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TÍTOL DEL TFC: Implementation and verification of a Lunar mission subsystems

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Resumen

El presente trabajo final de carrera consiste en implementar y verificar algunos de los subsistemas que forman la misión Lunar diseñada por el equipo Team FREDNET (www.teamfrednet.org) con motivo del *Google Lunar X Prize*, un concurso para conseguir alunizar, en 20XX, colaborando en el diseño de algunos de sus componentes. Este proyecto se realiza en colaboración con otros investigadores de múltiples nacionalidades por lo que requiere formar parte del grupo en un proyecto real enfocado a la utilización de software *Open Source* y la participación abierta y libre de la comunidad de Internet.

Especialmente importante es el desarrollo, con nuestra colaboración, de uno de los posibles *Rovers* (vehículo que se desplazará por la superficie lunar) bajo el nombre de Pico-Rover. Destaca su particular diseño, emulando una esfera de reducido tamaño. Creemos poder desarrollar un novedoso concepto de *Rovers* proponiendo su miniaturización y reducción de coste, aplicando conceptos comunes de la física pero poco convencionales o usuales (hasta ahora, todos los *Rovers* utilizados se tratan de enormes aparatos electrónicos de baja maniobrabilidad y costes muy elevados).

Especialmente, hemos estudiado y desarrollado un equipo de comunicaciones de corto alcance que permita el envío y recepción de datos al *Rover* como imágenes, vídeos, telemetría, etc. y de unos acelerómetros que permitan el control tanto a distancia como por parte del propio *Rover* autónomamente.
Además, procedemos al estudio, construcción y testeo de las tarjetas de comunicaciones CAN-Do para su posible utilización en el *Lunar Bus* y/o *Lunar Lander*, que más adelante comentaremos detenidamente.

También se ha iniciado la investigación para proporcionar al *Rover* un sistema de detección de obstáculos bajo el nombre de PicoSAR (micro-RADAR). Se ha estudiado también posibles características de un enlace vía satélite, entre *Rover* y *Lunar Lander*, que permita estar en contacto continuo con el *Rover*.
Es un proyecto muy ambicioso, pero que a la vez nos permite participar de una idea innovadora y de gran interés formativo del que ya podemos decir que formamos una parte importante dentro del equipo.

Title: Implementation and verification of a Lunar mission subsystems
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Date: July, 17th 2009

Overview

This final project is to implement and verify some of the subsystems that make up the Lunar mission designed by the team FREDNET Team (www.teamfrednet.org) for the Google Lunar X Prize, a competition to land on the moon in 20XX, collaborating on the design of some components. This project is developed in collaboration with other researchers of many nationalities and therefore needs to be part of the group in a real project focused on the use of open source software and the Internet community.

Especially important is the development of, with our collaboration, one of the possible *Rovers* (vehicle that will move through the lunar surface) under the name of Pico-Rover. Highlights its particular design, emulating a small ball. We can develop a new concept of proposing Rovers miniaturization and cost reduction by applying concepts of physics but unconventional or usual (by now, all are Rovers used have low manoeuvrability and very high cost).

Especially, we have studied and developed a short-range communication to allow the sending and receiving data to the Rover as images, video, telemetry, etc, and accelerometers to achieve radio-control and autonomous *Rover* control.

Furthermore, we proceed to the study, construction and testing of communications boards CAN-Do for possible use in the Lunar Bus and / or Lunar Lander, which will commented in detail later.

It has also initiated an investigation to give the Rover a system for detecting obstacles under the name of PicoSAR (micro-RADAR). It has also studied possible characteristics of a satellite link between the Rover and the Lunar Lander, which allows you to be in contact with the Rover.

It is a very ambitious project, but which also allows us to participate in an innovative and very interesting format that we can already say that we are an important part in the team.

Dedicado a toda esa gente que nos
ha ayudado a seguir adelante,
y en especial a Joshua Tristancho por
darnos la oportunidad de participar
en este proyecto.

Dedicated to all those people
who has helped us to move forward,
and specially, dedicated to
Joshua Tristancho who
give us the opportunity
to participate in this project.

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OVERVIEW

We are taken part of **Google Lunar X Prize**[1] competition being active members of Team FREDNET[2].

The past year, the Rover Group which is part of the Team FREDNET, proposed a kind of Rover competition based on the idea of parallel development. This idea only could be implemented in an Open Source based team like Team FREDNET. Other teams have to focus their efforts due to the reduced number of components while Team FREDNET has a constant flow of involved people. The first competitor was Joerg Schnyder who developed from the scratch the so called Wheeled Rover Vehicle 1 (WRV1). This design has four straight wheels the body Rover is divided by the steering unit. The second competitor was Tobias Krieger who developed and made the so called Just another Lunar Rover (JALURO). This rover is based on two wheels and the body is in the bottom of them. Finally, the third competitor was Joshua Tristancho who developed the so called Pico-Rover concept. This Rover is based in a single wheel in form of ball self-driven.

The Pico-Rover group is formed by a local team of students and a teacher from the UPC in Spain. Because is a collaborative competition we take part in some system development in the whole mission. Team FRDNET is organized as a matrix. Each group has the System, the Hardware and the Software department which are represented by Joshua, Enric and Raúl. We have added a fourth member who is in charge of Quality Control represented by Andrés and independent of the Pico-Rover group by definition.

Following we present the objectives for the Pico-Rover group reflected in the present Bachelor Final Work. Joshua Tristancho will be in charge of system design and coordinate the Pico-Rover group. Enric Fernández will be in charge of some hardware like the *Bus CAN-Do Board* and the micro radar *PicoSAR*. Raúl Cuadrado will be in charge of programming some software like the *Pico-Rover Short-Range Communication System* and the *Pico-Rover Attitude and Thrust Control*. Finally, Andrés Petilo will be in charge of some documentation like the *System Requirements Document*, the *System Design Document*, the *Program Management Plan* and the *System Engineering Management Plan*.

[1] http://www.googlelunarxprize.org/
[2] http://www.frednet.org

Acknowledgements

As a Team, we want be grateful for the collaboration of the Team FREDNET members: Fred Bourgeois, Sean Casey, Alexander Csete, Anders Feder, Jeyram Jadenthradevan, Tobias Krieger, John Pritchard, Jörg Schnyder, Vu Trong Thu, etc.

We want be grateful to the ICARUS research group members: Enric Pastor, Cristina Barrado, Xavier Prats, Joshua Tristancho, Pablo Royo, Jorge Ramirez, Juan López, Eduard Santamaria and the students Juanma, Borja, Alex, Arnau, Julio, etc.

Finally we want to thanks our sponsors and collaborators:

Particularly,

Raúl wants to be grateful to his family and Alba Martinez Trujillo helping him moving forward when things became dark. He wants to be grateful to Enric Fernandez helping him in everything he needed and also to Joshua Tristancho, by all you have helped us, giving us the opportunity to know a community like Team FREDNET and participate in a so big project.

Enric wants to be grateful to his family who was expecting this day during twenty-three years. Finally, the work has been done. He wants to be grateful to Raúl Cuadrado and Joshua Tristancho, who give him the opportunity to be a part of this project. Finally, he wants to be grateful to UPC Technical Services and Stephen Moraco, without your help nothing would have been possible.

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

APCP	Ammonium Perchlorate Composite Propellant
AM	Arrival Mooncast
Delta	Unbalance ratio
Delta_V	Variation in velocity
EIRP	Equivalent Isotropic Radiated Power
Elphel	Open source High Definition camera E353
GLXP	Google Lunar X Prize
GTO	Geostationary Transfer Orbit
HTO	Hohmann Transfer Orbits
HTPB	Hydroxyl-terminated polybutadiene
IMU	Inertial Measurement Unit
ITAR	International Traffic in Arms Regulations
LDO	Lunar Descend Orbit
LEO	Low Earth Orbit
LOI	Lunar Orbit Insertion
LOS	Line of Sigh
LPO	Lunar Polar Orbit
MCM	Mission Complete Mooncast
MCU	Main Control Unit
NMH	Mono Methyl Hydrazine (CH_3-NH-NH_2)
N_2O_4	Nitrogen Tetroxide
PCB	Printed Circuit Board
PIREX	Pyrex® is a registered trademark of Corning Incorporated
PPMP	Pico-Rover Program Management Plan
PSAN	Phase-Stabilized Ammonium Nitrate
RADAR	Radio Detection And Ranging
SNR	Signal to Noise Ratio
SPI	Serial Peripheral Interface. Bus SPI.
TAP	Testing Antenna Protocol
TLI	Trans Lunar Injection
UDMH	Unsymmetrical dimethylhydrazine ($C_2H_8N_2$)
UWB	Ultra Wide Band
VSWR	Voltage Standing Wave Ratio

CHAPTER 1. Lunar mission design

1.1 Mission requirements

The lunar mission has to be compliance with the Google Lunar X Prize (GLXP) constrains. For this reason we will follow the version 3.0 of the Team FREDNET mission requirements[3]. The team will try to win the GLXP grand prize consisting of land the moon and drop a rover able to travel over the lunar surface a distance of 500 meters and transmitting an "*Arrival Mooncast*" and a "Mission *Complete Mooncast*". In addition of that, the team must adhere to local, regional, national, and international laws, and regulations for all aspects of the project. Following we will present a plan to land the Pico-Rover and all related to this mission without taking into account the mission of the Pico-Rover. This design is based on the Pico-Rover Program Management Plan[4] in the Annexes.

1.1.1 Lunar mission design

NOTICE: Due to Pico-Rover design implements **Critical Design** and **Quality Assurance**, Team FREDNET mission design may be also compliance with these requirements. For this reason Pico-Rover Group will design the whole lunar mission. This design may change respect to the official Team FREDNET.

We will launch our designed rocket in a place near to the Earth Equator, in the easting direction and in an elevated mountain in order to take benefit and reduce the propellant weight. Because de size of the launcher, it could be transported by truck to the launch point. The payload will be a Lunar Rover of equal or less than 500 grams of mass able to win at least the grand prize of the GLXP. There are three vehicles in this mission: The **Launcher**, the Trans Lunar Injection (TLI) called **Lunar Bus** and the **Lunar Lander**.

For trajectory calculations we use the **Delta_V** (ΔV) instead of the altitude because the vehicle is always referred to a gravity field. This is as follows:

$$\Delta V = V_e \cdot ln\,(M_i / M_f) \qquad \textbf{(1.1.)}$$

Where:

ΔV: Speed (scalar) is the amount of "effort" needed to carry out an orbital maneuver [m/s]
$V_e = g_0 \cdot I_{sp}$ is a constant measured in the Earth [m/s]
g_0: Acceleration at the Earth's surface [m/s2]
I_{sp}: Specific impulse measured in the Earth [s]
M_i: Initial mass [kg]
M_f: Final mass [kg]

3 http://wiki.xprize.frednet.org/index.php/GLXP_Requirements_v3.0
4 http://wiki.xprize.frednet.org/index.php/Picorover_Program_Management_Plan

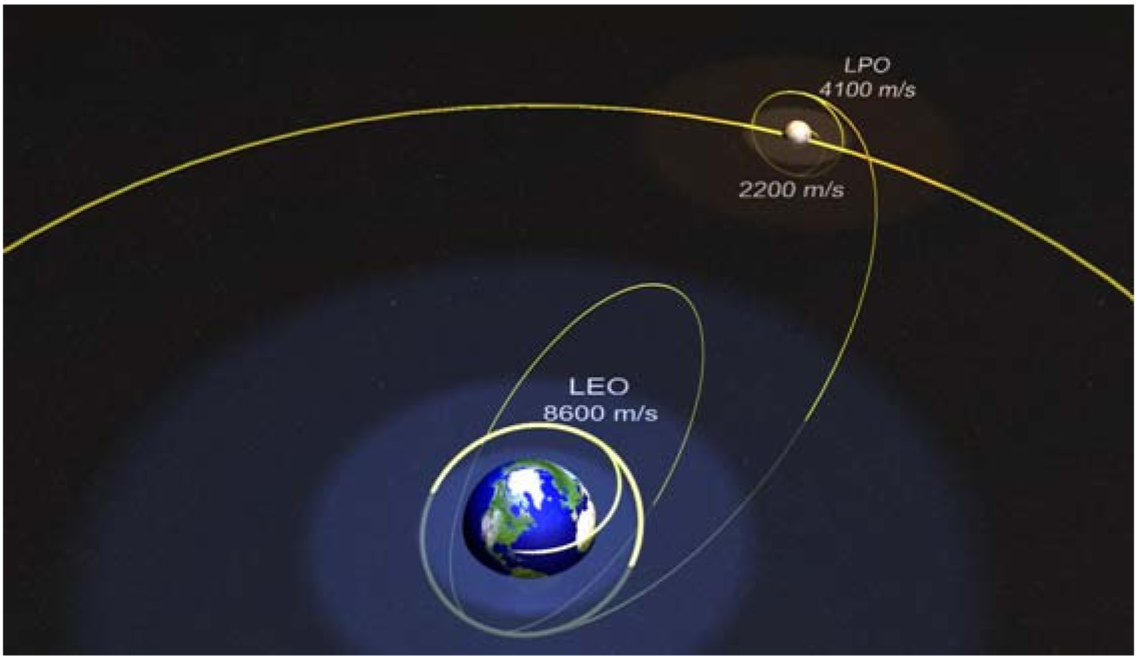


Fig. 1.1 Trajectory to the Moon

The Launcher will jettison three stages to reach the parking orbit LEO at 200 km adding 8600 m/s of Delta_V. Then the Lunar Bus will perform two Hohmann Transfer Orbits[5] by elliptic orbits adding 4100 m/s of Delta_V.

A series of maneuver corrections, showed in Table X, will put the Lunar Bus in the Lunar Orbit Insertion (LOI) which is a Lunar Polar Orbit (LPO) adding 4100 m/s of Delta_V. In this moment the Lunar Bus is separated from the Lunar Lander.

The Lunar Bus will stay in a Lunar Polar Orbit. The Lunar Bus will be used as a relay for coverage to the Lunar Rover when the line of sight between the Lunar Lander and the Lunar Rover are not possible.

The Lunar Lander will follow a Lunar Descend Orbit (LDO) adding 2200 m/s of Delta_V and land in the target point 26°8′ N 3°38′ E near the Apollo 15 site[6].

[5] http://en.wikipedia.org/wiki/Hohmann_transfer_orbit
[6] Apollo 15 site 26°8′ N 3°38′ E Moon. http://en.wikipedia.org/wiki/Apollo_15#Lunar_surface

Table 1.1 Delta_V budget

Delta_V (m/s)		
2867 2867 2866	First stage 67 km Second stage 134 km Third stage LEO 200 km	**Launcher**: ~1967 kg APCP solid propellant Total 8,600 m/s from Earth to LEO. No margin available
2406 339 339 50 378 438 50 100	GTO 36,000 km Perigee Maneuver 1 Perigee Maneuver 2 Perigee Maneuver Correction margin Lunar Orbit Insertion 1 Lunar Orbit Insertion 2 Lunar Orbit Insertion correction margin Lunar Orbit Maintenance	**Lunar Bus**: ~22 kg N_2O_4 + MMH/UDMH liquid bi-propellant Total 4,100 m/s from LEO to LPO. Used 6% margin
63 2104 33	Lunar Descent Orbit Insertion 100 km Descend and Landing Descend correction margin	**Lunar Lander**: ~1.5 kg N_2O_4 + MMH/UDMH liquid bi-propellant Total 2200 m/s from LPO to Moon. Used 2% margin
-	GLXP mission	**Lunar Rover**: 0.5 kg LiPo batteries From Lunar Lander to Target
TOTAL 14,867		

In the Table 1.2 we study the worst case for a direct link between the Lunar Rover and the Earth using a frequency of 2.4 GHz and an antenna temperature of 373 K (100 ºC). The maximum bandwidth, having a Noise to Signal Ratio (SNR) of 2.1 dB, is 100 kHz.

Table 1.2 Link Budget

WORST CASE LINK BUDGET

Distance:	384000.00	km	3.84E+08	m		
Frequency f:	2.40	GHz	2.40E+09	Hz		
Bandwidth BW:	100.00	kHz	1.00E+05	Hz		
EIRP:	20.00	dBW				
Gain Grx:	50.00	dB				
Temperature T:	100	ºC	373.00	K		
Tx Losses:	3.00	dB				
Offset losses	3.00	dB				
Rx losses	3.00	dB				
Wave length λ:	0.13	m				
Free space Lfs:	211.73	dB	dBm = dBW-30			
Power Signal PR:	-150.73	dBW	-120.73	dBm	8.45E-16	W
Power Noise PN:	-152.88	dBW	-122.88	dBm	5.15E-16	W
Ratio SNR:	2.1	dB				

Detailed studies about the link budget will be done in the CHAPTER 3. PicoSAR.

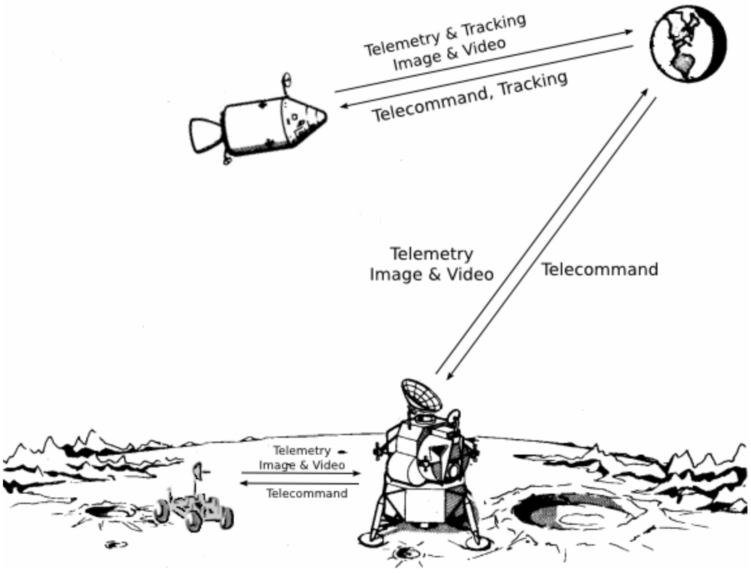
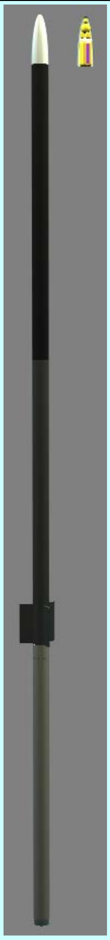


Fig. 1.2 Link schema (Source: FREDNET)

1.1.2 *Launcher design*

The Launcher has three stages with solid propellant and has to be repeatable in order to be compliance with the GLXP requirements. The total launcher weight is ~2036 kilograms where the structure ratio is the 2%. The empty weight is 40 kilograms; the propellant Launcher mass is ~1967 kilograms. The payload is ~29.7 kilograms and is located inside the fairing at the top. The Launcher uses the Lunar Bus components for guidance and navigation, for Attitude Control and for Telemetry. The first stage will be disposed in the ocean and the other two stages will be disintegrated during the reentrance. The three stages are equals and made of carbon fiber with a mobile nozzle. The stage jettison will be by pyrotechnic means and commanded by the Lunar Bus.



Launcher Specifications

Payload = ~29.7 kg
Structure ratio 16.9% of the total weight (~21.64 kilograms)
3 stages of solid propellant[7] APCP
Propellant cost = US$74,438.24
Launcher height = 6 + 6 + 6 + 1 = 19 meters

Stage Specifications

Solid propellant mass = ~655.6 kg per stage
Grain height (83.3%) 5 meters
Diameter = 0.338 meters
Frontal area = 9 dm^2
Structure ratio 1.96% of the total weight

APCP Solid Propellant Specifications

Specific Impulse I_{sp} = 260 seconds
Burn rate coefficient = 0.0032
Burn rate exponent = 0.6
Propellant density = 1458.73 kg/m^3
C-star range = 1000 to 1250 m/s depending on motor size.
Gamma = 1.23
Cost per weight[8] 37.85 $/kg (2004 pricing)

19.27% (20%) R45HT or R45M HTPB[9]
19.27% (20%) Magnesium (-650 to 1000 mesh)
57.8% (60%) PSAN-I Blend C Ammonium Nitrate
3.66% (Curing ratio = 0.19) *Mondur* MR MDI Curing Agent

For US units use this converter[10]

[7] http://en.wikipedia.org/wiki/Ammonium_Perchlorate_Composite_Propellant
[8] No reference will be allowed due to the ITAR restrictions for US providers.
[9] http://en.wikipedia.org/wiki/Hydroxyl-terminated_polybutadiene
[10] http://es.metric-conversions.org/cgi-bin/util/convert.cgi

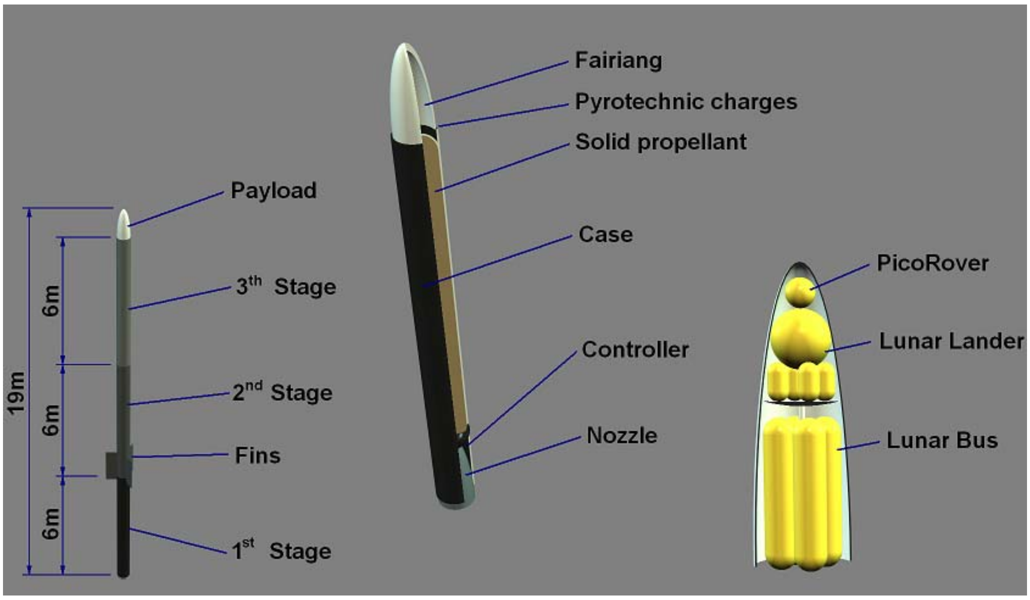


Fig. 1.3 Low Cost Launcher

A schematic view of the launcher and payload is shown in Fig. 1.3. Lunar Lander mass is 2 times the Lunar Rover mass; Lunar Bus mass is 10 times the Lunar Rover mass; Launcher mass is 80 times the Lunar Rover mass and total propellant mass is 3,980 times the Lunar Rover mass (Fig. 1.4). The cost of Lunar Rover mass is USD 1.8 M per kilogram.

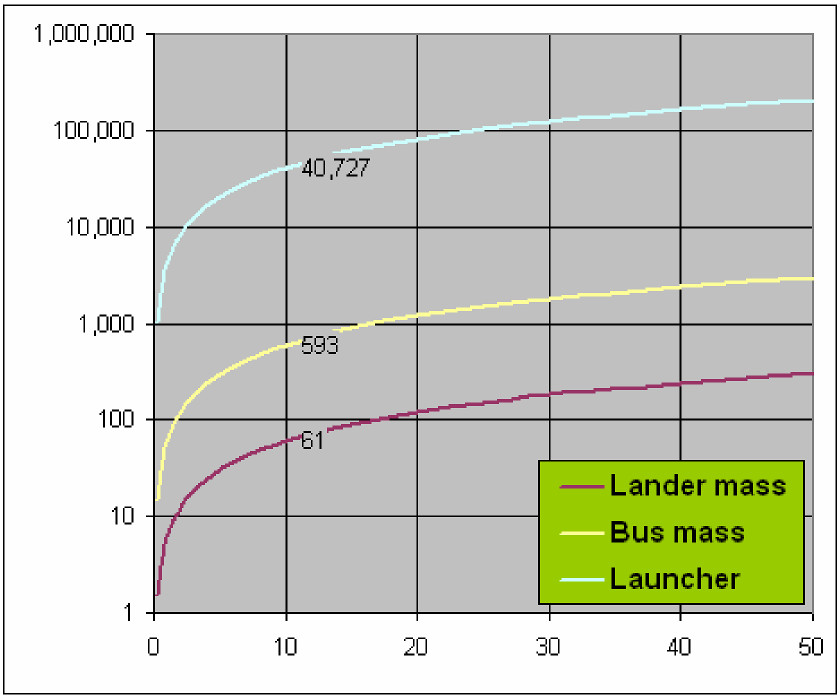
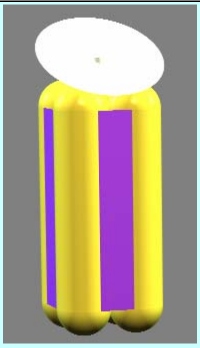


Fig. 1.4 Launcher, Bus and Lander mass vs Lunar Rover Mass (kg)

1.1.3 Lunar Bus design and Relay Satellite

The Lunar Bus is composed by 4 propellant tanks, the payload compartment in the top and the thruster in the center. The total Lunar Bus weight is ~29.67 kilograms where the structure ratio is the 16.7%. The propellant mass is ~21.64 kilograms, the empty weight is ~5 kilograms and the payload mass is ~3 kilograms. The Lunar Bus has Guidance, Navigation, Attitude Control, Uplink, Downlink and Telemetry systems.



Lunar Bus specifications

Height = 1 meter
Diameter = 0.338 meters
Frontal area = 9 dm^2
Structure ratio 16.9% of the total weight (~21.64 kilograms)
Payload = ~3 kg
1 engine with liquid bi-propellant[11] N_2O_4 + MMH/UDMH
Liquid bi-propellant mass = ~22 kg
Bi-propellant cost = US$??? (Not available)

N_2O_4 + MMH/UDMH bi-propellant specifications

Specific Impulse I_{sp} = 320 seconds
Burn rate coefficient = ??? (Not available)
Burn rate exponent = ??? (Not available)
Bi-propellant density = 1190 kg/m^3
C-star = 1745 m/s
Temperature chamber = 3395 K (3122 ºC)
Cost per weight[12] ??? $/kg (Not available)

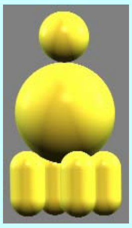
Oxidizer: N_2O_4 (Nitrogen Tetroxide[13])
Fuel: Hypergolic propellant[14] in 50/50 ratio
NMH (CH_3-NH-NH_2 Mono Methyl Hydrazine[15])
UDMH ($C_2H_8N_2$ Unsymmetrical dimethylhydrazine[16])
Mixture ratio; 2.15 mass oxidizer / mass fuel

For US units use this converter[17]

[11] http://en.wikipedia.org/wiki/Liquid_rocket_propellants
[12] No reference will be allowed due to the ITAR restrictions for US providers.
[13] http://en.wikipedia.org/wiki/Dinitrogen_tetroxide
[14] http://en.wikipedia.org/wiki/Hypergolic
[15] http://en.wikipedia.org/wiki/Monomethylhydrazine
[16] http://en.wikipedia.org/wiki/Unsymmetrical_dimethylhydrazine
[17] http://es.metric-conversions.org/cgi-bin/util/convert.cgi

1.1.4 Lunar Lander design and Lunar Base Station

The Lunar Lander is composed by 4 propellant tanks, the payload compartment and the thruster in the center. The total Lunar Lander weight is 3,025 grams where the structure ratio is the 30.1%. The propellant mass is 1,525 grams, the empty weight is 1,000 grams and the payload mass is 500 grams. The payload compartment is a volumetric sphere of 0.2 meters of radius, having an extra place to carry out a Pico-Rover in top of them without protection. The Lunar Lander has Guidance, Navigation, Attitude Control, Uplink, Downlink and Telemetry systems.



