AtmoCube: a Nano-Satellite to Observe the Near-Earth Space Environment

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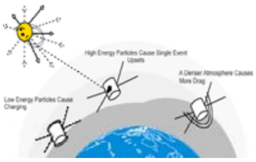
SPACE WEATHER in the Near-Earth Environment

The Radiation Measurement

Radiation risk estimations is a basic scientific problem in the planning and designing of the manned and automatic missions.

Earth atmosphere allows adequate protection of humans on ground but astronauts can undergo lethal doses of radiation. The penetration of high-energy particles into living cells, measured as radiation dose, leads to chromosome damage and, potentially, cancer. Large doses can be fatal immediately.



The Earth Magnetic Field

Geomagnetic field affects biological systems, physically stressed human systems may respond to its fluctuations: the Union of Radio Science International (URSI) created a new commission "Electromagnetics in Biology and Medicine". Astronauts on extra-vehicular activities can be more susceptible to such an effect when crossing the magnetic field lines continuously changeable along e.g. the International Space Station orbits.

The Atmospheric Density

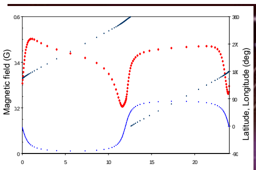
Atmospheric density is highly dependent on solar heating and geomagnetic activity.

The element constituents vary with height and geographical location. These dependencies complicate accurate modeling of drag forces. Models (MSIS, DTM) suffer from incomplete global coverage and lack of continuous measurements.

REQUIREMENTS

- Scientific Measurement : Study of the Earth Atmosphere "SPACE-WEATHER"
  - *Measurement of the Radiation Flux impinging on the satellite*
    - *Dosimeter*
  - *Measurement of the Magnetic Field*
    - *Magnetometer*
- Constraints/issues:
  - Low cost: very simple, small and light system
    - Quasi-standard structure - CubeSat-like
    - *13 cm side cube, 1.5 kg mass, 2÷3 W power*
    - Avoid moving parts (mechanisms) if possible
    - Use of any available launcher: non-optimized orbit
  - Non-dedicated instrumentation: commercial off-the-shelf (COTS) devices
    - Limited accuracy of the measurement
    - Limited data rate (radio-amateur band)
  - *Avoid interference with measurements (magnetic field)*
    - *Limited use of electro-magnetic systems (coils)*

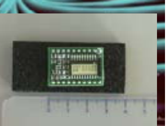
MAGNETIC FIELD



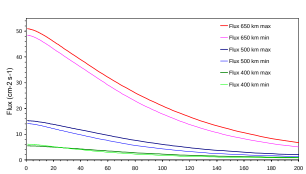
Effects	ΔB ($\times 10^{-4}$ G)	%
Day-night	5	0.15
Seasonal	5	0.15
Annual	5	0.15
Solar activity	19	0.54

Honeywell HMC 2003:
- dimensions 25.4×19.1 mm
- mass 4 g
- power 120÷300 mW
- range 40 μG ÷ 2 G

Available: tested and calibrated !



SPECTRO-DOSIMETER



	Dosimeter	Simulations
Deposited Energy (MeV):	0.0814 ÷ 20.83	Up to beyond 200 MeV
Flux (part/cm^2/s):	0.01 ÷ 1250	25 ÷ 220
Dose:	0.093 nGy ÷ 1.56 mGy	0.28 ÷ 0.35 μGy
LET [MeV cm^2 g^{-1}]:	0.114 ÷ 298.04	≤100

GPS

Trimble M-Loc MPM Module

- dimension 25.4 × 25.4 × 6.9 mm
- dimension 20.1 × 20.0 × 8.0 mm (antenna)
- mass 5.7 g
- power 68 mW, max 86 mW (antenna included)
- accuracy ≤ 7 m horizontal position
  ≤ 10 m altitude position
  0.1 m/s velocity
- rate 1 Hz

SGR-05U by SSTL highly recommended !

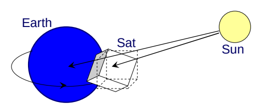
ORBIT

Different conditions analyzed:

h = 400 km
500 km
650 km
i ≅ 98.2°

Altitude (km)	650	500	400
Max length (s)	375.8	298.6	245.5
Average length of a passage (s)	294.5	235.6	192.5
Average # of communications/day	2.86	2.39	2.06
Average time between passages	8h 17'	9h 54'	11h 30'

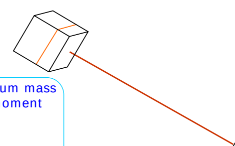
ATTITUDE DETERMINATION



SENSORS

SOLAR CELLS
PHOTO-DIODES
MAGNETOMETER

ATTITUDE CONTROL



COIL

Compromise between minimum mass and maximum magnetic moment

Number of wires: 300
Wire diameter: 0.2 mm
Coil side: 11 cm
Mass: 37 g

BOOM

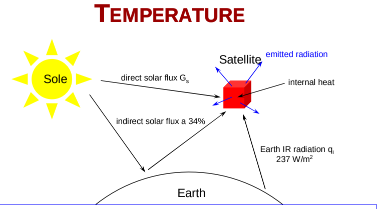
Compromise between maximum gravity gradient and minimum displacement of the center of mass

