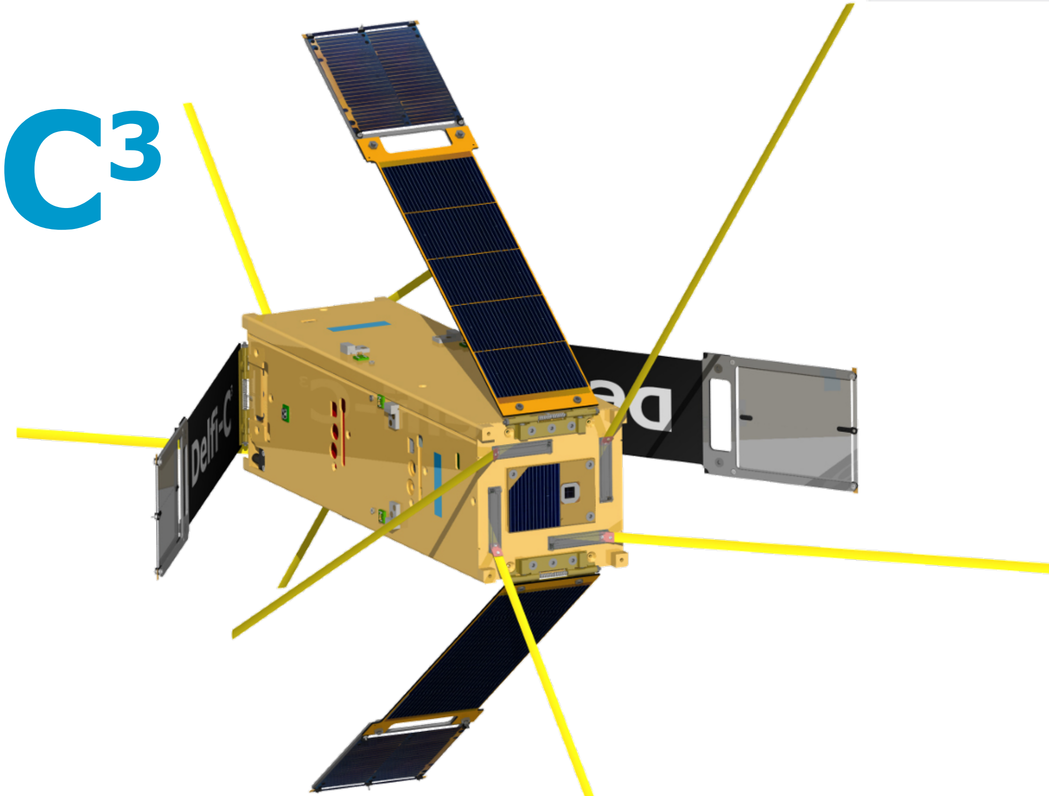
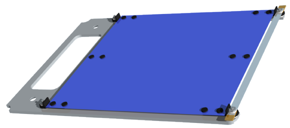
Delfi-C^3



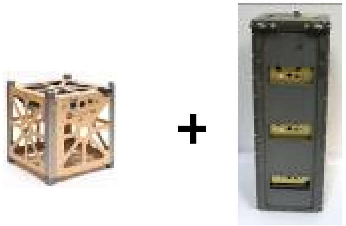
Realizing the First Dutch Student Nanosatellite & OSCAR

Wouter Weggelaar
PA3WEG
Delft University of Technology, The Netherlands

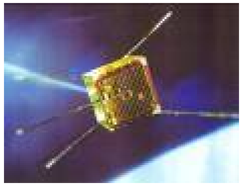
November 2004:



Thin Film Solar Cells
(Dutch Space)

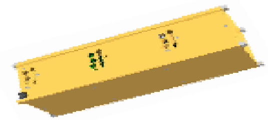


CubeSat + P-POD Standard
(Stanford and CalPoly)



Delfi-1 Heritage
(1998-2005)

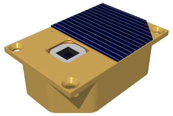
TU Delft Satellite Opportunity

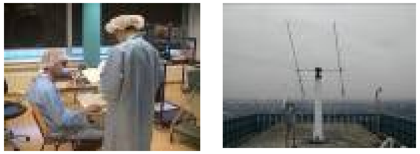


3-unit CubeSat Kit
(Pumpkin Inc.)

MiSat Program
- Wireless Sun Sensor (TNO)
- Advanced Transceiver (EEMCS)

MicroNed

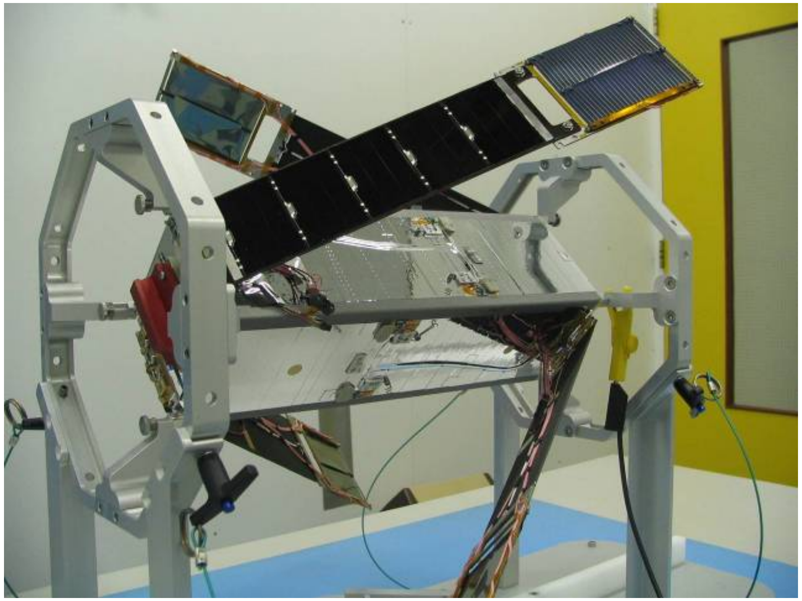


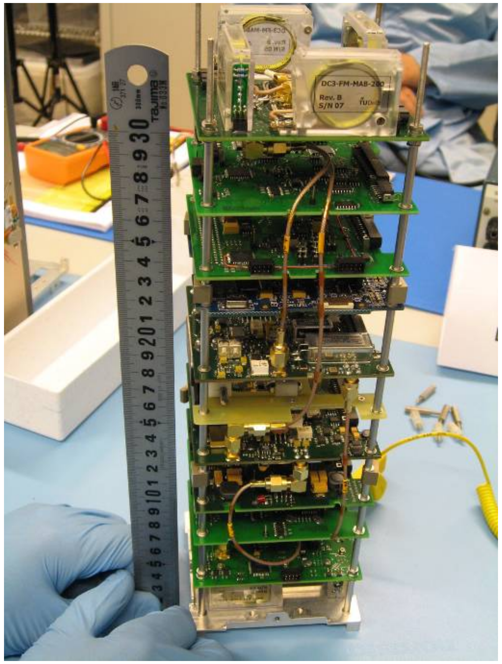


TU Delft Facilities
- Clean Room
- Delfi Ground Station

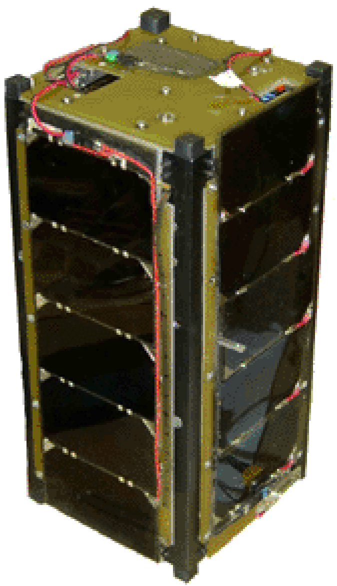
April 2008:

- Satellite ready for launch
- Over 60 students have worked on Delfi-C3 (+ 3 new HAMs!)
- Successor Delfi-n3Xt



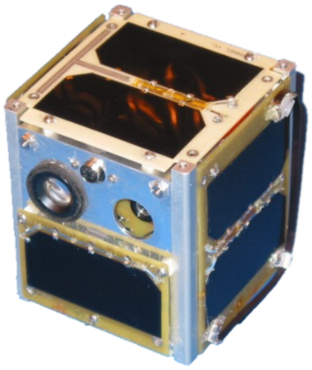


CubeSats



U. Of Illinois ION

Cal Poly CP1



CAN-X1

Delfi-C^3 Mission Overview - Objectives

Summarized Technical Objectives:

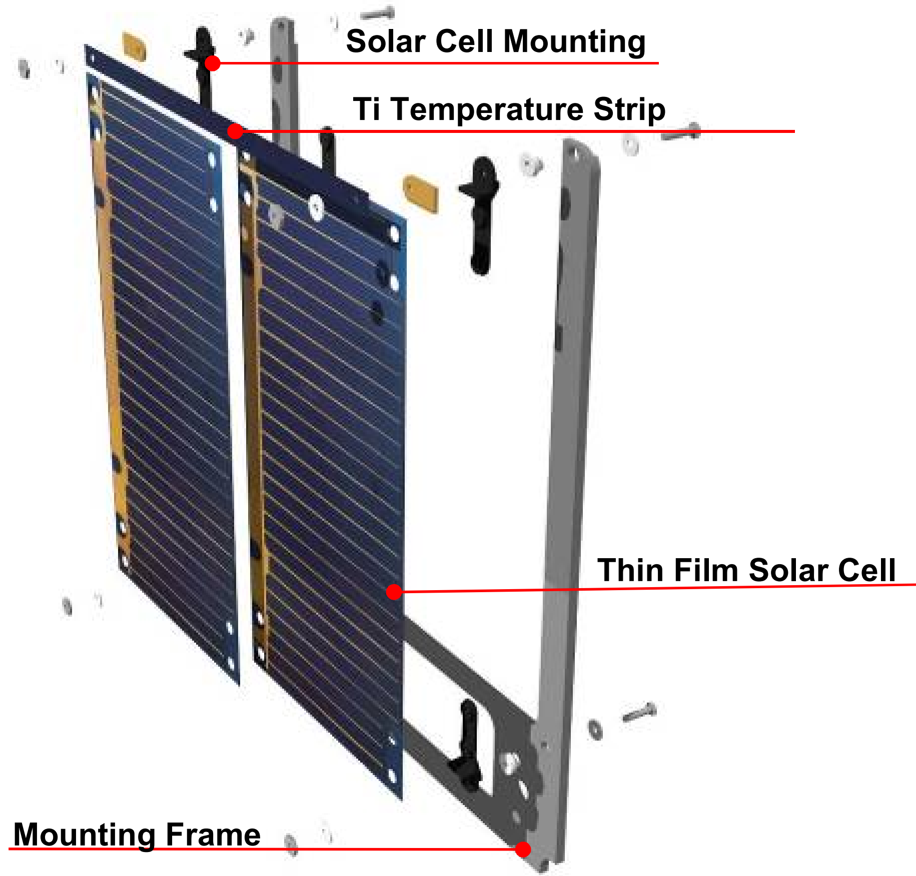
- Perform in-orbit test of a Thin Film Solar Cells
- Perform in-orbit test of an Autonomous Wireless Sun Sensor
- Create a distributed ground station network for Delfi-C3 and future missions

Summarized Educational Objectives:

- Provide interdisciplinary hands-on engineering experience
- Develop teamwork, leadership, and communication skills
- Interface with the MSc. programs of TU Delft
- Provide an opportunity to a variety of educational organizations to participate

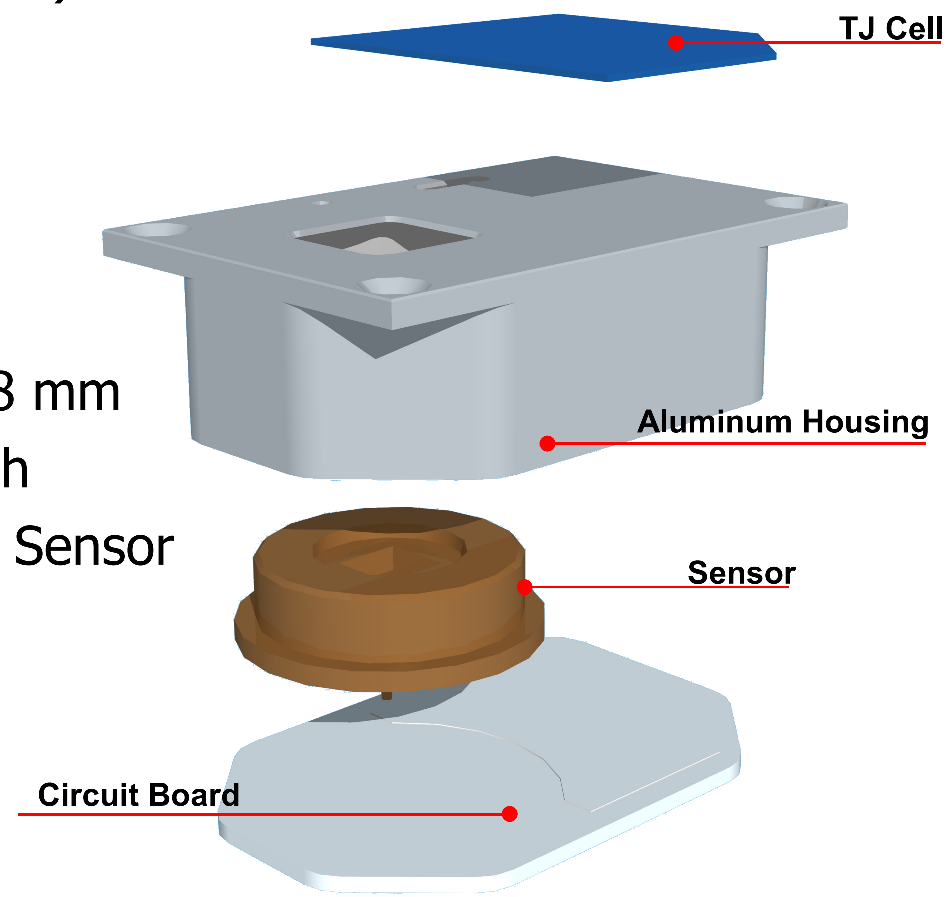
Thin Film Solar Cells (Dutch Space)

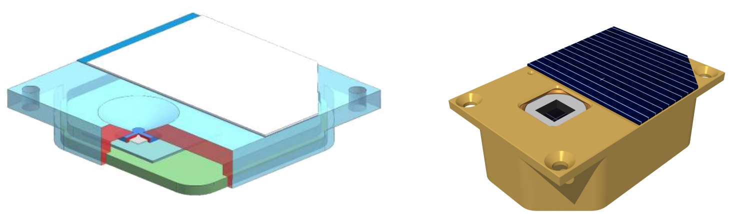
- First flight opportunity
- Innovative technology:
  - Thin film titanium substrate ~ 25 μm
  - High power to mass ratio
  - Very low stack height
- IV-curve measurement
- Temperature measurement
- Modular payload
- *No body mounting*



Autonomous Wireless Sun Sensor (TNO)

- Analog Quadrant Sun Sensor (OTS)
- Wireless RF-Interface
  - UHF Link (915 MHz)
  - Patch antenna on sensor
  - 1 RF-receiver connected to OBC
- Integrated GaAs solar cell
- Sensor envelope ~ 60x40.5x17.8 mm
- 2 Sensor units, mass ~ 75 g each
- Predecessor to Micro Digital Sun Sensor





Digital Sun Sensor [TNO]