Lunar Lander specifications

Height = 0.4 meters
Diameter = 0.338 meters
Structure ratio 33.1% of the total weight (1.525 kilograms)
Payload = 0.500 kg
1 engine with liquid bi-propellant[18] N_2O_4 + MMH/UDMH
Liquid bi-propellant mass = 1.525 kg
Bi-propellant cost = US$??? (Not available)

N_2O_4 + MMH/UDMH bi-propellant specifications

Specific Impulse I_{sp} = 320 seconds
Burn rate coefficient = ??? (Not available)
Burn rate exponent = ??? (Not available)
Bi-propellant density = 1190 kg/m^3
C-star = 1745 m/s
Temperature chamber = 3395 K (3122 ºC)
Cost per weight[19] ??? $/kg (Not available)

Oxidizer: N_2O_4 (Nitrogen Tetroxide[20])
Fuel: Hypergolic propellant[21] in 50/50 ratio
NMH (CH_3-NH-NH_2 Mono Methyl Hydrazine[22])
UDMH ($C_2H_8N_2$ Unsymmetrical dimethylhydrazine[23])
Mixture ratio; 2.15 mass oxidizer / mass fuel

For US units use this converter[24].

[18] http://en.wikipedia.org/wiki/Liquid_rocket_propellants
[19] No reference will be allowed due to the ITAR restrictions for US providers.
[20] http://en.wikipedia.org/wiki/Dinitrogen_tetroxide
[21] http://en.wikipedia.org/wiki/Hypergolic
[22] http://en.wikipedia.org/wiki/Monomethylhydrazine
[23] http://en.wikipedia.org/wiki/Unsymmetrical_dimethylhydrazine
[24] http://es.metric-conversions.org/cgi-bin/util/convert.cgi

1.2 Pico-Rover specifications

The sphere has the minimum surface respect to a cube for the same volume; moreover, the sphere has a constant radiation area without angle dependence while cube solar cells depend on the angle. The sphere is the minimum expression to drive a Rover and could be at the time a good shield and a good wheel. No mobile parts are required outside the sphere[25] what makes a very simple and robust design.

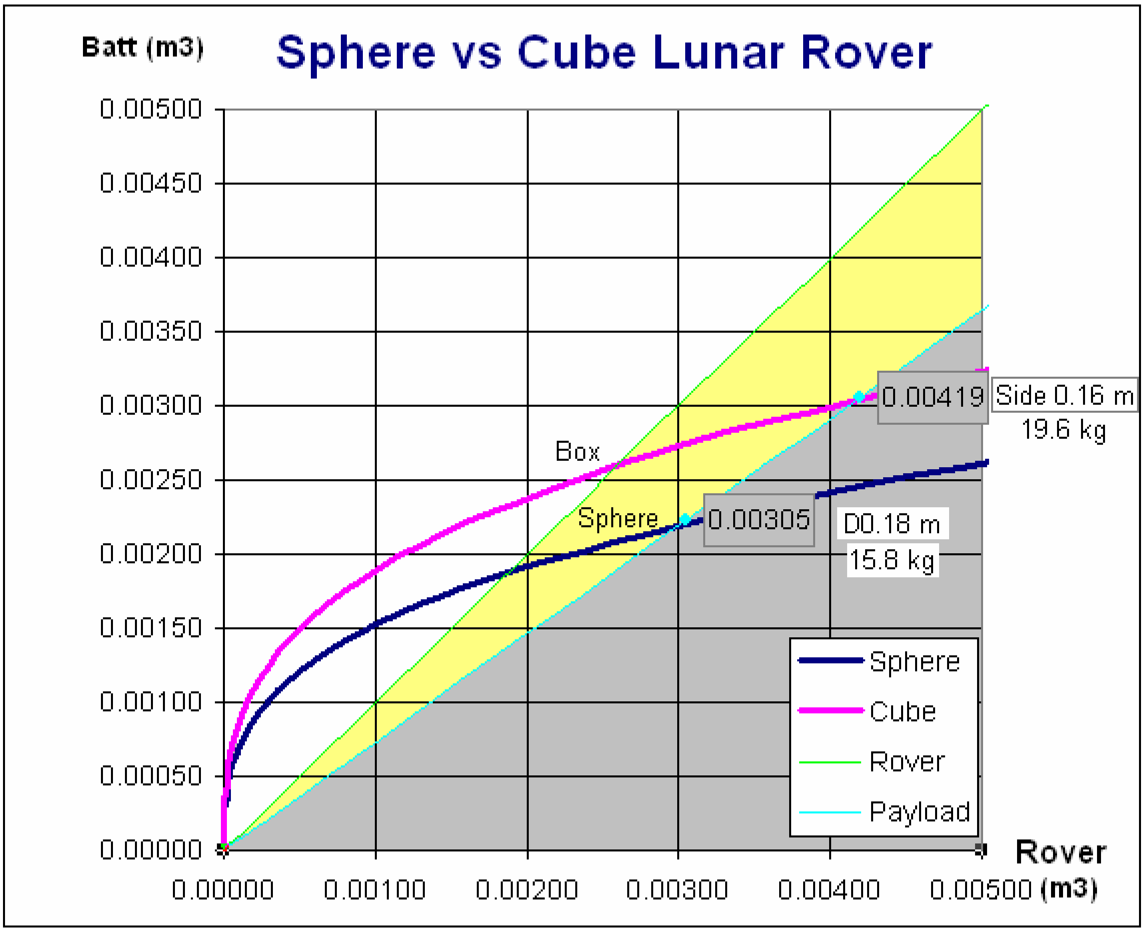


Fig. 1.5 Sphere and Cube Lunar Rover

In Fig. 1.5 the minimum volume to survive a lunar night based on batteries is calculated. The graphic shows the payload or battery volume versus the total Rover volume. The Sphere requires less battery volume than the cube. This minimum represents 15.8 kilograms of batteries and a Rover diameter of 0.18 meters. The cube requires higher battery volume. The minimum represents 19.5 kilograms of batteries and a side of 0.16 meters. This is because the cube has double surface of radiation than the sphere for same volume.

[25] 70's philosophy '*Think outside the box*'. http://openspacex.org/2009/03/04/outside-of-the-box/

Can a Pico-Rover climb a slope? It is possible to thrust a sphere from the inside without the help of other wheel which compensate the torque. It is possible to demonstrate that the maximum thrust reachable by a counterweight inside a sphere depends on the ratio center of gravity radius to the geometric center radius. We called this unbalance ratio as Delta.

$$Delta = R_{mass} / R_{geom} \qquad \textbf{(1.2.)}$$

Where:

R_{mass}: Is the projection of the center of mass in the radius where $R_{mass} = 0$ if centered [m]
R_{geom}: Is the sphere radius [m]
Delta = 0: All the mass is locate in the center of the ball
Delta = 1: All the mass is locate in the surface of the ball

In Fig. 1.6 a 10º slope without slipping is showed. If we not neglect the wheel slip then the ball loses the adherence in the moon surface before reach 30º. Experimentally we have found[26] that it is possible to reach a static angle of 37º having a Delta of 0.85 and a dynamic test has showed a Pico-Rover climbing 10º slope with a Delta of 0.45 of unbalance ratio.

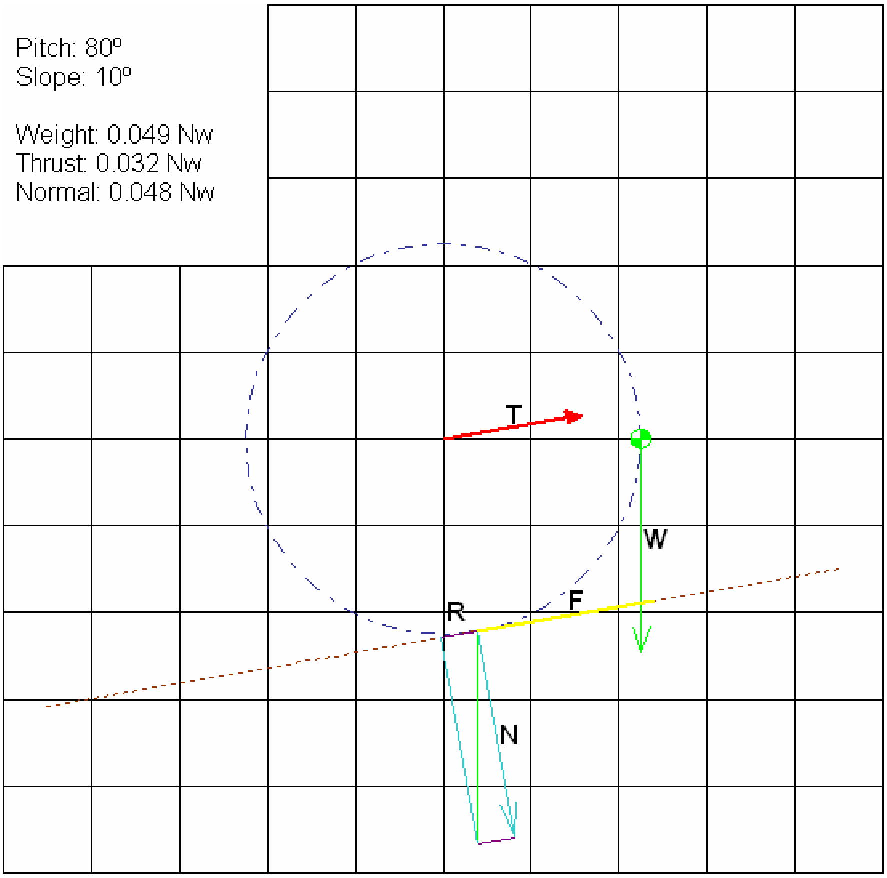


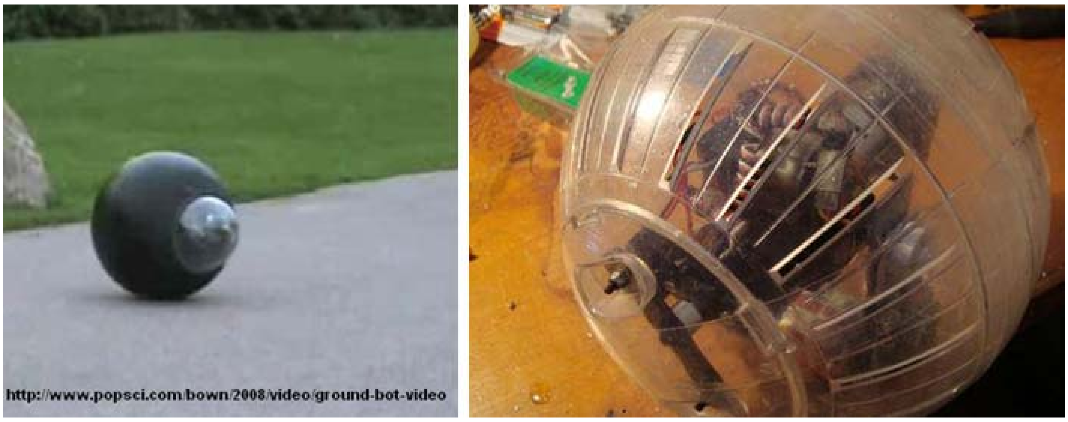
Fig. 1.6 Pico-Rover vector distributions

[26] http://wiki.xprize.frednet.org/index.php/Picorover_Feasibility_Study

In the previous Fig. vectors are marked as follow:

- **W** vector (GREEN) is the weight vector. Because this vector is located at a different point from the geometry center, we have an unbalanced counterweight.
- **F** vector (YELLOW) is the force applied in the contact surface. This force is due to the momentum produced by the unbalanced counterweight with respect to the contact point.
- **N** vector (CYAN) is the normal vector applied in the contact surface which is in charge of adherence. When the slope is very high, the wheel loses adherence. This phenomenon is not considered in these study cases.
- **R** vector (PURPLE) is the tangential vector which pulls the Pico-Rover down-hill.
- **T** vector (RED) is the resultant thrust vector. This vector is the resultant vector between the force vector F added to the tangential vector **R** but applied in the geometry center.

We have found seamless vehicles since this concept is not new and is well known. In Fig. 1.7 we present the *Rotundus AB*, picture a), having two lateral cameras and the *Peter's Hamster ball*, picture b), where the thrust mechanism is very similar to the Pico-Rover design.



a) Left. © 2008 Rotundus AB. All rights reserved. Reference: http://www.rotundus.se/press.html
b) Right. Peter's Hamster Ball. Reference http://hackaday.com/2009/02/05/radio-controlled-sphere/

Fig. 1.7 Examples of ball-like Rovers

1.3 Pico-Rover design

To build a Lunar Rover inside a ball presents some technical challenges to be overcome. The main challenge is thrust and steer the ball with no other wheels than the shield; having enough performances than the rest of Rovers. The second challenge is to be an autonomous Lunar Rover; detect the terrain and take decisions in order to reach the waypoints required by the GLXP organization. The third challenge is to be able of take a video in front of it while moving when the camera has to be inside the shield. And the worst challenge to be overcome is to communicate with the Lunar Lander when the height of the Rover is very small and rotates when moving.

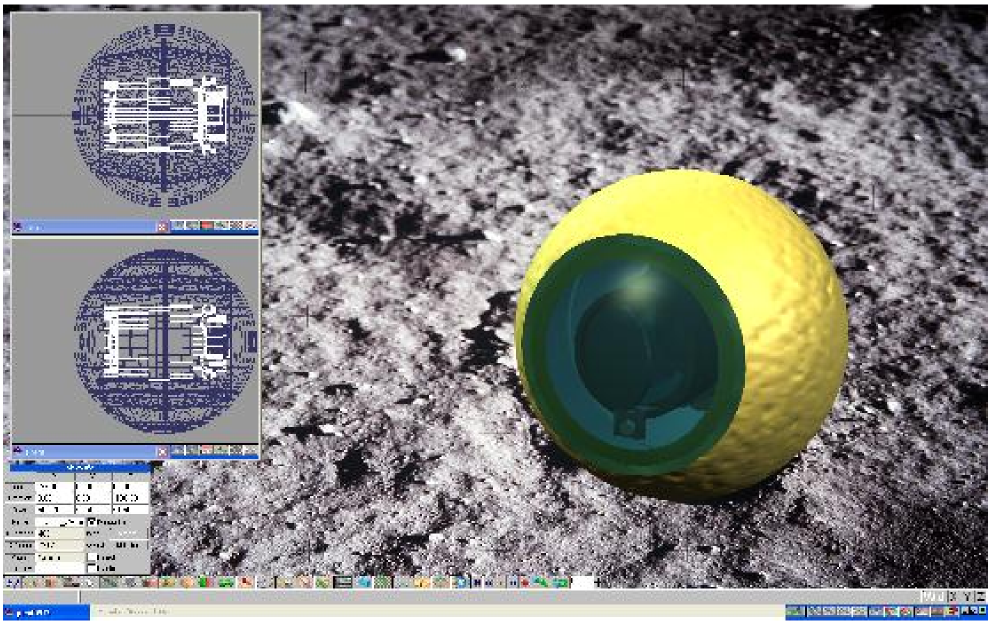


Fig. 1.8 Pico-Rover CAD design with Caligari® TrueSpace

We have proposed and tested some solutions to overcome these four main challenges but many other solutions require additional development and testing.

The result is showed in Fig. 1.8. The design starts from the Pico-Rover payload: a HD camera from one of our sponsors: Elphel. The camera it self is two times the size of the Rover so we separated the optics from the boards and integrated inside the ball as a part of the Rover. The shield turns around the camera so a lateral spherical window made in PIREX and a moveable mirror orientates the view to the desired direction: Lateral view, Front view, Tilt view, etc.

Inside the shield there is a metallic hail which protects the CORE components like the camera. The micro-radar antenna is located in the shield but protected by composite materials able to resist abrasion and extreme heat. Due to the small height of the Pico-Rover the transmition distance is limited to 50 meters in line of sigh (LOS) and we reuse the micro-radar directive antenna in order to communicate with the Lunar Bus in 100 km orbit. The Pico-Rover shape doesn't allow solar cells so we decide use thermal-electric cells.

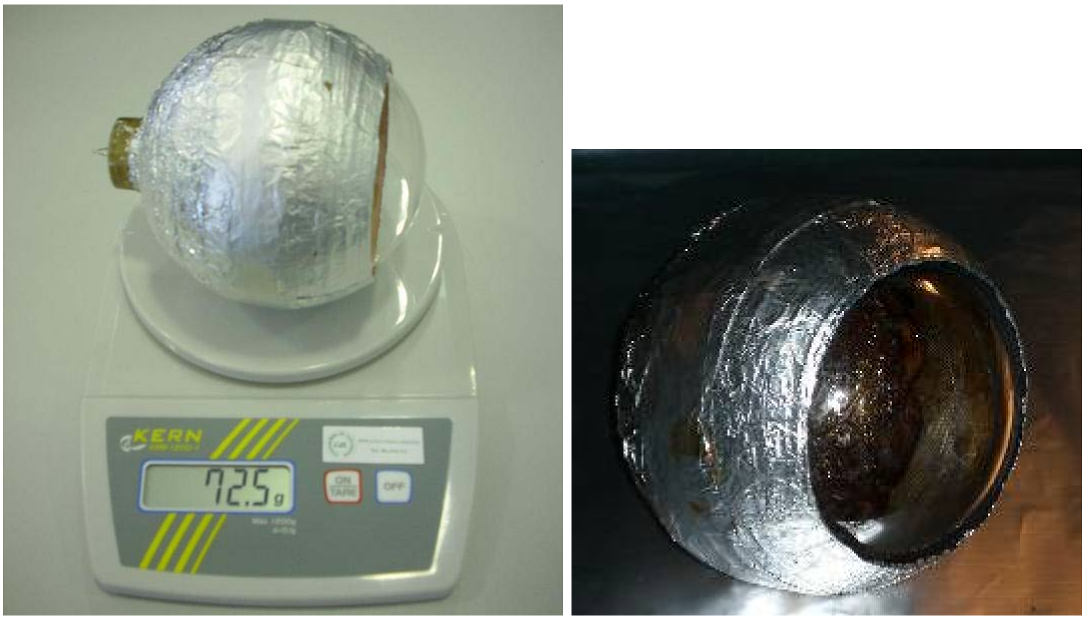


Fig. 1.9 Last Pico-Rover prototype and the last thermal test inside the oven

Many prototypes were done. You can see the results in the Pico-Rover portal[27] and also in the YouTube[28] channel.

27 http://wiki.xprize.frednet.org/index.php/Portal:Picorover
28 http://www.youtube.com/watch?v=x8EbbKPpfSk

CHAPTER 2. CAN-Do

2.1 Introduction

CAN-Do widget is an open source system implemented by AMSAT in many satellites. CAN-Do allow a secure communication between IHU and different devices like a digital camera, IMU & Attitude control, etc...

Bus CAN is usually used by car industry [9]. CAN-do development [10] was guided by a group of volunteers under CAN-Do developers website[29] were we have found information required to build firsts test widgets.

The diagram at right presents the structure of the CAN-Do architecture in an example. CAN-Do widgets interconnect on lines shared with the bus master Internal Housekeeping Unit (IHU).

- CAN-Do is compatible with the open space FREDNET philosophy because it has had an open architecture since 2003. You can build it by your self
- CAN-Do is supported by two main sponsors: AMSAT DL and AMSAT NA, one in EU and one in USA which gives a good accessibility for our teams
- CAN-Do has the Accepted to fly on Satellites certification
- CAN-Do use is justified when the system size is large or when the complexity is large (like Lunar Bus)

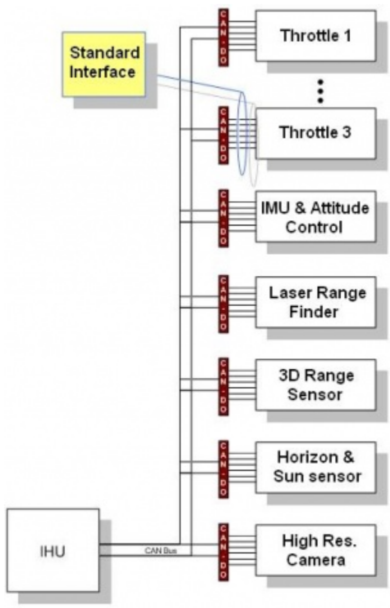


Fig. 2.1 CAN-Do interface

[29] http://can-do.moraco.info

2.1.1 CAN-DO details

These widgets (24 x 74 mm) provide a standard module interface to the spacecraft consisting of:

- Digital outputs/inputs
- Analogical inputs
- Switched power
- Current sensing
- Temperature sensing

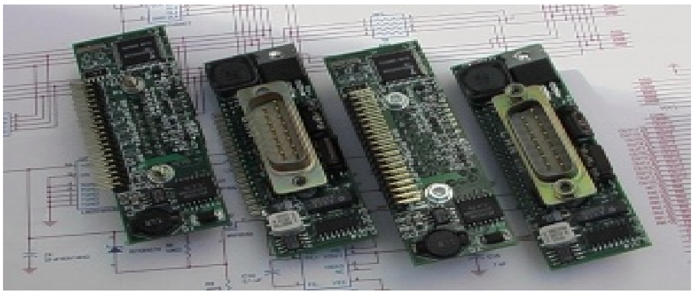


Fig. 2.2 CAN-Do widgets

There are three possible modes for which a widget can be configured, modifying number of digital inputs/outputs and analogical inputs (the widget does not support the use of more than 63 outputs or 64 inputs). The three modes currently defined are (detailed in **2.8**, **2.9** and **2.10**):

- Standard.
- Multiplexed (If you need 13 to 63 digital outputs or 9 to 64 digital inputs).
- Byte-pipe (If Module contains a microprocessor that needs to exchange bulk data (download of pictures, upload of tables, etc.) with the IHU or if the microprocessor within the Module needs to have code loaded).

There are six pads for address (A0-A5: 0x01-0x3F (NOTE: 0x00 must remain unused)) and two pads for mode (M0, M1).

Table 2.1 Mode configuration

M1	M0	Mode
0	0	Reserved(not defined)
0	1	Byte-pipe(0x01)
1	0	Multiplexed(0x02)
1	1	Standard(0x03

Three of the eight analogical sensor lines (AIN5 thru AIN7) have a dedicated purpose on the Widget. The remaining channels (AIN0 thru AIN4) are available for tasking by Module Designer. The three dedicated sensors are:

- AIN7: the Widget switched-power current sensor (an LT1787HVHS8 device)
- AIN6: the Widget temperature sensor (an LM60CIM device)
  Linear 6.25 mV/ºC (174 mV to 1.205 V: -40 to +125 ºC)
- AIN5: the Widget switched-power current measuring circuit bias

Note: The value of sensor AIN5 combined with the value of AIN7 provide the single current sense value for the Widget.

2.2 Materials for bus CAN-Do widget

On a first approach, we decided to build two CAN-Do widgets. We include a bill of materials in Annexes. Definitive CAN-Do materials price for a single widget is around 50 €, including some mistakes ordering. There are some difficult materials to find and we had to do different orders. Finally we have a stock to build ten CAN-Do widgets.

2.3 Schematics

A PDF with the electric schematics is provided by developers. We can take it into consideration, especially in building process. These have been attached in Annexes (**1.2**)

2.4 PCB

The PCB can be opened with "*OrCAD 16.0*" and particularly with "*OrCAD Layout Engineer's Edition*". They have an estimated cost of 40 € per PCB built by PCB-Pool[30]. You can see a picture below and PCB's screenshots included in annexes (**1.3**).

[30] http://www.pcb-pool.com

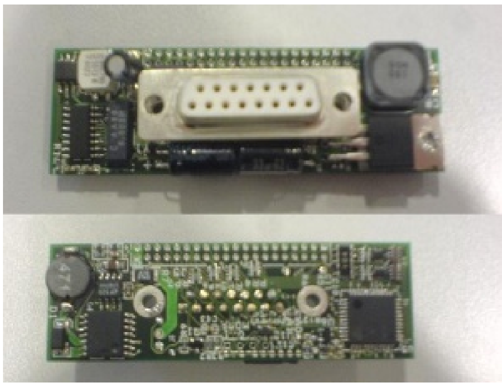


Fig. 2.3 CAN-Do board development and assembling

2.5 Reset

There are two reset types:

- Restart and jump back into the firmware
- Restart jumping into the built-in CAN boot loader in order to accept new firmware

A push button shorts pins one (VCC) and two (RESET) when pressed. The slide switch connects a 100 ohm resistor between pins three (PSEN) and four (GND). If the resistor is in circuit at reset pushbutton release, the device jumps into the boot-loader (new firmware). If the resistor is not in circuit at release the device jumps into the current firmware. These parts are mounted on an 8-pin DIP socket with one row of pins cut off close to addressing pads.

We have built a reset device without a switch. For that reason, this device only is able to reset a widget in order to be flashed with a new firmware. The other reset mode can be achieved disconnecting the widget from source and connecting it again. A picture has been taken and included in Annexes.

2.6 PC connection

We use a Lawicel CAN232 serial interface (**Fig. 2.4**) with and approximated cost of 160$ (shipping included). We can test it with any software able to establish a RS232 communication like *HyperTerminal* (Windows) or *GTKterm* (Linux). More details later.

Fig. 2.4 CAN to RS232 converter for PC computer

CAN devices are wired to the bus in parallel. The D15P connector provides for two CAN-HI and CAN-LOW connections to simplify the creation of the wiring harness.

The typical wiring harness for a single CAN232 controller and a single widget consists of the following parts:

1 – DB15S
1 – DB9S
A length of cable to be used for power (2 conductors)
A length of cable to be used for the CAN communication (2 conductors)
2 – 120 Ohm resistors
1 – Power connector socket

Power routes to both the Widget and to the CAN232 Bus adapter. A picture showing how connect it is included in Annexes.

The CAN232 device requires that PWR be 8-15 VDC (we decided to apply a 12V source feed).

A cable to connect more than a single widget can be built. Remember CAN-Do widgets works in parallel. In a future, we will use a cable for more than a single widget.

In our case we have built a cable with a 15 pin male connector and 9 pin male / female connector.

For 15 pin male connector:

- CAN HI: Yellow (10)
- CAN LOW: Blue (11)
- POWER: Red (8&15)
- GROUND: Green (1&9)

For 9 pin male/female connector:

- CAN HI: Yellow (7)

- CAN LOW: Blue (2)
- POWER: Red (9)
- GROUND: Green (3)

Including a 120 ohms resistor between CAN HI and CAN LOW pins both sides.

Note: Our CAN-Do first board has been built using a 15 pin female connector (developers of CAN-Do has been built theirs Widgets using a male connector).

2.6.1 Testing CAN232

A manual for CAN232 configuring is available at CAN232 downloads[31]. After reading it we decided to execute Windows HyperTerminal in order to establish an initial connection configuring CAN232. A screenshot showing connection to CAN232 is included in Annexes (**1.4**). The test was successful.

Valuable info:

- CAN speed configured up to 125k
- RS232 speed up to 57600 baud
- Auto Poll/Send ON
- Time Stamp ON

2.7 Firmware Overview

We have the IHU to which is wired a number or payloads (Modules) all connected via the CAN bus. Each module contains a Widget which is its interface to the CAN bus. This is common to all three widget modes.