Cylinder dimensions: 18 × 18 × 18 mm
Cylinder mass: 40 g
Strip dimensions: 2.5 m × 18 mm × 0.3 mm
Strip mass: 124 g

Height (km)	$T_{AERODYNAMIC}$ (Nm)		$T_{GGRAVITY}$ (Nm)	T_{COIL} (Nm)	
650	min sol max sol	1.347×10^{-9} 3.890×10^{-8}	1.427×10^{-7}	50°C -100°C	3.879×10^{-6} 5.313×10^{-6}
500		1.350×10^{-8} 2.711×10^{-7}	1.523×10^{-7}		4.138×10^{-6} 5.668×10^{-6}
400		1.120×10^{-7} 1.154×10^{-6}	1.590×10^{-7}		4.324×10^{-6} 5.923×10^{-6}
300		1.270×10^{-6} 6.144×10^{-6}	1.664×10^{-7}		4.521×10^{-6} 6.193×10^{-6}

Below 400 km, under maximum (or average) solar activity conditions, the gravity gradient CAN NOT overcome aerodynamic torques and the coil should be also used

TEMPERATURE



$$Q_{ABSORBED} - Q_{CELLS} + Q_{GENERATED} = Q_{IRRADIATED}$$

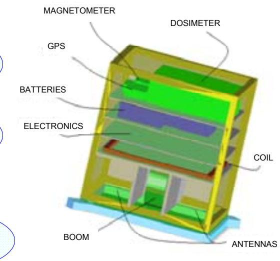
T_{MAX}	(9÷33)°C
T_{MIN}	-(96÷119)°C

SISTEMS		T_{MIN} (°C)	T_{MAX} (°C)
Battery	charge	0	50
	discharge	-40	60
Dosimeter		-20	40

ATMOCUBE / CUBESAT

SPACEWEATHER: to build a MAP of

- Earth Magnetic Field
- Radiation Flux impinging on AtmoCube
- and …
- INVOLVE STUDENTS !



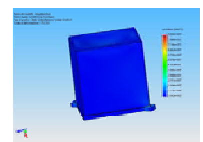
STRUCTURE SIMULATIONS

Density (kg/m^3)	2.71×10^3
Ultimate tensile strength (N/m^2)	2.90×10^8
Ultimate compression (N/m^2)	2.40×10^8
Young's module (N/m^2)	68×10^9

Aluminum 6061

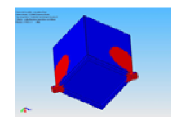
LAUNCHER:

Static and pressure loads



$T = 2.151 \times 10^7$ N/m^2

Dynamic loads



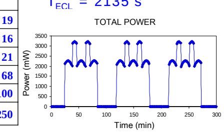
$T = 2.372 \times 10^9$ N/m^2

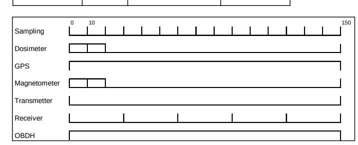
POWER

Instrument	Power (mW)	Duty cycle (%)	Average power (mW)
Transmitter	2000	300 s x 3.7= 1300 s/day -> 1.3	26
Receiver	250	6+1.3	19
Dosimeter	120	13	16
Magnetom.	160	13	21
GPS	67.7	100	68
OBDH	100	100	100
Total			~250

Worst condition:

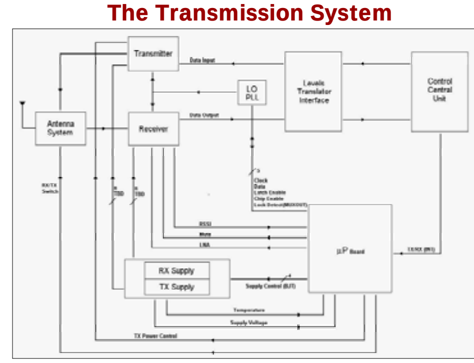
T_{SUN} = 3549 s
T_{ECL} = 2135 s





P_{MIN} = 2 W

The Transmission System



Telemetry Data Rate

Scientific measures: one each 10° → about 150 s (5400 s x 10°/360°)

Instrument	bit	Number of coord or ch.	Measures/ rev.	Total bit/rev.(Kb)
GPS	16	4 (x,y,z,t)	36	2.3
Dosimeter	10	1024 (channels)	36	370
Magnetometer	16	3 (x,y,z)	36	1.7
Total				373

i.e. 400 Kb/revolution → 6.4 Mb/day

With 3.7 passages/day → 282 s*3.7~1000 s/day → 6.4 Kb/s → 19.2 Kb/s should be enough

Radio-amateur Bands	
Uplink:	145.835 MHz, FSK
Downlink:	437.490 MHz, FSK

INFN Istituto Nazionale di Fisica Nucleare
INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS
OSSERVATORIO ASTRONOMICO TRIESTE
COST
COST 724