Mission Characteristics, launch and Realization

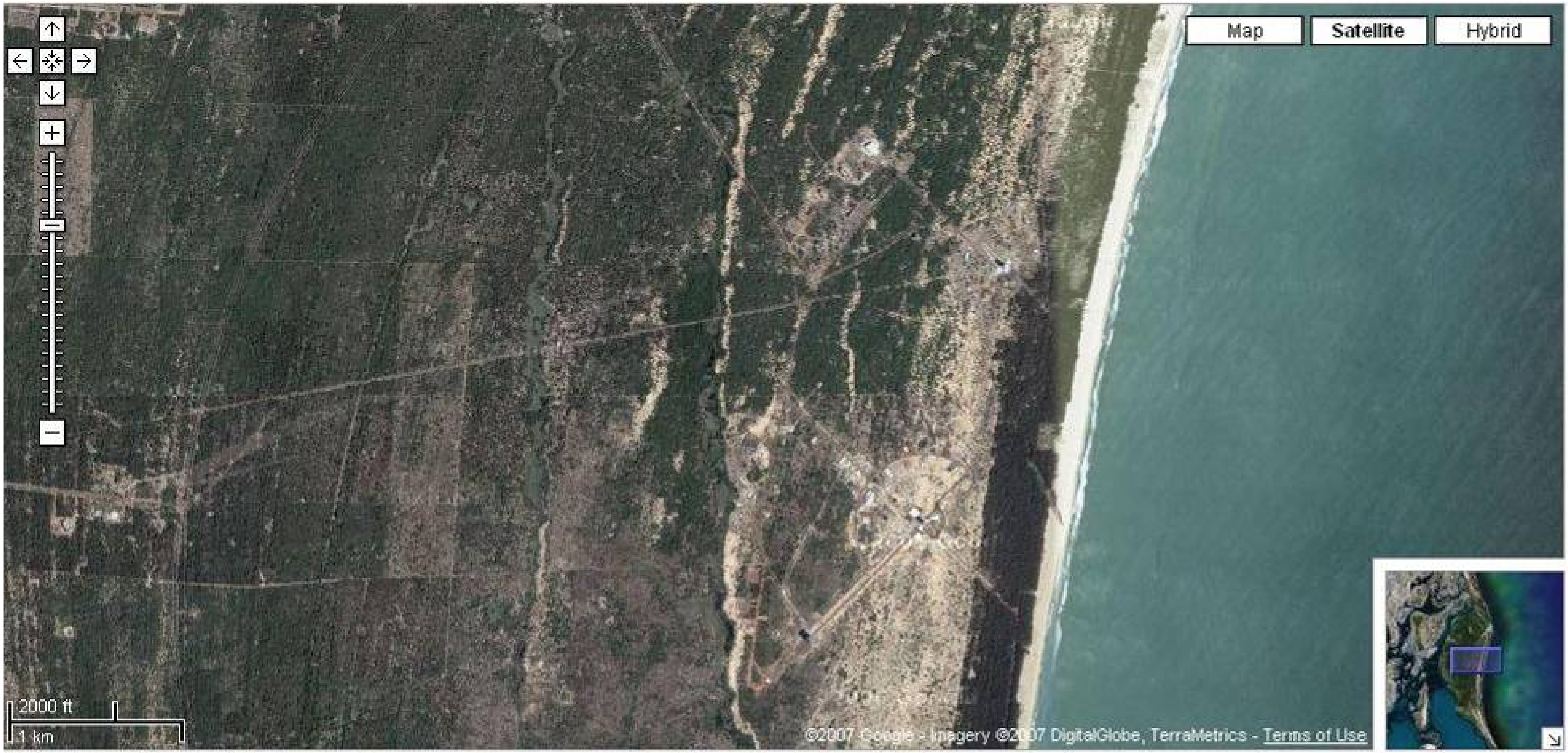
- Design and development by a self-organized student team
- Telemetry gathering through Radio Amateurs
- *Mode U/V Linear transponder*
- Designed for 1 year LEO

X-POD

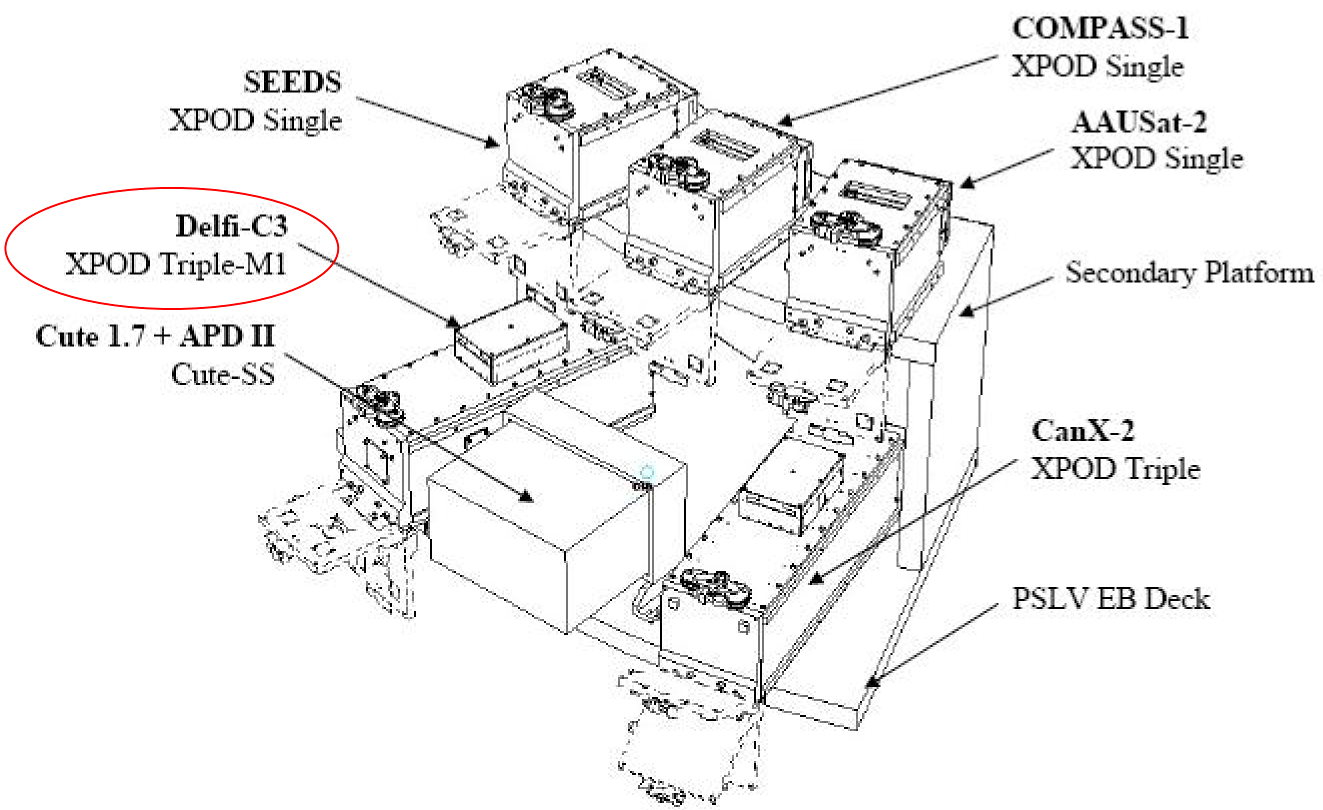
PSLV

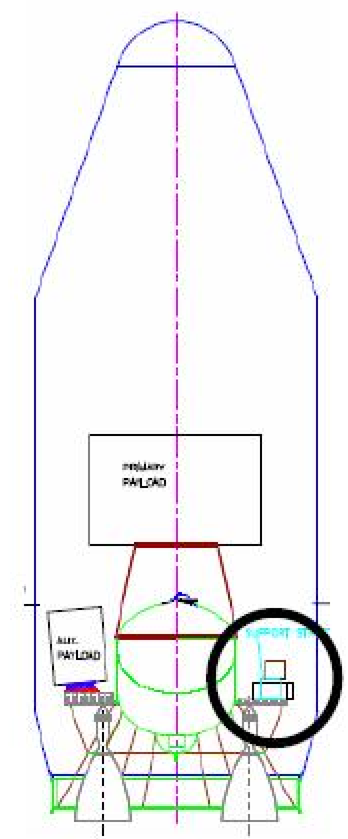
- "Piggyback" Launch in X-POD NLS-4 launch Polar Satellite Launch Vehicle (PSLV), India, **21st of April 2008**
- Orbit:
  - Inclination: 97.91°
  - Sun synchronous
  - Altitude: 630 km, circular orbit
- 3 months science mission, after which linear transponder mode

Shriharikota Launch Site



Launch configuration



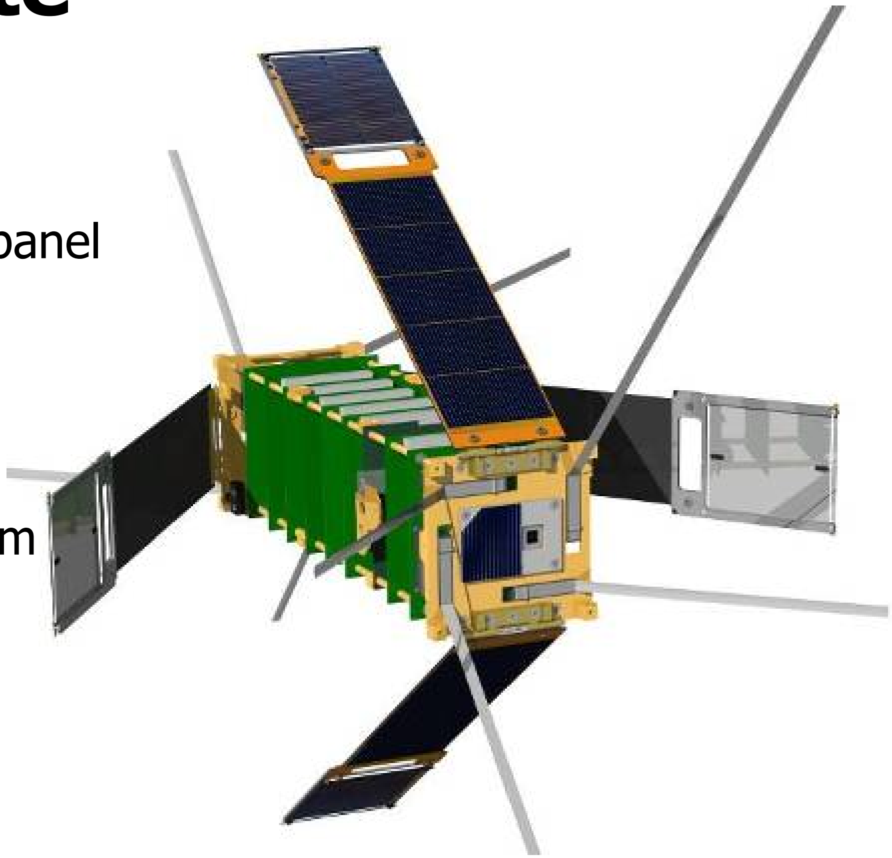


The Delfi-C3 satellite

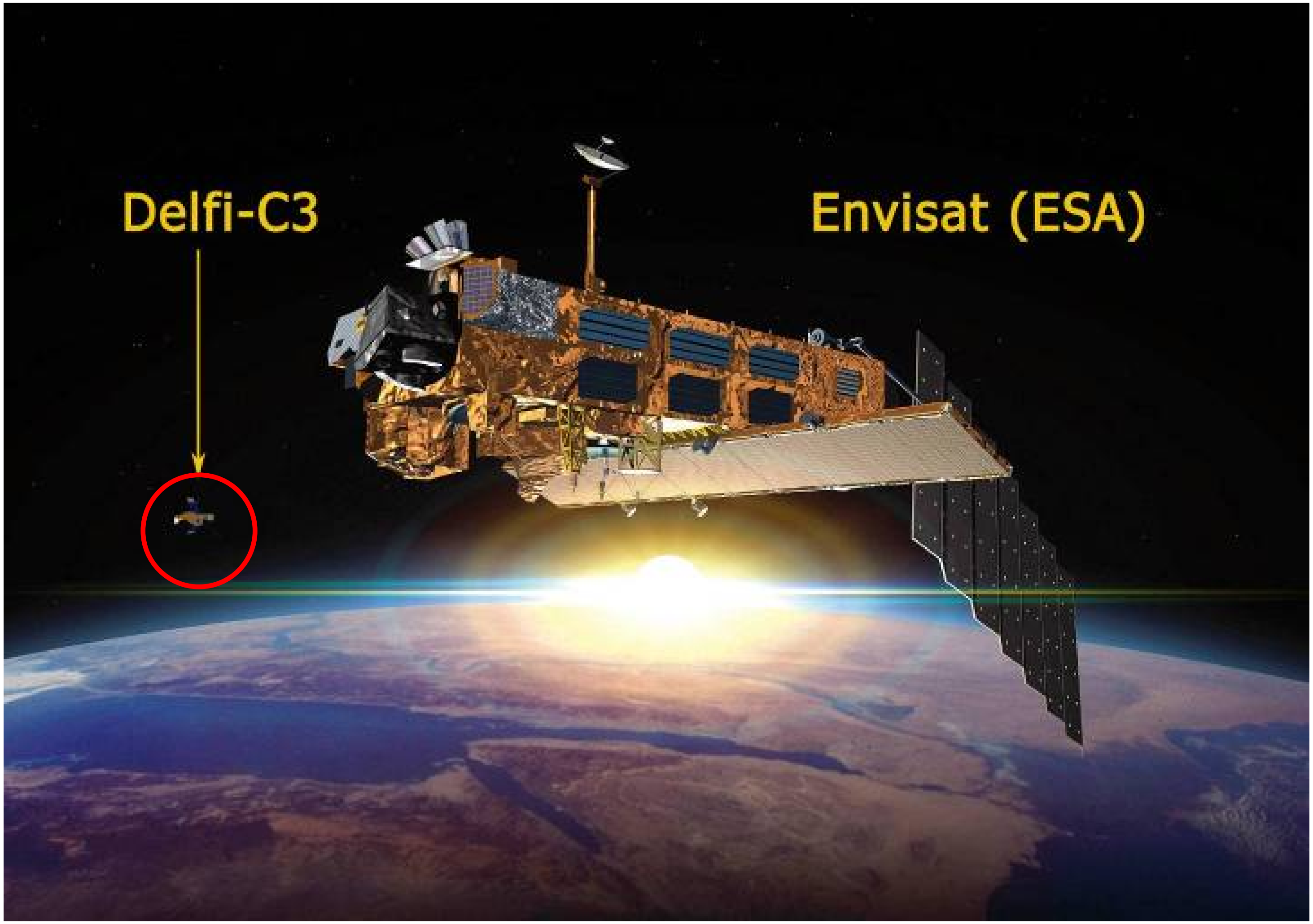
- 3 unit CubeSat structure, 3kg
- 2 AWSS payload units
- 4 deployable panels at 35 degrees (max/min power):
  - –Carbon Fiber Reinforced Plastic
  - –TFSC payload suspension frame
  - –5 TEC1 GaAs TJ solar cells
- 2.5 W min. power available
- 8 antennas:
  - –4 VHF 50 cm downlink
  - –4 UHF 18 cm uplink
- ***No battery***
- ***No active attitude control***

The Delfi-C3 satellite

- EPS
  - 1 DC DC converter per solar panel
  - Current measurement
- CDHS
  - TI MSP430 OBC
  - Microchip PIC18LF4220 microcontrollers per subsystem
- Attitude Control
  - Magnetic hysteresis rods
- COMMS
  - Two Redundant Transceivers
- Standard board interface
  - I^2C bus
  - 12 V DC power bus
- Passive thermal subsystem (thermal tapes)