The IHU:

- Write control values to all of these Modules.
- Record the telemetry from each of these Modules (both analogical channels and digital inputs).
- Every 20 milliseconds (50 times a second).
- Is effectively sending a configured packet to each Widget on the bus, to all of the Widgets (within this 20 milliseconds period).
- Each configured packet is addressed to one specific Widget.

The Widget intended to receive the configured packet is then expected to digitize all built-in analogical channels and read all digital inputs returning both sets of values as one or more answer packets.

In conclusion, the IHU can send and receive data from all Widgets in each 20 milliseconds period.

[31] http://www.can232.com

2.7.1 Analogical to Digital Conversion Process

There are eight analogical channels (provided by the T89C51CC01 microcontroller). The firmware, in response to a configured packet, will digitize all of the channels and report these values in response packets. Important details:

- The firmware digitizes all eight channels in sequence
- It makes 16 digitizing passes over all eight channels accumulating a sum for each channel. When this process finish, divides each sum by 16, which produces the result reported in the answer packet
- Meanwhile the firmware digitizes, microcontroller is placed into a quiet mode (to reduce noise)
- The process to convert all eighty channels 16 times and divide each channel sum takes roughly 6.2 milliseconds

In conclusion, there are 6.2 milliseconds delay between the widget receiving a configured packet and the widget starting to send the answer packets. This means that an IHU will be able to send a number of configured packets before any of the answer packets start arriving at the IHU.

2.7.2 Hardware Watchdog Recovery System

ATMEL T89C51CC01 microcontroller has a hardware implementation of a watchdog (WD) timer (**Fig. 2.5**).

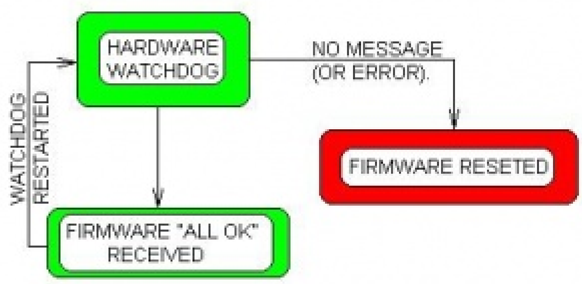


Fig. 2.5 Watchdog scheme

WD timer is set to expire in roughly 3.12 seconds. In order to keep our watchdog from expiring we simply report to it that the firmware is running well each time the Widget sends a response to the IHU. The firmware maintains more than one copy of the last known good configured value in RAM. If WD expires:

- The microcontroller resets itself
- Upon reset, all I/O pins are driven high

The Widget firmware implements a WD event log written to ERAM. This log tracks two kinds of WD events when the WD expired: (1): "no configured traffic heard, so resetting". (2): "firmware was locked in an infinite loop" (the firmware logs which loop the firmware was in at the time of expiration).

In summary then, Watchdog (WD) events can be useful during ground based testing and maybe even we are in space to monitoring the WD event log within our Widgets.

2.7.3 CAN Traffic Health Indication

The CAN controller within the ATMEL microcontroller tracks a set of transient errors or warnings during packet transmission and reception. The Widget firmware extends this tracking by adding counters of these events.

2.7.4 Flashing a widget (flasher / Linux)

We must download flasher utility from developer's website plus firmware. To flash a widget we must work with Linux (*Ubuntu*) and follow the examples provided by CAN-Do developers.

2.7.5 Controlling a widget (CDNC / Windows)

We must download CDNC[32] software (web link works only with Internet Explorer). This software allows us to connect with more than a widget, but for the moment, we only have a cable ready to connect with a single widget.

2.8 Standard Mode

Standard mode CAN-Do provides:

- 12 Digital Output bits
- 8 Digital Output bits
- 5 Analogical Input signals
- Module Power Control
- Current sensing and Temperature sensing

No additional hardware is required.

[32] http://cdnc.moraco.us/

2.9 Multiplex Mode

Multiplex mode requires external latches and 3-to-8 latch-address decoding to complete the system. A hardware module is required. Multiplex mode provides,

- 63 Digital output signals
- 64 Digital input signals
- 5 Analogical inputs
- Module Power Control
- Current and Temperature sensing

2.10 Byte-pipe Mode

Byte-pipe mode has less general I/O than other modes, but provides a byte-wide input port and a byte-wide output port. Both ports can send/receive info using free bandwidth obtaining 7 Kbytes/sec data transfer. Builders comment we could obtain a maximum peak of 90 Kbytes/sec data transfer modifying some capacitors from previous CAN-Do design. In conclusion Byte-pipe mode provides,

- 8 output bits
- 8 input bits
- 3 analogical input signals
- Module Power Control
- Current and temperature sensing

2.11 Running tests and simulations

The first CAN-Do board has been built. Soldering some components was really difficult a beta version has now able to be wrote it firmware and tests it. Some problems were present like difficulties finding some special components like series resistor arrays and soldering microcontrollers or SMD components. We have done a power test checking for short-cuts. The test was done by a current controlled Power Source and was very successful. The board has passed the first Quality Control.

Some pictures below:

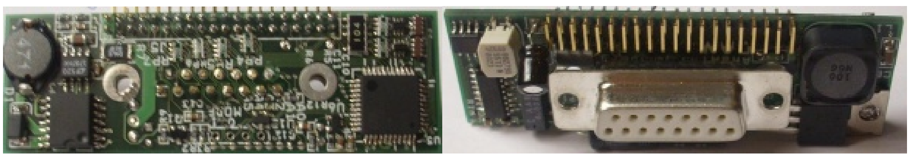


Fig. 2.6 CAN-Do back and frontal view

To install firmware inside our microcontroller flash memory, we must download code source provided by CAN-Do developers. Now we have problems with firmware installation, because we obtain an error during flashing. We are in contact with them in order to conclude firsts CAN-Do operative widgets. Once we reach it with success we will be able to send some widgets to some team members (they will be a part of Lunar Bus and any Team FREDNET member can order someone.

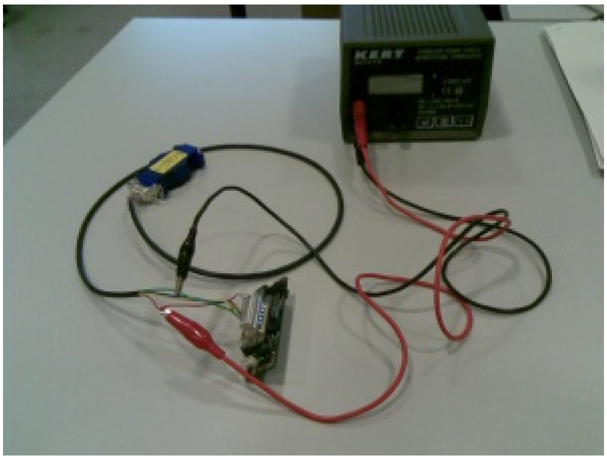


Fig. 2.7 CAN-Do power supply

2.11.1 CAN bus utilization

An excel file helps us to calculate which bandwidth we will use depending on widgets number and working mode. This excel is provided by CAN-Do developers. Ideally, up to 50 widgets can be connected at the time (any Widget occupies around the 2% bandwidth).

CHAPTER 3. PicoSAR

3.1 PicoSAR introduction

First of all, this component is a home made product in order interconnects different devices. The following product is intended to be used as an antenna for Lunar Bus, Lunar Lander and Lunar Rover connection and terrain scanning subsystem (acting like a micro-RADAR). For this reason, we have selected the UWB band. This band is used for through the wall radar and imaging. Also, is low used in the moon and has a free usage compatible with other devices in the earth. UWB band requires a high frequency technology with a high integration level. Frequency bands included in Annexes (**1.6**)

In conclusion, PicoSAR serves us to:

- Establish a high range communication (acting like an antenna)
- Terrain Scanning (acting like a SAR [35])

3.1.1 Ultra-wideband SAR

Ultra-Wideband (UWB) is a technology for transmitting information spread over a large bandwidth (>500 MHz) that should, in theory and under the right circumstances, be able to share spectrum with other users. Regulatory settings of FCC are intended to provide an efficient use of scarce radio bandwidth while enabling both high data rate *personal-area network* (PAN) wireless connectivity and longer-range, low data rate applications as well as radar and imaging systems.

3.2 PicoSAR high range antenna

Previously, we suggested the possibility to achieve a radio-link communication using PicoSAR antenna. It's functionality depending on low range radio-link failure (chapter 4). For that reason, we have studied different possibilities, like a hundred of meters direct vision link, a lunar orbital satellite link and a direct earth transmission. Also, a calculation for terrain scanning subsystem is added to be compared with the rest of result. Calculations are detailed in link budget.

3.2.1 *Link budget*

For a line-of-sight radio system, a link budget equation (expressed in dB) might look like this:

$$P_{RX} = EIRP - L_{FS} - L_M + G_{RX} - L_{RX} \quad \textbf{(3.1.)}$$

$$EIRP = P_{TX} + G_{TX} - L_{TX} \quad \textbf{(3.2.)}$$

$$SNR = P_{RX} / P_N \quad \textbf{(3.3.)}$$

$$P_N = k * T * B \quad \textbf{(3.4.)}$$

Terms above defined in Annexes (**1.7**).

We have done some calculations to give us an initial idea about system requirements. After mature consideration, we have decided work with:

- PIRE (EIRP = 50dBm)
- A_{effTX} = PicoSAR antenna efficiency of 70% (Antenna Directivity approx. 43 dB)
- L_{TX} = 3 dB
- L_m = 3 dB
- G_{RX} = 50 dB (Lunar Bus antenna gain)
- A_{effRX} = 90% (gives us a Lunar Bus antenna approx. 56 dB)
- L_{RX} = 3 dB

(For terrain scanning subsystem, the same antenna will work like transmitting and receiving antenna).

About L_{FS} (Free Space Losses):

Table 3.1 Free Space Losses in dB units as a function of distance (km) and frequency (GHz)

L_{FS}	0.03	0.5	100	10,000	59,763 ([33])	86,709 ([34])	384,000 km ([35])
f = 2.4 GHz	70	94.0	140	180	195	196	212
f = 10 GHz	82	106.5	152	192	211	212	224

[33] R_{L2} Lagrangian point.
[34] Theoretical stationary orbit in Lagrangian point L2. Not stable due to the Earth gravity field.
[35] Distance to the Earth.

Hence, we can develop the previous equation to find the P_{RX} received power:

$$P_{RX} = EIRP - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX} \qquad (3.5)$$

Table 3.2 Received power (PRX) in dBm units as a function of distance (km) and frequency (GHz)

P_{RX}	0.03	0.5	100	10,000	59,763	86,709	384,000 km
f=2.4 GHz	24	-0.01	-46	-86	-101	-102	-121
f=10 GHz	12	-12.5	-58	-98	-117	-118	-133

The value of P_N, noise power, depends on the brightness temperature radiated by a noise source which is absorbed by the ideal antenna (considering only the main beam) but also in the **BW** bandwidth and the receiving system temperature. We have considered 4 temperatures to compare results obtained (temperatures range is from 3 K to 290 K after study possible sceneries).

Table 3.3 Noise power

P_N	BW = 1 MHz	BW = 10 MHz
T = 3 K	-133.8 dBm	-123.8 dBm
T = 100 K	-118.6 dBm	-108.6 dBm
T = 200 K	-115.6 dBm	-105.6 dBm
T = 290 K	-114 dBm	-104 dBm

Finally, we can obtain the SNR (Signal to Noise Ratio). Some tables showing how different parameters affect our SNR have been included in Annexes. Some valuable info obtained from tables:

- Highest T decrease SNR
- Lowest B (bandwidth) increase SNR
- Distance and frequency have a quadratic dependence in SNR

3.3 Pico-Rover Terrain Scanning Subsystem

Principally, the “Terrain Scanning Subsystem” provides a 3D shape of the terrain in front. This is an ambitious project but will help us to learn a lot about SAR design. After all, this is the idea of the project (to learn and to explore new concepts and ideas). At the moment, important words to concepts we are going to explain in advance are:

- RADAR
- Antenna array
- Phasor

3.3.1 SAR introduction

Synthetic-aperture radar (SAR) is a form of radar in which multiple radar images are processed to yield higher resolution images than would be possible by conventional means. Either a single antenna mounted on a moving platform (such as an airplane or spacecraft) is used to illuminate a target scene or many low-directivity small stationary antennas are scattered over an area near the target area. The many echo waveforms received at the different antenna positions are post-processed to resolve the target. SAR can only be implemented by moving one or more antennas over relatively immobile targets, by placing multiple stationary antennas over a relatively large area (our design will follow this idea, applying different phase signals, with phasors, in order to achieve different directions of measurement), or combinations thereof. SAR has seen wide applications in remote sensing and mapping.

3.3.2 Radar equation

The amount of power P_r (3.1.) returning to the receiving antenna is given by the radar equation:

$$P_R = \frac{P_T G_T A_R \sigma F^4}{(4\pi)^2 R^4} \qquad \textbf{(3.6.)}$$

Where:

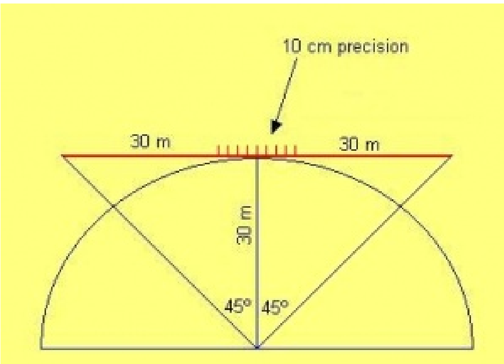
- P_t = transmitter power
- G_t = *gain* of the transmitting antenna
- A_r = effective aperture (area) of the receiving antenna
- σ = *radar cross section*, or scattering coefficient, of the target
- F = pattern propagation factor
- R = distance to the target

This shows that the received power declines as the fourth power of the range, which means that the reflected power from distant targets is very, very small. The equation above with *F* = 1 is a simplification for *vacuum* without interference. The propagation factor accounts for the effects of *multipath* and shadowing and depends on the details of the environment. *Pathloss* effects are not critical due to there isn't atmosphere interferences in the moon environment.

Different radars system can be achieved. In particular, we are working with a monostatic radar (transmitting and receiving antenna are both the same).

3.3.3 Mission requirements

- Range 30 m with
- 10 cm precision
- EIRP approx. 31 dBm (G: Antenna gain = 30 dB)
- Patch Array working at 2 to 10 GHz (UWB band)
- Input impedance 50 Ohms
- Beamwidth(-3dB) = pi/1200 rad = 0.15 degrees



$$\frac{60m}{0.1m} = 600\,points$$

$$\frac{90^\circ}{600} = 0.15^\circ\,precision$$

$$D = 10\log\left(\frac{4\pi}{\Delta\theta\cdot\Delta\phi}\right) = 10\log\left(\frac{4\cdot 600^2}{\pi}\right) \approx 56.61dB$$

Fig. 3.1 PicoSAR beam calculations

3.3.4 Link budget

In this section we present some considerations and calculations of the analysis of the link. Following the radar equation previously defined we will determine the individual parts of the operation.

"Free Space Losses" defined as,

$$L_{FS} = \left(\frac{\lambda}{4\pi R}\right)^2 \qquad \textbf{(3.7.)}$$

- if r = 30 m and λ = 0.12m then L_{FS} = 140 dB
- if r = 1 m and λ = 0.12m then L_{FS} = 80 dB

Total analysis budget,

$$P_{R,\min} = \frac{EIRP \cdot \sigma \cdot G_r}{4 \cdot \pi \cdot L_{fs}} = 31dBm + 10\log(\sigma = 1) + 30dB - 10\log(4\pi) - 140dB = -90dBm$$

$$P_R(r = 1m) = \frac{EIRP \cdot \sigma \cdot G_r}{4 \cdot \pi \cdot L_{fs}} = 31dBm + 10\log(\sigma = 1) + 30dB - 10\log(4\pi) - 140dB = -30dBm$$

$$SNR_{\min} = \frac{P_{R,\min}}{P_N} = \frac{P_{R,\min}}{k \cdot T(T = 50^\circ K) \cdot B(B = 1MHz)} = -90dBm - 10\log(1.38 \cdot 10^{-23} \cdot 50 \cdot 10^{6}) = 62dB$$

Fig. 3.2 Analysis budget calculations

Finally, the time we have to wait for the signal return can be modelled as,

$$R = \frac{c \cdot t}{2}[m] \qquad \textbf{(3.8.)}$$

Note: "c" is the speed of light in vacuum and "t" the time of flight

- for 30 m distance, t = 0.0000002 s = 0.2 microseconds
- for 1 m distance, t = $6.7 \cdot 10^{-9}$ s = 6.7 nanoseconds

Note: we will work always inside far field zone, defining a minimum distance (d) for an antenna size (D):

$$d = \frac{2D^2}{\lambda} \qquad \textbf{(3.9.)}$$

3.3.5 Bandwidth

A pulse will be generated. More large in time is the pulse, less bandwidth will occupy. This pulse will occupy a narrow bandwidth (few MHz as maximum).

3.4 Previous design @ 2.4 GHz

Initially, we are going to study and build an experimental prototype made by:

- 4 antenna patch array
- Guidelines adapters
- SMA connector

Our first consideration is to work around WiFi band (2.4 GHz) frequency. We have found a project design that will serve as a guide[36]

It is a **broadside array** (the maximum is perpendicular to the array) because all the antenna paths are working with the same phase. The distance between antenna paths determine the "visible range" of the array, modifying it we can introduce o remove secondary lobes (we are going to work with *landa/2* distance). Sifting the phase of the antenna array, we could point the mean lobe of the array at the direction desired. At last, typically patch bandwidth is around 5%. Next antenna development will consider all those effects. A SAR scheme is included in Annexes (1.8).

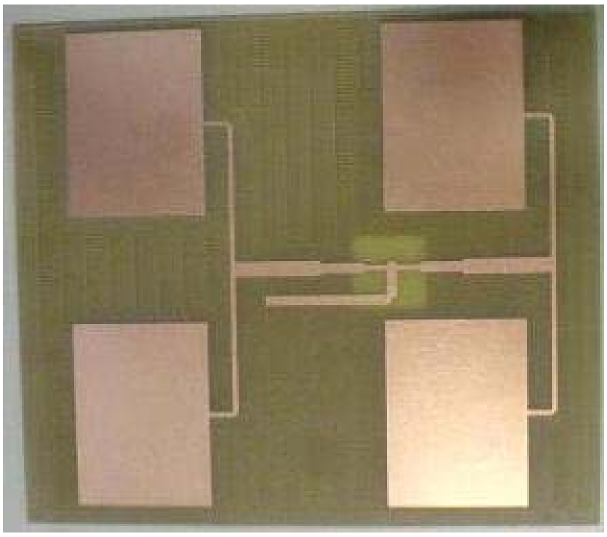


Fig. 3.3 PicoSAR front view

3.4.1 Microstrip calculations design @ 2.4 GHz

Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board (PCB) technology, and is used to convey microwave-frequency signals. It consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate. UPC technical services help us building PCB designed with *FreePCB* software.

[36] http://www.proyectoradio.com/

PCB important values:

$E_r = 4.7$
h = 1.507 mm
t = 0.015 mm

Patch Impedance:

This is the most important value in order to start a design. Generally, it's so difficult to obtain an exact value; I have spent a lot of time learning about it. Some books like *Balanis (bibliography [29])* talk about antennas features (I recommend it) and simulation software are useful for this purpose (ADS o HFSS), also there are some forums (em_talk and eda_board).

Typically, patch impedance values are 100-300 ohms. In our case, we simulated a patch with *ADS* and *HFSS* in order to be compared, obtaining an impedance close to 280 ohms with *ADS* and an impedance of 235 ohms with HFSS. An accurate laboratory work will be done in a future in order to find more accurate results.

Next, 4 patches simulations have been done, because patch impedance change due patches interactions when them work like an array (few lambdas distance between patches). We obtained an input impedance for any patch close to 250 ohms with *ADS*.

The single patch simulation was done feeding the patch with a 50 ohms lambda/2 line to 50 ohms wave port. Simulations are going to be detailed later.

Initial design doesn't consider an important concept. The patch impedance isn't equal on all patch points. It's higher at patch edge and decrease at center patch. Following graph shows it dependence.

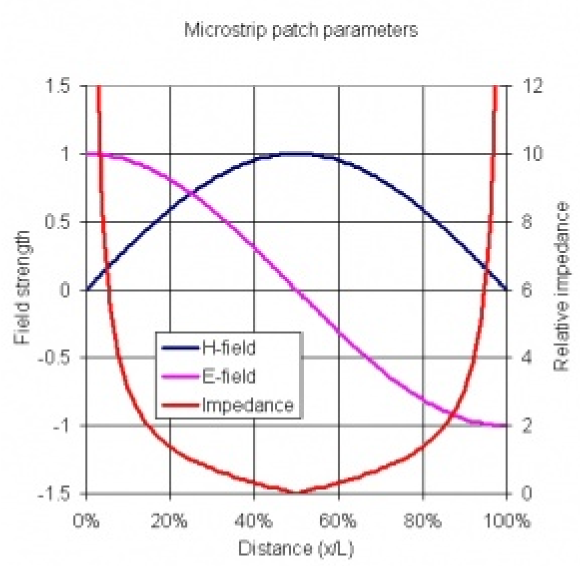


Fig. 3.4 Patch impedance depends on feeding position

Feeding patch with a coaxial it's a possibility, but for the final design we will prefer to modify patch shape with a microstrip feeding like below,

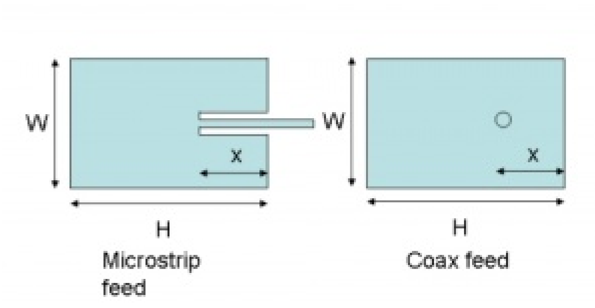


Fig. 3.5 Feeding possibilities

Line impedance:

We must obtain line impedances for determine final antenna input impedance. Some books show how to calculate it. But more efficient will be use different software available like *ADS* Line Calculator, included in ADS2006A. Besides the line impedance theory:

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2}$$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{ref}}}\ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right) \qquad \left(\frac{W}{h} \le 1\right)$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{ref}}}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right]^{-1} \qquad \left(\frac{W}{h} \ge 1\right)$$

Fig. 3.6 Microstrip line impedance

3.4.2 Simulating previous design @ 2.4 GHz

Now we know how theoretically and mathematically our design works, then we proceed to obtain more info working with different simulators (*HFFS*, *SuperNEC* and *ADS*). We will compare obtained results and discuss it after all. Look that now we only work with professional and commercial software, but we desire work with open source software. For that reason, we are studying a new option: *4Nec2*, an *open source* possibility.

Software features and capabilities are detailed below:

- **HFSS**: It is a complex simulator. We had never worked before with *HFSS* and a lot of time had required learning how it works. Specially, simulations with *HFSS* serve us to obtain images about radiation diagram, **E** field and Return loss for a single patch and final design. These simulations require a lot of time and an accurate work (around some hours)

- **ADS** (Advanced Design System, *Agilent* software): allows us to see scattering parameters (S parameters), obtaining important analysis values like VSWR and reflection coefficient with a relatively short execution time. It's common software used for circuit designs. Exactly, we work with *ADS2006A*. But like HFSS, it is a new software never used before

- **SuperNEC** (running with *Matlab* [28]): Allows us to see quickly radiations diagrams and how it change depending on feeding patches, applying different delays to any patch. Isn't very accurate but its main advantage is we have more experience working with it before at the university lessons

Single patch:

Below is a schematic of simulation realized and a 3D gain pictures for a single patch with HFSS. More pictures are included in Annexes (1.9 and 1.10) for a single patch simulation with HFSS and ADS software.

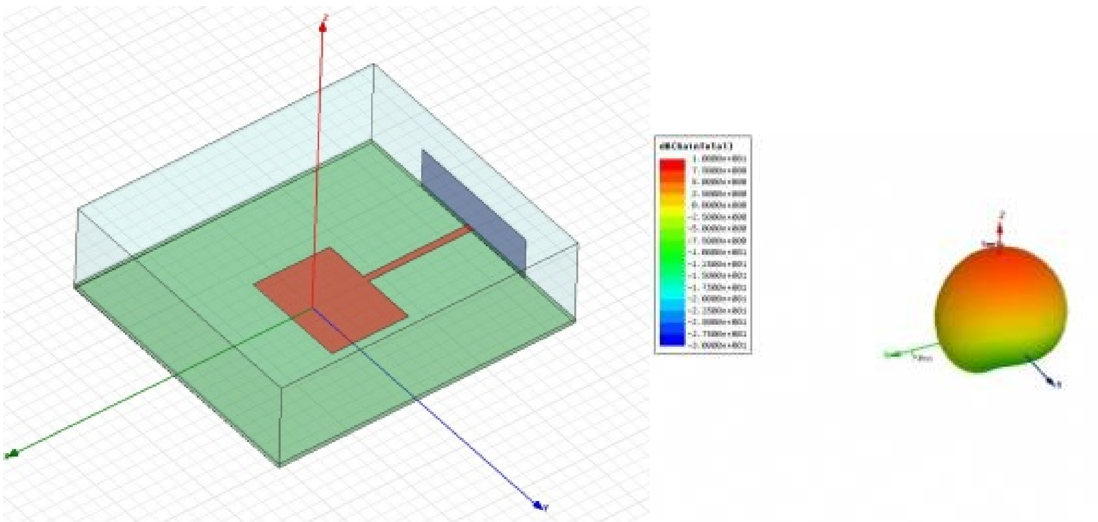


Fig. 3.7 Patch schematic and 3D Gain

Important conclusions from simulation, which has a line of length lambda/2 and impedance of 50 ohms:

- E field close to zero at centre patch
- Max. Gain= 6 dB (Beamwidth = 90 degrees)
- Return Loss (HFSS) = S_{11} = -3.8 dB (VSWR = 4.6, Z_{patch} = 230 ohms for a Z_{source} = 50 ohms)
- Return Loss (ADS) = S_{11} = -3.1 dB (VSWR = 5.6, Z_{patch} = 280 ohms for a Z_{source} = 50 ohms)
- Bandwidth is around few MHz

Four patches:

Below are four patches simulations with SuperNEC and ADS.

By one hand, the simulations with *SuperNEC*.

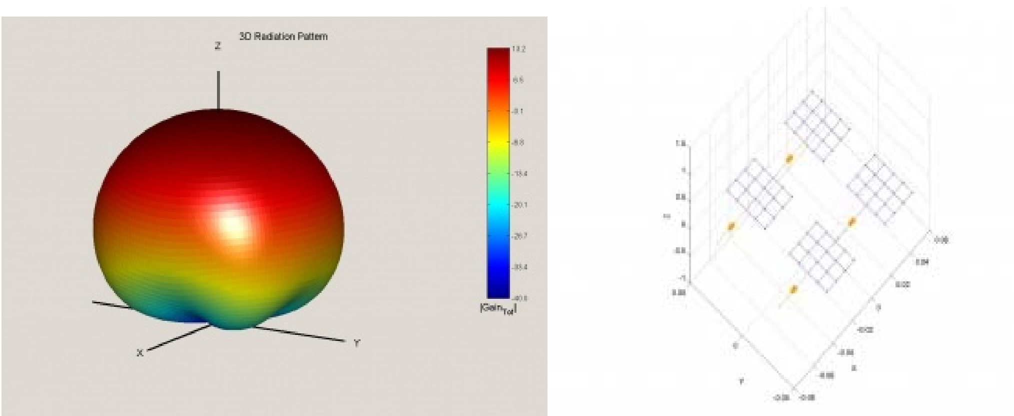


Fig. 3.8 Four patches radiation diagram and schematic

SuperNEC shows a 13dB maximum gain with a 44 degrees beamwidth.

