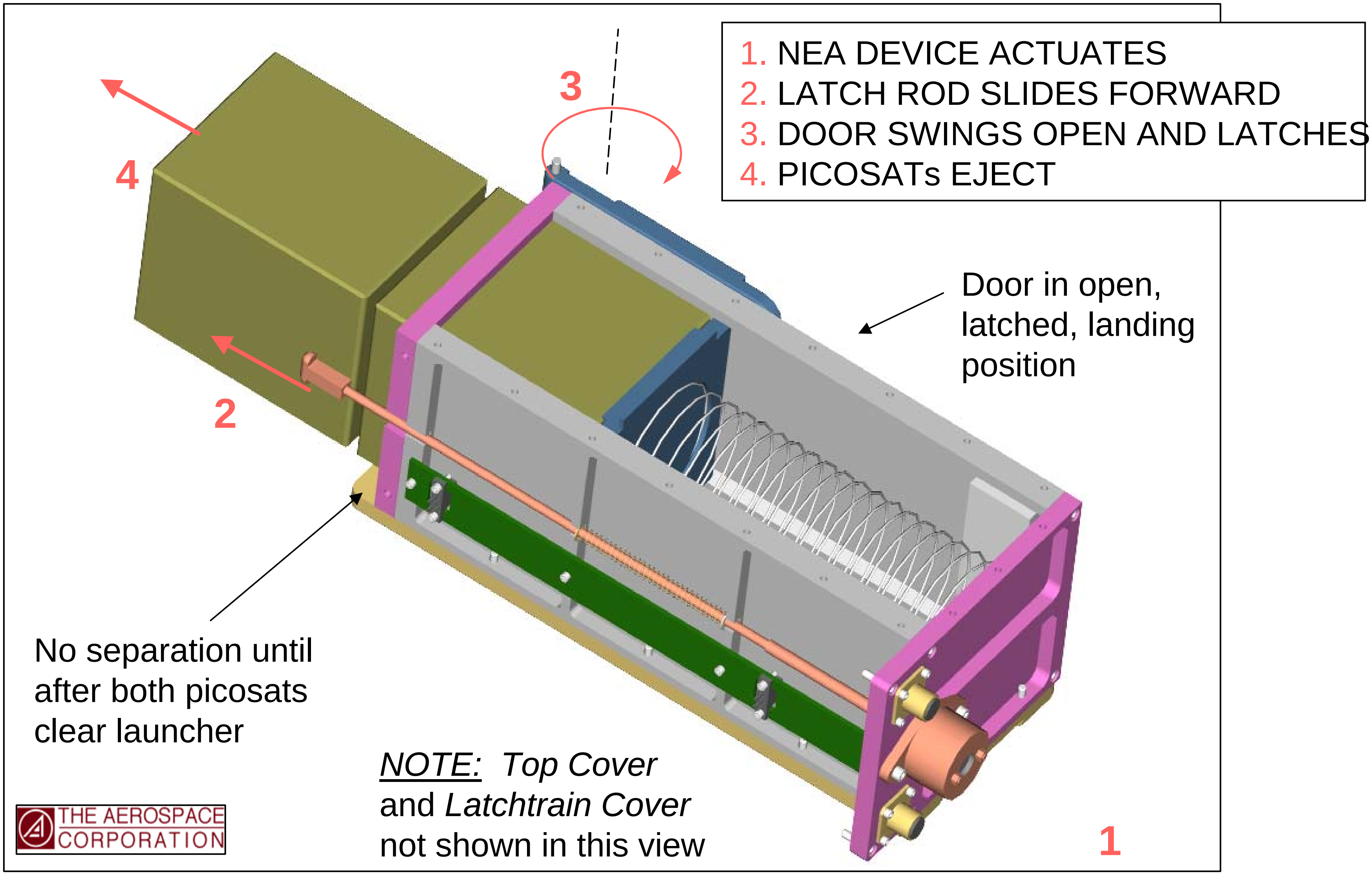

- Cannot XMT even in full Sun without main battery (needs 500 mA, only 130 mA avail)
- Light leaks in launcher are only 1.25 sq" (out of 25 sq") or only 15 mA
- Indefinite float rating of batteries is 35 mA (factor of 2 safety)
- Waste heat is only 0.12W compared to solar heat gain of over 40W

See Charge Safety Document: http://www.ew.usna.edu/~bruninga/craft/RAFTchargeSafety.txt