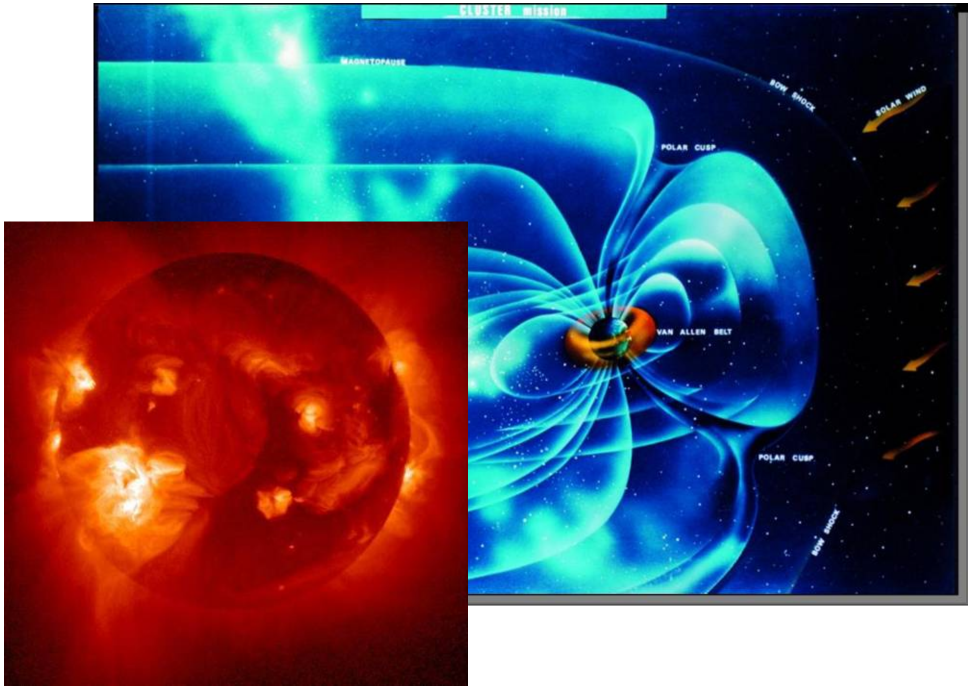


Delfi-C3 is Small…

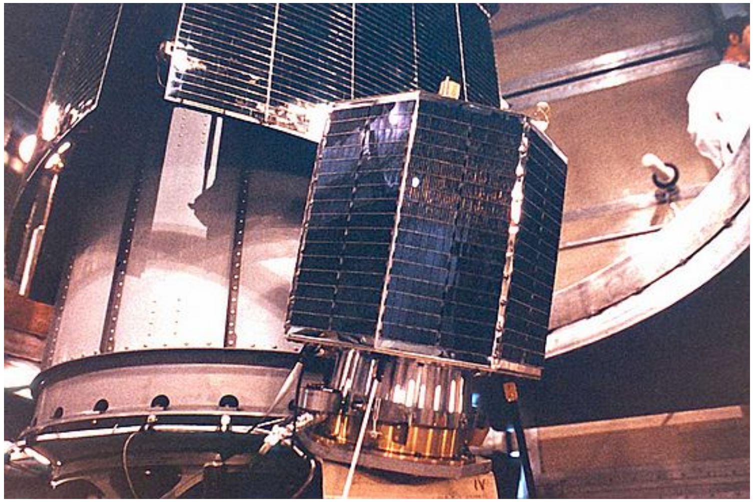


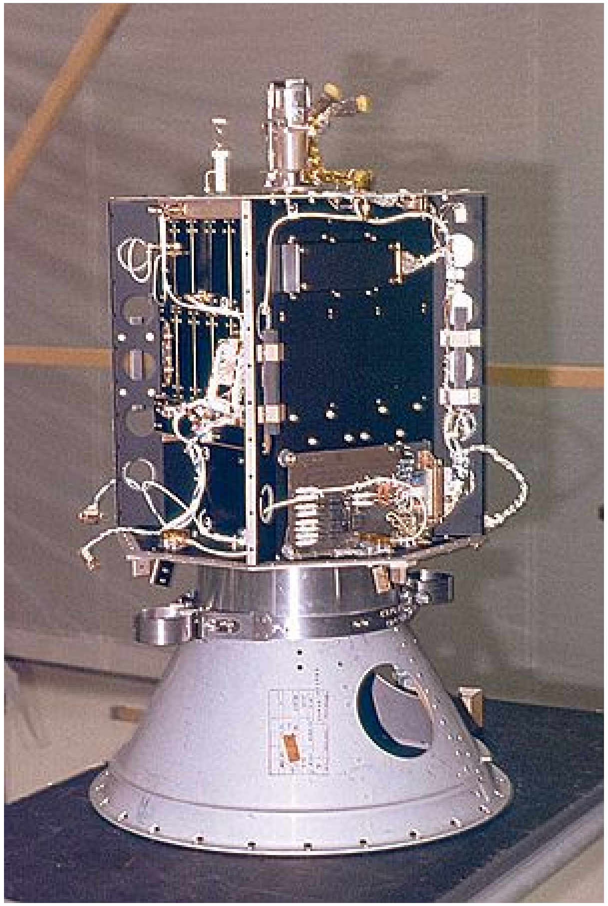
Designing electronics for space

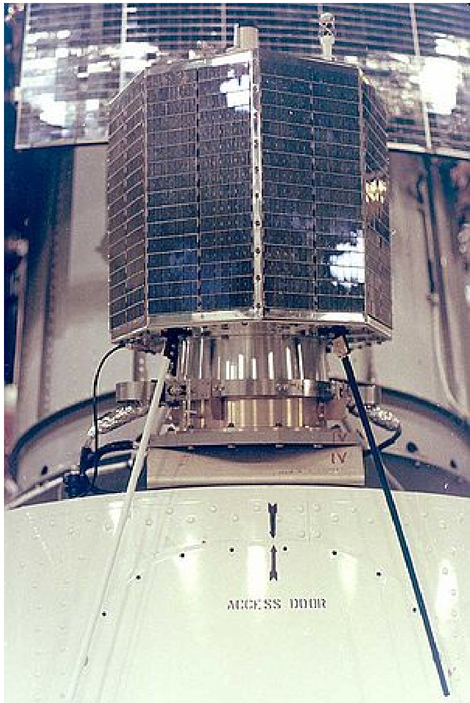
- Radiation
- Temperature
- Vacuum…
- EMC & ESD
- Radiation effects
- Low power / low voltage electronics
- Structural loads
- Thorough testing
- Redundancy
- Commercial Off The Shelf parts



AMSAT OSCAR-7 story...







Communications subsystem

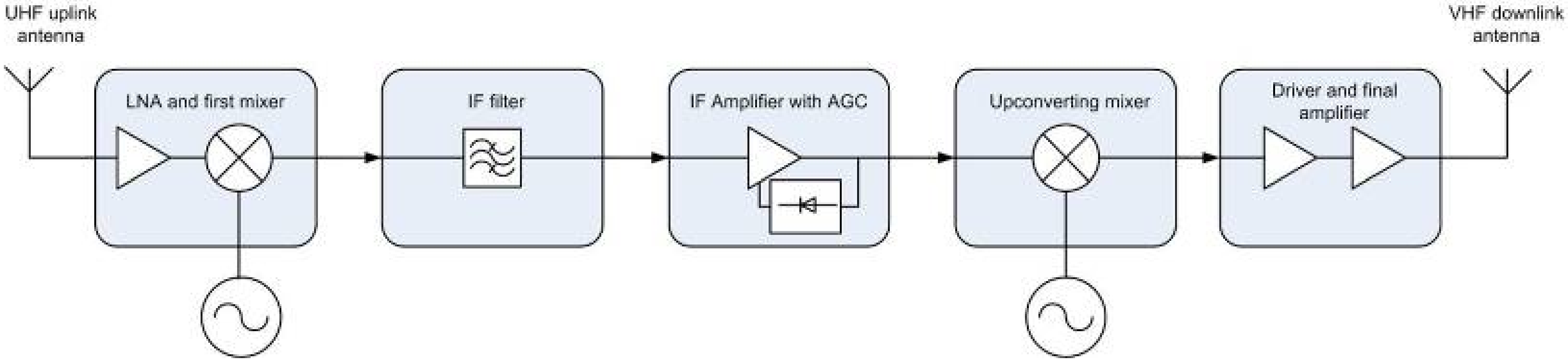
- 2 redundant transceivers
- UHF Receiver
  - 70MHz first IF, 10.7MHz second IF, 455kHz 3rd IF (telecommand RX, based on MC3362DW)
  - Selectivity is more important than noise figure (+/-6dB NF)
  - SAW frontend filters
  - 3rd harmonic problem
  - Required in-band dynamic range is low
- Transponder IF based on AD8367 log amp + detector
- VHF transmitter
  - PIC AX.25 formatting, NRZ-I encoding, bit shaping (D/A)
  - 10.7MHz BPSK modulator (SA612), power combiner to combine with transponder IF
  - Conversion & amplification stage to 145MHz (Opamps)
  - MRF313 class A / AB final amplifier (400mW PEP) with ALC (QRP!!)

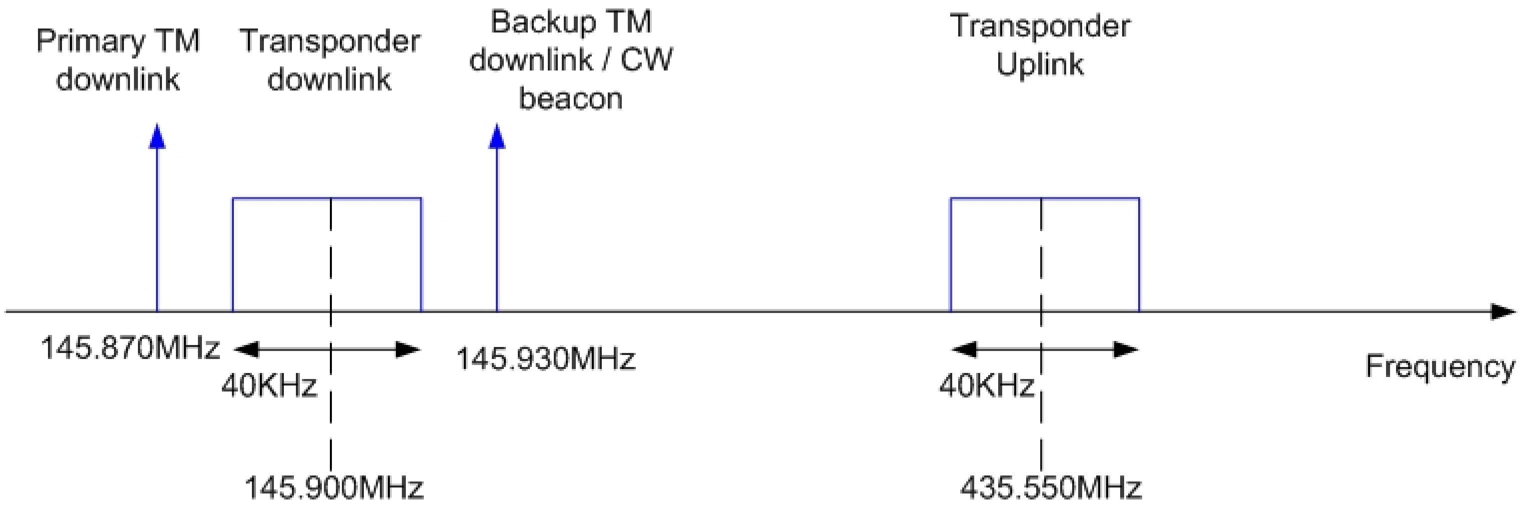
Frequencies

- Primary telemetry downlink: 145.870MHz
  - RC-BPSK, 1200bd AX.25, UI frames, 1 frame/sec
- Back-up: 145.930MHz
- Transponder downlink: 145.880-145.920MHz linear (inverting) + CW telemetry 40mW at 145.930MHz *(Hi Hi de Delfi-C3 Delfi-C3)*
- Transponder uplink: 435.570-435.530MHz
  - 40kHz passband, 400mW PEP
  - Simple transponder
  - No HELAPS
  - Basic AGC circuit
- Telecommand uplink: unpublished
  - Authentication

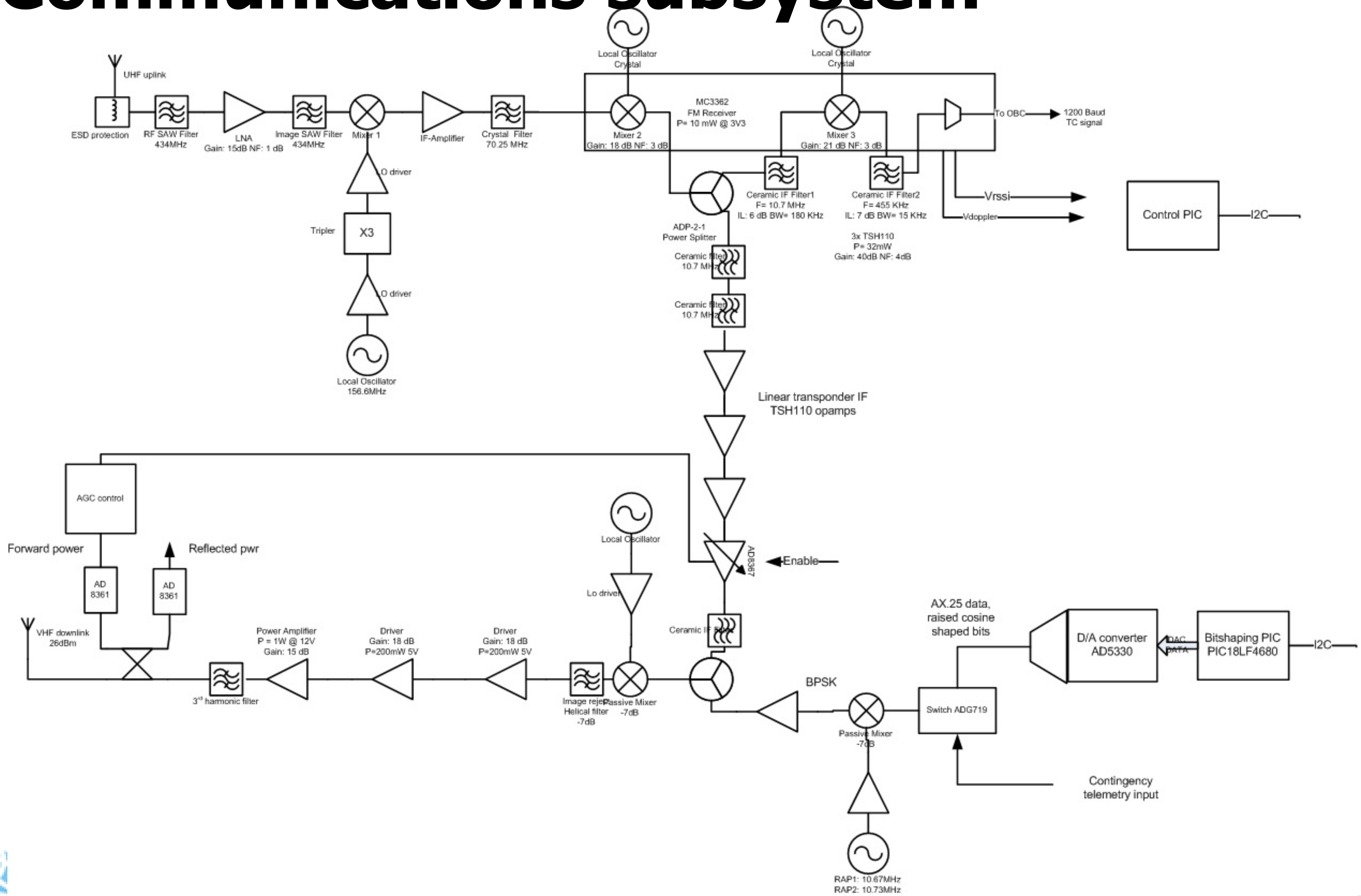
Coordinated by the International Amateur Radio Union (IARU)