By other hand, *ADS* simulations. At first, we simulated only 4 patches in order to obtain an input impedance for any patch. Important info obtained from these simulations (some screenshots in Annexes 1.11 and 1.12):

- S_{22} = -3.6 dB
- Z_{patch} = 240 ohms
- VSWR = 4.8

PicoSAR:

Now is the moment to simulate the complete system. *ADS* simulations aren't coincident with laboratory results for VSWR or Return Loss. We have to improve *ADS* design. A picture from layout measures is included Annexes (1.13). Some screenshots included in Annexes (1.14)

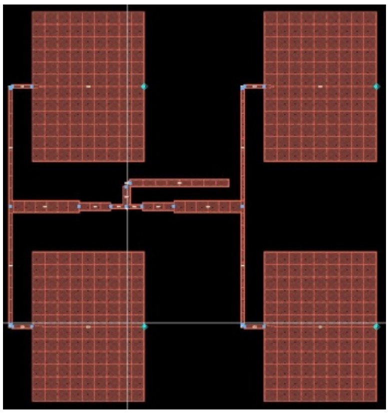


Fig. 3.9 ADS PicoSAR layout

Valuable info from *ADS* simulations:

- Operative frequency = 2.5 GHz
- Gain = 10.60 dB (perpendicularly to dielectric)
- Directivity = 10.40 dB
- Antenna radiation efficiency = 92%
- Antenna reflection efficiency = X %
- Antenna beamwidth = 60 degrees
- Effective area = 0.003 m2 (for antenna surface = 0.0126 m2)

Finally, from *HFSS* simulations below is a picture about antenna input impedance from 2 to 3 GHz. For our resonant frequency imaginary part is zero (blue line). Some screenshots included in Annexes (**1.15**).

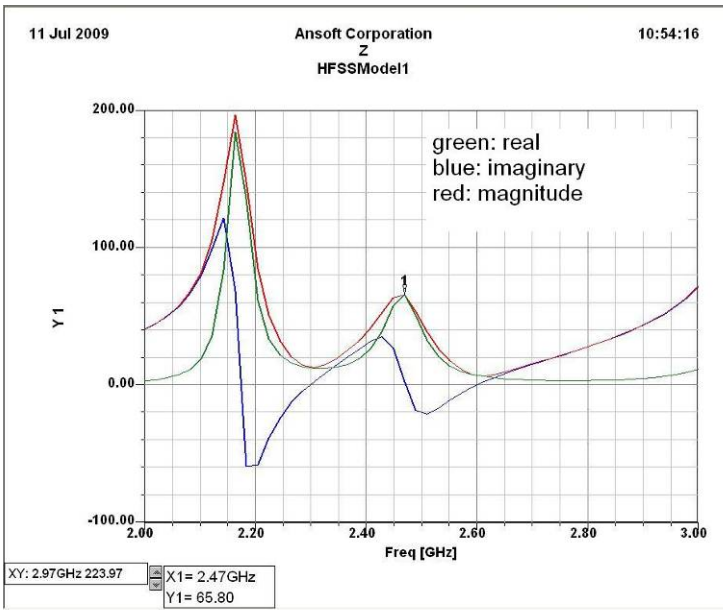


Fig. 3.10 PicoSAR input impedance

Conclusion from *HFSS*,

- Operative frequency = 2.47 GHz
- Directivity = 8.66 dB
- Gain = 6.83
- Efficiency = 80 %
- Z_{in} = 65.8 ohms
- VSWR = 1.33
- S_{11} = -16.94 dB
- Beamwidth = 60 degrees

3.4.3 *Testing previous design @ 2.4 GHz*

Tests must follow the TAP (Testing Antenna Protocol) self designed. It's a simply guide. This will allow us to do an accurate an easy to follow work.

Test 0: Receiving an unknown signal

Material requirement.

We need:

- SMA male to N male cable
- Bluetooth device (*Nokia 6210 classic*)
- PicoSAR
- Spectrum analyzer (*Agilent* up to 4 GHz)

Procedure showing the how to do.

This test is simply. Applying an electromagnetic source, the antenna will capture the signal and show it connecting to spectrum analyzer.

Results.

The noise level was in the -75 dBm as shows the Fig. 2. We have received some peaks near the 2.4 GHz only when the PicoSAR antenna is connected. The Fig. 3 shows the frequency of one of these peaks in -46 dBm. The Fig. 1 shows the function generator up to 4 GHz which is connected to the PicoSAR antenna with a SMA connector.

A table comparing available Bluetooth power classes has been included in Annexes (**1.16**).

Transmitted signal is out our bandwidth, at this frequency *our gain is under -40 dB.*

Test 1: Receiving a known signal

Material requirement.

We need:

- SMA male to N male cable
- Z340 transceiver (1 dBm output power)
- PicoSAR
- Spectrum analyzer (Agilent up to 4 GHz)

Procedure showing how to do.

This test follows test 0 idea. Now we apply a known electromagnetic source (1 dBm). The antenna will capture the signal and show it connecting to spectrum analyzer. Following we present some photos showing the testing process.

Fig. 3.11 Laboratory equipment, PicoSAR and eZ430

Results.

For 1 dBm maximum output power best signal we obtained was close to -22 dBm (channel 1). We can see the **eZ430** board two channels working on pictures included in Annexes (**1.17**).

We continue working out of range. **Our gain is under -20 dB** for the transmitting signal. That's an expected result.

Test 2: VSWR and antenna input impedance

Material requirement.

We need:
- SMA male to N male cable.
- SMA terminations: Open circuit, Short circuit and Adapted impedance (50 ohms)
- PicoSAR
- Spectrum analyzer (*Agilent* up to 4 GHz)

Procedure showing how to do.

This test is more complicated than previous. Before, we must calibrate our spectrum analyzer following instructions that appear on our screen. After that we connect our PicoSAR antenna and determine which is our VSWR for different frequencies.

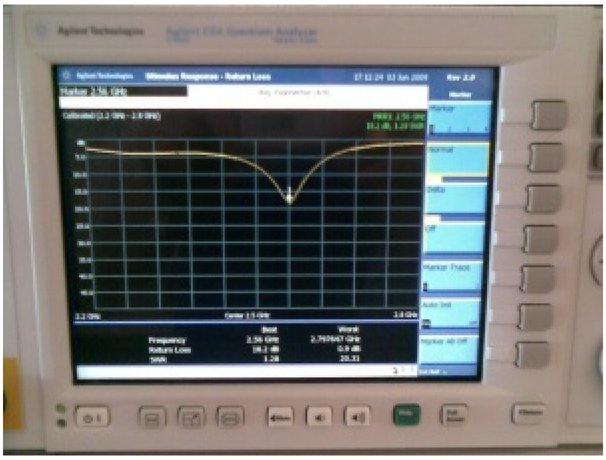


Fig. 3.12 PicoSAR VSWR measure

Results.

Our best antenna adaptation is close to 2.56 GHz (**antenna working frequency**) with a 1.28 value. This determines our input impedance:

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1+\rho}{1-\rho} \qquad \textbf{(3.10.)}$$

Obtaining an input impedance close to 64 ohms for a reflection coefficient close to 0.123:

$$\rho = \frac{Z_L - Z_S}{Z_L + Z_S} \qquad \textbf{(3.11.)}$$

Note:

- $\Gamma = -1$: maximum negative reflection, when the line is short-circuited
- $\Gamma = 0$: no reflection, when the line is perfectly matched
- $\Gamma = +1$: maximum positive reflection, when the line is open-circuited

In conclusion, we have a deviation for the antenna matching frequency. We design antenna to work between 2.4 GHz and 2.5 GHz but our best adaptation is for a 2.56 GHz signal. That doesn't very important for the previous PicoSAR design but must be considered for future designs. We *played* with the stub, modifying it appearance and obtaining non-remarkable info. **Our best input impedance is 64 ohms for a 2.56 GHz signal.**

Test 3: Two PicoSAR establishing a communication

Material requirement.

We need:

- Two SMA male to N male cables
- Two PicoSAR antennas
- Spectrum analyzer (*Agilent* up to 4 GHz)
- Function generator (*Agilent* up to 4 GHz)

Procedure showing how to do.

It's the definitive test we are going to realize. Now we apply a known electromagnetic source (0 dBm) at PicoSAR resonance frequency (2.56 GHz). One antenna will transmit the signal (a pulse) with a known input power and the other antenna (0.5 m, far field, losses close to 35 dB) will capture the signal and show it (maximum peak of –25 dBm).

Results.

The test was successful. **The antenna's gain is approximately 5 dB** when two antennas are face to face.

3.5 Future design

Now it's time to continue our work, applying concepts learned before. As you saw before, our previous design only can send and receive a pulse in octagonal direction. Now, different models can be modelled to define a new SAR design, more complex. That will serve us as first *terrain scanning* model working with some phase shifters. Different possibilities were simulated below to help us to decide about final design with SuperNEC. A 4x3 array has been simulated and a possible new substrate (PCB) was found. Some screenshots and PCB information included in Annexes (**1.18 and 1.19**).

Patch sizes will be for a 10,7 GHz working frequency (amateur frequency):

- W = 9.5 mm
- L = 6.4 mm

CHAPTER 4. SHIELD AND PAYLOAD ZONAL SUBSYSTEMS

4.1 Introduction

The system Pico-Rover is divided by three zonal subsystems (**Fig. 4.1**):

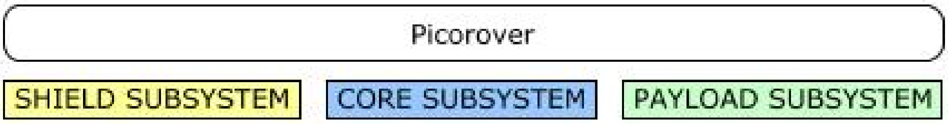


Fig. 4.1 Zonal subsystems

The SHIELD zonal subsystem is a set of exposed subsystems: power accumulating, terrain feeling, etc. and the PAYLOAD zonal subsystem a set of non critical subsystems but important for de mission: downlink transferring, recording, etc.

4.1.1 Shield zonal subsystems

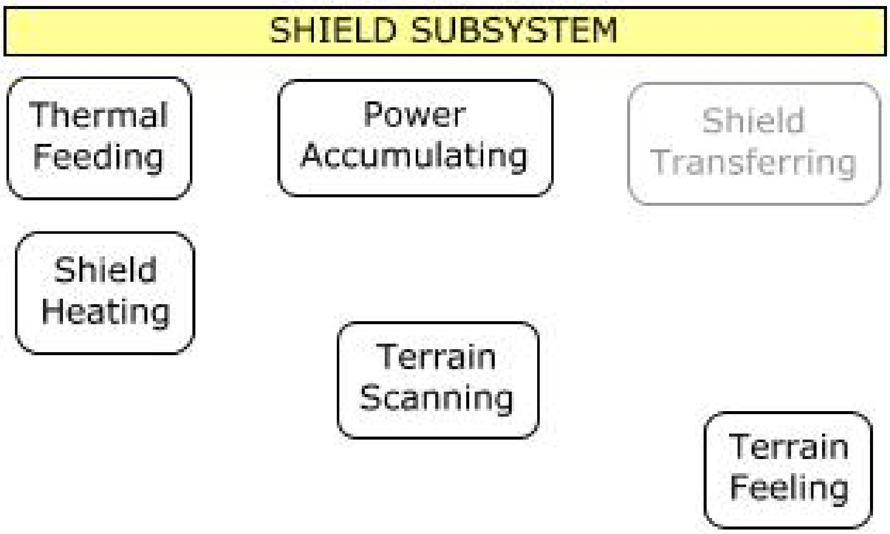


Fig. 4.2 SHIELD zonal subsystems

The functional subsystems for the SHIELD are:

- **Power Accumulating:** The Power Accumulating subsystem shall store electrical power temporally
- **Thermal Feeding:** The Thermal Feeding subsystem shall provide electrical power
- ***Shield Transferring*:** The Shield Transferring subsystem shall transfer electrical power between the Core and the Shield in both directions only if 2 degrees of freedom is implemented
- **Shield Heating:** The Shield Heating subsystem shall heat or cool the Shield
- **Terrain Scanning:** The Terrain Scanning subsystem shall provide a 3D shape of the terrain in front
- **Terrain Feeling:** The Terrain Feeling subsystem shall provide a footprint with the terrain

4.1.2 Payload zonal subsystems

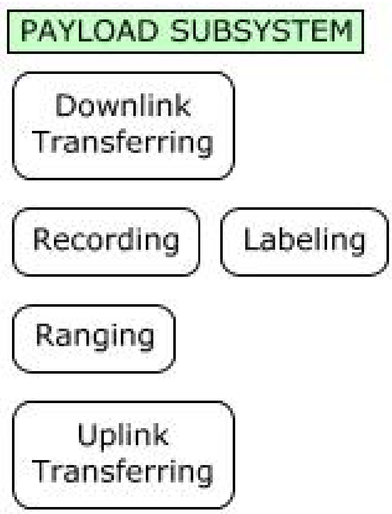


Fig. 4.3 PAYLOAD zonal subsystems

The functional subsystems for the PAYLOAD are:

- **Downlink Transferring:** The Downlink Transferring subsystem shall transfer near real-time streaming to the Lunar Lander
- **Recording:** The Recording subsystem shall provide high definition video on demand
- **Labeling:** The Labeling subsystem shall show the requested GLXP label
- **Ranging:** The Ranging subsystem shall determine the distance between the body system and one of the lunar vehicles as a reference
- **Uplink Transferring:** The Uplink Transferring subsystem shall receive the ground station secure commands and updates

4.1.3 Data Flow Diagram

In this section we present the component distribution using a data flow diagram (see Fig. 4.4) in order to have a global view of the subsystems of the Pico-Rover and the link with the Lunar Lander. No link with Lunar Bus has been considered in this diagram. In this diagram, a dashed line stands for radio-link. Between the CORE and the SHIELD zonal subsystems a radio-link is required due to the rotation of the Shield respect to the Core; this function is covered by the Transferring subsystem.

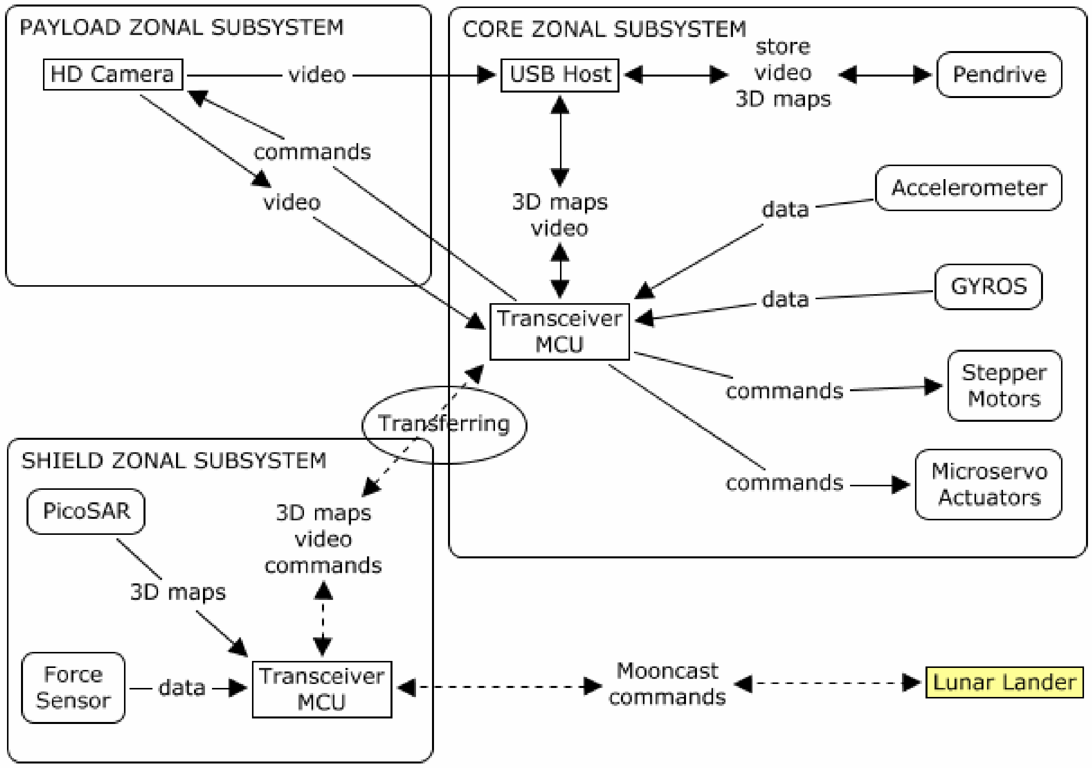


Fig. 4.4 Data flow diagram and relation between components

4.2 Component selection

In the following figure we present the selected component distribution using a data flow diagram. This diagram presents a global view of the subsystems of the Pico-Rover and the link with the Lunar Lander but no link with Lunar Bus has been considered.

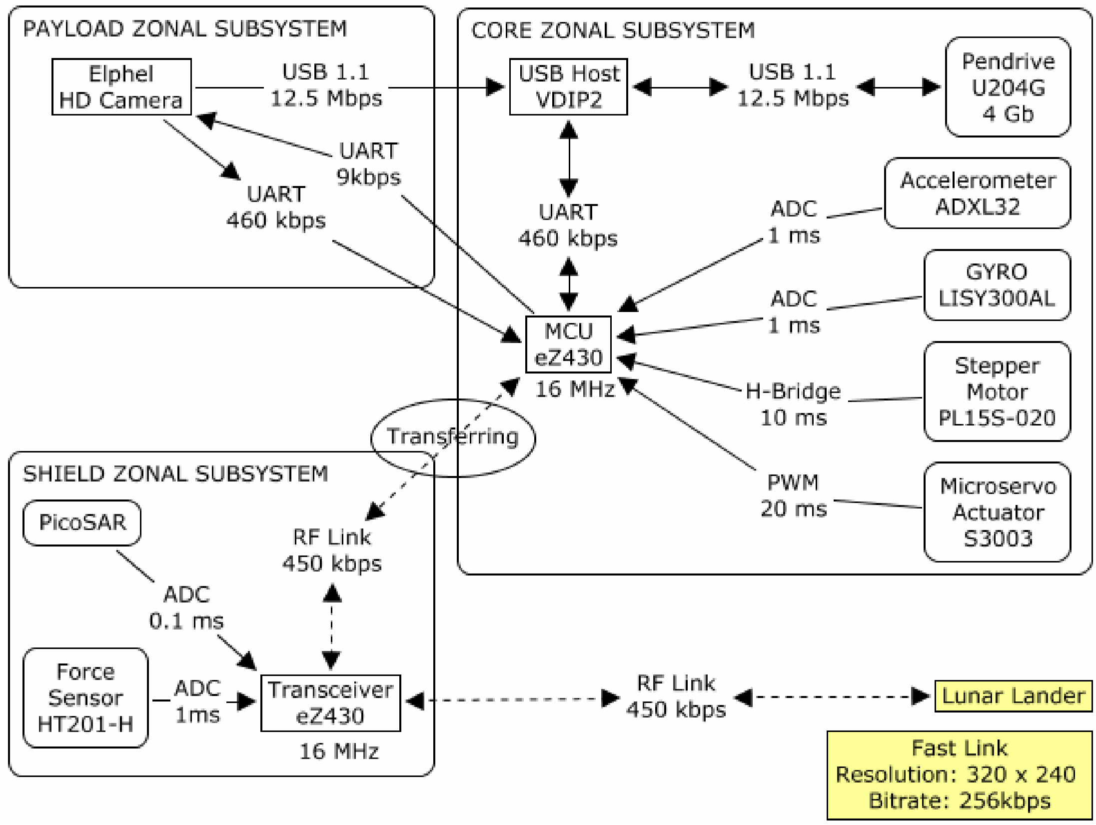


Fig. 4.5 Data flow diagram of selected components and related bandwidth

Notice that in the final design we use two transceivers (same model: eZ430) but in the *Demo1.3degrees* we use two transceiver in order to replicate the Lunar Rover and Lunar Lander schema.

4.2.1 Light weight capacitors: CL12

Capacitors have to provide enough electrical power in order to be transferred to the Core. The **CL12** capacitor has a small size and light weight.

4.2.2 Thermoelectric cell: G1-1.0-127-1.27

On the surface of the moon are great temperature changes. Employing the effect which *Seebeck* observed, thermoelectric power generators convert heat energy to electricity. The **G1-1.0-127-1.27** thermoelectric cooling module [21] manufactured by *Tellurex* can generate up to 1.5 W.

4.2.3 PicoSAR

The PicoSAR is a Synthetic Aperture Radar developed by the Pico-Rover group and has to be able of scan the terrain with a range of 30 meters and a resolution of 0.1 meters. See CHAPTER 3. PicoSAR for details. The **eZ430_RF2500** [30] will use it only if low range antenna isn't able to establish a communication.

4.2.4 Micro force sensors: HT201-H

Sensing allocation all around the contact perimeter in order to determine the Pico-Rover position and detect obstacles. We have two alternatives:

- **LPM562**: have a reduced size and weight, but temperature range is -11 to 40 ºC
- **HT201-H**: is bigger than **LPM 562**. The temperature range is -9 to 204 ºC which is in accordance with the thermal[37] test have done with the Pico-Rover Shield Test2

The **HT201-H** is bigger [24] than **LPM562** but your size and weight are valid. We don't choose the **LPM562** due to maximum temperature [27] is lowest than desired.

4.2.5 Transceiver: eZ430_RF2500

The transceiver receives ground station secure commands and firmware updates. In the other sense, the transceiver transfers to the Lunar Lander the near real-time streaming and telemetry. We look for a wireless transceiver as smaller as possible.
In first time we selected **DCBT-24AX** board because is so small and its bitrate is higher than others boards.

- Data rate: 2 Mbps or 1 Mbps
- Weight 1.28 grams
- Size 25 x 10 mm

We have tested this target and the results are not satisfactory. The data rate is not real because delay between adjacent packets is very high. Other problem is that the **DCBT-24AX** module has few accessible pins and development environment are not finished.

Finally, we have chosen **eZ430_RF2500** board. The **eZ430_RF2500** board [30] has a higher real data rate than the **DCBT-24AX** board but it has a bigger size. This module has 18 available development pins.

- Data rate: 500 kbps
- Weight: 2.7 grams
- Size 25 x 30 mm

[37] http://wiki.xprize.frednet.org/index.php/Picorover_Feasibility_Study#Vacuum_Test

4.2.6 HD Camera: Elphel 353HD

The HD Camera provides high definition video on demand. We have selected the **353 HD *Elphe*l** camera [19] because *Elphel* company is a Team FREDNET sponsor.

This camera have 5MPix sensor and it have some ports to connect with others devices.

4.3 Development short-range communication system

This is the subsystem responsible for the communication with Lunar Lander. We have divided the communication system in two subsystems:

- **Short-range communication subsystem:** High transfer rate required at least 100 meters from Rover to Lunar Lander in line of sight
- **Large-range communication subsystem:** Low transfer rate required updated at least ten seconds from Rover to Lunar Bus (100 km of directive zenith radiation, *power to be specified*). Radar antenna and nano-SAR band may be used for this purpose. Special band in the Lunar Bus required

Below 100 meters of distance between the Pico-Rover and the Lunar Lander, many different tasks have to be done than above. The short-range communication system has to be conformed to the minimum required for streaming the video called *Mooncast*.

The GLXP doesn't require any bandwidth. The GLXP requirements set a sufficiently high quality. A reference bit-rate is 256 kbps comes from knowledge about a recently developed proprietary codec based on **H.264** that probably runs in an *ASIC* or *FPGA*, combined with the motion profile and limited color space of a video recorded on the moon.

4.3.1 Component selection and tested

4.3.1.1 DCBT-24AX

We researched a component with features needed for design a little Rover and complete the lunar mission. The Pico-Rover has a very small volume inside and there is no place for large batteries. For this reason, all their elements have low consumption and size.

First of all we selected a very small device in order to develop the short-range communication system; it was the **DCBT-24AX** board as showed in **Fig. 4.6**.
The **DCBT-24AX** is an embedded transceiver using the *Nordic Semi* **nRF24L01** and *Atmel* **ATMega168 8-bit** MCU [7], with up to 2Mbps data rate.

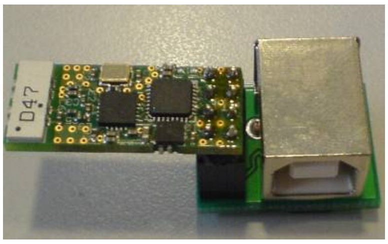


Fig. 4.6 The transceiver board DCBT-24AX

The more important features are:

Table 4.1 DCBT-24AX features

Size	25 x 10 mm
Weight	1.28 grams
MCU	8-bit RISC ATmega168
Transceiver	IC nRF24L01
Power supply	2.7 V to 5.25 VDC
Active supply current	17 mA
Frequency Worldwide	2.4GHz ISM band operation
Max Data rate	2 Mbps or 1 Mbps
Interface	SPI
Output Power	0, -6, -12, -18 dBm
Programming language	Assembler, C

We decided to order a development kit (which helps us to test it). It is able to be programmed with *C* or *Assembler* code. But all the libraries (to establish a communication with the transceiver) must be done in assembler code due *C* libraries are under development.

The first place, we have done a test to determine devices range using an example code. In this program module 1 starts sending (TX) and module 2 starts receiving (RX). When 248 bytes data is received, the same data is sent back and so forth, forever. Even if link was down for any time period, the sequence will always catch up and the cycle will continue. In addition, when RX module receives a packet, turn the LED on, if communication is down the LED stays off. Using this example we find the maximum distance that **DCBT-24AX** module established communication.

We start together closer in the street and increasing the distance between us. We reached up to 70 meters although we observed that 40 meters the module lost packets and communication is established again.

Once the test is done we have decided to work with an example provided with development kit. This will allows us to establish a communication with a PC. Unfortunately, this tests isn't finished (is under development by the provider).
Nevertheless, we work doing an assembler code to establish the *Arduino* to the **DCBT-24AX** board communication via SPI showed in **Fig. 4.7**. But when we implemented RF functions the module stop to work and seems to be into an infinite loop.

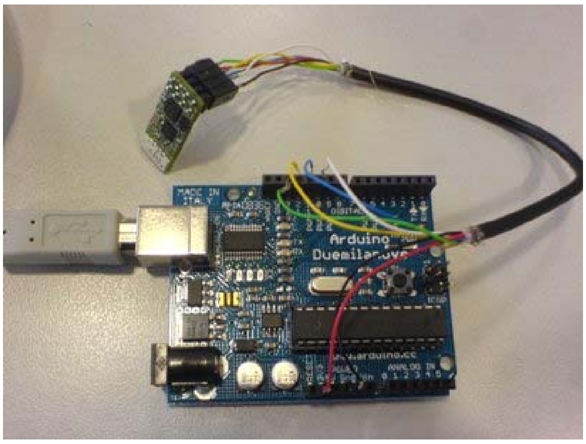


Fig. 4.7 Arduino-DCBT-24AX communication via SPI

We see in the development kit datasheet that the data rate is very low because delay between adjacent packets is very high. Using this module we can transfer 32 bytes every 0.9 ms what means a real bit-rate of 284 kbps.