# MARScom Lifetime Estimate



# SSPL4410 LAUNCHER: Operation



# Mass Budget (kg)

## RAFT1

| Component | Mass (kg) | Comments |
|---|---|---|
| Spool w/ HF Antenna | 0.0536 | Estimate |
| VHF Antenna | 0.0046 | Estimate |
| UHF Antenna | 0.0046 | Estimate |
| PSK-10 Board | 0.1215 | Includes Interface |
| TNC Board | 0.1409 | Actual |
| Interface Board | 0 | Estimated in PSK-10 |
| Transmitter Board | 0.0941 | Actual |
| Receiver Board | 0.083 | Actual |
| Battery Boxes (2) | 0.0406 | Actual |
| AA Batteries (11) | 0.2607 | Actual |
| B1 Panel | 0.138 | Estimate |
| B2 Panel | 0.138 | Estimate |
| Transmitter Panel | 0.138 | Estimate |
| Receiver Panel | 0.138 | Estimate |
| Bottom Panel | 0.138 | Estimate |
| Top Panel | 0.138 | Estimate |
| PCSat Solar Panels (5) | 0.3255 | Actual |
| **TOTAL** | **1.9571** | |
| **Max Allowed** | **4** | |

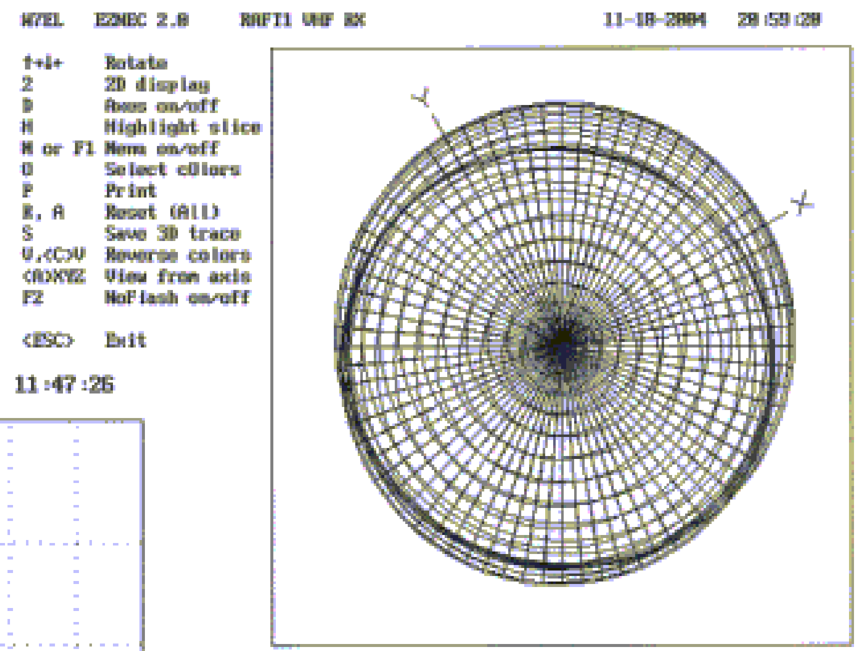
## MARScom

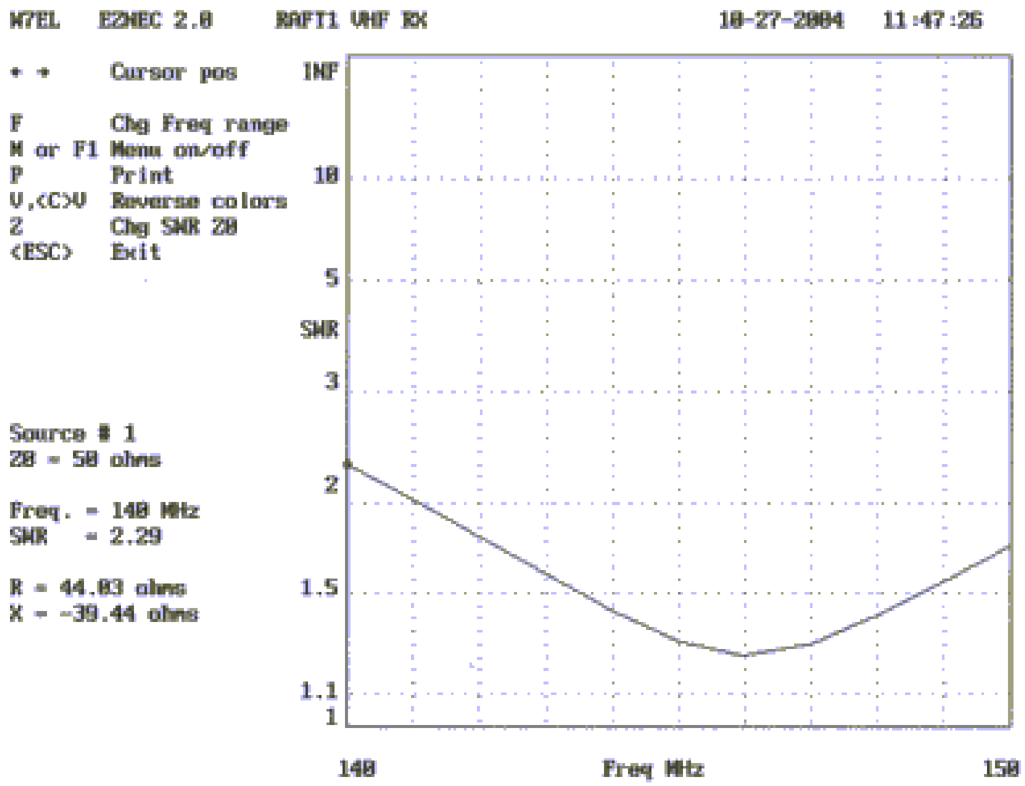
| Component | Mass (kg) | Comments |
|---|---|---|
| VHF FM RCVR | 0.094 | Estimate |
| VHF AM RCVR | 0.094 | Estimate |
| SSB Exciter | 0.1 | Estimate |
| 1W Linear PA | 0.04 | Estimate |
| Splitter | 0.04 | Estimate |
| Decoder | 0.04 | Estimate |
| Batteries | 0.168 | Estimate |
| Ant/Spring combo | 0.3 | Estimate |
| 20% Reserve | 0.1752 | Estimate |
| 1/4" Aluminum | 1.5 | Estimate |
| **Total** | **2.5512** | |
| **Max Allowed** | **3** | |