Linear transponder

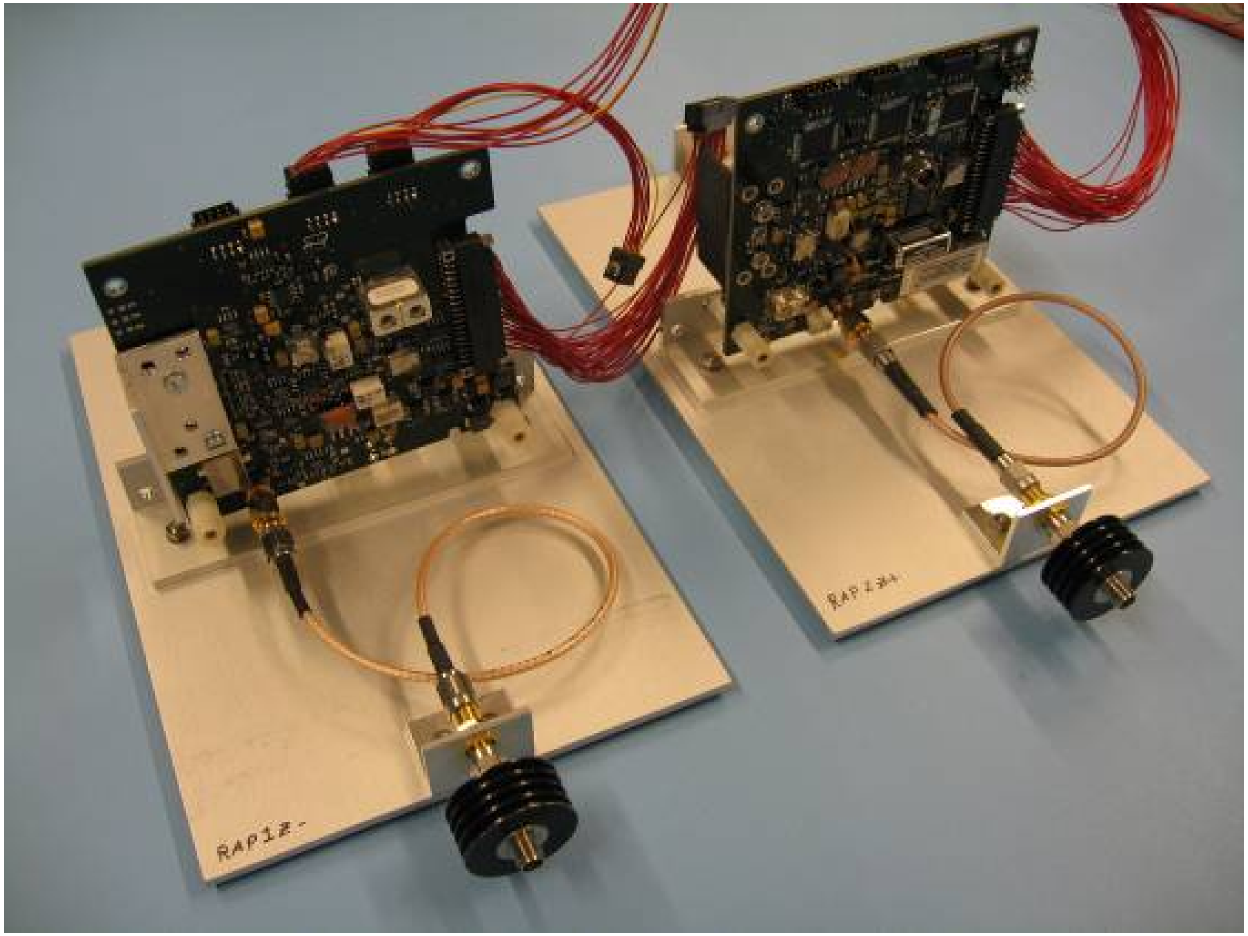




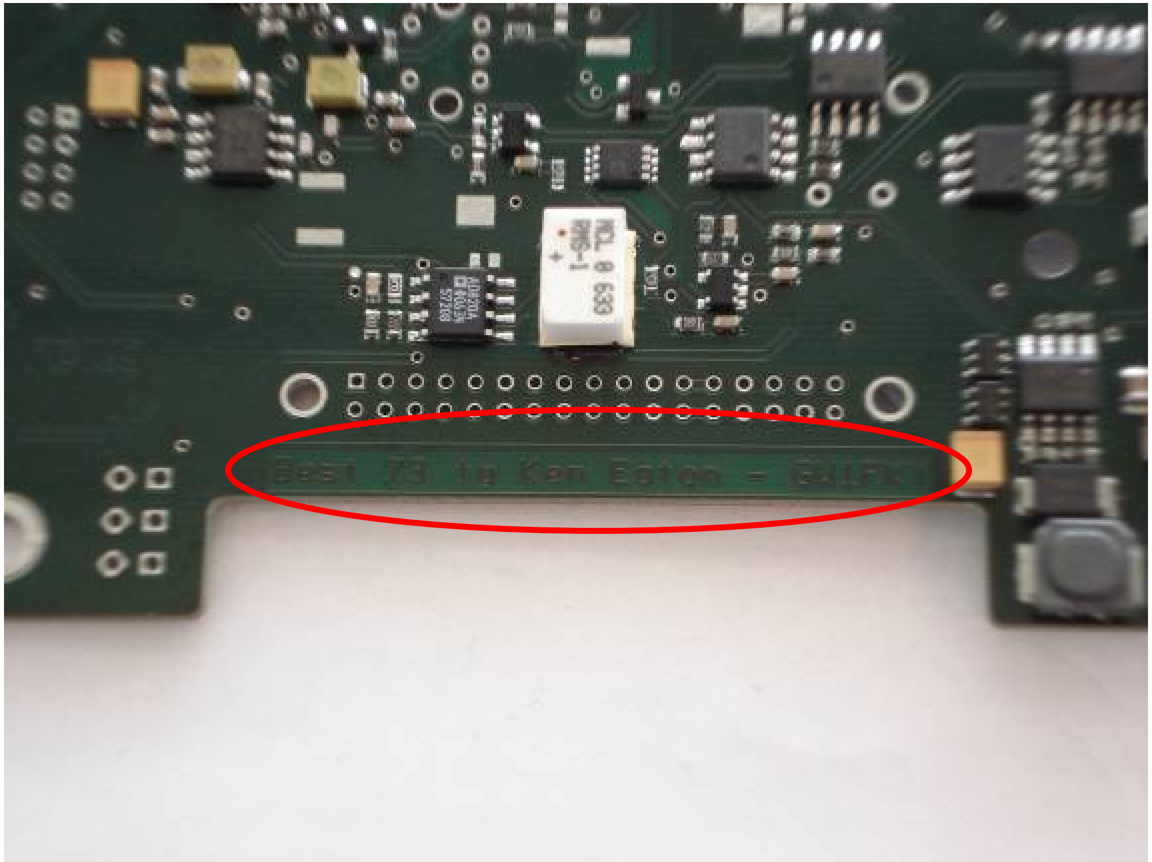
Communications subsystem



Communications subsystem



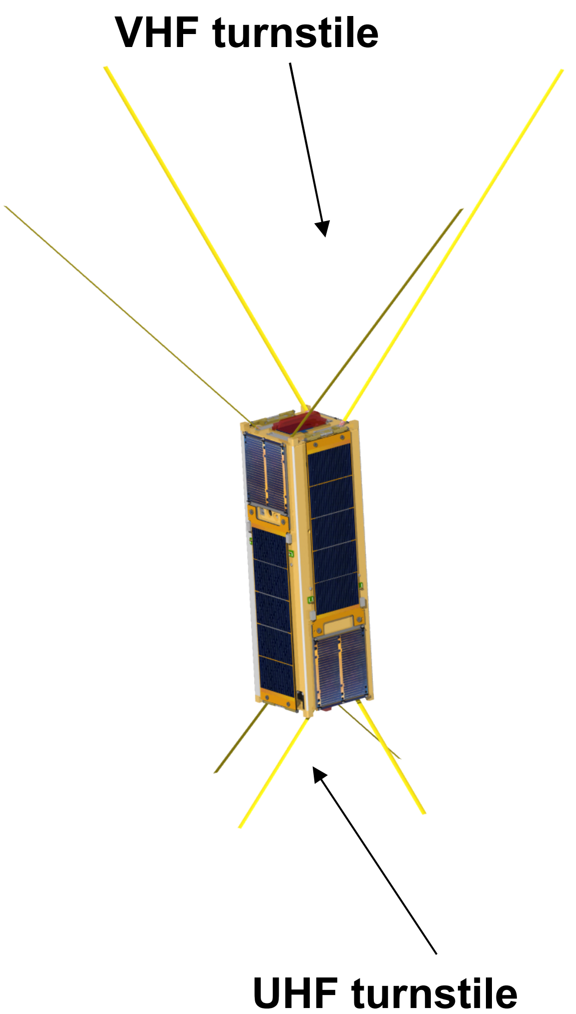
GW1FKY flies aboard



Antenna subsystem

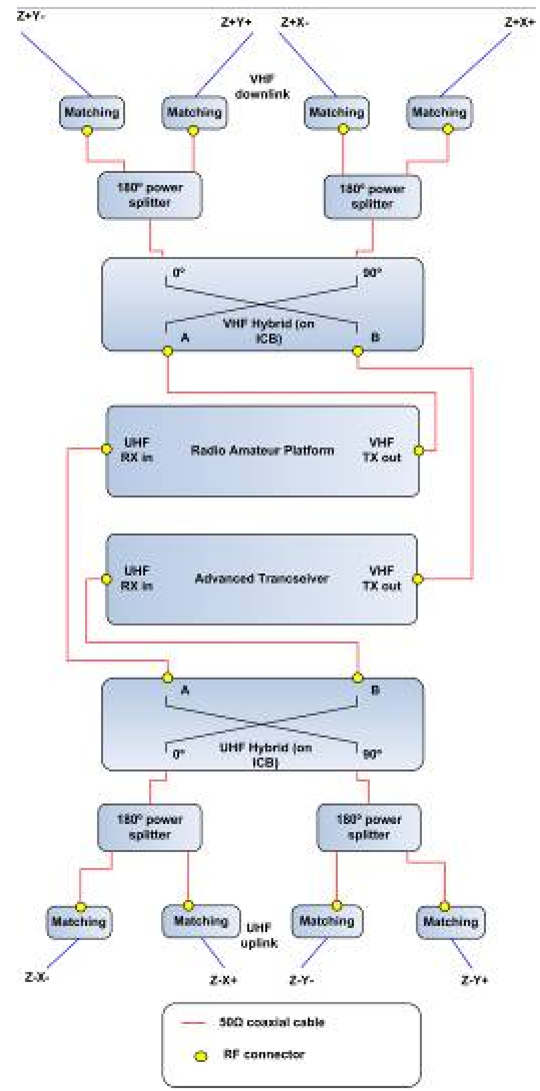
Uplink & downlink: turnstile antenna system

- 4 whips in phase quadrature → pattern and polarization
- VHF: 50cm
- UHF: 18cm
- Phasing harness to achieve phase relationship
- 6mm tape measure antenna whips
- Modular Antenna Boxes

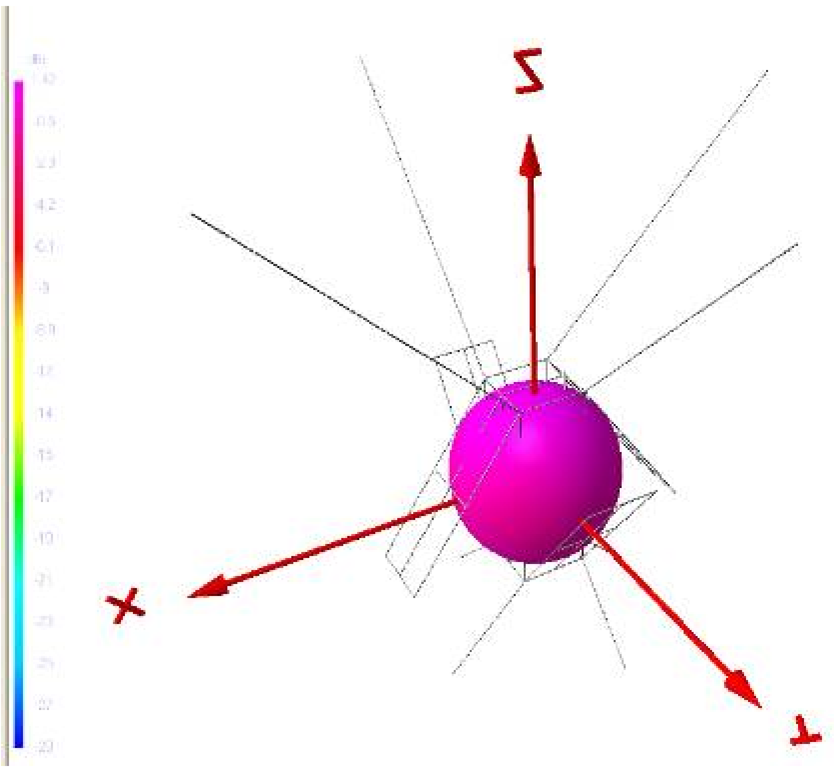


Phasing circuit

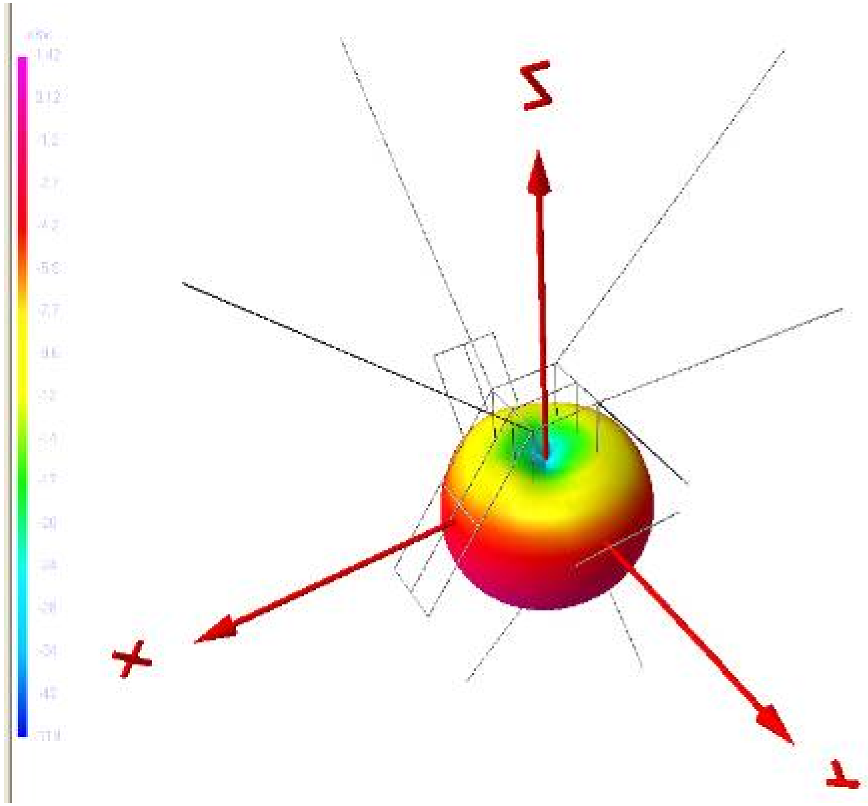
- Quadrature hybrids to split and combine RF from two transceivers
- 180º power splitters to achieve final phase relationship
- Provide ESD discharge path
- Provide isolation
- Low pass filtering
- Provide progressive phase shift per antenna



NEC simulation results



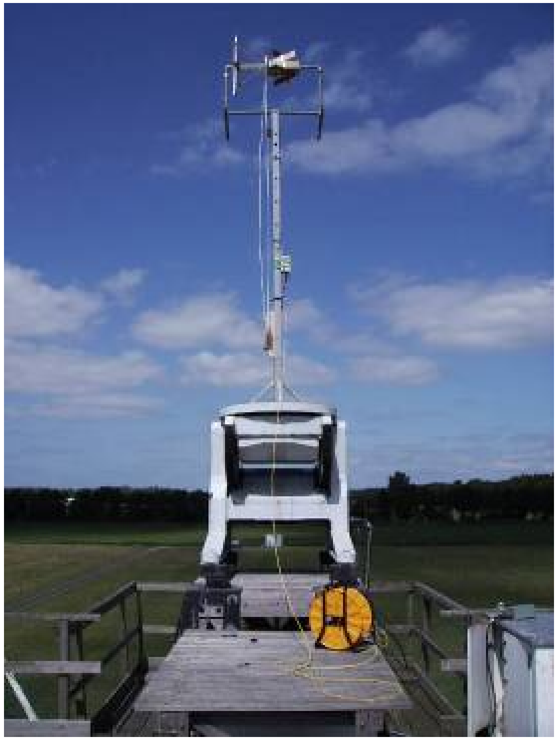
Total gain



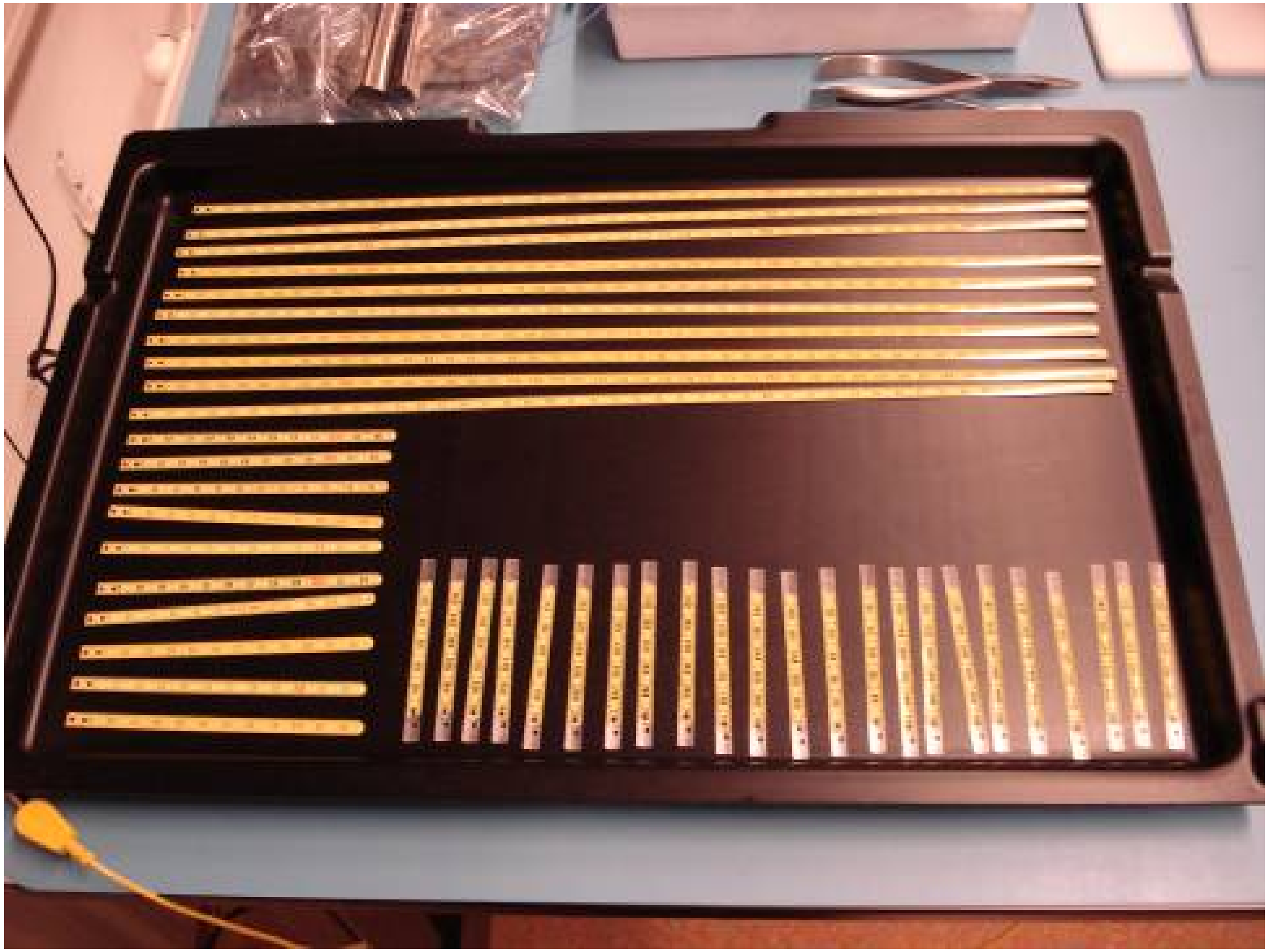
RHCP gain

Antenna testing

- NLR Far Field range
- Verification of VHF / UHF radiation pattern
- Radiation pattern in case of deployment failure