We decided discard this wireless board because **DCBT-24AX** module has a small number of accessible pins, development environment are not finished, the data rate is low and we have lost one module which doesn't respond because the programmable pin is locked.

4.3.1.2 eZ430_RF2500

We look for a wireless board with good technical support and a good development kit and finally, we have chosen the **eZ430_RF2500** board [30] sowed in **Fig. 4.8**. We buy a kit consisting of two boards and an USB to transceiver adapter.

The **eZ430_RF2500** board is designed by *Texas Instruments (TI)*. This large company designs and manufactures semiconductor solutions for analogical and digital embedded and application processing.

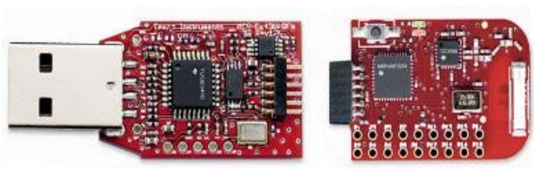


Fig. 4.8 eZ430_RF2500 evaluation kit board

The main features are:

Table 4.2: eZ430_RF2500 features

Size	25 mm x 30 mm
Weight	2.7 grams
MCU	16-bit RISC MSP430F2274
Transceiver	CC25000
Power supply	1.8 V to 3.6 V DC
Active supply current	18.8 mA
Frequency Worldwide	2.4GHz ISM band operation
Max Data rate	500 kbps
Interface	2 UART, 18 development pins
Output Power	-30 to 0 dBm
Programming language	Assembler, C

The **eZ430_RF2500** is a complete USB-based **MSP430** wireless development tool providing all the hardware and software to evaluate the **MSP430F2274** microcontroller and **CC2500** 2.4 GHz wireless transceiver [11]. The **eZ430_RF2500** uses the Code Composer Essentials (CCE) to write, download, and debug an application. The **eZ430_RF2500** target board is an out-of-the box wireless system that may be used with the USB debugging interface or as a stand-alone system.

In the development kit CD find every examples for learn to programming **MSP430** MCU and *SimpliciTI* tool [37]. *SimpliciTI* is a set of libraries and examples for controller the **CC2500** transceiver with **MSP430** CPU.

Before testing the board, we have written some programs in order to have an initial contact with the board and the development kit. We try to learn about the MCU peripherals (Timers, UART, ADC10, Temperature sensor, etc.) which will used in the Pico-Rover.

After test the MCU peripherals we have written a RF module test program. For do the test it is necessary three modules.

- **eZ430_RF2500** in a stand-alone system: it is a **LinkTo** device. It establishes communication and sends the packets. We have established 0 dBm to power output
- **eZ430_RF2500** with the USB debugging interface: it is a **LinkListen** device. This device receives the packets.
- PC (laptop): show the test results

This program is based upon sending a packet, with its sequence number; every 1 ms. The reception module (**ListenTo**) received the packets with its sequence number and calculate the received and lost packets. Finally, the PC program sends a request count packet message and show results in a table.

The sequence diagram is:

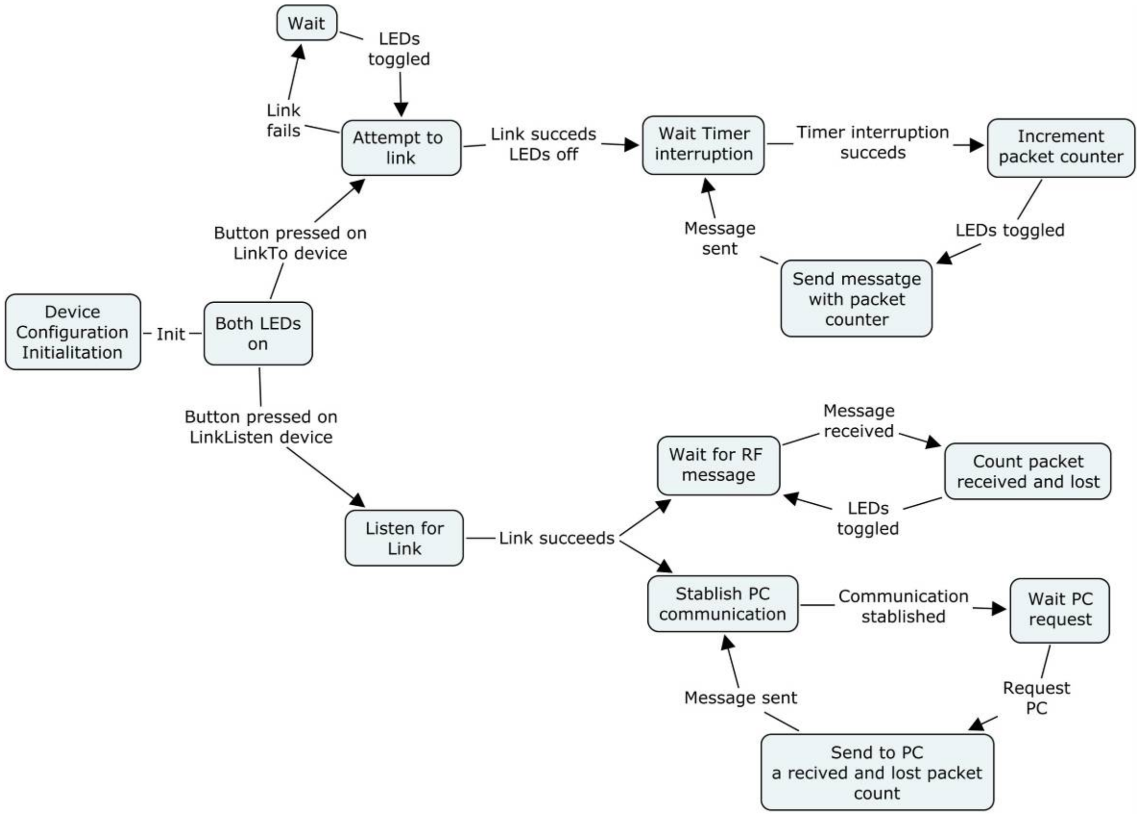


Fig. 4.9 Sequence diagram program test

We have done two radio-link tests in order to achieve the maxim communication distance. In both tests, the output power is configured at 0 dBm and **LinkTo** Device send packets during 45 seconds.

- **eZ430_RF250 test 1:** This test we have done in a street with few people. Two RF modules start together and increasing the distance between them. The **LinkTo** Device position can be seen in **Fig. 4.10**. The device is connected to the side of the batteries and the antenna is oriented towards the PC

Fig. 4.10 eZ430_RF2500 in a stand-alone system

Results can be seen in the graph below (**fig. 4.11**):

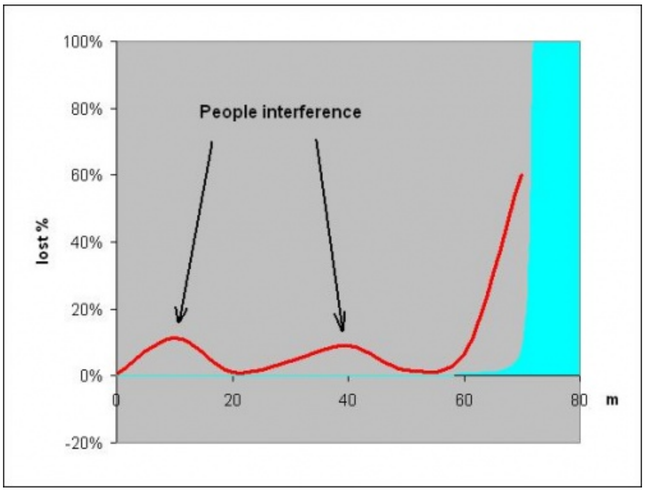


Fig. 4.11 Test 1. Percent lost packages vs distance

- **eZ430_RF250 test 2:** We have done this test in a clear street. The same manner as test 1, two RF modules start together and increasing the distance between them. This time the **LinkTo** device position (**Fig. 4.12**) was different that the **LinkTo** device position in test 1; see **Fig. 4.10**

Fig. 4.12 eZ430_RF2500 in a stand-alone system

The results can be seen in the graph below in **Fig. 4.13**:

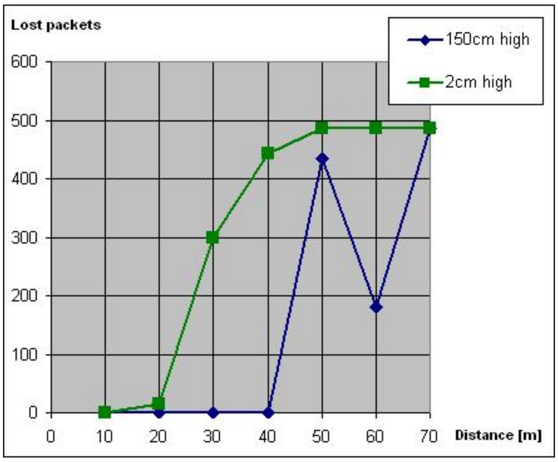


Fig. 4.13 Test 2. Lost packages vs distance in meters and antenna high

Both tests show a range without lost packages. Beyond a distance tests show exponentially degradation in performances. Communication is sensible to surrounding obstacles and especially to the antenna high. This effect is due to the so called *Fresnel Areas* [38] which in a line of sign any obstacle inside these areas affects to the transmission performances.

Test2 shows a high number of lost packages at 50 meters of range but it recovers in 60 meters, like Tes1 does. Any test was done many times in order to diminish procedure errors like sporadic interferences or occasionally echoes. When the battery was near the antenna we lost about 15 meters of maximum range.

4.3.2 Development with eZ430_RF2500

Soon test are done, and validated the subsystems, we generate the main program for the Demo1.3degrees prototype. The aim of the program is to control the pitch angle of the counterweight what it produces a thrust. For this reason we called this pitch angle as thrust angle. The laptop, which works as a role of the Lunar Rover, it can read the telemetry consisting of: Temperature and XYZ accelerations. The laptop can emulate the remote control functionality sending the desired thrust angle.

The Pico-Rover transceiver sends the telemetry. When the telemetry is received by the Lunar Rover, it responds with a set of remote commands. Hence, if the Pico-Rover doesn't receive the response it means that the communication is lost due to an obstacle or is out of range. This event could be translated to the imminent autonomous mode.

[38] http://en.wikipedia.org/wiki/Fresnel_zone#Determining_Fresnel_zone_clearance

The Pico-Rover program has to control the stability of the thrust angle. The attitude angle works similar to the thrust angle but in the lateral axis.

The sequence diagram for the Pico-Rover (using only one eZ430 transceiver) is as follows:

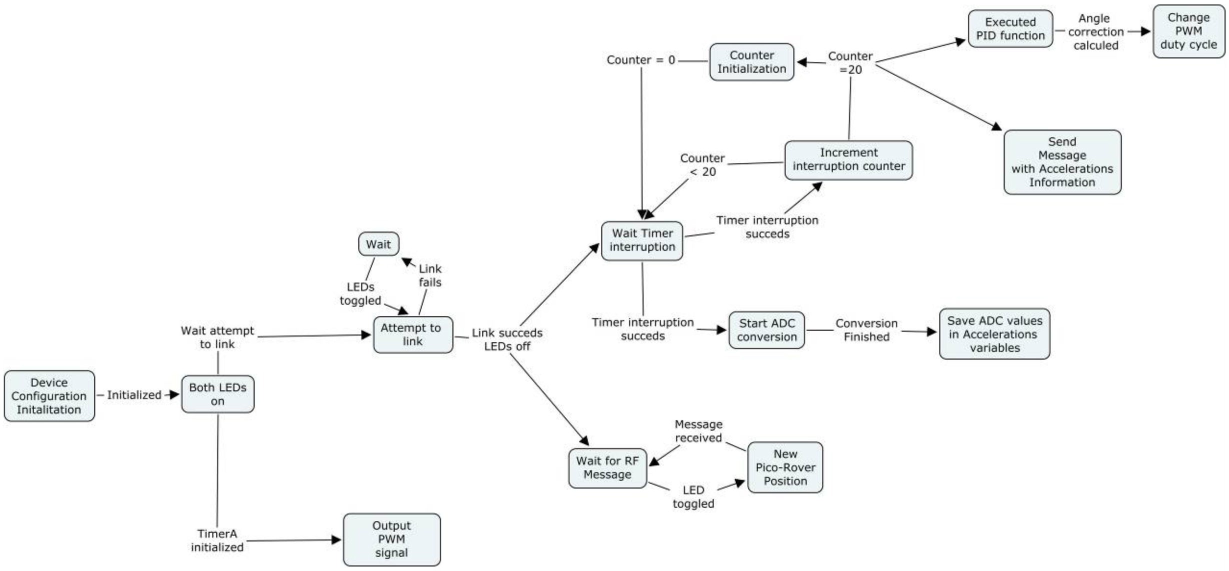


Fig. 4.14 Sequence diagram for Pico-Rover

The sequence diagram for the laptop, which works as Lunar Lander, is as follows:

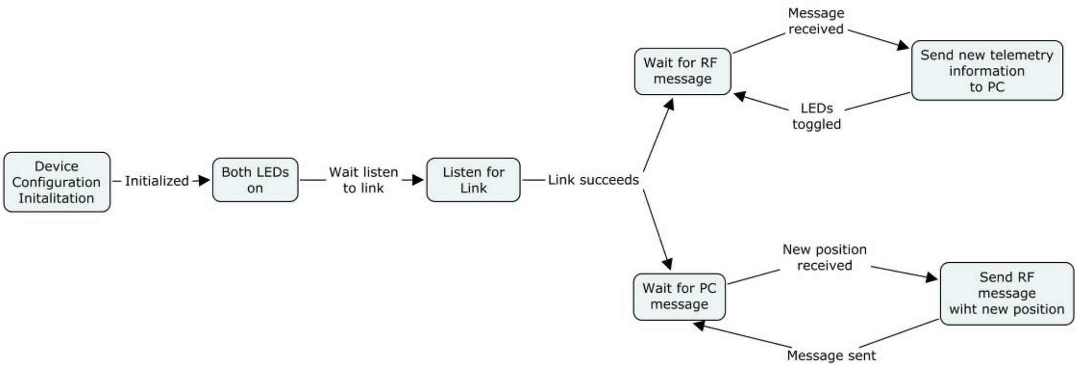


Fig. 4.15 Sequence diagram for PC module (Lunar Lander)

CHAPTER 5. CORE ZONAL SUBSYSTEMS

5.1 Introduction

The system Pico-Rover is divided by three zonal subsystems (Fig. 5.1):

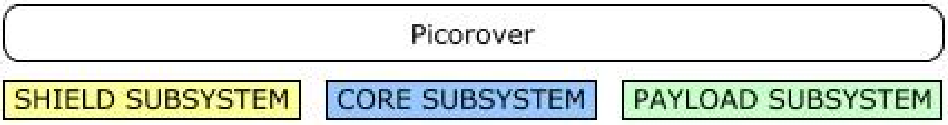


Fig. 5.1 Zonal subsystems

The core zonal subsystem (Fig. 5.2) is a set of critical subsystems in order to survive: power storing, temperature sensing, data storing, processing, etc.

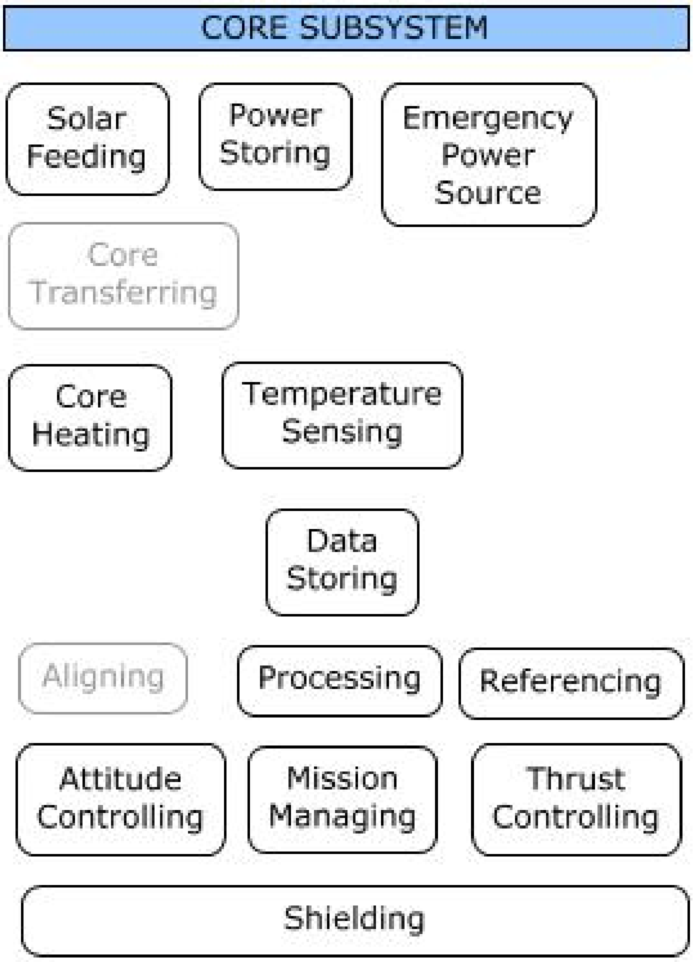


Fig. 5.2 CORE zonal subsystem

The functional subsystems for the CORE are:

- **Solar Feeding:** The Solar Feeding subsystem shall provide electrical power
- **Power Storing:** The Power Storing subsystem shall provide electrical power in case of no power feedings is available
- **Emergency Power Source:** The Emergency Power Storing subsystem shall provide electrical power in case of no power feedings is available and Power Storing is empty
- **Core Transferring:** The Core Transferring subsystem shall transfer electrical power between the Core and the Shield in both directions only if 2 degrees of freedom is implemented
- **Core Heating:** The Core Heating subsystem shall heat or cool the Core
- **Temperature Sensing**: The Temperature Sensing subsystem shall provide the chassis temperature
- **Data Storing:** The Data Storing subsystem shall store the streaming from the Recording and the Terrain Scanning
- **Aligning:** The Aligning subsystem shall detect the alignment between the Core and the Shield only if 2 degrees of freedom is implemented
- **Processing:** The Processing subsystem shall attend in real-time all the calculations
- **Referencing:** The Referencing subsystem shall provide the angular rate and the acceleration in the 3 axes of the body system
- **Attitude Controlling:** The Attitude Controlling subsystem shall maintain the roll angle in order to steering the body system
- **Mission Managing:** The Mission Managing subsystem shall configure the system in function of the mission phase
- **Thrust Controlling:** The Thrust Controlling subsystem shall maintain the pitch angle in order to drive the body system
- **Shielding:** The Shielding subsystem shall protect from radiation the critical components

5.1.1 Data Flow Diagram

In this section we present the component distribution using a data flow diagram (see Fig 5.3) in order to have a global view of the subsystems of the Pico-Rover and the link with the Lunar Lander. No link with Lunar Bus has been considered in this diagram. In this diagram, a dashed line stands for radio-link. Between the CORE and the SHIELD zonal subsystems a radio-link is required due to the rotation of the Shield respect to the Core; this function is covered by the Transferring subsystem.

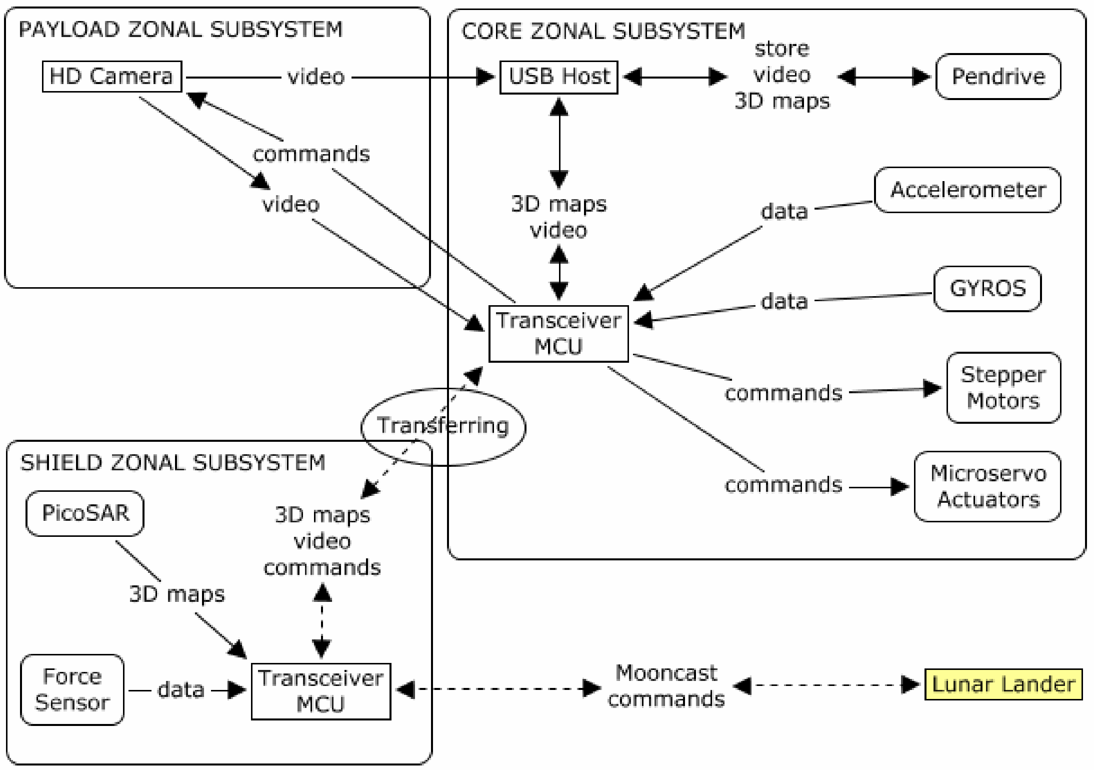


Fig. 5.3 Data flow diagram and relation between components

5.2 Component selection

In the following figure we present the selected component distribution using a data flow diagram. This diagram presents a global view of the subsystems of the Pico-Rover and the link with the Lunar Lander but no link with Lunar Bus has been considered.

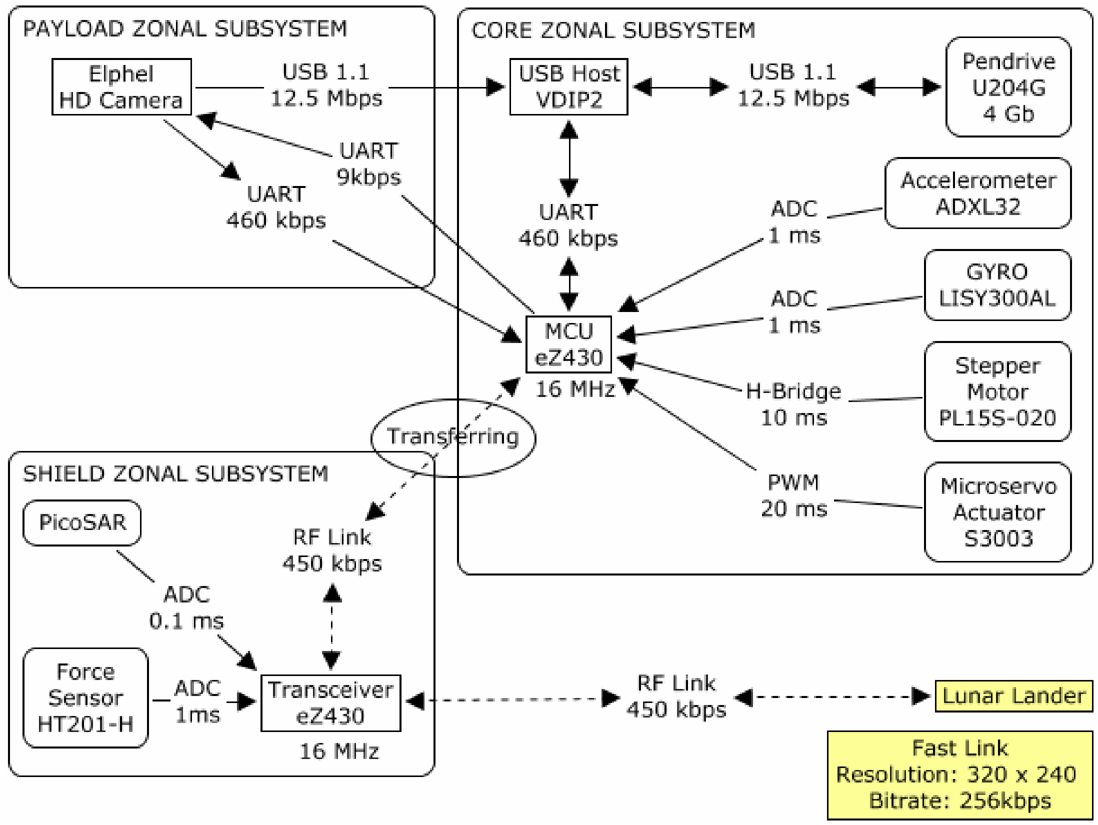


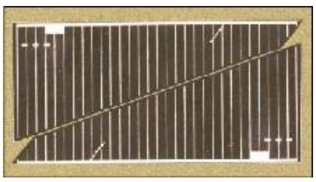
Fig. 5.4 Data flow diagram of selected components and related bandwidth

Notice that in the final design we use two transceivers (same model: eZ430) but in the *Demo1.3degrees* we use two transceiver in order to replicate the Lunar Rover and Lunar Lander schema.

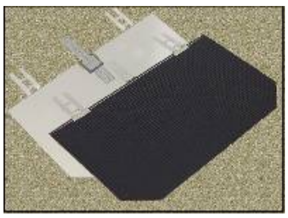
5.2.1 Solar cells: TASC27

A solar cell or photovoltaic cell is a device that converts light directly into electricity by the photovoltaic effect. Although we have found the **TNJ3**, a better solar cell than the **TASC27**, we discarded due the size. Based on ITAR regulations, *Spectrolab*[39] only exports outside U.S. large amounts. Solar cells became too large and we chosen Azurspace[40] (Germany) as preferred provider.

The two alternatives are:



- **TASC27** [39] *Spectrolab*
  - Efficiency: 27%
  - Size: 1.55 x 3.18 cm
  - Weight: 102 mg/cm^2



- **TNJ3** [40] *Spectrolab*
  - Efficiency: 28.3%
  - Size: 32 cm^2
  - Weight: 84 mg/cm^2

39 http://www.spectrolab.com/DataSheets/TNJCell/utj3.pdf
40 http://www.spectrolab.com/DataSheets/PV/PV_NM_TASC_ITJ.pdf

5.2.2 Power Storing: ANR26650

This is a power system for survive one lunar night. The batteries should rechargeable. We have chosen an **ANR26650** because we found that the power Storing-Weight relation is better than others [5].

The more important characteristics are:

- Nominal voltage: 3.3 V
- Nominal capacity: 2.3 Ah
- Height: 66.5 mm
- Diameter: 26 mm
- Weight: 70 g

5.2.3 Emergency Power source: CR2477

This is a power system for survive one lunar night when the power storing subsystem fail. It supplies some power so that the MCU is turned on at low power until the day is done. We chose a **CR2477** lithium coin battery. This battery is not rechargeable.

The more important characteristics are:

- Nominal voltage: 3 V
- Nominal capacity: 1 Ah
- Height: 7.7 mm
- Diameter: 24.5 mm
- Weight: 10.5 grams

5.2.4 Thermoelectric cell G1-1.0-127-1.27

Is the same component explained in 4.2.2 point but having a different function. In this case we use the **G1-1.0-127-1.27** cell [21] in order to cool the CORE.