Light mass design for future missions

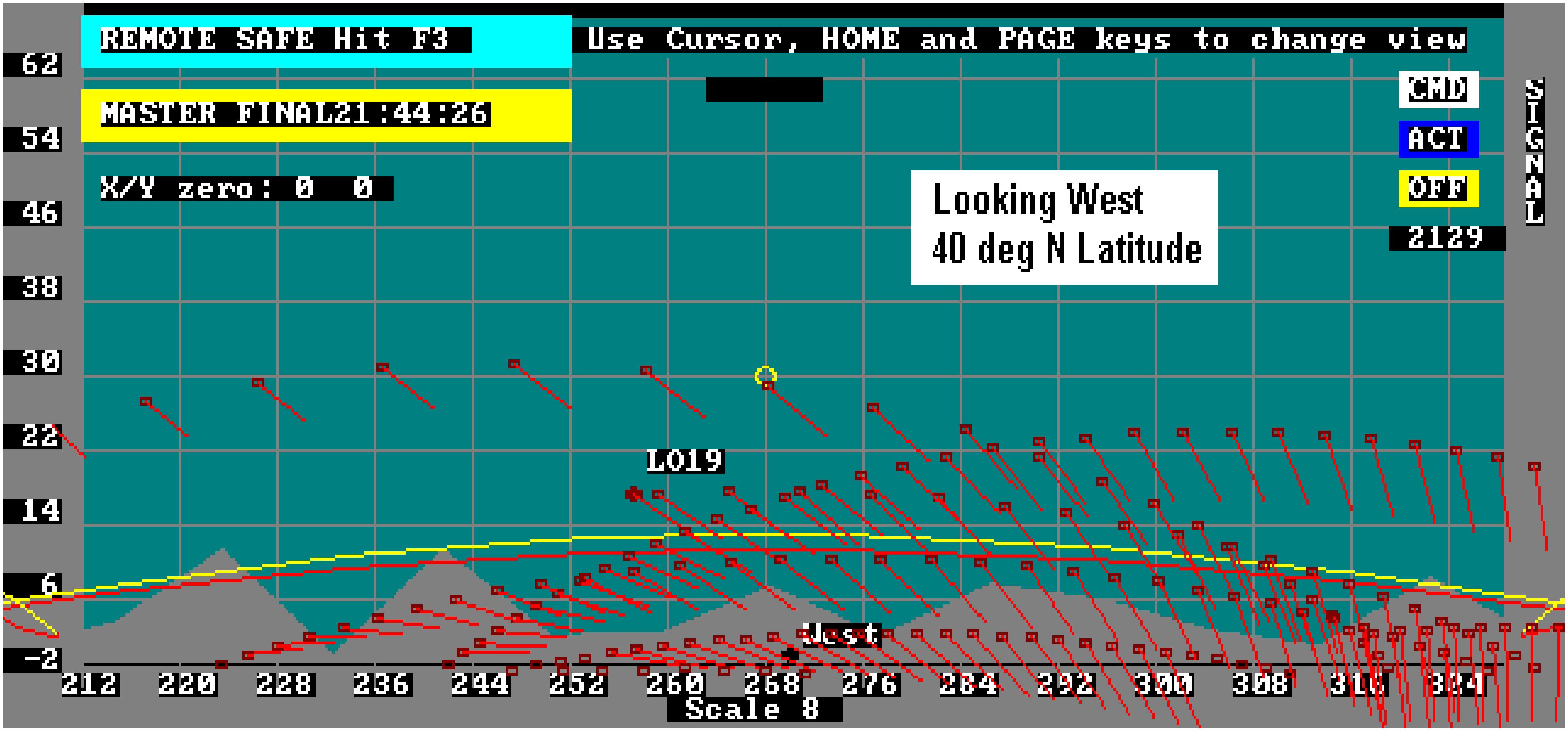
Will ballast for RAFT

# VHF EZNEC Plots