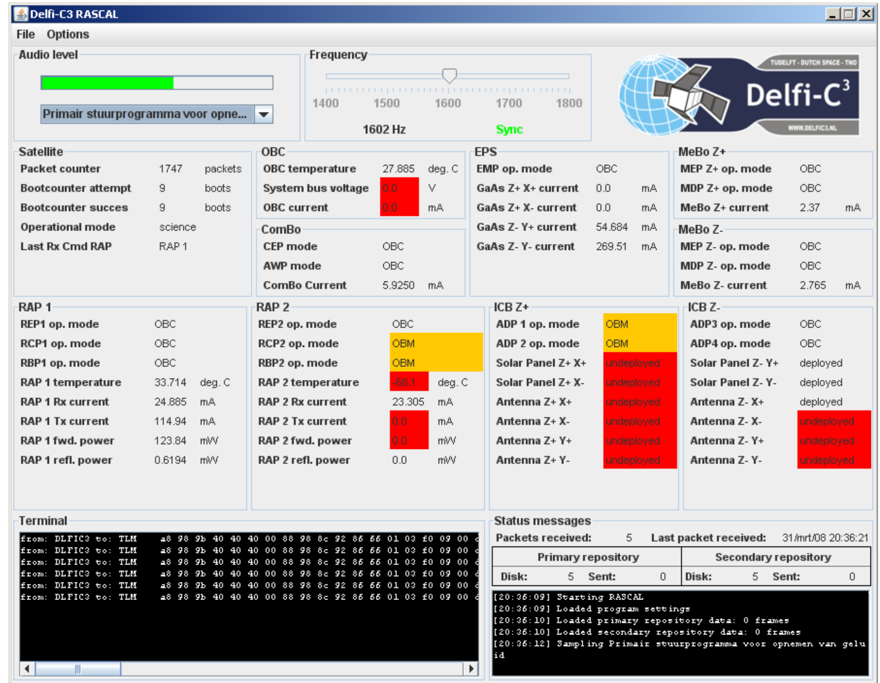
Flight VHF / UHF antennas



Modular Antenna Boxes

Ground Segment & Data Collection

- Command stations in Delft and Eindhoven (PI4TUE)
- Distributed ground station network
  - Radio amateurs worldwide
  - Universities worldwide
  - Modest setup equipment
  - Software will be made available
- Soundcard software
- RASCAL
  - Displays data realtime
  - Packet storage
  - Website with statistics
  - (amateur competition)
  - Payload data processing
  - Attitude reconstruction
- Satellite status reconstruction / verification
  →Data delivery to customer



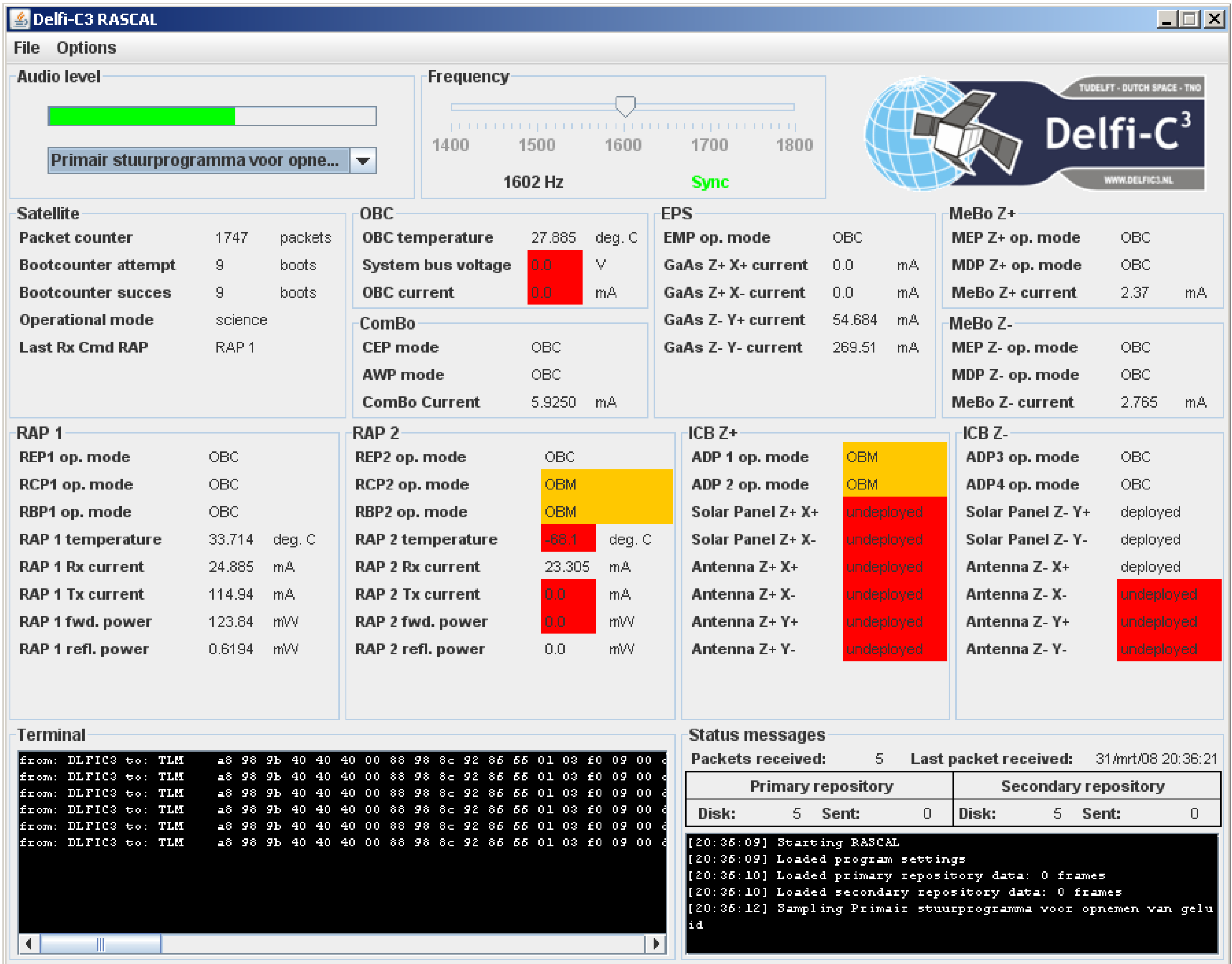
Minimum required equipment

- Azimuth/ Elevation rotor
- VHF linearly polarized yagi antenna (preferably 5 elements or more) or
- VHF circularly polarized yagi antenna (preferably 5 elements or more, and with polarization switching)

or

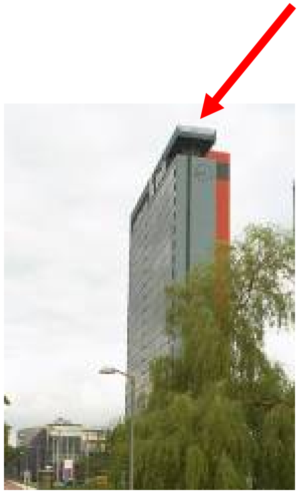
- Omnidirectional antenna (e.g. turnstile, eggbeater) → approx 10dB worse performance, so worst case link margin is 0dB for same BER of 10-5
- VHF SSB Transceiver or Receiver
- PSK modem and TNC (only required when no soundcard is available)
- Personal Computer running MixW & RASCAL and internet connection

RASCAL


Delfi-C3 RASCAL
File Options
Audio level
Primair stuurprogramma voor opne...
Frequency
1400 1500 1600 1700 1800
1602 Hz
Sync
TUDELFT - DUTCH SPACE - TNO
Delfi-C3
WWW.DELFIC3.NL
Satellite
Packet counter 1747 packets
Bootcounter attempt 9 boots
Bootcounter succes 9 boots
Operational mode science
Last Rx Cmd RAP RAP 1
OBC
OBC temperature 27.885 deg. C
System bus voltage 0.0 V
OBC current 0.0 mA
ComBo
CEP mode OBC
AWP mode OBC
ComBo Current 5.9250 mA
EPS
EMP op. mode OBC
GaAs Z+ X+ current 0.0 mA
GaAs Z+ X- current 0.0 mA
GaAs Z- Y+ current 54.684 mA
GaAs Z- Y- current 269.51 mA
MeBo Z+
MEP Z+ op. mode OBC
MDP Z+ op. mode OBC
MeBo Z+ current 2.37 mA
MeBo Z-
MEP Z- op. mode OBC
MDP Z- op. mode OBC
MeBo Z- current 2.765 mA
RAP 1
REP1 op. mode OBC
RCP1 op. mode OBC
RBP1 op. mode OBC
RAP 1 temperature 33.714 deg. C
RAP 1 Rx current 24.885 mA
RAP 1 Tx current 114.94 mA
RAP 1 fwd. power 123.84 mW
RAP 1 refl. power 0.6194 mW
RAP 2
REP2 op. mode OBC
RCP2 op. mode OBM
RBP2 op. mode OBM
RAP 2 temperature -68.1 deg. C
RAP 2 Rx current 23.305 mA
RAP 2 Tx current 0.0 mA
RAP 2 fwd. power 0.0 mW
RAP 2 refl. power 0.0 mW
ICB Z+
ADP 1 op. mode OBM
ADP 2 op. mode OBM
Solar Panel Z+ X+ undeployed
Solar Panel Z+ X- undeployed
Antenna Z+ X+ undeployed
Antenna Z+ X- undeployed
Antenna Z+ Y+ undeployed
Antenna Z+ Y- undeployed
ICB Z-
ADP3 op. mode OBC
ADP4 op. mode OBC
Solar Panel Z- Y+ deployed
Solar Panel Z- Y- deployed
Antenna Z- X+ deployed
Antenna Z- X- undeployed
Antenna Z- Y+ undeployed
Antenna Z- Y- undeployed
Terminal
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
from: DLFIC3 to: TLM a8 98 9b 40 40 40 00 88 98 8c 92 86 66 01 03 f0 09 00
Status messages
Packets received: 5 Last packet received: 31/mrt/08 20:36:21
Primary repository
Secondary repository
Disk: 5 Sent: 0
Disk: 5 Sent: 0
[20:36:09] Starting RASCAL
[20:36:09] Loaded program settings
[20:36:10] Loaded primary repository data: 0 frames
[20:36:10] Loaded secondary repository data: 0 frames
[20:36:12] Sampling Primair stuurprogramma voor opnemen van geluid

Ground Station

- Fully automated
- Tracking yagi antennas
- VHF / UHF / S-Band
- Backup power
- Tracking and decoding telemetry from LEO satellites
- Remotely controllable