5.2.5 Temperature sensor: MCU sensor

This component has evolved due to the selection of other components. In first time we chosen use a temperature sensor is in IMU, but the IMU was discarded.

How the transceiver board have a one temperature sensor, finally we have decided use this sensor. The range operation is -50 to 100 ºC

5.2.6 USB pen-driver: KU204G

The USB pen-driver stores the streaming from the Recording and the terrain scanning. To select the components we have looked for a smaller memory possible. The **KU204G** is a 4 Gbytes USB memory and its size is 12.4 x 34.3 mm.

5.2.7 Host USB Controller: VNC1L

For read and write in memory we need a master USB and the selected MCU have a slave USB interface.

The **VNC1L** USB Host Controller ICs [43] not only handle the USB Host Interface, and data transfer functions but owing to the inbuilt 8/32-bit MCU and embedded Flash memory, **VNC1L** encapsulates the USB device classes as well. When interfacing to mass storage devices such as USB Flash drives, **VNC1L** also transparently handles the FAT file structure communicating via UART, SPI or parallel FIFO interfaces via a simple to implement command set.

For test this component we have bought a **VDIP2** development board.

5.2.8 MCU: C8051F340

Selected CPU [8] for final Pico-Rover design differs from CPU used in *Demo1.3degrees*. For this demo, we reuse MCU provided into **eZ430_RF2500** board. We try to check if the transceiver MCU is enough for our purposes; if not we will use any selected component. One possibility could be **C8051F340** (*Silicon Laboratories Inc.*) but we prefer the **MSP430F430F2274**.

Some **C8051F340** MCU characteristics are:

- Nominal voltage: 3.3 V
- Current: 18 mA
- RAM memory: 4352 bytes
- Flash memory: 64 kb
- I/O port (5 V): 40 ports
- 10-bit ADC (200 kbps): Up to 17 external inputs
- Comparator: 2 units
- Built-in temperature sensor: 1 sensor
- CPU clock: 24 MHz
- Size: 9.00 x 9.00 x 1.20 mm
- Temperature Range: -40 to +85 ºC
- Weight: 1.8 grams

5.2.9 IMU: ADXL32 and LISY300AL

In the first place, to acquire the angular velocity and accelerations we selected an IMU (**GYROCUBE3A** [22]), but due distributor problems **(5.4.1)**. After that, we didn't found any other device with similar characteristics, so we decided to self design a prototype able to be implemented in *Demo1.3degrees.* By one hand, we built a PCB design soldering an accelerometer, but due its small size and pins disposal, this possibility was finally rejected. By other hand, the acquisition of a complete accelerometer and gyroscope system was accepted. As an accelerometer device, we ordered **ADXL32** (±18 G, analogical output [2]). As a gyroscope device we ordered **LISY300AL** (±300 º/sec).

5.2.10 Stepper Motor: PL15S-020

It is the implemented Attitude Controlling device. This has been extracted from CD device [33] (reusing waste). Some tests have been done successfully. Some features:

- Size: D15.0 (x10.9) x 67.0 mm
- Weight: 7 grams
- Voltage: 5.0 V
- Current: 400 mA
- Step angle: 21.7 degrees
- Pitch: 4.5 mm x 10 turns
- Pitch error: 0.020 mm per turn
- Torque: 30×10^{-4} N·m

5.2.11 Servo-Motor: Futaba S3003

It is the implemented Thrust Controlling device. Servomotors can be characterized by its high torque. This motor only will be used for *Demo1.3degrees* due it is built using plastic.

More important features are:

- Speed: 0.23 seg/60 degrees (260 degrees/seg)
- Torque: 3.2 Kg·cm (0.314 N·m)
- Size: 40.4 x 19.8 x 36 mm
- Weight: 37.2 grams
- Frequency PWM: 50Hz (20ms)
- Rotation range: 180º

5.3 Development of a CORE zonal subsystem

In order to realize some tests inside the Pico-Rover, we implemented an initial demo version (called *Demo1.3degrees*). This first version includes some subsystems like “Thrust Controlling” and “Temperature Sensing” (**Fig. 5.5**). The Attitude Controlling isn’t developed yet, so we decided don’t implement it in initial design by the moment. The basic architecture uses two transceivers to replicate the Lunar Rover to Lunar Lander schema.

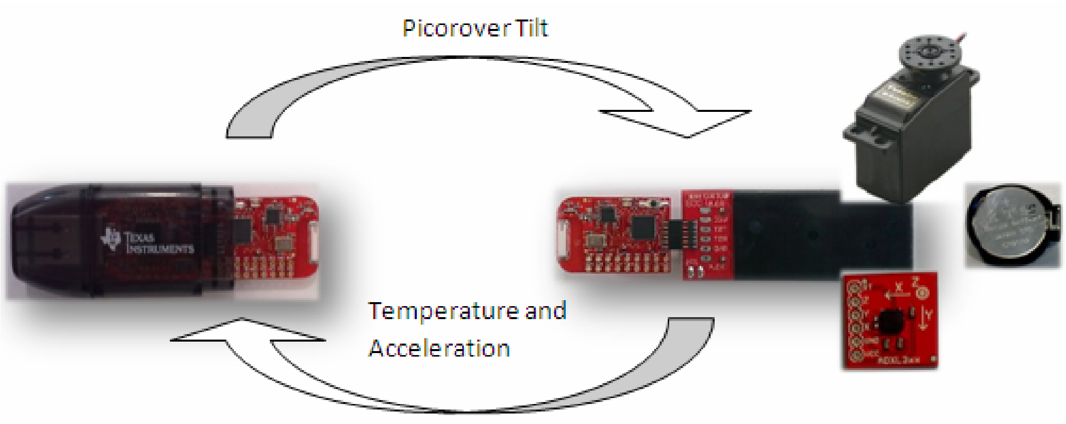


Fig. 5.5 Demo1.3degrees diagram

Therefore, elements included in tests are:

- Motors (stepper motor and servo-motor)
- Sensors (temperature and acceleration)
- Batteries

5.3.1 Component selection and test

5.3.1.1 Motors

Motors are a critical component. For this reason, we have done different tests with different models studying them advantages and disadvantages in order to find the best solution to our requirements.

Initial versions of Demo1.3degrees use DC motors we reused a radio-controlled aircraft device. In consequence, these motors were difficult to control achieving high velocities and some difficulties to hold the desired position. As a consequence, we focused our next development based on stepper motors; also called step by step motors.

These motors offer a high precision control. Like before, we reuse the motors from another device, now from a CD reader. Inside a CD reader we found two

different models as we can see in the Fig 5.6; one is for the **Thrust Subsystem** and the other for the **Attitude Subsystem**.
Both are bipolar motors (these have a single winding per phase). The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement.

Fig. 5.6 Stepper Motors

We started searching a H bridge implemented in a chip, offering the best performance with a low size requirement. We decided to use the IC **L293D**.
Some features [26]:

- Supported current up to 600 mA (500mA required)
- Protection diodes (reducing components requirements)

A test was done using Arduino board. Arduino is a hardware platform, easy to use, with some inputs and outputs. It works with an environment for development called “Processing/Wiring”.

The H-Bridge and the motors needed a 4.5 volts feeding. Hence, we decided to feed the circuit via three batteries (**AAA**), of 1.5V everyone, due the controller (**eZ430_RF2500**) must be fed with 3.3 volts.

We did a simple program establishing a first contact and testing its strength. By one hand, the centered axis cylinder motor we have found a datasheet. By other hand, nothing datasheet was found for sensor motor. With this program we selected angular velocity (two possibilities, 100 or 10 steps by second)

Conclusions from builder’s available info and tests done:

Centered axis cylinder motor:

- Works well at low and high velocity
- High response velocity
- Good torque-size relation
- Good turn precision (has 20 positions by turn having a small size)
- It’s a good solution for Attitude Controlling

Sensors motor:

- For lowest velocities has a synchronization problem
- Need a progressive velocity increasing
- Torque available doesn't work well when Pico-Rover is built (Thrust Controlling fails)
- Not implemented in final design (due above conclusions)

Now, we have to found another motor for the Thrust Controlling subsystem. Our next step is achieved by a servo-motor which provides a high strength but a low turn velocity.

These motors need a PWM signal to be controlled. The PWM allows easily maintain a desired position. Its working range is around 180 degrees usually but modifying its internal circuit we could reach a 360 degrees movement.

In order to realize the "*Demo1.3degrees*" we selected a *Futaba* type **S3003** (**Fig. 5.7**) servomotor. This motor only works well in typical temperatures (25º C) but due its building materials doesn't supports low or high temperatures. Also a feeding is required.

Fig. 5.7 Futaba type S3003 servo-motor

This motor requires a 4.5 volts feeding. For that reason, we provided it with an independent source. A simple program was done to verify the motor and learn to program a PWM inside one board timer. In this program, *TimerA* generates the PWM signal and *TimerB* modify the motor position (0, 90 and 190 degrees cycle).

We concluded this motor isn't able to Demo1.3degrees due its low strength, big size and slow velocity.

5.3.1.2 Acceleration and Temperature sensors

In the first place, an IMU acquisition was decided.

An IMU works by sensing motion including the type, rate, and direction of that motion and using a combination of accelerometers and gyroscopes. After mature consideration, GYROCUBE3A [22] by *O·Navi* (Fig. 5.8) was our option.

Fig. 5.8 GYROCUBE3A board

These device measure accelerations up to ±10 g and an angular velocity up to ±400 °/sec.

But a big problem was found. This is a high technology device, and due USA laws, these devices can't be sent out of the USA. They consider these devices dangerous to be sold based on ITAR regulations. For that reason, we restart our IMU search, but without success.

Finally, a 3-axis low-consumption accelerometer [36] was acquired (**SCA3000-E05**). This device works with SPI interface. A PCB was done with FreePCB software (25 x 30 mm). UPC Technical Services built it in a few days (**Fig. 5.9**).

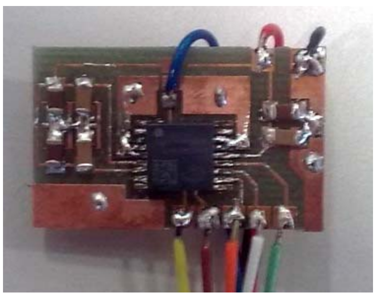


Fig. 5.9 Board with SCA3000-E05 accelerometer

Some tests were did working with Arduino board. We did a simply program to connect it, and no info were obtained from this device (communication fails). After a mature consideration, we concluded the device wasn't well soldered. This device is hard to be soldered due pins position (device's backside). Also, its encapsulated was so sensible to high temperatures, doing the soldering process hard to be done.

As a last option, we have bought a definitive device which implements accelerations measures (analogical output). The device is an ADXL32 (Fig. 5.10) which incorporates three axis accelerations [2] measures up to ±18 g.

It is a good device and the tests were successful. With the accelerometer, a gyroscope was bought and will be used into a future *Demo1.3degrees* design

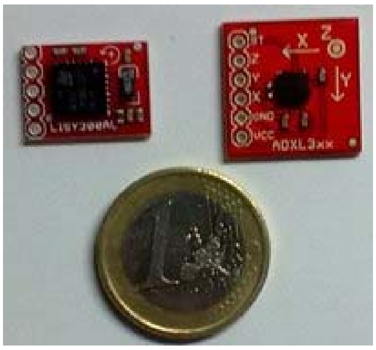


Fig. 5.10 From left to right, The Gyro and the Accelerometer Breakout Board

To verify the board a program was done with eZ430_RF2500. In this program via ADS pins we can read the measured accelerations.

Program a timer or temporizer, which execute a routine every millisecond. This routine demands ADC conversion, deploying this info into a buffer. Debugger tool shows us conversion process.

Finally, we decided use ADXL32 board as accelerometers sensor and eZ430_RF2500 as a temperature sensor

5.3.1.3 *Batteries*

As a first idea, we feed the Demo1.3degrees with a single 3 volts battery. Due all motors found need a great volts supply, an initial option was implemented. A dual feed system has been done connecting 3 AAA batteries (providing 3 and 4.5 volts depending feeding position). When the tests were done, a problems was found. Both devices feeding requirements were higher than feeding available. Due this problem, the eZ430_RF2500 was resetting itself.

In order to solve this problem, we developed two independent feedings. One with three AAA batteries (4.5V) and the other with a CR2032 battery (3.5 volts, reused from a PC motherboard unused).

5.3.2 Development Demo1.3degrees

Once we have all the components ready to be implemented, we have to assemble them.

Finally, used components are:

- A *Futaba* S3003 servomotor. It is the weight position controller (which allows us to move the rover)
- Two eZ430_CC250. One connected to the PC and the other connected to the *Demo1.3degrees* transmitting sensors information, system control and temperature
- An ADXL32 accelerometer
- Three AAA batteries (1.5 volts)
- One CR2032 battery (3 volts)

Hence, connecting devices follow the next diagram (Fig. 5.11):

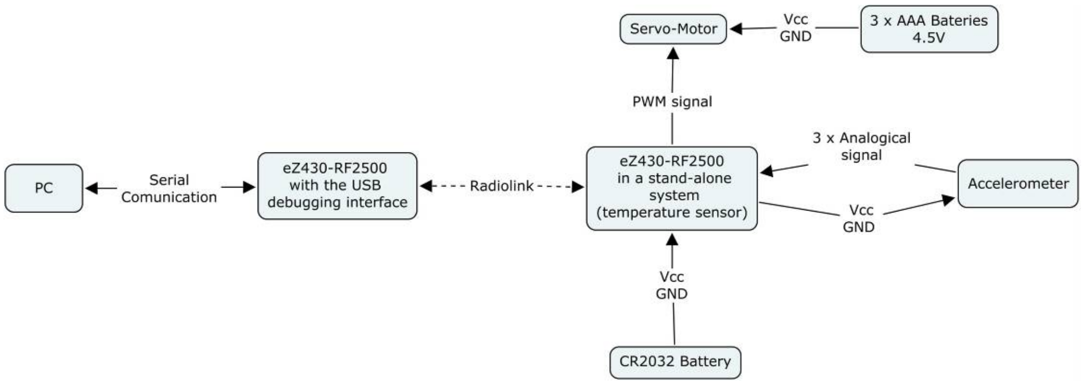


Fig. 5.11 Diagram for the prototype *Demo1.3degrees*

The final design is presented in **Fig. 5.12** for the *Demo1.3degrees*:

Fig. 5.12 Some CORE and SHIELD zonal subsystems implementation

CHAPTER 6. Conclusions

Working with Team FREDNET has showed us how aeronautical industry works, its actual situation and what kinds of problems are actually under study. Furthermore, we are learning about self project guiding, doing things we could be more efficient according to team necessities. Also, the necessity of publicity the work done, practicing with Wiki posting procedure. But, some problems like eventual a bad eventual team information, insufficient work leaders, collaborators or resources are present into an open project.

In details, CAN-Do widgets are actually been flashed (isn't successful). It is an ambitious project, depending on work done by others. By one hand, some problems like material recollecting and verifying, soldering or flashing the firmware (software and firmware wasn't updated for today requirements and didn't work well until they decided to update after our needs) are so difficult for a non CAN-Do designer. By other hand, we are in permanent contact with principal CAN-Do designer (after some months without help, they decided help us due our implication). Furthermore, info available is accurate and very helpful. This could be a final component added to Lunar Bus once the test will be successful.

PicoSAR differs totally from previous device. It is a self design so few help is available requiring high time searching and selecting info from internet (our principal source). In the beginning, we worked understanding microstrip antenna design, patches features and arrays designs. Then, we learnt some electromagnetic simulation software obtaining good results and impressive pictures. Finally, we required the help of “UPC technical services” building PCBs and providing required material to different tests requirements.

About Zonal Subsystems development we can experience some difficulties when we have selected the components. Development has to be adapted to the constrains like volume, weight, power consumption, thermal ranges, component size and interference between components.

Nowadays, the fast prototyping of commercial companies force to manufacturers to offer development kits for each component. These kits allow us to adapt the component to our needs inside the testing platform or inside a subsystem. We have seen a big difference between large and small manufacturers. A small company offers lower prices and personalized attention but not so well tested components. These companies fail to offer a well documented component or proven examples. A large company offers a very good service quality but an expensive price. Large companies offer well documented components and you can find many examples in the community where your component was tested in similarly conditions or purposes.

We denote a big difference between small providers and large providers as we have experimented with the transceiver and the USB host components. The first transceiver (DCBT_24AX) was an example of very good performances but manufactured by a small company. We have to discard it due to a bad documentation of the component. We spend some weeks to test the component and finally to see that the component is not useful for our purposes. This fact makes us unable to program the transceiver to our needs. Then we have to select the second option, a transceiver (eZ430_RF2500). This component was so good that we were able to cover many subsystems with the same component. In addition of that, we were able to reuse the development of this component for the CORE and for the SHIELD.

We have experience some problems with U.S. providers that based on ITAR regulations they only export outside the USA large amounts of components. ITAR regulations[41] set that U.S. space manufacturer can’t export this technology to non-citizen clients. We have found this a kind of incongruence.

Large volume of technical documentation has been processed and catalogued. Many disciplines have been used for the development of this project. We have to work closer to many people of different fields and different countries. The help of many teachers known through our studies make possible such challenger.

We are glad by the work done, but rest some work to be finished and until final design we doesn't will see our work been applied (but our knowledge are been improved everyday, this is the better project part).

[41] http://en.wikipedia.org/wiki/International_Traffic_in_Arms_Regulations

CHAPTER 7. Environmental impact

Our design will be delivered in to moon. In the last face of design we have taken into account disposal of the Lunar Rover and Lunar Lander. As per the Lunar Bus, at the end of its mission will be controlled crashed on the moon. Coordinates of disposal devices will be published and catalogued.

The launch phase is the most contaminant source in the mission, but debris will reentered soon in the Earth’s atmosphere. In the path to the Moon, some debris will be deployed; those who will larger than 10 cm radius will be catalogued as space debris.

Environment care has been considered optimizing project design. In example, we have reused some components of waste devices like DVD motors. In the *Demo1.3degrees* we have used some stepper motors from CD and floppy disk drives.

We have tried to optimize resources in order to reduce the impact to the Environment. Waste the lowest electricity as possible and reusing materials in the development.

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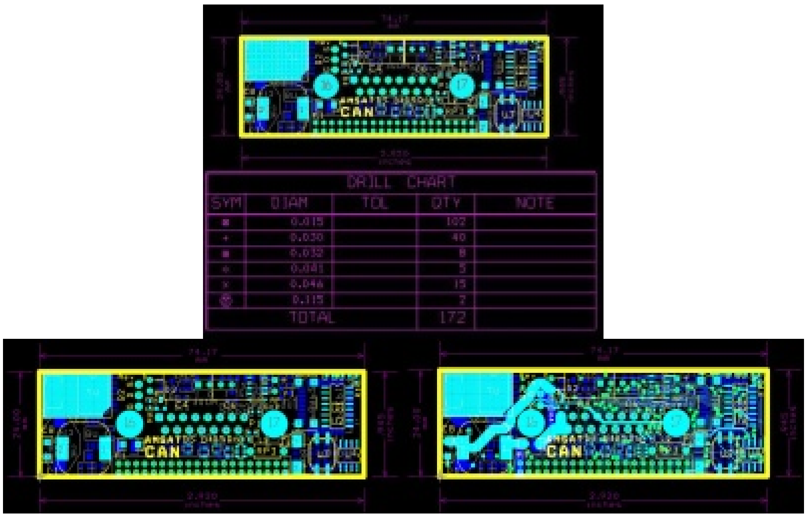
ANNEXES

1.1 CAN-Do one widget bill of materials

Quantity	Component	PCB Footprint	Provider link	Cost (Per unit)
2	0.1 uF Capacitors	1206-8	Digi-Key	0.40 $
8	0.1 uF Capacitors	0603	Digi-Key	0.65 $
1	33 uF/63 V Capacitor	RC25X440+	Digi-Key	0.33 $
1	100 uF/25 V Capacitor	RC25X440+	Digi-Key	0.52 $
1	0.1 uF Capacitor	1206	Digi-Key	0.38 $
1	10 uF/30 V Capacitor	7243	Digi-Key	0.19 $
2	22 pF Capacitors	0603	Digi-Key	0.06 $
1	1 uF Capacitor	1206	Digi-Key	0.13 $
1	B130L Diode	SMA	Digi-Key	0.81 $
1	BZX84C12 Diode	SOT23	Digi-Key	0.54 $
4	BAT54TW	SOT363	Digi-Key	0.77 $
1	2A Fuse	1206	Digi-Key	0.77 $
1	10 uH Coil	CDRH125	Digi-Key	0.64 $
1	Bead Coil	R300/150	Digi-Key	0.15 $
1	470 uH Coil	DO3308	Digi-Key	0.77 $
1	MMBT3904	SOT23	Digi-Key	0.09 $
1	IRF9530	TO220-132V	Digi-Key	0.77 $
2	Paralel resistors array 100 kOhms	EXB-A	Digi-Key	0.19 $
7	Series resistors array 1 kOhms	1206-8	Digi-Key	0.18 $

3	2k67 Ohms resistors	0603	Digi-Key	0.08 $
1	33k2 Ohms resistor	0603	Digi-Key	0.08 $
1	68k1 Ohms resistor	0603	Digi-Key	0.08 $
1	27k4 Ohms resistor	0603	Digi-Key	0.08 $
1	1M Ohms resistor	0603	Digi-Key	0.08 $
1	0R02 Ohms resistor	0603	Digi-Key	1.40 $
2	47k5 Ohms resistors	0603	Digi-Key	0.08 $
2	287k Ohms resistors	0603	Digi-Key	0.08 $
1	2k00 Ohms resistor	0603	Digi-Key	0.09 $
1	74HC165/SO	SO16NB	Digi-Key	0.50 $
1	S+M(specify)	S+M	Digi-Key	5.00$
1	PCA82C250T	SO8NB	Digi-Key	1.4 $
1	T89C51CC01-VQFP	VQFP44	Digi-Key	10.4 $
1	LM385M3-2.5	SOT23	Digi-Key	1.40 $
1	LM2574HVM-5.0	SO14WB	Digi-Key	5.12 $
1	LT1787HVHS8	SO8NB	Linear Technology	5.00 $
1	QSBT40DICT	SOT363	Digi-Key	1.00 $
1	LM60CIM	SOT23	Digi-Key	0.50 $
1	8 MHz oscillator	CM309S	Digi-Key	1.00 $
			Shipping cost	10.00 $
			TOTAL	**47.50 $**

1.2 CAN-Do OrCAD print screens



1.3 Frequency bands

The traditional band names originated as code-names during *World War II* and are still in military and aviation use throughout the world in the 21st century. They have been adopted in the United States by the *IEEE*, and internationally by the *International Telecommunication Union (ITU)*. Most countries have additional regulations to control which parts of each band are available for civilian or military use.
Other users of the radio spectrum, such as the *broadcasting* and electronic countermeasures (*Electronic counter-measures, ECM) industries, have replaced the traditional military designations with their own systems.*

Source: Wikipedia

Radar frequency bands Band Name	Frequency Range	Wavelength Range	Notes
HF	MHz	m'	coastal radar systems, over-the-horizon radar *(OTH) radars; 'high frequency'*
P	< 300 MHz	1 m+	'P' for 'previous', applied retrospectively to early radar systems
VHF	50–330 MHz	0.9–6 m	very long range, ground penetrating; 'very high frequency'

UHF	300– 1000 MHz	0.3–1 m	very long range (e.g. *Ballistic Missile Early Warning System*), ground penetrating, foliage penetrating; 'ultra high frequency'
L	GHz	cm	long range air traffic control *and* surveillance*; 'L' for 'long'*
S	2–4 GHz	7.5–15 cm	terminal air traffic control, long-range weather, marine radar; 'S' for 'short'
C	4–8 GHz	3.75–7.5 cm	Satellite transponders; a compromise (hence 'C') between X and S bands; weather
X	8–12 GHz	2.5–3.75 cm	missile *guidance,* marine radar*, weather, medium-resolution mapping and ground surveillance; in the* USA *the narrow range 10.525 GHz ±25 MHz is used for* airport *radar. Named X band because the frequency was a secret during WW2.*
K_u	12–18 GHz	1.67–2.5 cm	high-resolution mapping, satellite altimetry; frequency just under K band (hence 'u')
K	18–24 GHz	1.11–1.67 cm	water vapour, so K_u and K_a were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz.
K_a	24–40 GHz	0.75–1.11 cm	mapping, short range, airport surveillance; frequency just above K band (hence 'a') Photo radar, used to trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz.
mm	40– 300 GHz	7.5 mm – 1 mm	*millimetre band*, subdivided as below. The frequency ranges depend on waveguide size. Multiple letters are assigned to these bands by different groups. These are from Baytron, a now defunct company

			that made test equipment.
Q	40–60 GHz	7.5 mm – 5 mm	Used for Military communication.
V	50–75 GHz	6.0–4 mm	Very strongly absorbed by the atmosphere.
E	60–90 GHz	6.0–3.33 mm	
W	75–110 GHz	2.7 – 4.0 mm	used as a visual sensor for experimental autonomous vehicles, high-resolution meteorological observation, and imaging.
UWB	1.6–10.5 GHz	18.75 cm – 2.8 cm	used for through the wall radar and imaging systems.