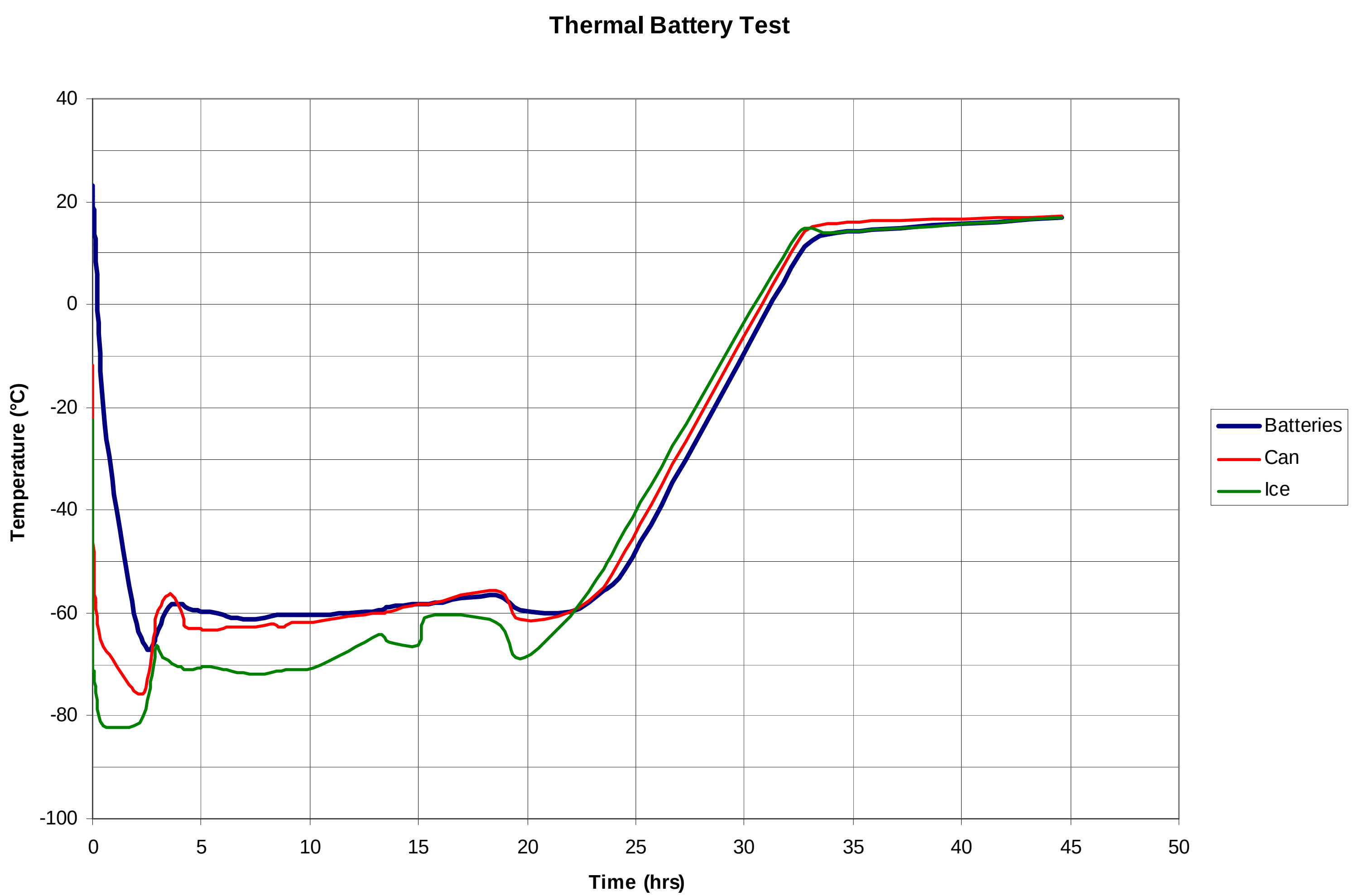
# RAFT1 Magnetic Attitude Control



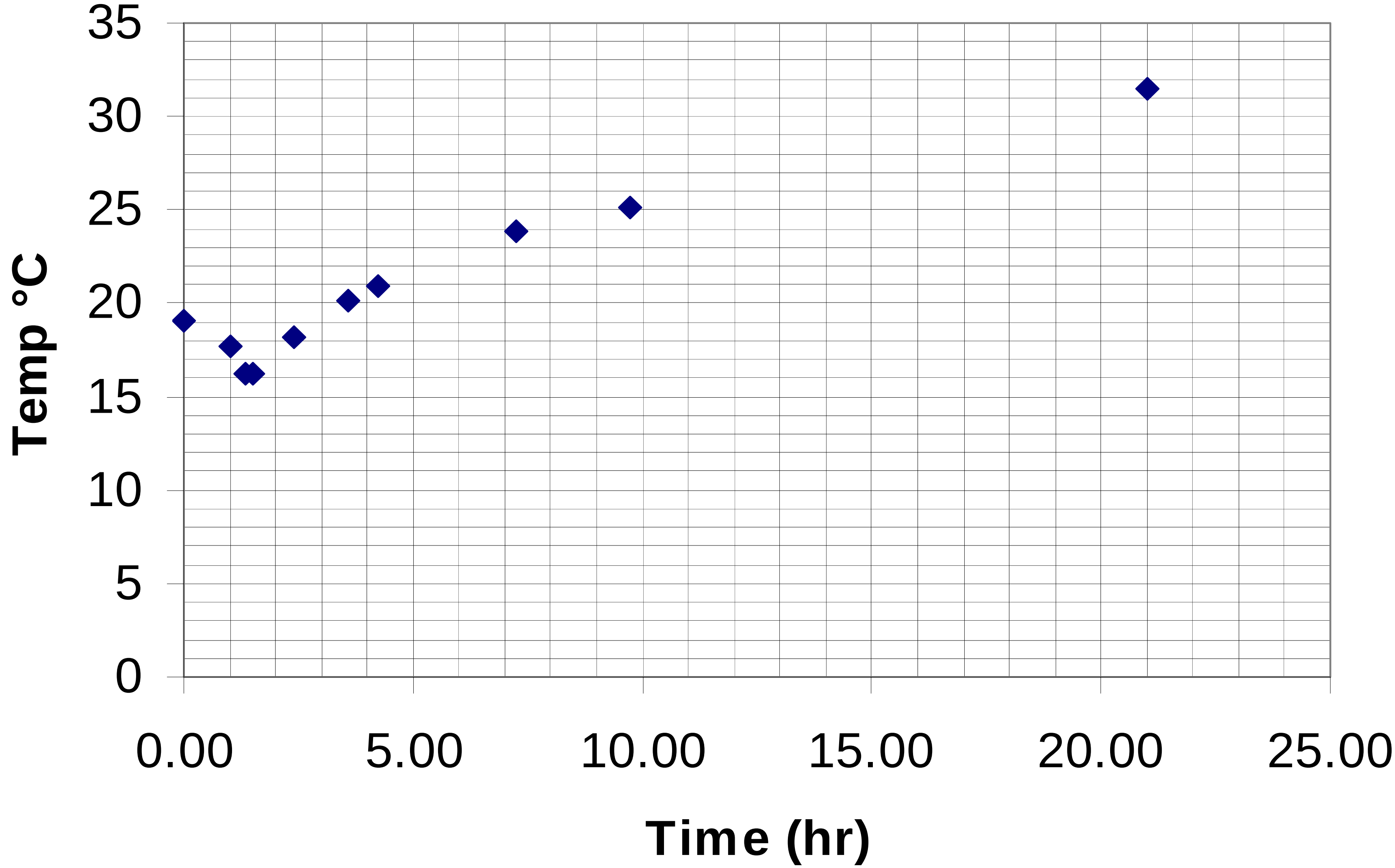
# Post Cold Test Battery