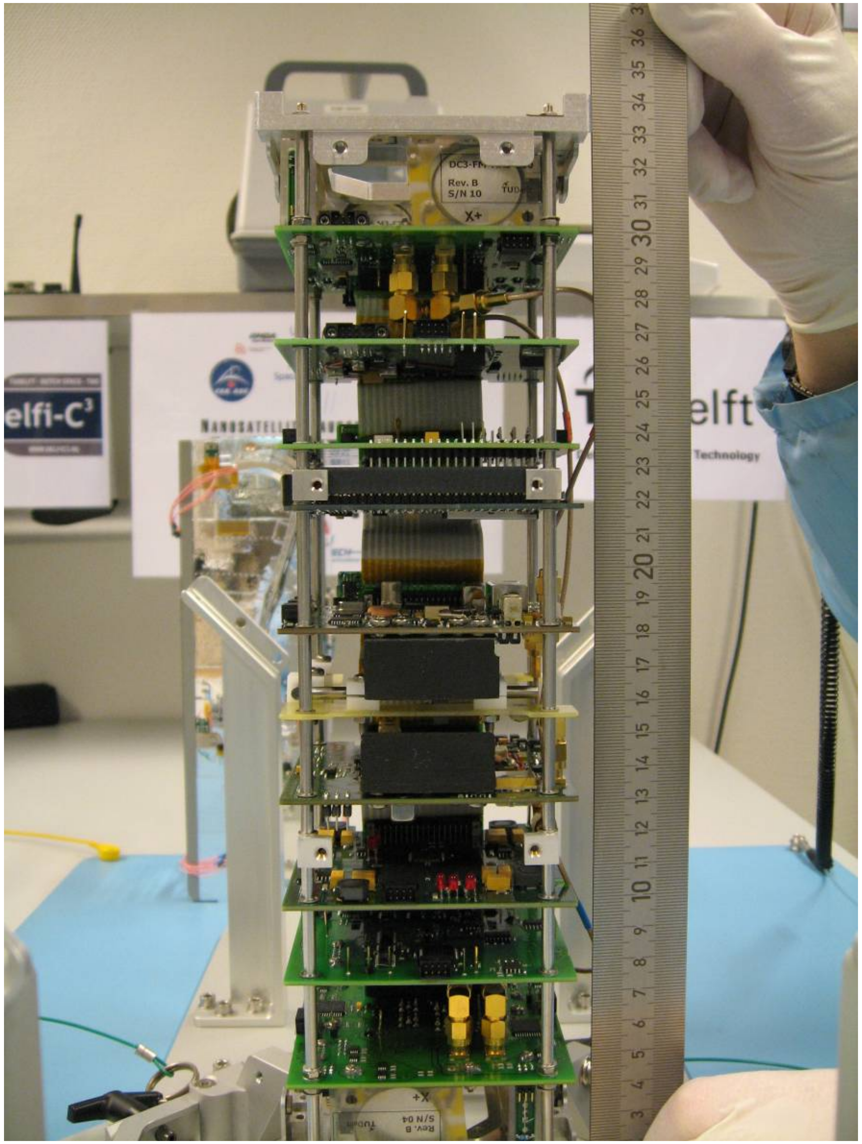


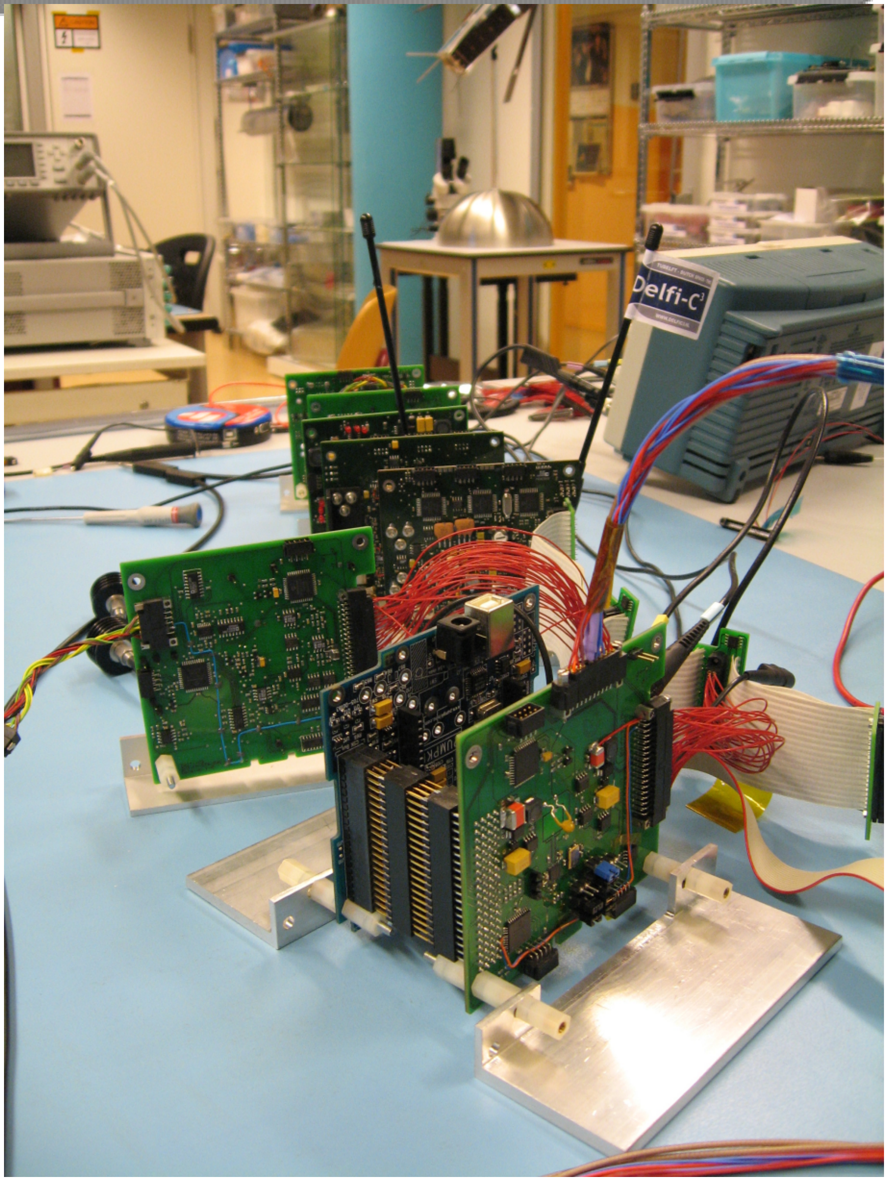
Soundclips

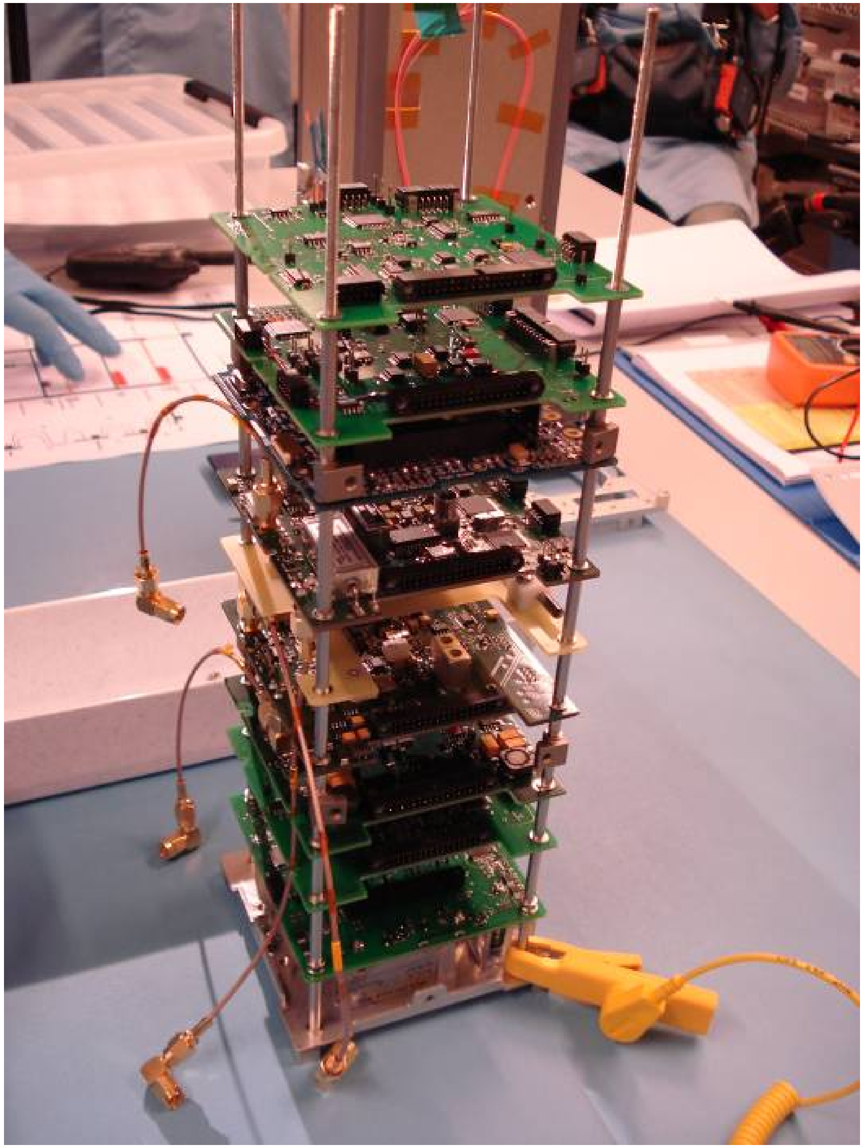
Beacon

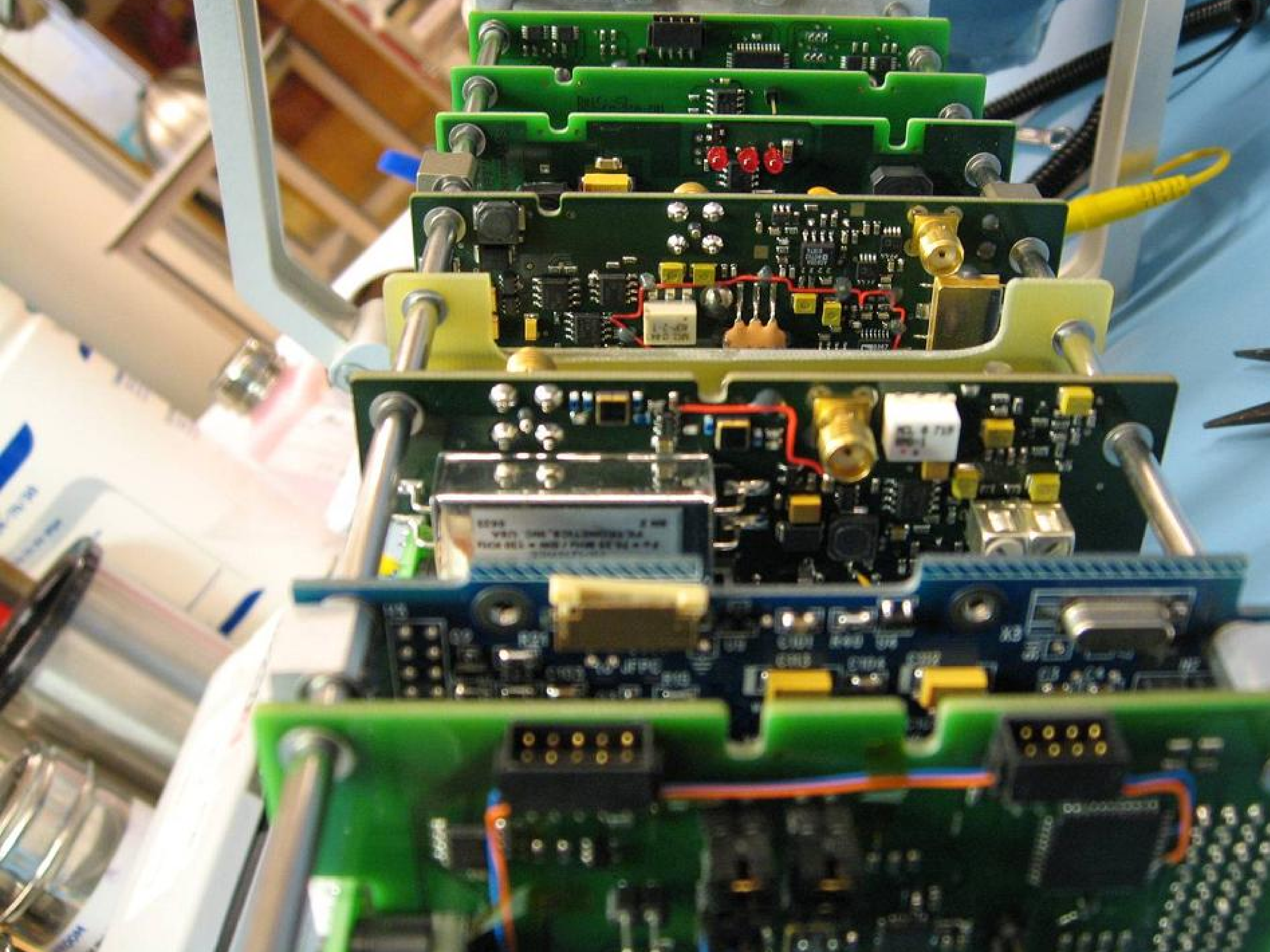
First test link

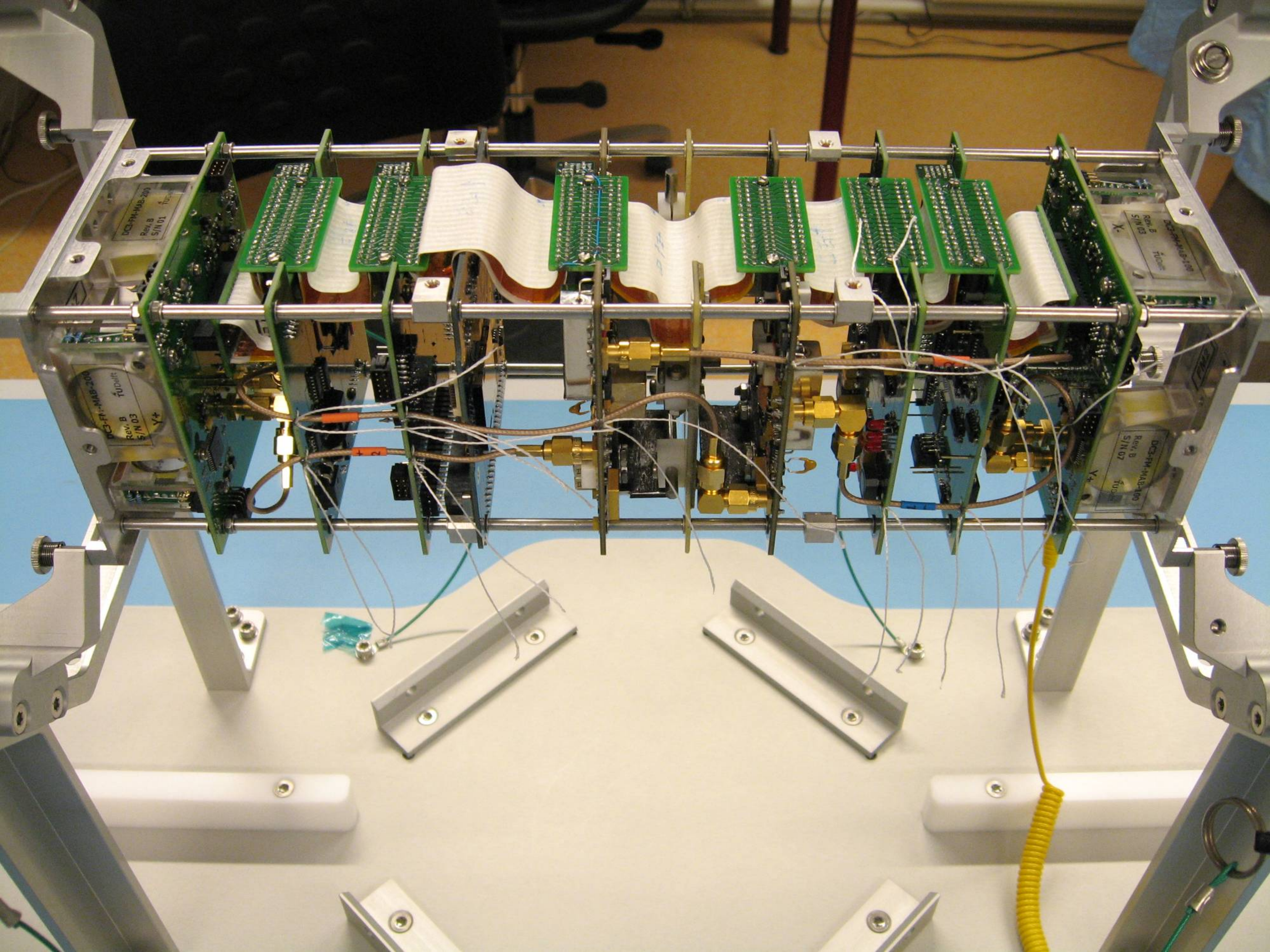
Delfi-C3 flight stack




Delfi-C3

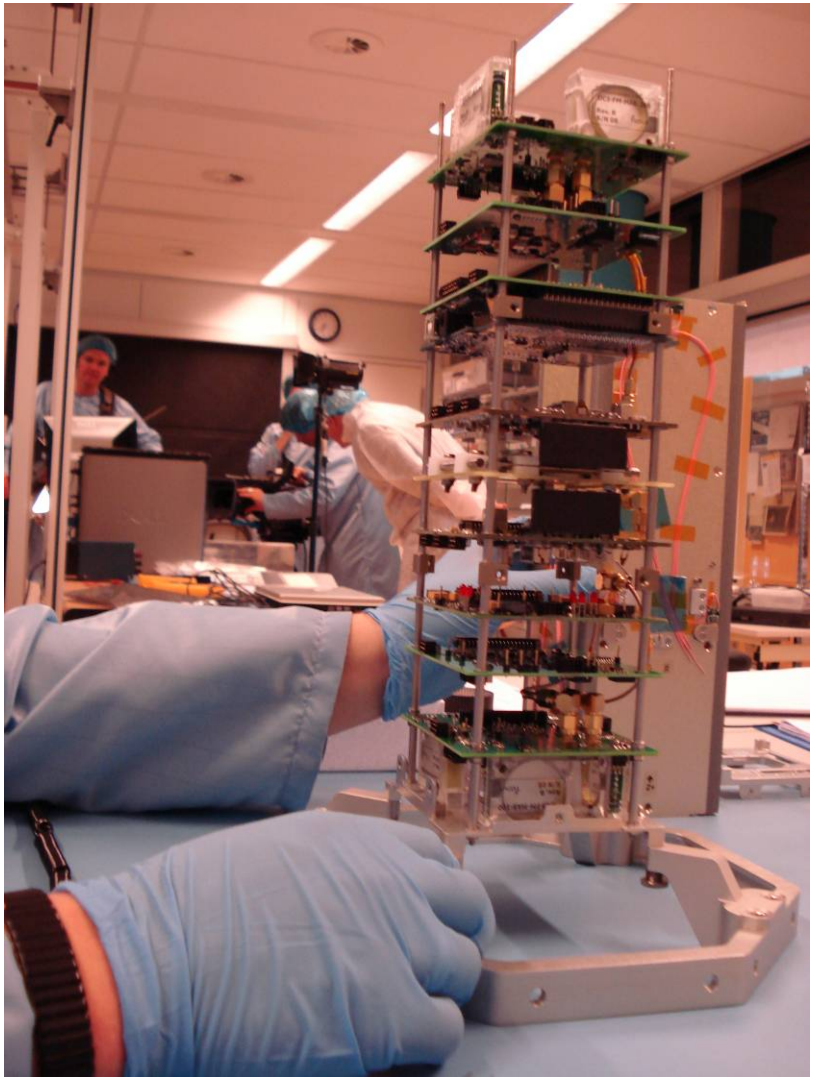





DC3-FM-MAB-200
TUDelft
Rev. B
S/N 03
Y+

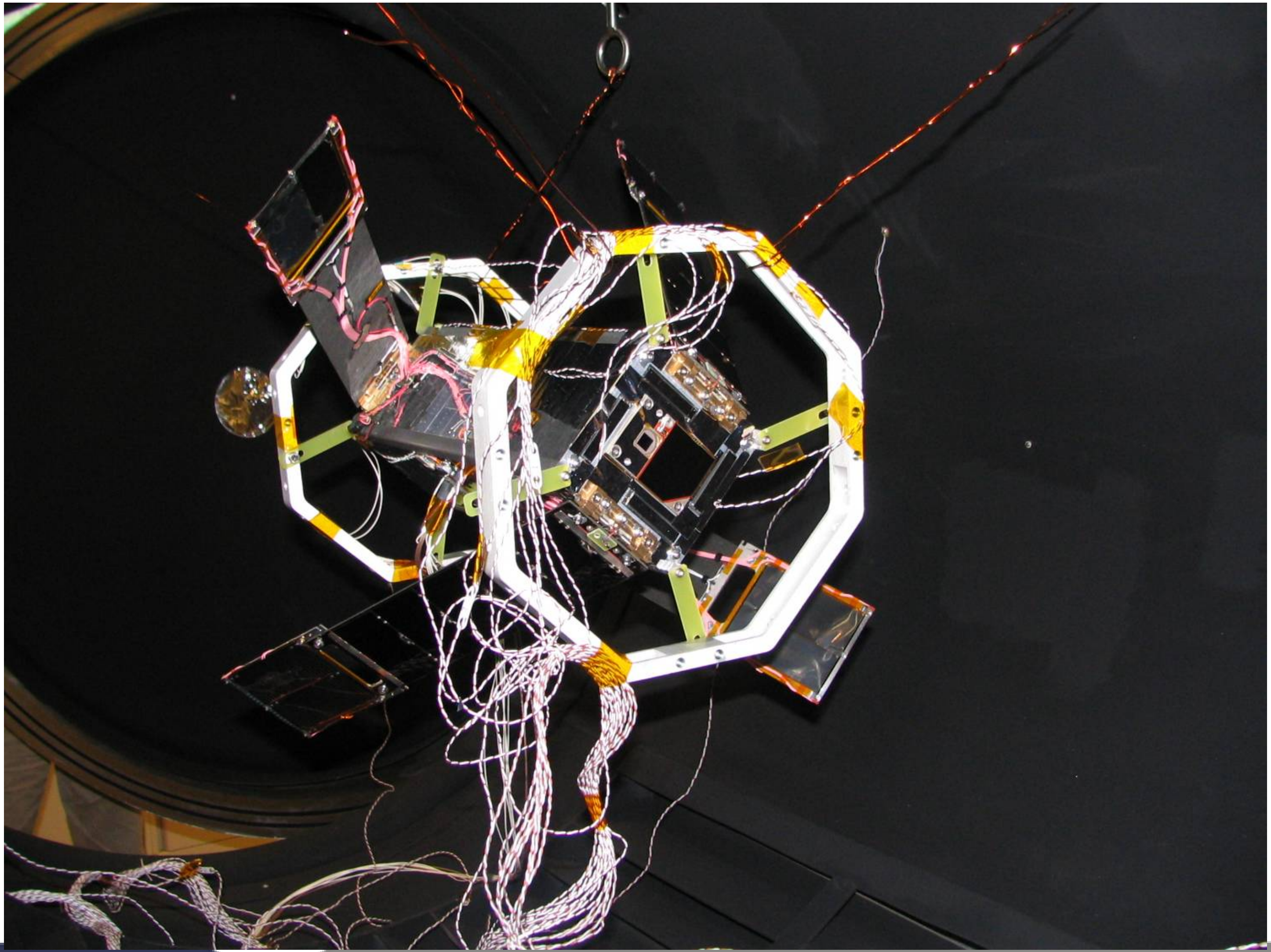
Klokhuis (dutch TV)