1.4 PicoSAR SNR tables

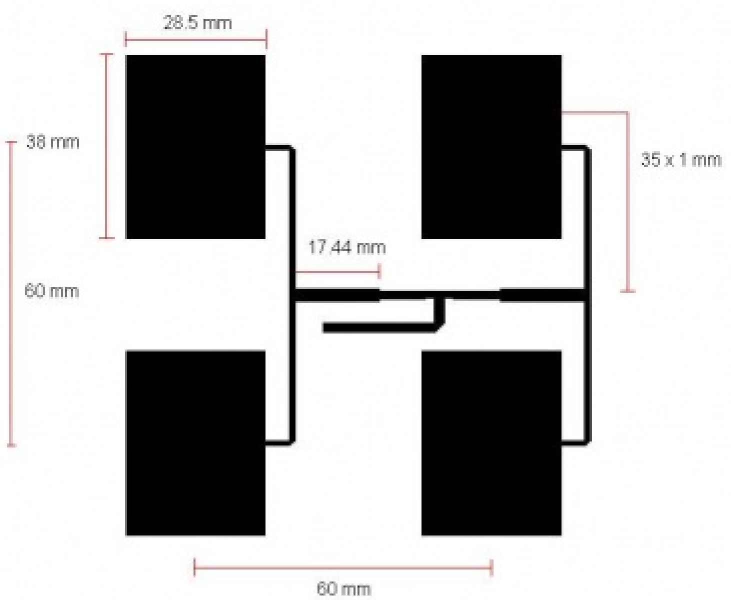
Assuming a bandwidth of BW = 10 MHz

SNR	f = 2.4 GHz d = 0.03 km	f = 2.4 GHz d = 0.5 km	f = 2.4 GHz d = 100 km	f = 2.4 GHz d = 10,000 km	f = 2.4 GHz d = 59,763 km	f = 2.4 GHz d = 86,709 km	f = 2.4 GHz d = 384,000 km	f = 10 GHz d = 0.03 km	f = 10 GHz d = 0.5 km	f = 10 GHz d = 100 km	f = 10 GHz d = 10,000 km	f = 10 GHz d = 59,763 km	f = 10 GHz d = 86,709 km	f = 10 GHz d = 384,000 km
T = 3 K	147.8 dB	123.8 dB	77.8 dB	37.8 dB	22.8 dB	21.8 dB	3.1 dB	135.8 dB	111.3	65.8	25.8 dB	6.8 dB	5.8 dB	-9.3 dB
T = 100 K	132.6 dB	108.6 dB	62.6 dB	22.6 dB	7.6 dB	6.6 dB	-12.1 dB	120.6 dB	96.1 dB	50.6 dB	10.6 dB	-8.4 dB	-9.4 dB	-25.4 dB
T = 200 K	129.6 dB	105.6 dB	59.6 dB	19.6 dB	4.6 dB	3.6 dB	-15.1 dB	117.6 dB	93.1 dB	47.6 dB	7.6 dB	-11.4 dB	-12.4 dB	-27.5 dB
T = 290 K	128 dB	104 dB	58 dB	18 dB	3 dB	2 dB	-16.8 dB	116 dB	91.5 dB	46 dB	6 dB	-13 dB	-14 dB	-29.2 dB

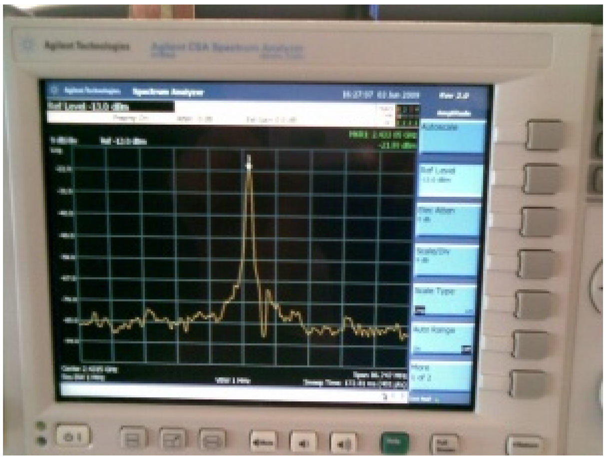
If bandwidth is BW = 1 MHz means increasing in 10 dB the SNR

SNR	f = 2.4 GHz d = 0.03 km	f = 2.4 GHz d = 0.5 km	f = 2.4 GHz d = 100 km	f = 2.4 GHz d = 10,000 km	f = 2.4 GHz d = 59,763 km	f = 2.4 GHz d = 86,709 km	f = 2.4 GHz d = 384,000 km	f = 10 GHz d = 0.03 km	f = 10 GHz d = 0.5 km	f = 10 GHz d = 100 km	f = 10 GHz d = 10,000 km	f = 10 GHz d = 59,763 km	f = 10 GHz d = 86,709 km	f = 10 GHz d = 384,000 km
T = 3 K	157.8 dB	133.8 dB	87.8 dB	47.8 dB	32.8 dB	31.8 dB	13.1 dB	145.8 dB	121.3	75.8	35.8 dB	16.8 dB	15.8 dB	0.7 dB
T = 100 K	142.6 dB	118.6 dB	72.6 dB	32.6 dB	17.6 dB	16.6 dB	-2.1 dB	130.6 dB	106.1 dB	60.6 dB	20.6 dB	1.6 dB	0.6 dB	-14.5 dB
T = 200 K	139.6 dB	115.6 dB	69.6 dB	29.6 dB	14.6 dB	13.6 dB	-5.1 dB	127.6 dB	103.1 dB	57.6 dB	17.6 dB	-1.4 dB	-2.4 dB	-17.5 dB
T = 290 K	138 dB	114 dB	68 dB	28 dB	13 dB	12 dB	-6.8 dB	126 dB	101.5 dB	56 dB	16 dB	-3 dB	-4 dB	-19.2 dB

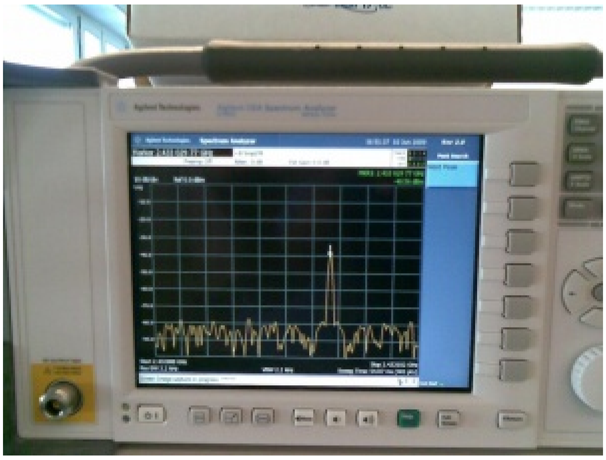
1.5 PicoSAR layout measures



1.6 PicoSAR and eZ340 picture



PicoSAR eZ430 channel 1



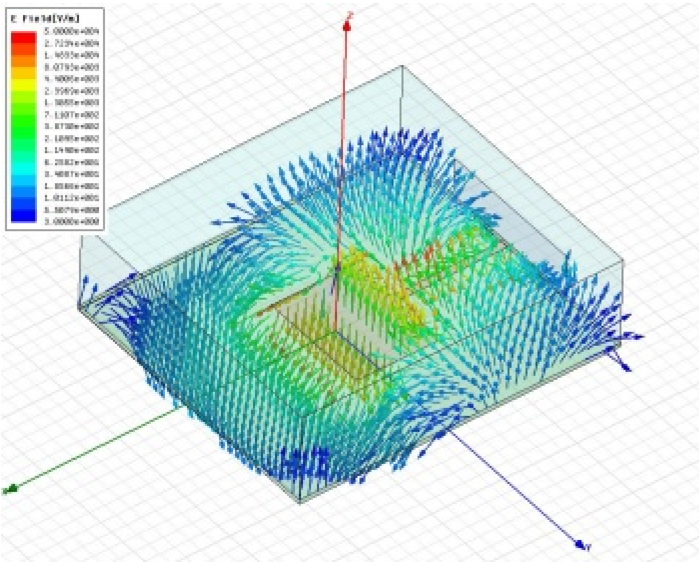
PicoSAR eZ430 channel 2

PicoSAR eZ430 both channels

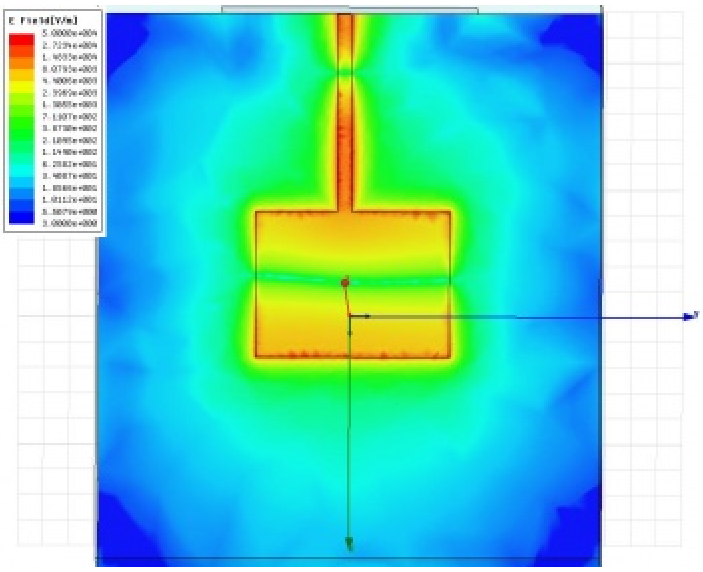
1.7 Bluetooth table

Class	Power	Max. range
1	100 mW (20 dBm)	100 meters
2	2.5 mW (4 dBm)	10 meters
3	1 mW (0 dBm)	1 meter

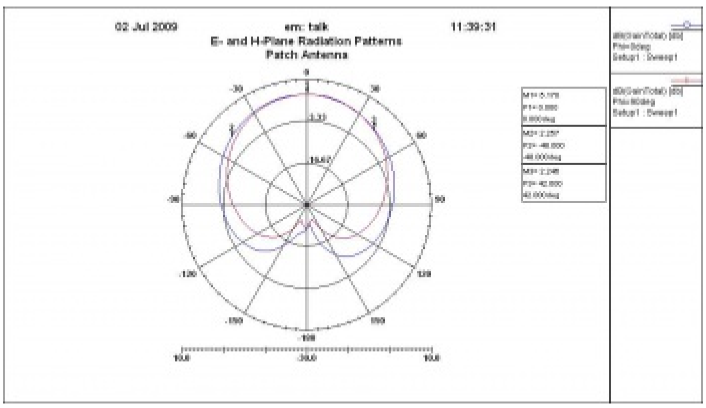
1.8 HFSS single patch simulation



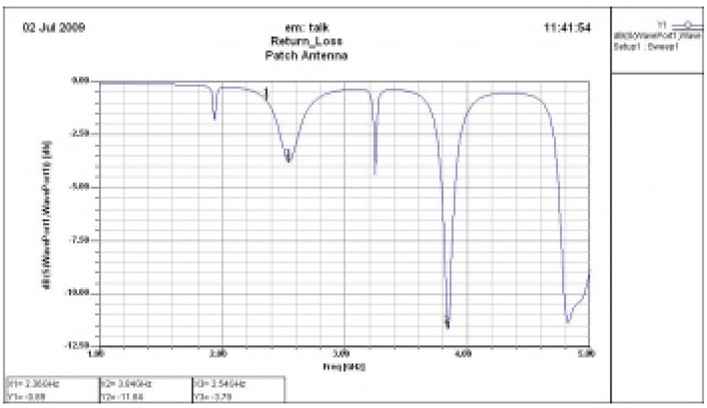
Patch E field direction



Patch E field magnitude

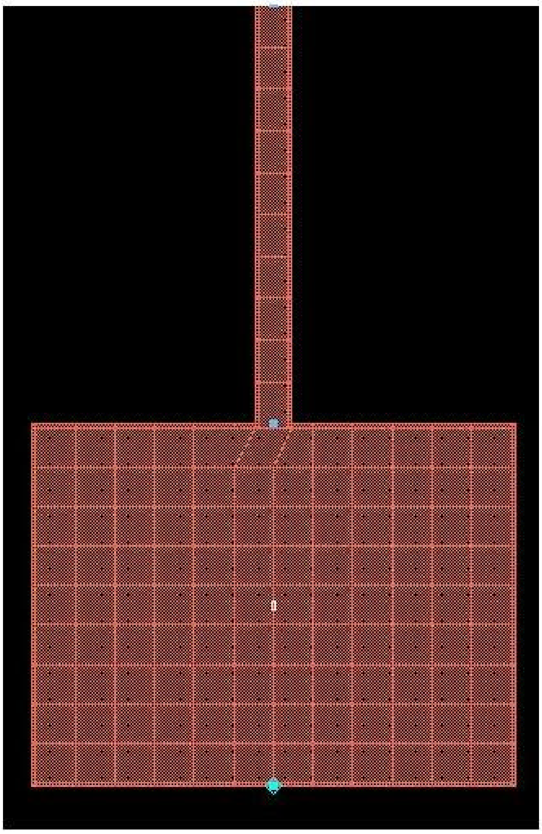


Patch 2D Gain



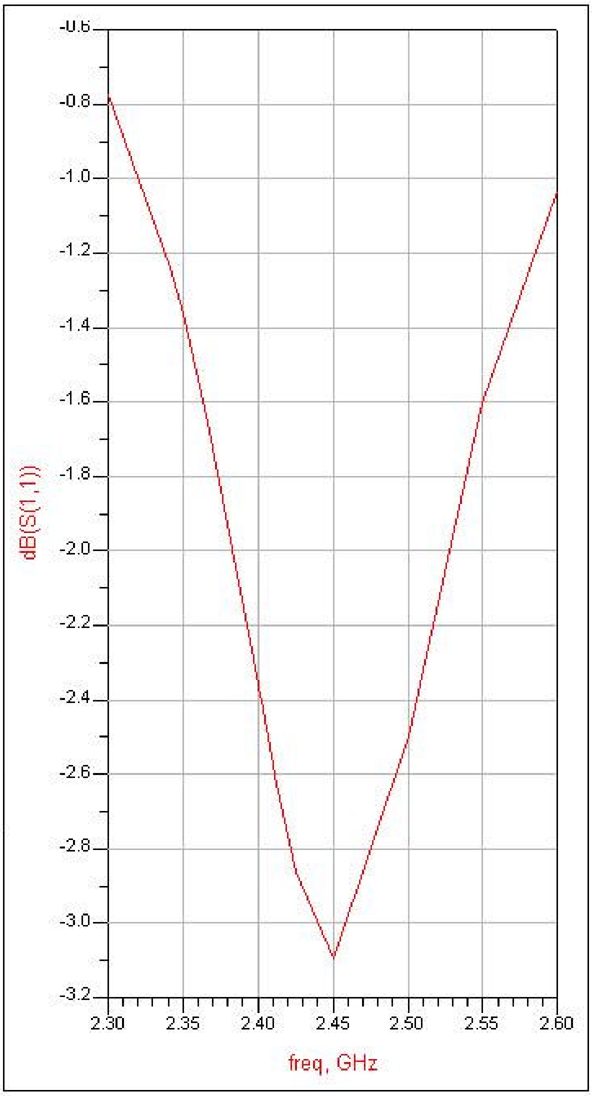
Patch Return Loss

1.9 ADS single patch simulation

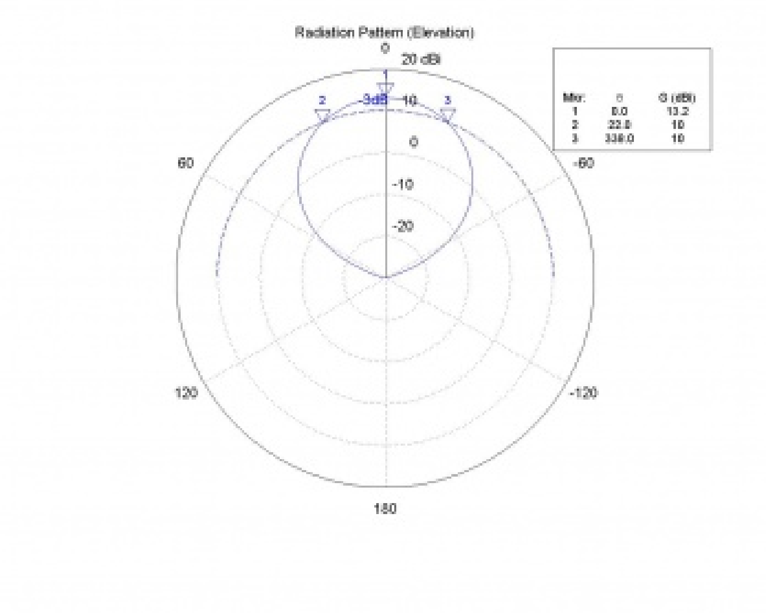


S11 = - 3.1 dB
(feed line lambda/2, Zo = 50 ohms, f = 2.45 GHz)

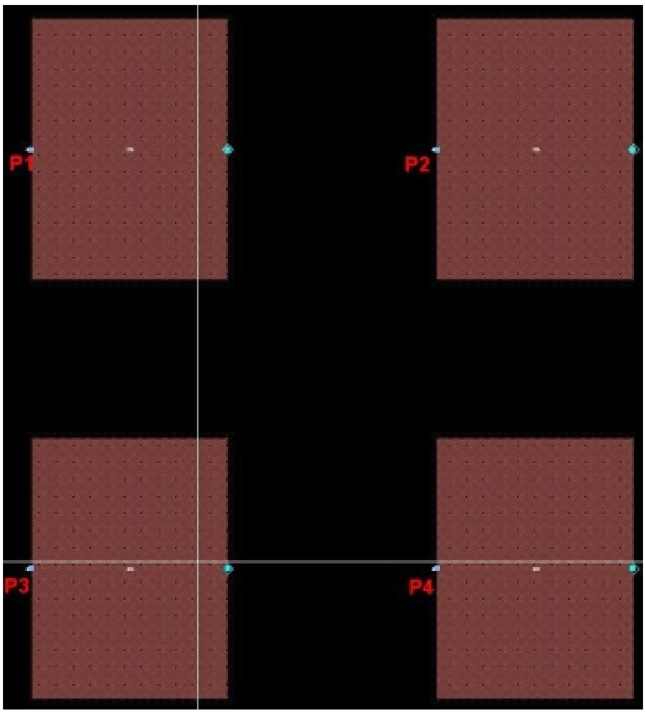
Zpatch = 280 ohms



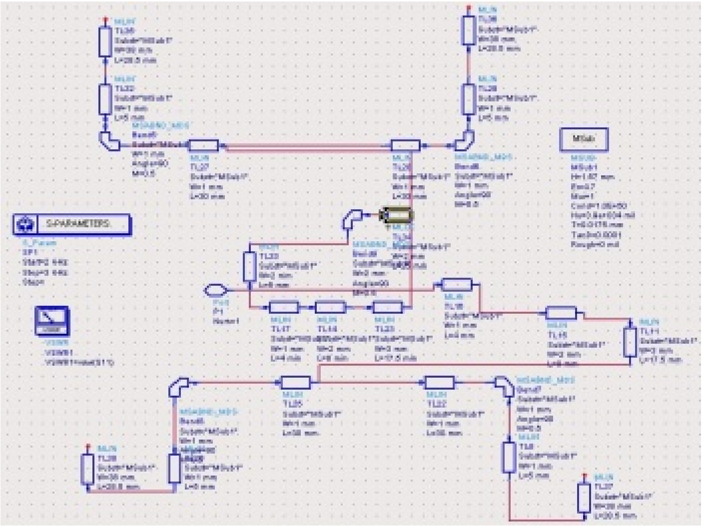
1.10 SuperNEC 4 patches beamwidth



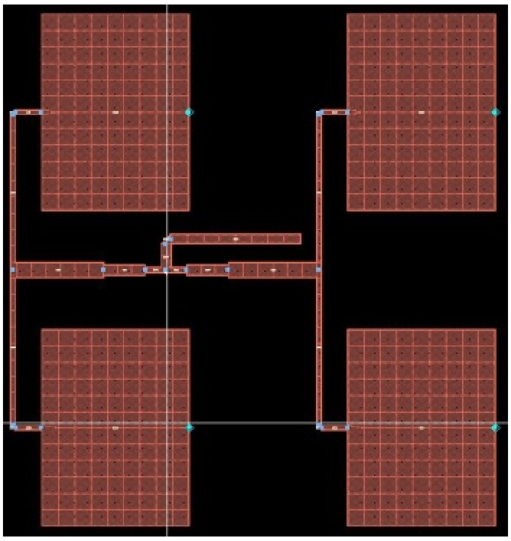
1.11 ADS 4 patches simulation



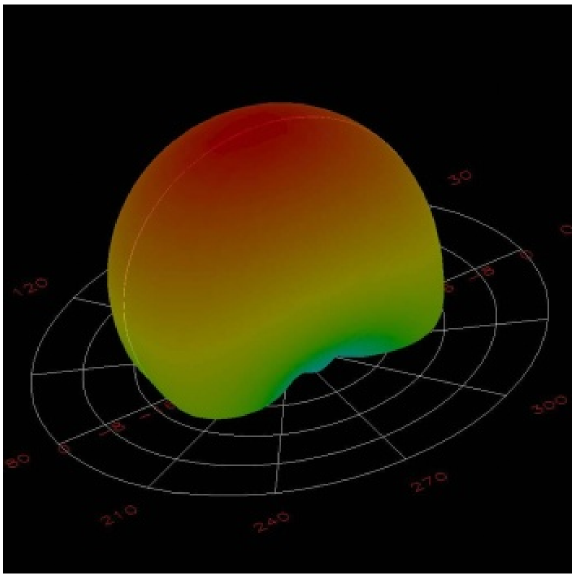
4 patches layout



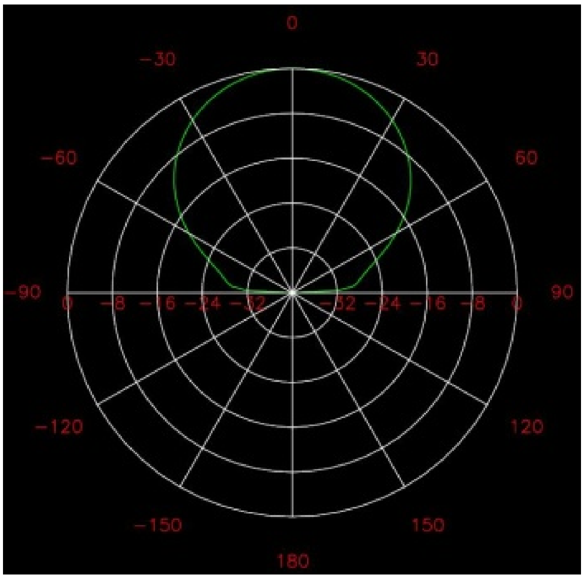
ADS PicoSAR schematic



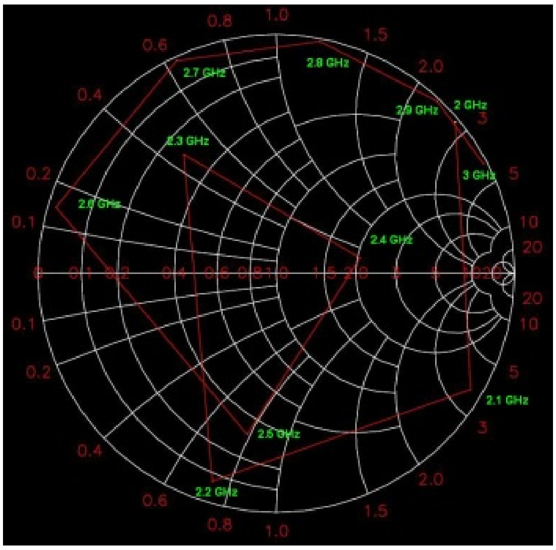
ADS PicoSAR layout



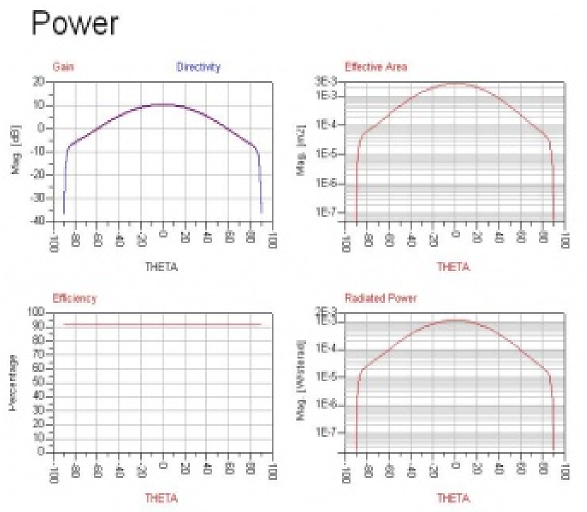
ADS PicoSAR 3D



ADS PicoSAR 2D

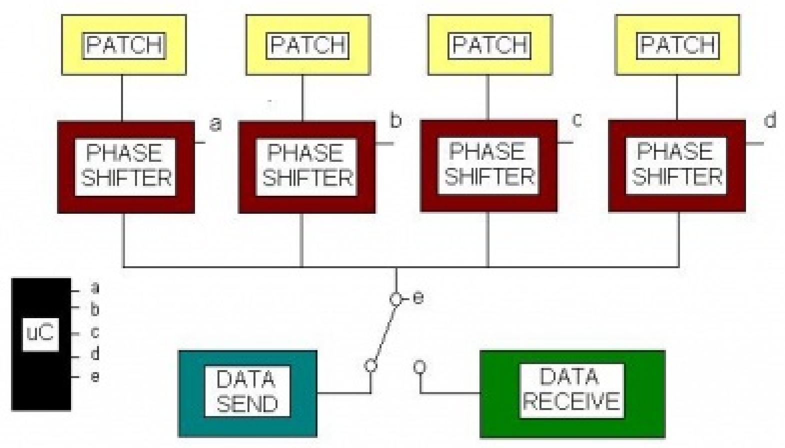


ADS PicoSAR Smith Chart



ADS PicoSAR Power results

1.12 Complete SAR schematic



1.13 PicoSAR analysis budget terms (units and definitios)

- P_{RX}: received power (dBW)
- P_{TX}: transmitter output power (dBW)
- G_{TX}: transmitter *antenna gain* (dBi)
- L_{TX}: transmitter losses, coax, connectors... (dB)
- L_{FS}: *free space losses* or *path loss* (dB)
- L_M: miscellaneous losses, *fading* margin, body loss, polarization mismatch, other losses... (dB)
- G_{RX}: receiver *antenna gain* (dBi)

- L_{RX}: receiver losses, coax, connectors... (dB)
- P_N: noise power (dBW)
- k: boltzman constant
- T: equivalent antenna temperature
- B: bandwidth

1.14 PicoSAR 10 GHz substrate proposal

ROGERS 4003 (from UPC technical servicies)

t = 35 µm
h = 1.524 mm
E_r = 3.38
E_{eff} = 2.668

Revision control

Date: 2009-Feb-13	Revision: 1.0	Prepared by: Joshua Tristancho	Revised by: Andres Petilo
Date: 2009-Apr-23	Revision: 2.0	Prepared by: Joshua Tristancho	Revised by: TO BE VALIDATED

1 GENERAL

The Concept of Operations (CONOPS) document, referring to IEEE Standard 1362-1998, is a powerful tool for communicating a customer's vision for a new system.

1.1 Purpose

We believe that open space is the way to win the Google Lunar X PRIZE. 'Open' gives access to the entire human knowledge and power. Our motivations are our dreams: enter the moon and give access to the whole world.

1.2 Background

Team FREDNET Long Plan Strategy summary
This long plan strategy is based in the main ideas of Team FREDNET and may change in a future.

- In order to gain business support, we have to achieve a competitive product to offer.
- In order to define what the launcher will be, we have to define constrains regarding the orbital transfer system.
- In order to define the Lunar BUS, we have to know how to operate the mission in the moon for the Lunar Lander.
- In order to define how to operate the Lunar Lander, we have to know how much is the weight of the rover, what is the size constrains and what coverage for communications it requires.
- In order to select what opportunities of chartering the free place left by a satellite in each launch, we have to know what our product is.
- In order to look for partners, we have to have any chartering to offer and a well adapted product to each launch opportunity.
- And finally we will have more possibilities if our product is light, small, feasible and safe because it will be cheaper and will have a large market segment.

1.3 Definitions

Accident: Undesired and unplanned event that results in a specified loss.

Error: Deviation from the desired or intended state or operation of the system.

Failure: Nonperformance or inability of the system, subsystem or component to perform its intended function for a specific time under specified environmental conditions.

Fault: Higher-order event. It says something about the system/subsystem/component behavior as a whole. Faults are not necessary failures.

Function: is the purposeful action performed by a system, subsystem or component.

Hazard: A state or set of conditions of a system, subsystem or component that, together with other conditions in the environment, will lead inevitably to an accident.

EIRP (PIRE)**:** Effective Isotropic Radiated Power. It's the power supplied at an ideal antenna multiplied by the antenna gain.

Requirements: is a singular documented need of what a particular product or service should be or do.

Safety: to protect against failure, breakage or accident.

Selenostationary: is an orbit which allows to put a satellite which is always in the same sky position from the moon at 86709 km of altitude.

SNR: Signal to Noise Ratio.

Specifications: is a mathematical description that may be used to develop an implementation. It describes what the system should do, not how.

Standards: is an established norm or requirement.

System: assemblage or combination of subsystems and components which form a unitary whole designed and implemented in order to complete a mission. A system engineering is composed by both, software and hardware.

TOA: Time Of Arrival. Is the time used for a given signal or wave to arrival from the source to the receiver.

UWB: Ultra-Wideband. is a technology for transmitting information spread over a large bandwidth (>500 MHz) that should, in theory and under the right circumstances, be able to share spectrum with other users. It is used for through the wall radar and imaging systems.