Condition (No Leakage)

# -60 °C Battery Tests

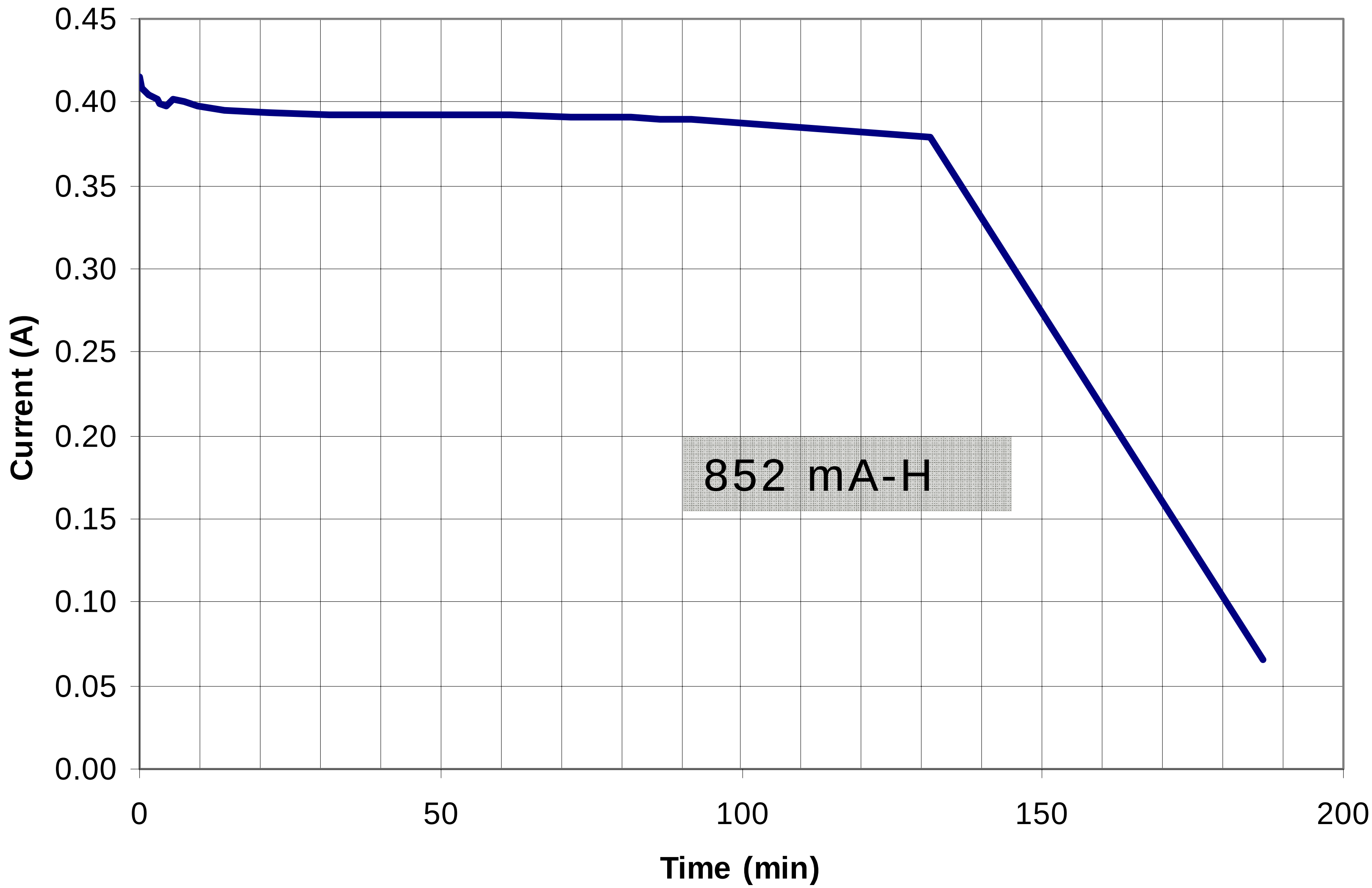
# -60 °C Battery Test: Thermal Conditions