Klokhuis

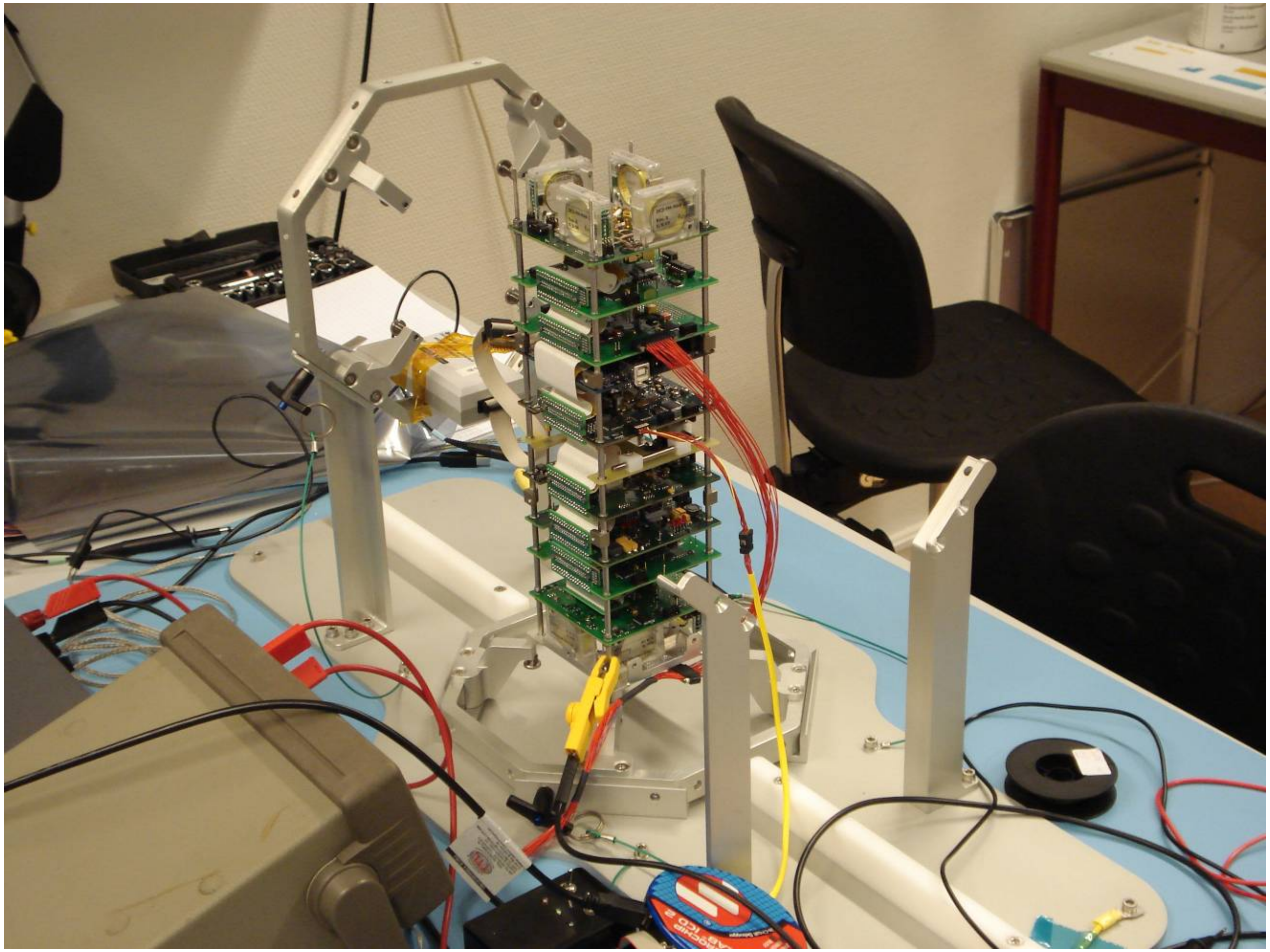


High school receiver kit

TVAC Test

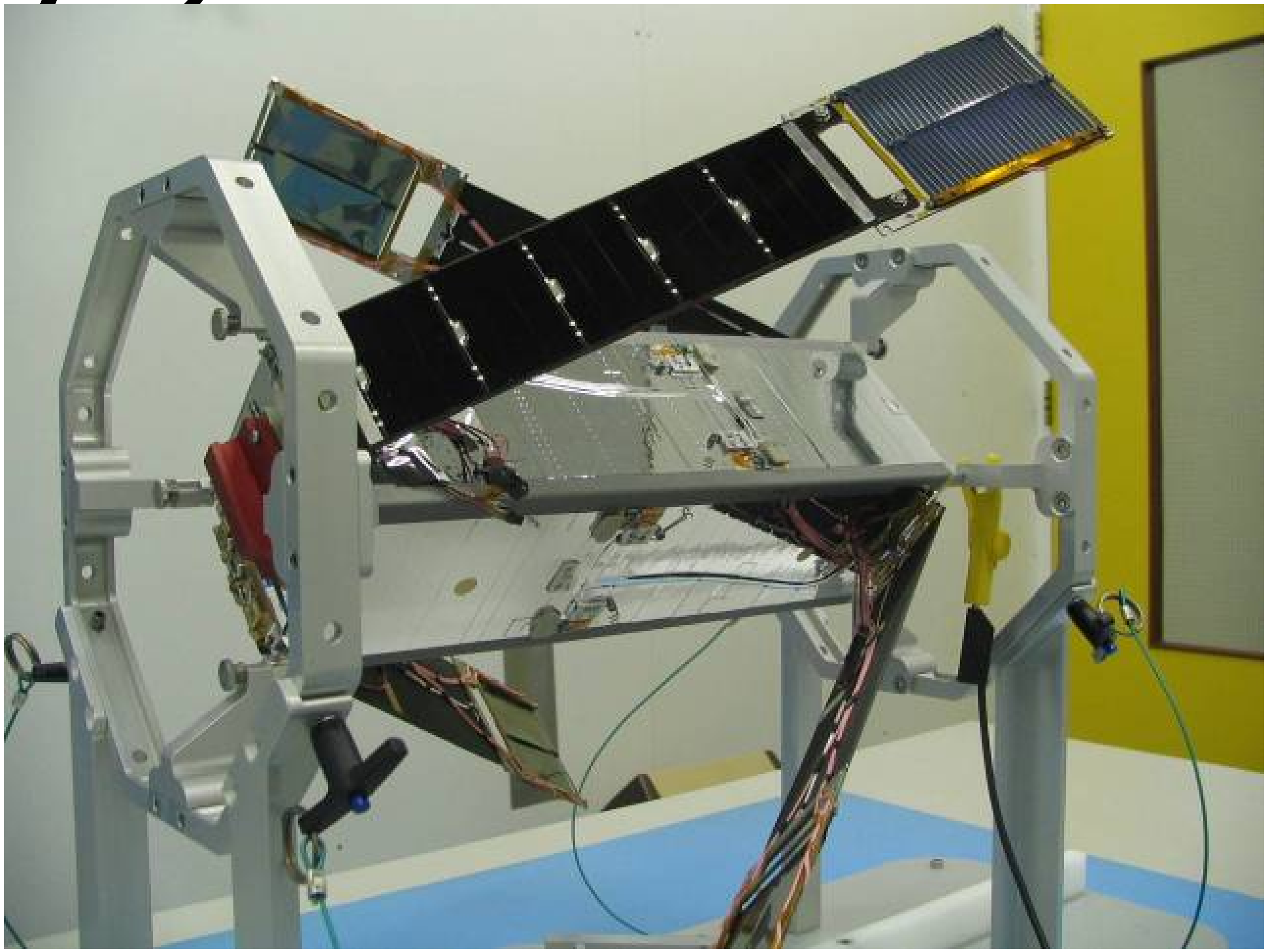


Testing

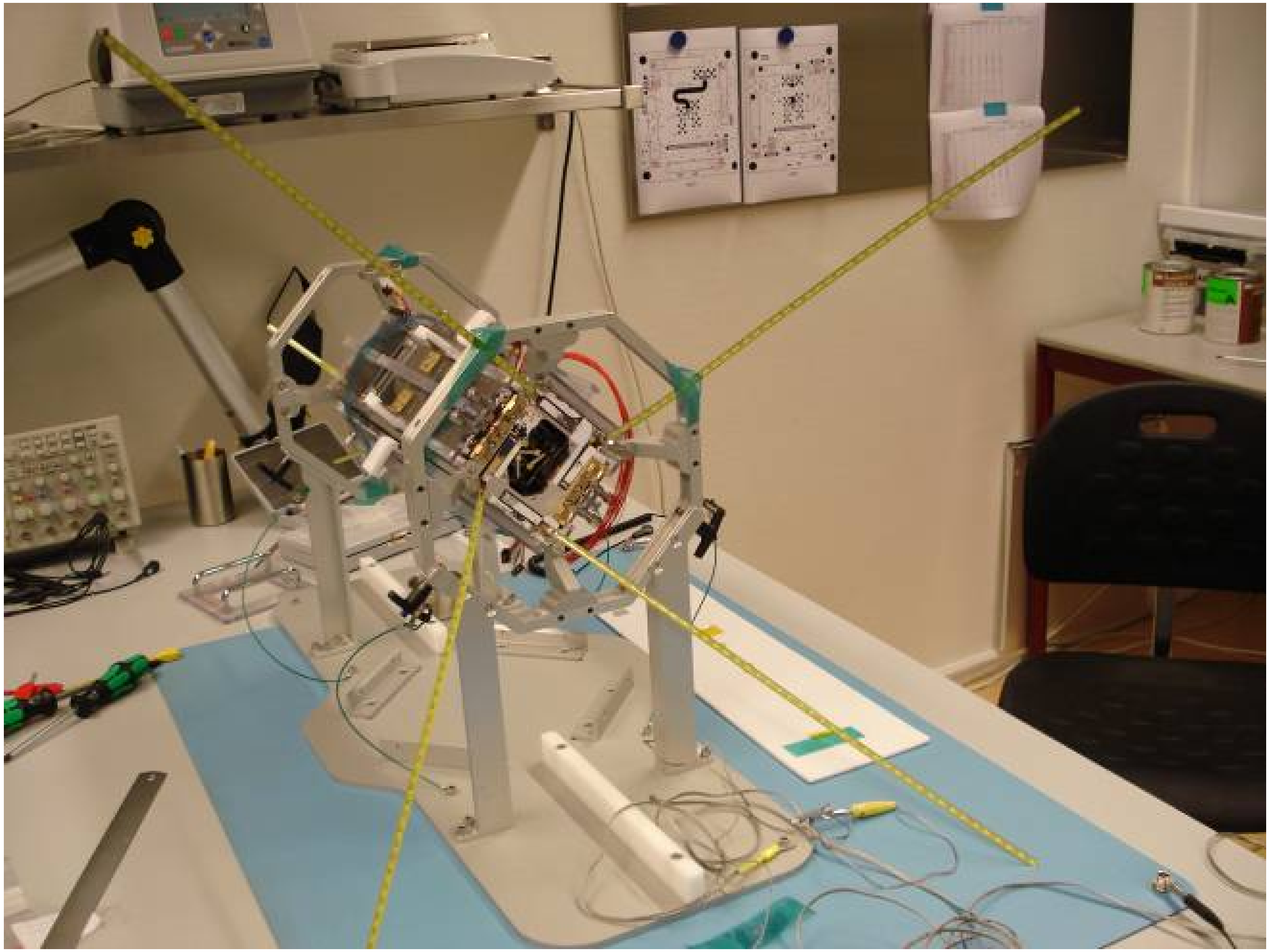


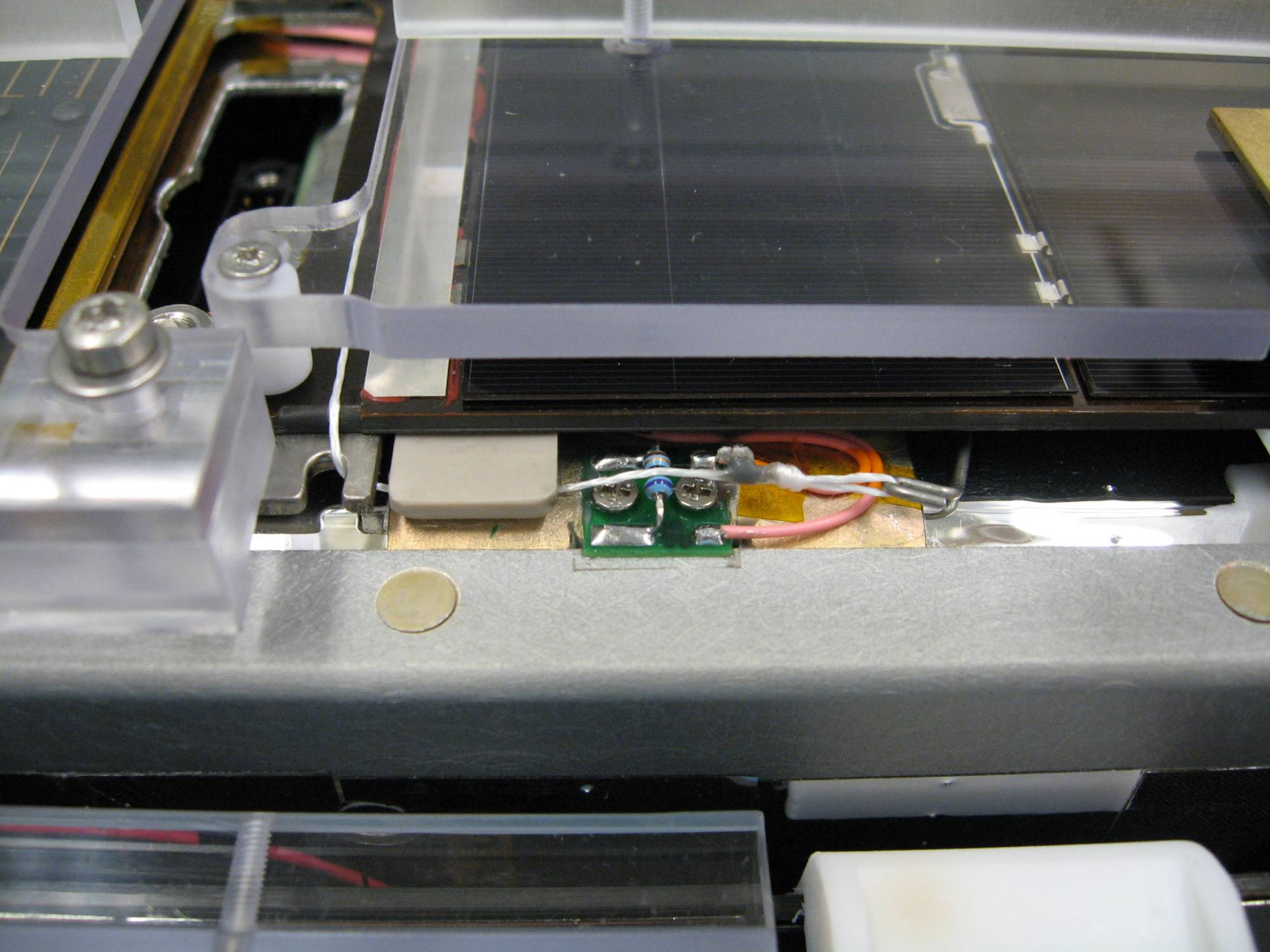
Vibe Test

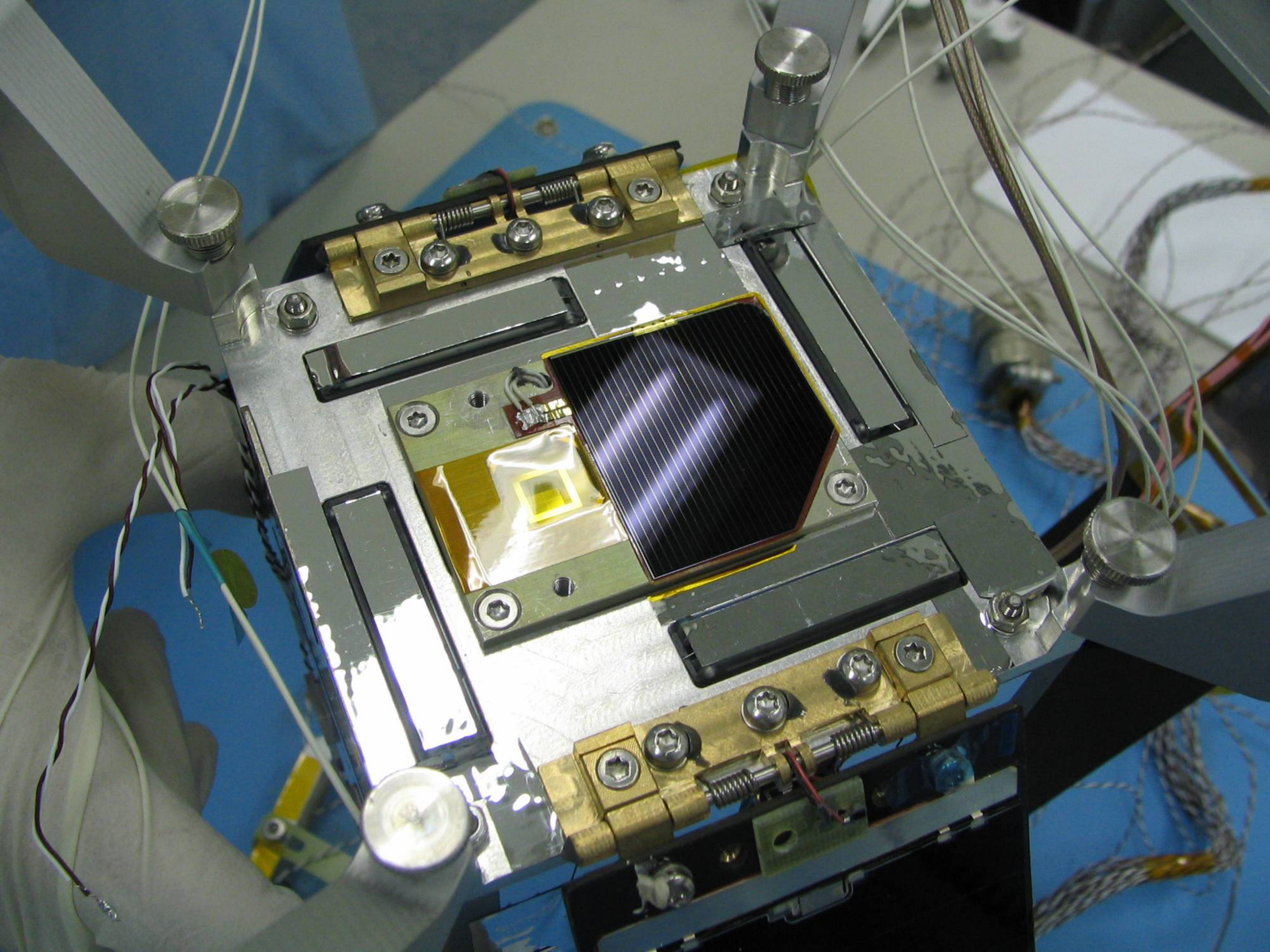
Flight configuration (antennas not deployed)



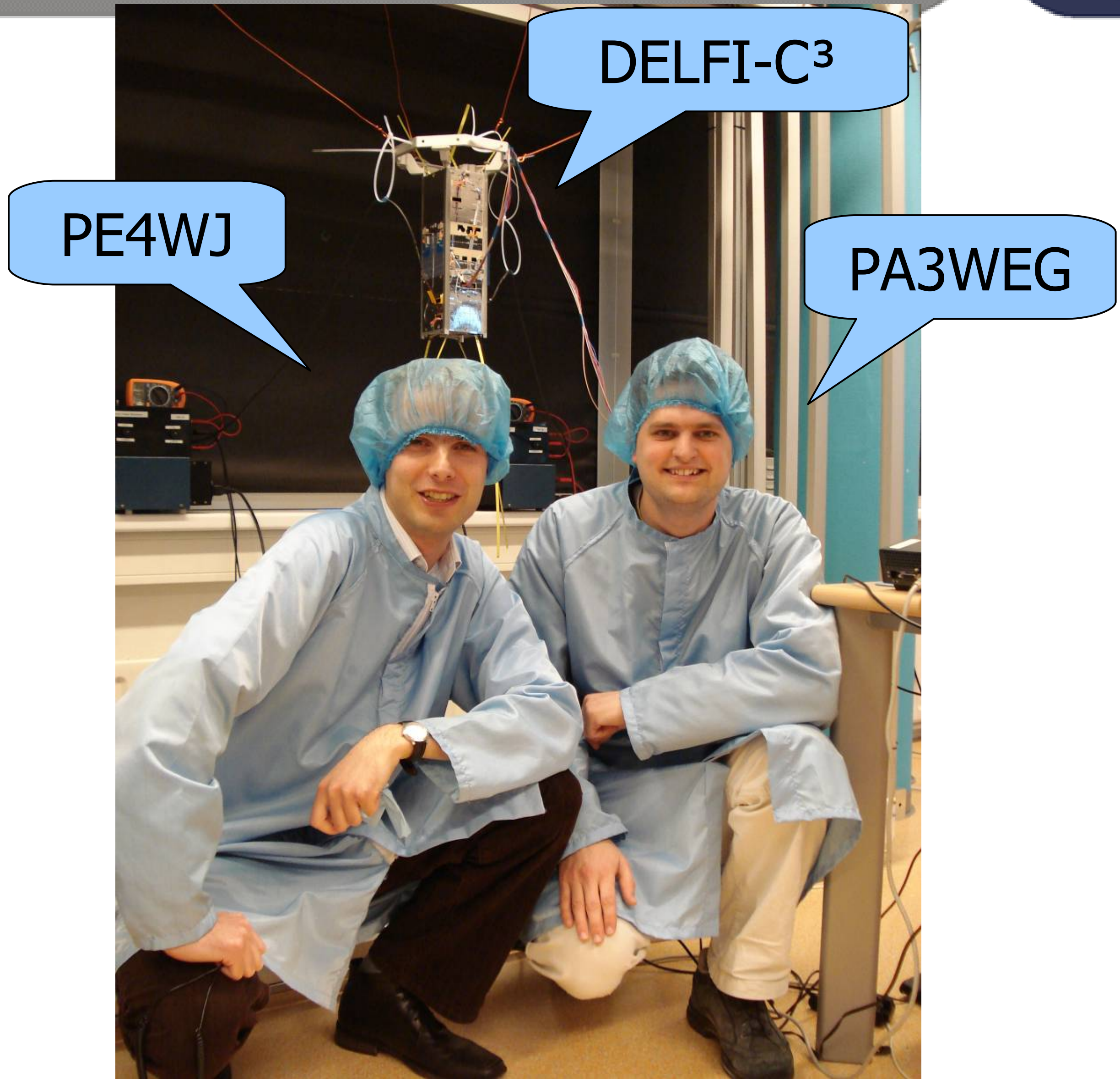
Deployed antennas



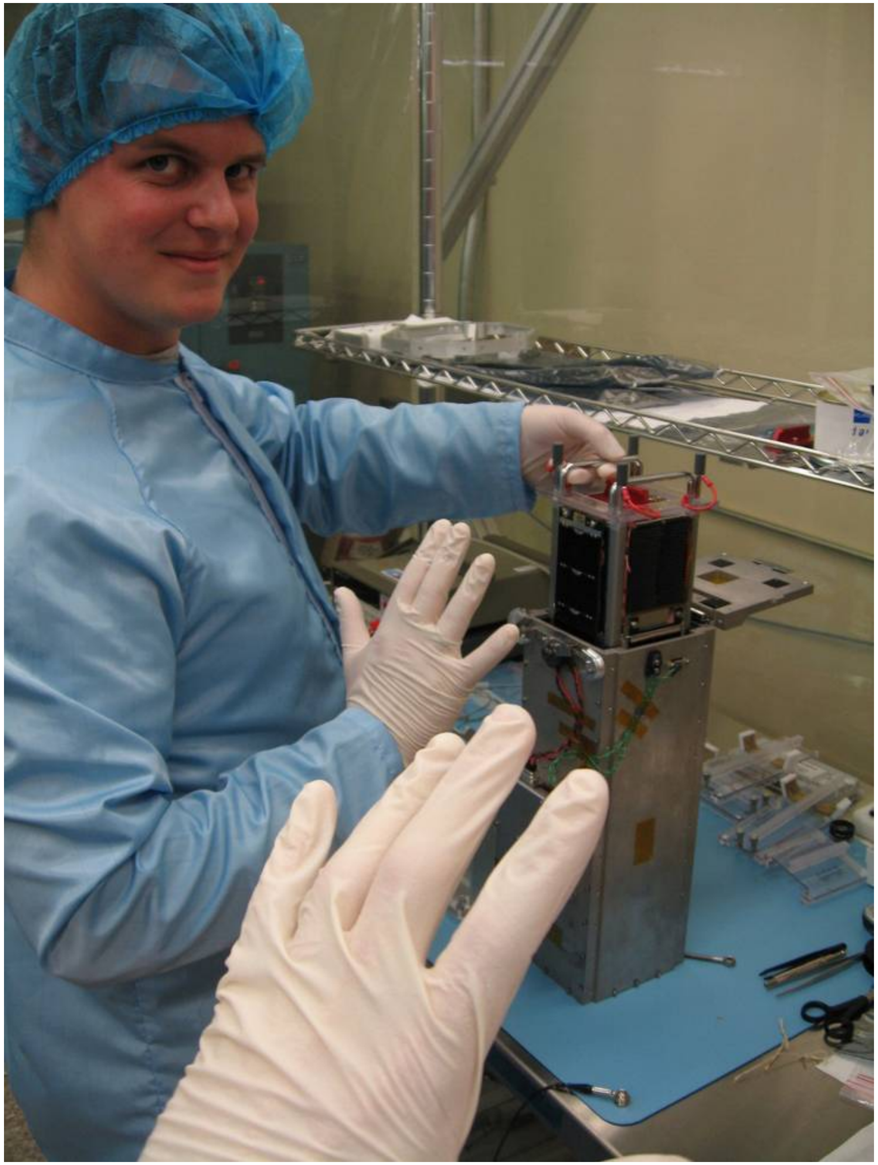





Static safe working?

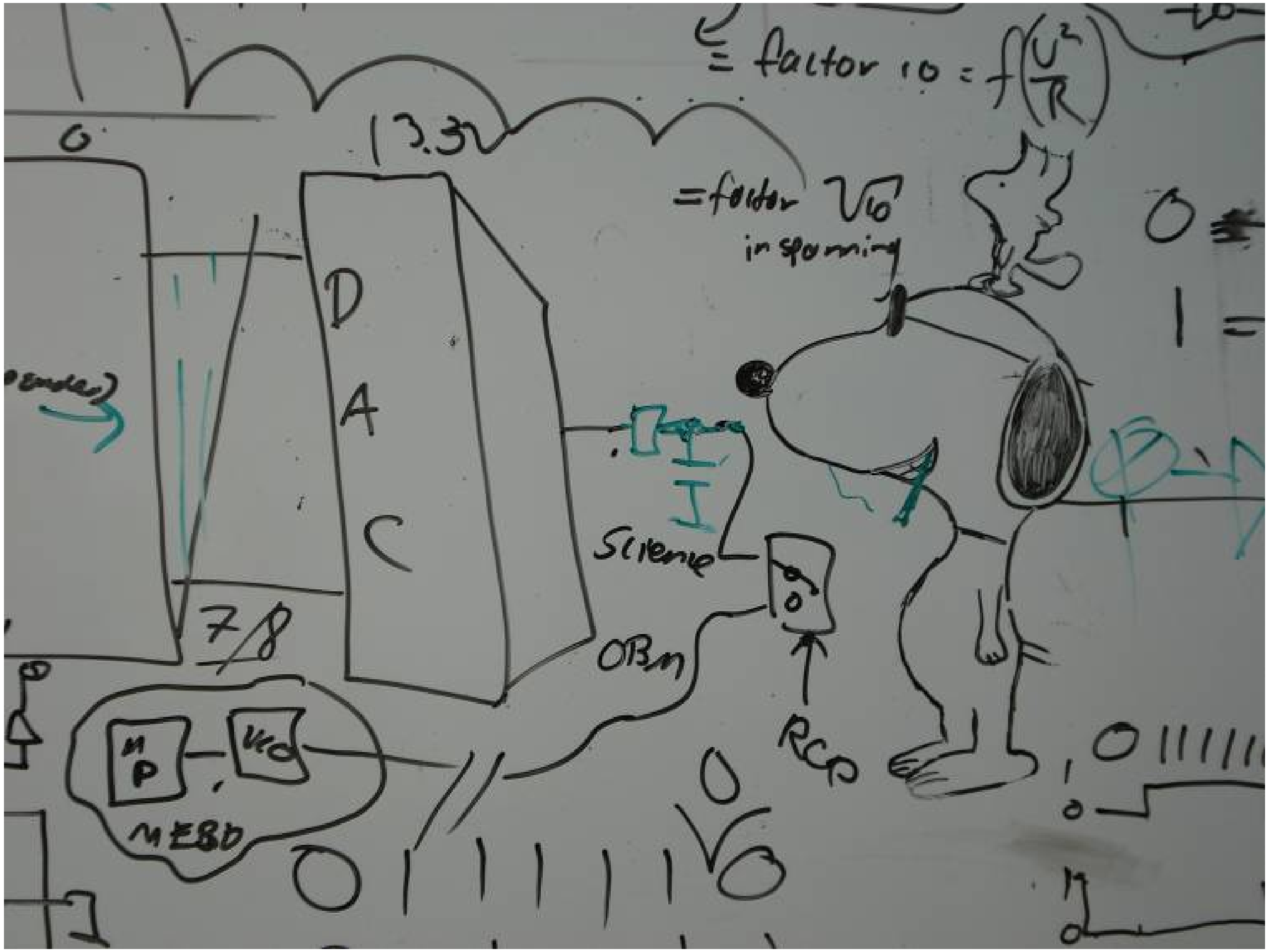

DELFI-C³
PE4WJ
PA3WEG

Bye Bye



Space Art

How to design a satellite...



Lessons Learnt

- Start building prototypes early!
- In RF circuits, power matching is not always necessary
- Opamps make nice RF/IF amplifiers
- Do not choose 0000 as bus reset command
- Parasitic oscillations can popup just about anywhere
- I2C repeaters / pull down by PICs
- Use ground lines between I2C data lines (**Doh!**)
- Reserve spare pins on connectors, you will need them!
- Use 0-ohm resistors to connect subcircuits
- **And…**

…Satellites are indeed, entirely constructed out of pizzas

Latest photos

- http://www.delfic3.nl/photoblog/

QRZ?

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