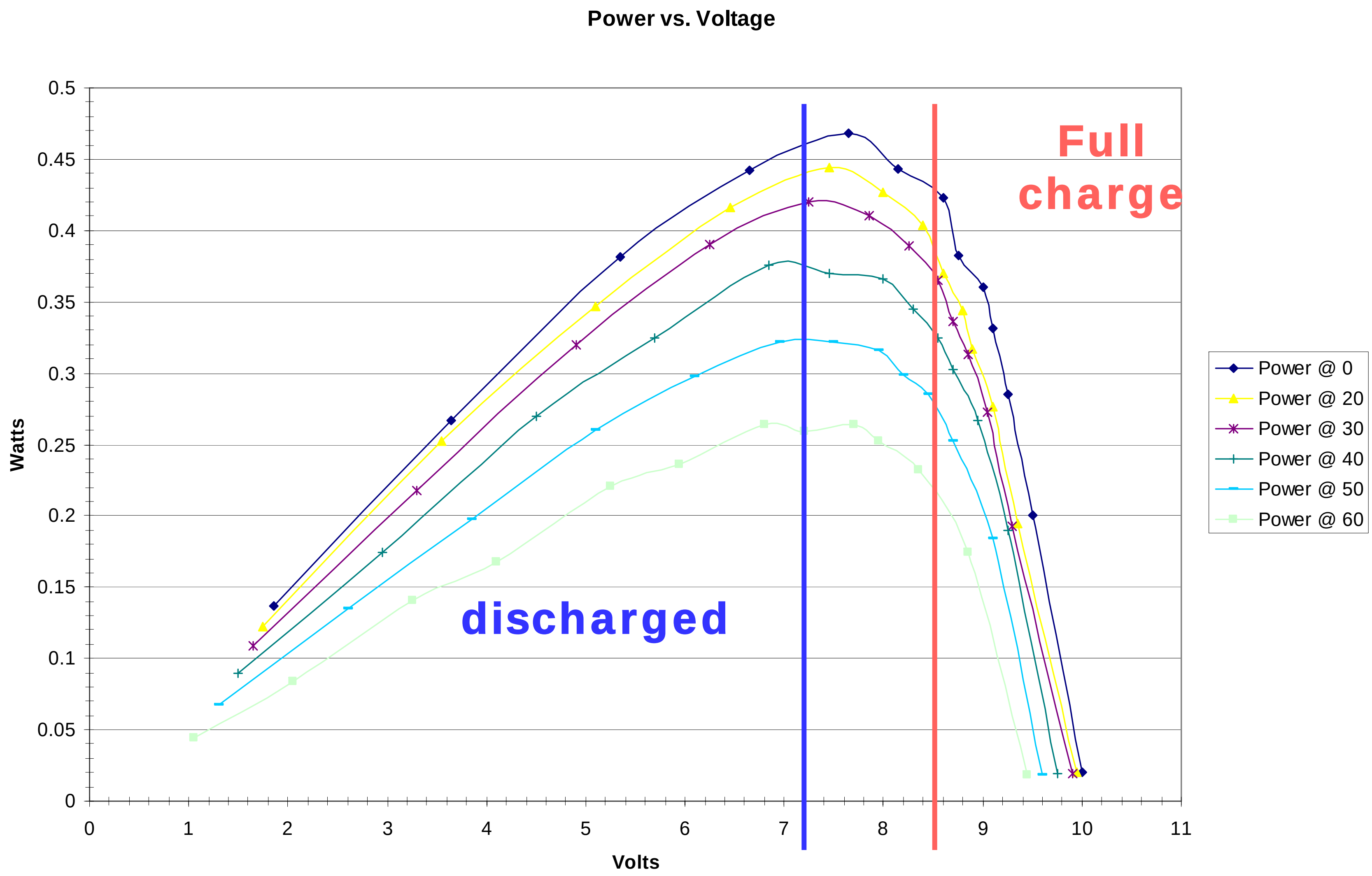
# Post -60 °C Charge Temp in Vacuum



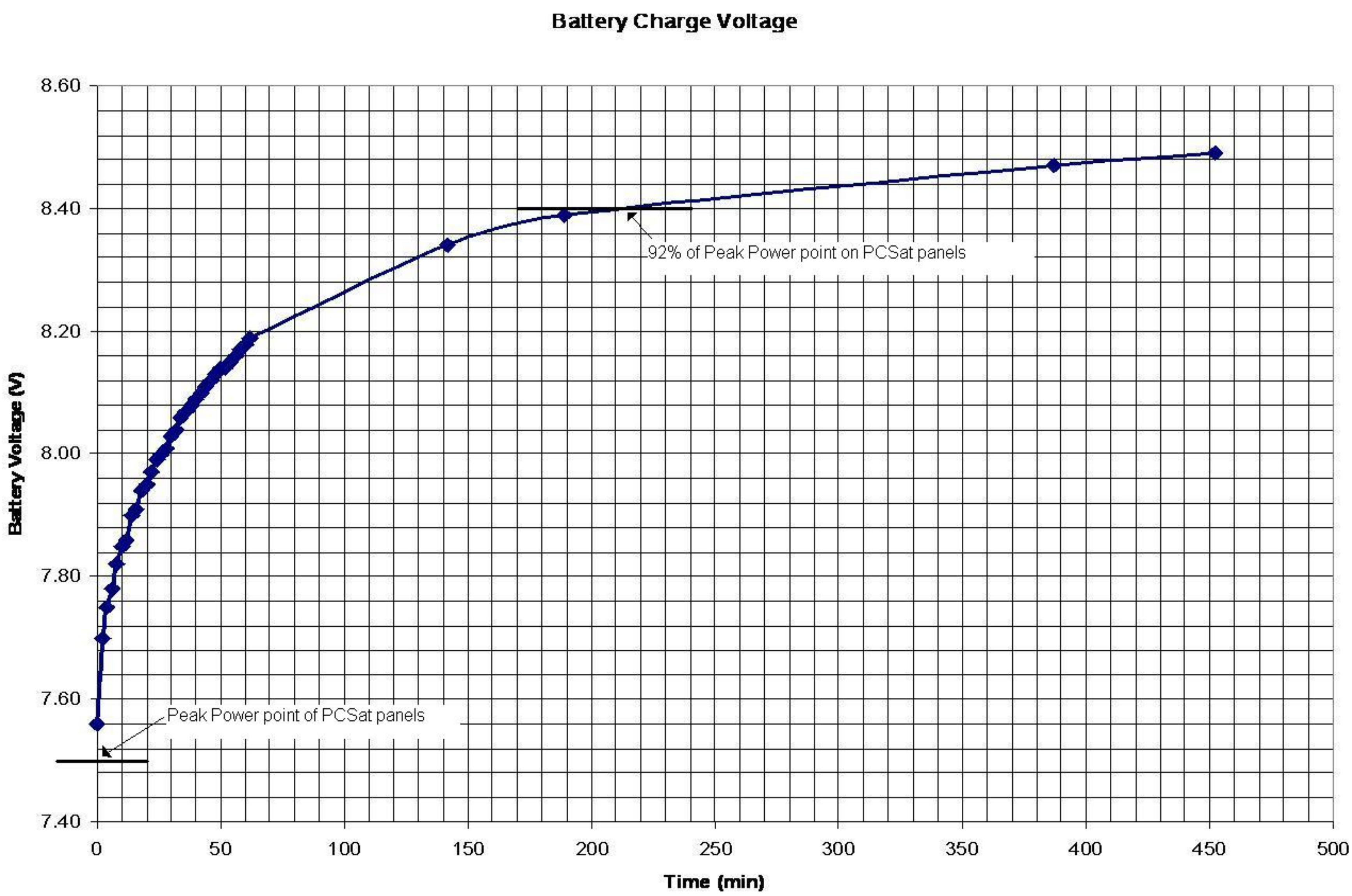
# Post Cold Test Discharge Current



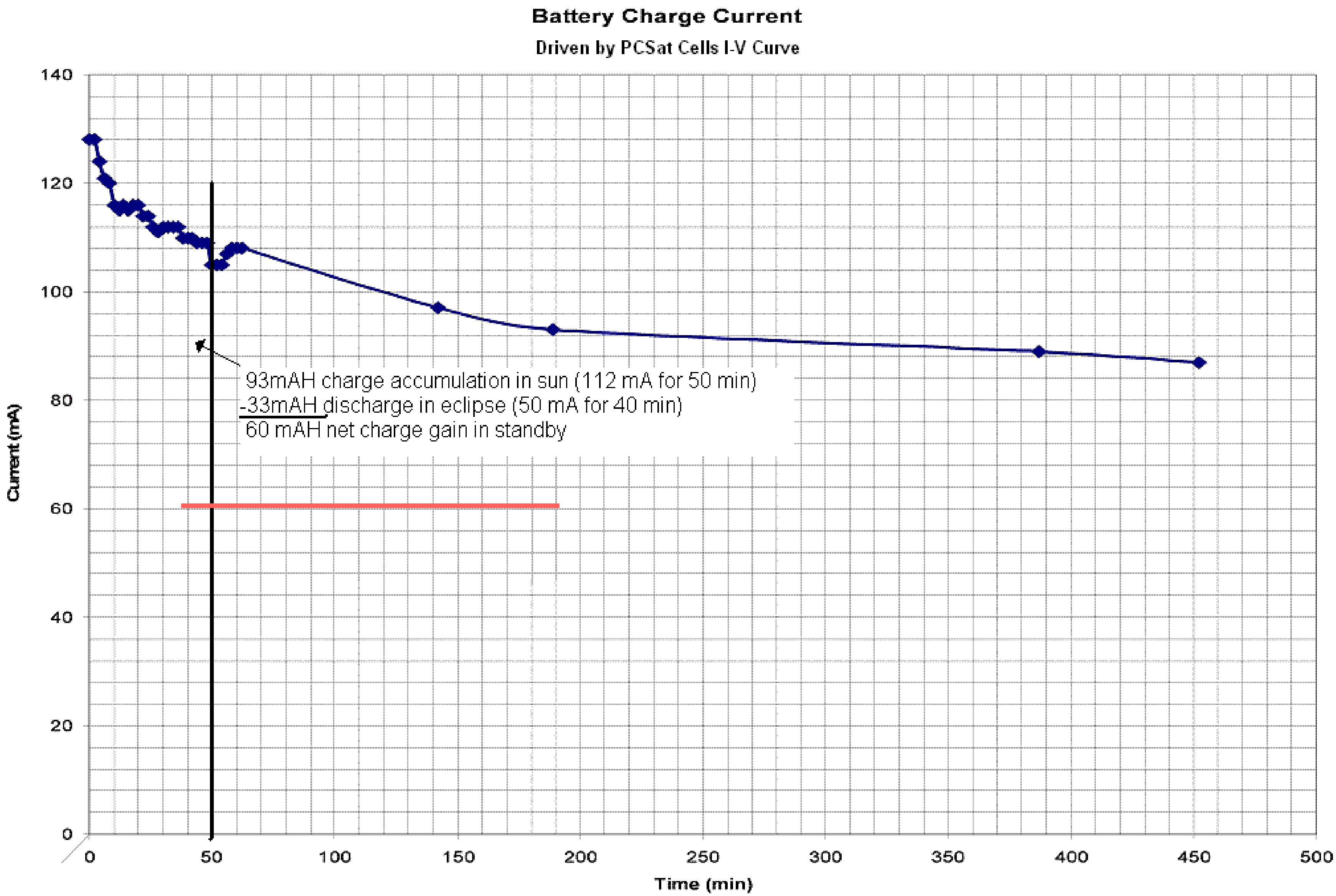
# PCsat P-V Curve



# Dead Battery Charge Efficiency



# Dead Battery Recovery Test



# Shuttle Safety Requirements

| | |
|---|---|
| ◆ Fracture Control Plan | Captive & Redundant |
| ◆ Fastener integrity | Captive & Redundant |
| ◆ Structural model of RAFT Buckling | Ideas model, |
| ◆ Venting analysis | Done. 0.04 " |
| ◆ Simple mechanisms | Antennas |
| ◆ Materials / Outgassing | COTS, Replace Electrolytics |
| ◆ Conformal coat PC boards | Yes |
| ◆ Wire sizing and fusing | #24, fuse 1 amp |
| ◆ Radiation hazard | Below 0.1v/m |
| ◆ Battery safety | Yes |
| ◆ Shock and vibration | Yes |

# Battery Safety Requirements

- Must have circuit interrupters in ground leg
- Inner surface and terminals coated with insulating materials
- Physically constrained from movement and allowed to vent
- Absorbent materials used to fill void spaces
- Battery storage temperature limits are -30°C to +50°C
- Prevent short circuits and operate below MFR's max
- Thermal analysis under load and no-load
- Battery must meet vibration and shock resistance stds
- Must survive single failure without inducing hazards
- Match cells for voltage, capacity, and charge retention