1.4 Assumptions

Every activity is done in the context of Team FREDNET who is the owner of our production. Official mission definition may change respect to the Pico-Rover mission study because we practice parallelism. We need the figure of a partner who is the one who take benefit of the moon resources because our mission is not to take benefit. Our mission is to develop and to give a cheap access to the moon to our partners.

2 OPERATIONS

2.1 Employment

- Resources shall be paid by the group own resources
- Public resources are well received if they are for free
- Operations shall be paid by the partners

2.2 Implementation

- Introduce open space philosophy in the context of Team FREDNET
- Give access to commercial companies to the moon's resources
- We will give coverage to our partners during these operations
- We will set a local group based in Barcelona (Spain) called Pico-Rover Group

3 TRAINING

- Each person involved in the Pico-Rover group may have an initial training
- A training program must be implemented in order to maintain skills in the components

3.1 General

We believe that personnel may have a good level of skills and the way to reach this level is through the constant training process.

3.2 Training Requirements

- Training has to be done in a format of well defined course
- Courses may require almost an exam or evaluation process in order to ensure the course level
- Training also is done through formation and work experience
- Laddering role require a qualification of training

3.3 Training Support

- The training has to be done in an adequate place and by a qualified personnel

- A Course will use a maxim of 6 hours of daily teaching and if it possible without the weekend
- Support material will be provided by the own group
- The material used in a course has to respect the environment

4 CONOPS Products

- We offer an Open Space Technology giving access for free to the humanity
- We promote projects for exploration the moon and the resources in there
- We offer moon resources exploitation and/or operation in order to take benefit to our partners
- We will provide coverage in these operations

4.1 Why Team FREDNET?

Because we will be there and we will have the technology and the experience of the moon exploitation and because we try to bring these resources to our partners in a very cheap way. We are open; we don't have nothing to hide. Opponents, which are closed, could take advantage of this situation but we take advantage over our opponents because everybody is welcome to collaborate with us and then we will have unlimited man-power.

4.2 Why you may make business now?

Because our technology is so cheap that the first in make business will be the first in to be beneficed. There is no place for everybody so following our Open Philosophy is not the one who pay more, is the first to be compromised with us the one who will be benefited first.

5 SUMMARY

- We are developing the Open Space Technology for free in a very cheap way
- We offer resources in the moon to our partners and coverage to these operations
- The first to make business with us is the first to take higher benefit, is not the one who pay more

Revision control

Date: 2009-Feb-13	Revision: 1.0	Prepared by: Joshua Tristancho	Revised by: Andres Petilo
Date: 2009-Apr-23	Revision: 2.0	Prepared by: Joshua Tristancho	Revised by: TO BE VALIDATED

1 Requirements

```
ATTENTION:
The following subsection is used by a macro in order to validate the
process. Do not change the format
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1.1 System Requirements

S1: The Pico-Rover as a body system shall win the GLXP Grand Prize 2.1 for the Team FREDNET.
S2: The Pico-Rover system shall win the GLXP Bonus Prize 2.3.1 for the Team FREDNET.
S3: The Pico-Rover system shall win the GLXP Bonus Prize 2.3.2 for the Team FREDNET.
S4: The Pico-Rover system shall win the GLXP Bonus Prize 2.3.3 for the Team FREDNET.
S5: The Pico-Rover system shall win the GLXP Bonus Prize 2.3.4 for the Team FREDNET.
S6: The Pico-Rover system shall win the GLXP Bonus Prize 2.3.5 for the Team FREDNET.
S7: The Pico-Rover system shall survive at least six months before disposing.

1.2 High Level Requirements

HL01: The Power Accumulating subsystem shall store electrical power temporally.
HL02: The Thermal Feeding subsystem shall provide electrical power.
HL03: The Shield Transferring subsystem shall transfer electrical power between the Core and the Shield in both directions only if 2 degrees of freedom is implemented.
HL04: The Shield Heating subsystem shall heat or cool the Shield.
HL05: The Terrain Scanning subsystem shall provide a 3D shape of the terrain in front.
HL06: The Terrain Feeling subsystem shall provide a footprint with the terrain.
HL07: The Solar Feeding subsystem shall provide electrical power.

HL08: The Power Storing subsystem shall provide electrical power in case of no power feedings are available.
HL09: The Emergency Power Storing subsystem shall provide electrical power in case of no power feedings are available and Power Storing is empty.
HL10: The Core Transferring subsystem shall transfer electrical power between the Core and the Shield in both directions only if 2 degrees of freedom is implemented.
HL11: The Core Heating subsystem shall heat or cool the Core.
HL12: The Temperature Sensing subsystem shall provide the chassis temperature.
HL13: The Data Storing subsystem shall store the streaming from the Recording and the Terrain Scanning.
HL14: The Aligning subsystem shall detect the alignment between the Core and the Shield only if 2 degrees of freedom is implemented.
HL15: The Processing subsystem shall attend in realtime all the calculations.
HL16: The Referencing subsystem shall provide the angular rate and the acceleration in the 3 axes of the body system.
HL17: The Attitude Controlling subsystem shall maintain the roll angle in order to steering the body system.
HL18: The Mission Managing subsystem shall configure the system in function of the mission phase.
HL19: The Thrust Controlling subsystem shall maintain the pitch angle in order to drive the body system.
HL20: The Shielding subsystem shall protect from radiation the critical components.
HL21: The Downlink Transferring subsystem shall transfer near realtime streaming to the Lunar Lander.
HL22: The Recording subsystem shall provide high definition video on demand.
HL23: The Labeling subsystem shall show the requested GLXP label.
HL24: The Ranging subsystem shall determine the distance between the body system and one of the lunar vehicles as a reference.
HL25: The Uplink Transferring subsystem shall receive the ground station secure commands and updates.

1.3 Low Level Requirements

To be done

1.4 Implementation

To be done

2 Operational Requirements

- The Pico-Rover shall be compliance with the Team FREDNET rover operational requirements and these requirements will be conditioned by the Lunar Bus and by the Lunar Lander features
- The Pico-Rover shall be compliance with the MCS Rover Director commands
- The Pico-Rover shall follow the Team FREDNET standards like the Standard Units, the date format YYYY-MM-DD or time in GMT

3 Safety Requirements

- The Pico-Rover shall be compliance with the Team FREDNET safety requirements

4 Performance Requirements

- The Pico-Rover performances shall follow equal or higher than sets the Guidelines for Building Team FREDNET Lunar Rovers

5 Physical and Installation Requirements

- The Pico-Rover shall be compliance with the Team FREDNET philosophy about open space
- The Pico-Rover shall able to be built for any person in the world following the Pico-Rover design

6 Maintainability Requirements

- The Pico-Rover shall allows updating in production
- The Pico-Rover shall to be disposed once ended its mission

To be completed

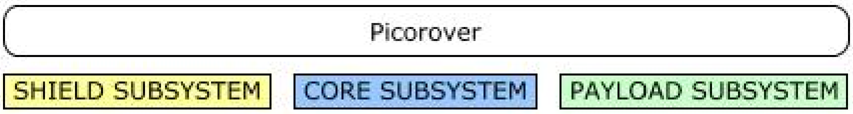
7 Interference Requirements

To be done

Intentionally empty

Revision control

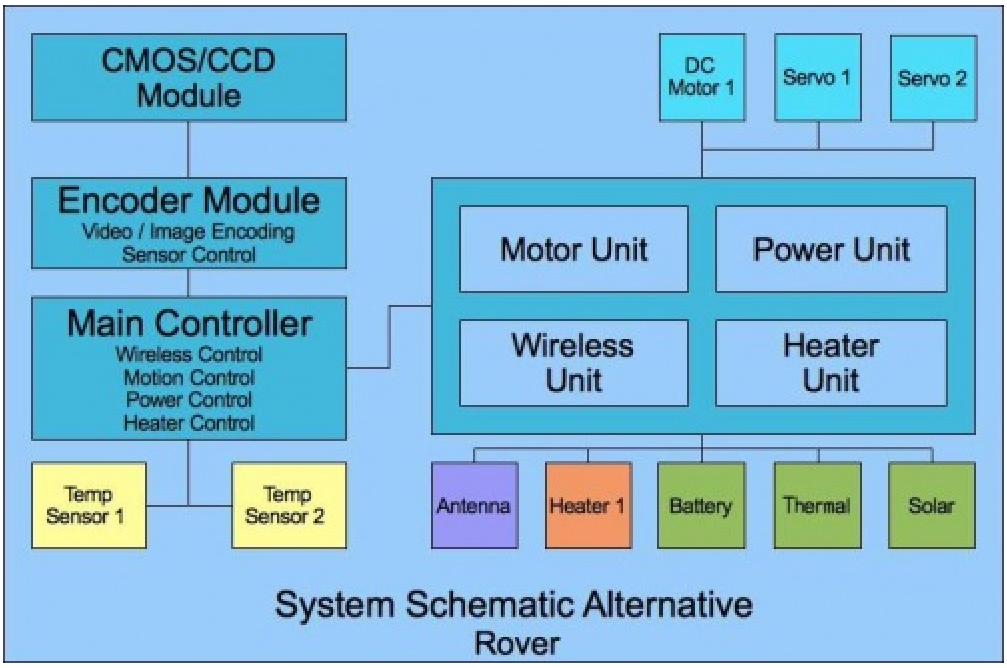
Date: 2009-Feb-13	Revision: 1.0	Prepared by: Joshua Tristancho	Revised by: Andres Petilo
Date: 2009-Apr-23	Revision: 2.0	Prepared by: Joshua Tristancho	Revised by: TO BE VALIDATED



The system Pico-Rover is divided by three zonal subsystems:

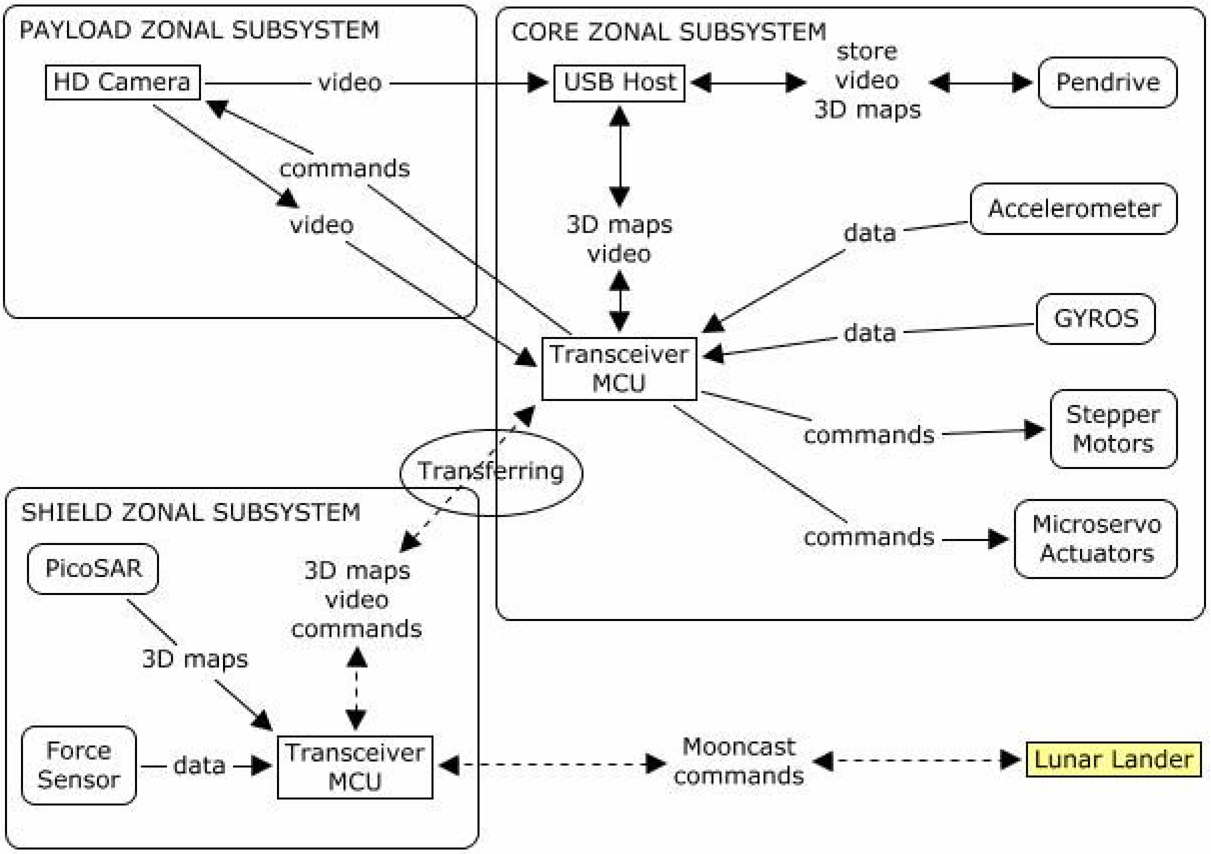
- SHIELD ZONAL SUBSYSTEM: A set of exposed subsystems
- CORE ZONAL SUBSYSTEM: A set of critical subsystems in order to survive
- PAYLOAD ZONAL SUBSYSTEM: A set of non critical subsystems but important for the mission

1 System schematics

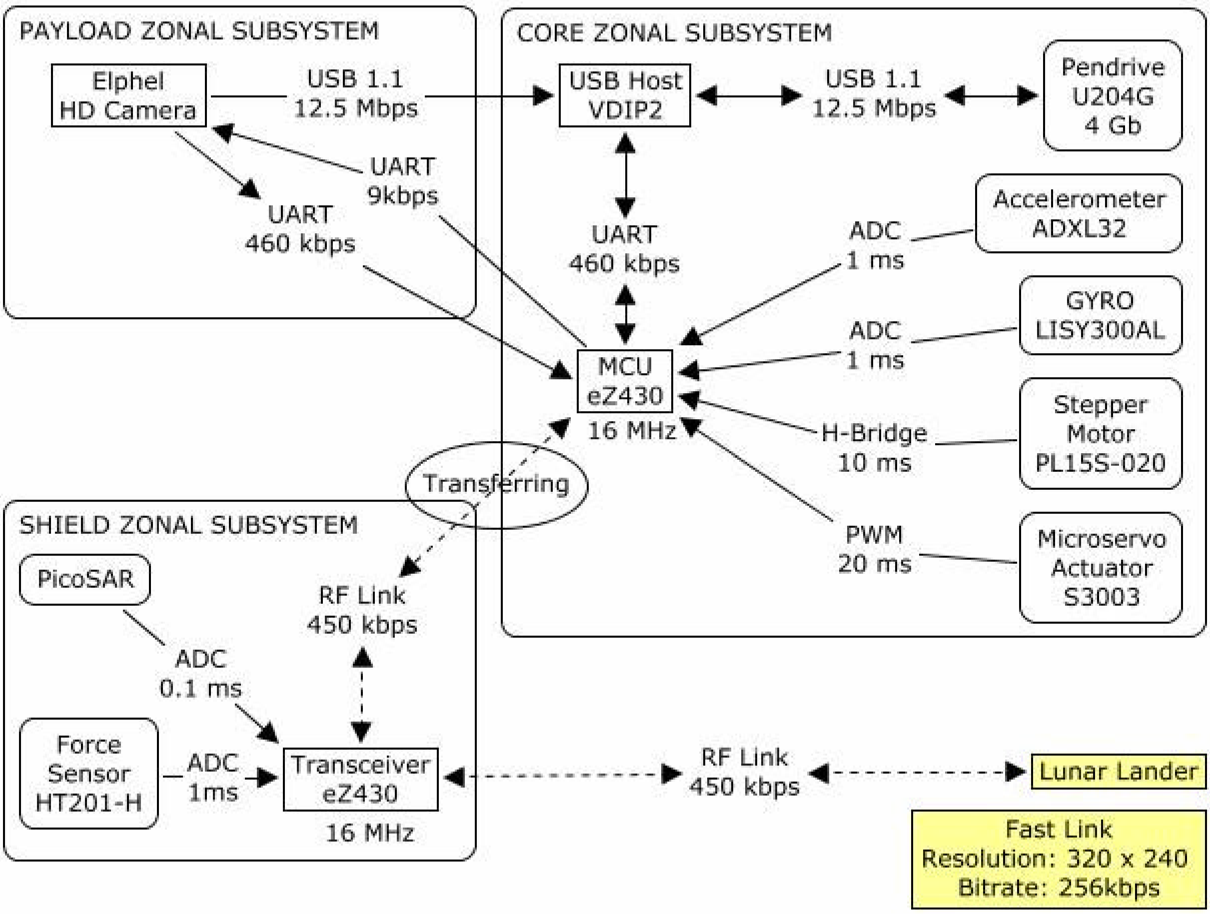


2 Data flow

2.1 Data flow Diagram



2.2 Data flow Diagram and Bandwidth



3 Pico-Rover Parameters

EXTERNAL SENSORS	INTERNAL SENSORS
Thermal Feeding Voltage [float]	Solar Feeding Voltage [float]
Radar Distance Density [float array]	Battery Voltage [float]
Foot Print Force [float array]	Emergency Battery Voltage [float]
External Temperature [float]	Chassis Temperature [float]
HD Camera [Streaming]	Free Memory [long]
Radio Link Ranging [float]	Local Time [double]
Horizont Angle [float]	Core to Shield Angle [float]
	Body Acceleration [float array]
	Body Angular Rate [float array]
	Target Pitch Angle [float]
	Target Roll Angle [float]
	Current Mode [int32]
	Labeling Illumination [Boolean]

3.1 Pico-Rover External Parameters

Parameter	Type	Bits	Range	Unit	Nominal	Bandwidth
Thermal Feeding Voltage	float	32	0 to 5,000.0	Volts	0 V (To be defined)	0.1 Hz
Radar Distance Density	float array	2x100x32	0 to 30 *0.1 to 10.0*	meters *kilograms/cubic decimeter*	0 m *1.200 kg/dm3*	0.1 Hz
Foot Print Force	float array	10x32	0 to 4,500.0	grams	0.0 g	40 Hz
External Temperature	float	32	73 to 473 (-200 to +200)	Kelvin (degree Celsius)	398K (125 ºC)	0.1 Hz
HD Camera	Streaming	?	?	?	?	?
Radio Link Ranging	float	32	0 to 100,000.0	meters	0.0 m	0.1 Hz
Horizont Angle	float	32	0 to 6.238185 (0 to 360º)	radians (degrees)	0 rad (0º)	1 Hz

3.2 Pico-Rover Internal Parameters

Parameter	Type	Bits	Range	Unit	Nominal	Bandwidth
Solar Feeding Voltage	float	32	0 to 4.000	Volts	2.731 V	1 Hz
Battery Voltage	float	32	0 to 4.000	Volts	3.300 V	1 Hz
Emergency Battery Voltage	float	32	0 to 4.000	Volts	3.000 V	1 Hz
Chassis Temperatu	float	32	218 to 488 (-55 to +125)	Kelvins (degree	298K (25 ºC)	1 Hz

re				Celsius)		
Free Memory	long	64	0 to 9,223,372,036,854,775,807	bytes	4 Gb	1 Hz
Local Time	double	64	±5.0E−324 to ±1.7E308	seconds	Refered to the launch moment	1000 Hz
Core to Shield Angle	float	32	0 to 6.238185 (0 to 360)	radians (degrees)	0 rad (0 º)	40 Hz
Body Acceleration	float array	3x32	-10 to +10 (-98.1 to 98.1)	Earth gravities (meters/square second)	0.17 g (1.6677 m/s2)	60 Hz
Body Angular Rate *Main motor rpm* [1]	float array	3x32	0 to 6.981317 (0 to 400)	radians/second (degrees/second)	0 rad/s (0 º/s)	40 Hz
Target Pitch Angle	float	32	0 to 6.238185 (0 to 360)	radians/second (degrees/second)	0 rad/s (0 º/s)	40 Hz
Target Roll Angle	float	32	0 to 6.238185 (0 to 360)	radians/second (degrees/second)	0 rad/s (0 º/s)	40 Hz
Current Mode	int32	32	(To be defined)		DEFAULT	40 Hz
Labeling Illumination	Boolean	32	0 or 1		FALSE	40 Hz

1. ↑ Conversion factor to be specified

4 Subsystem List

SHIELD	Subsystem	Component list	Weight	Cost
	Power Accumulating	2 Light weight capacitors	2	$2.00
	Thermal Feeding	2 Thermoelectric cells	20	$70.00
	Shield Transferring	*Not applicable for Picorover1.3degrees*	0	$0.00
	Shield Heating	1 Thermoelectric cell	10	$35.00
	Terrain Scanning	1 PicoSAR	10	$3,000.00
	Terrain Feeling	12 Micro force sensors	12	$1,404.00
		SUBTOTAL	**54.00 grams**	**$4,511.00**
CORE	**Subsystem**	**Component list**	**Weight**	**Cost**
	Solar Feeding	4 Solar cells	0.23	$10.00
	Power Storing	2 Lithium Ion batteries	140	$20.00
	Emergency Power Source	10 LiPo coin batteries	105	$50.00
	Core Transferring	*Not applicable for Picorover1.3degrees*	0	$0.00
	Core Heating	1 Thermoelectric cell	10	$35.00
	Temperature Sensing	1 Temperature sensor	0	$0.00
	Data Storing	1 USB pendrive 1 Host USB Controller *To be replaced by VDIP2*	2.65	$35.00
	Aligning	*Not applicable for Picorover1.3degrees*	0	$0.00
	Processing	1 MCU Microcontroller	1	$50.00
	Referencing	1 IMU Inertial Measurement Unit	7	$670.00
	Attitude Controlling	1 Attitude Stepper Motor 1 MCU Microcontroller	0 included in MCU	$200.00

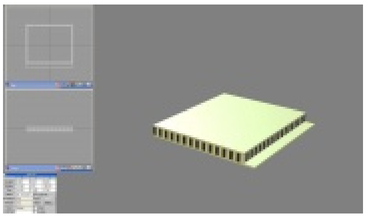
		1 IMU Inertial Measurement Unit	Microcontroller and Referencing	
	Mission Managing	1 MCU Microcontroller	0 included in Processing	$0.00
	Thrust Controlling	1 Thrust Stepper Motor 1 MCU Microcontroller 1 IMU Inertial Measurement Unit	0 included in Processing and Referencing	$0.00
	Shielding	1 Lead Shield	133.12	$1.00
		SUBTOTAL	**399.00 grams**	**$1071.00**
PAYLOAD	**Subsystem**	**Component list**	**Weight**	**Cost**
	Downlink Transferring	1 Transceiver	1.28	$22.71
	Recording	1 HD Camera 1 Cleared window	145 5.0	$2,000 $7.10
	Labeling	1 GLXP label 1 White LED	0	$0.00
	Ranging	1 Processor	0 included in Downlink Transferring	$0.00
	Uplink Transferring	1 Transceiver	0 included in Downlink Transferring	$0.00
		SUBTOTAL	**151.28 grams**	**$2,029.81**
		TOTAL	**604.28 grams**	**$7,611.81**

5 Component List

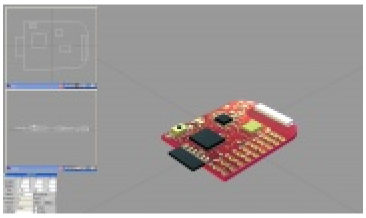
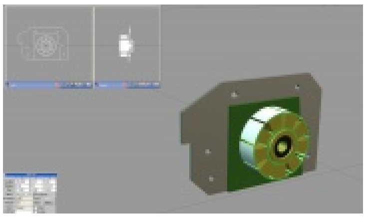
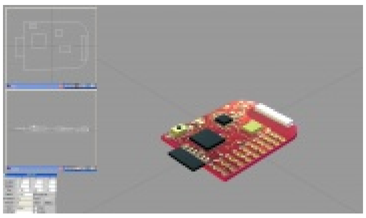
353	HD Camera	Blueprint 353
ANR26650	Lithium Ion Battery	
APR18650	Lithium Ion Battery	
C8051F340	MCU Main Control Unit *To be replaced by Z430-RF2500*	
CL12	Light weight capacitor	
CR2477	Lithium Coin Battery	
DCBT-24AX	Transceiver *To be replaced by Z430-RF2500*	
FR2505S	Cleared window	Blueprint FR2505S
G1-1.0-127-1.27	Thermoelectric Cell	Blueprint G1-1.0-127-1.27
HT201-H	Micro force sensor	
KU204G	USB Pen-drive	
ONI-23503-300-10-80	IMU Inertial Measurement Unit *To be replaced by ???*	
PL15S-020	Attitude Stepper Motor	Blueprint PL15S-020
T002A	Thrust Stepper Motor	Blueprint T002A
TASC27	Solar cell	
VDIP2	MCU-USB Host	
VNC1L	Host USB Controller *To be replaced by VDIP2*	
XR-E	White LED	
Z430-RF2500	MCU Transceiver	Blueprint Z430-RF2500

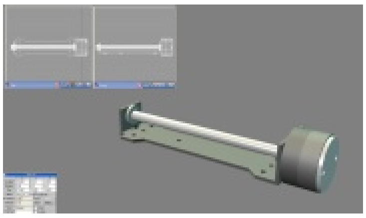
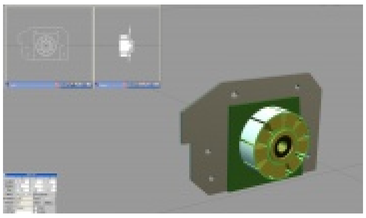
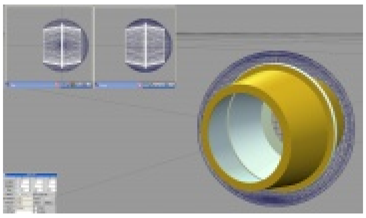
6 Part Tree

SHIELD ZONAL SUBSYSTEM

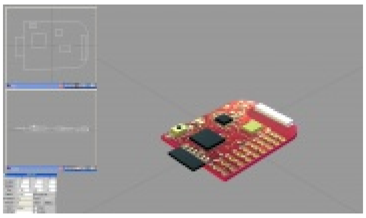
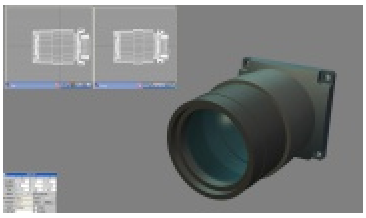
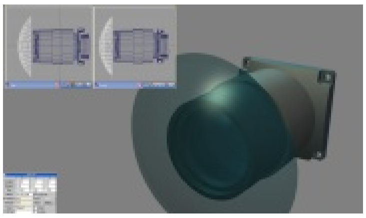
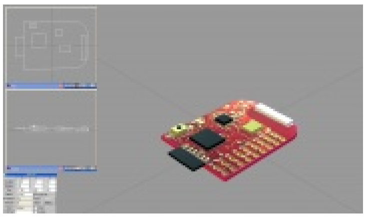
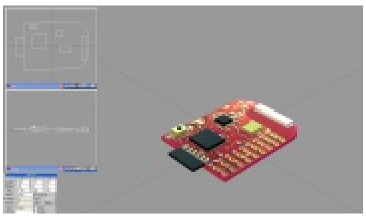
Subsystem	Component list	Size	Drawing
Power Accumulating	2 Light weight capacitors		
Thermal Feeding	2 Thermoelectric cell	34x31x3.2 mm	 G1-1.0-127-1.27
Shield Transferring	*Not applicable for Picorover1.3degrees*		
Shield Heating	1 Resistor		
Terrain Scanning	1 PicoSAR		
Terrain Feeling	12 Micro force sensors		

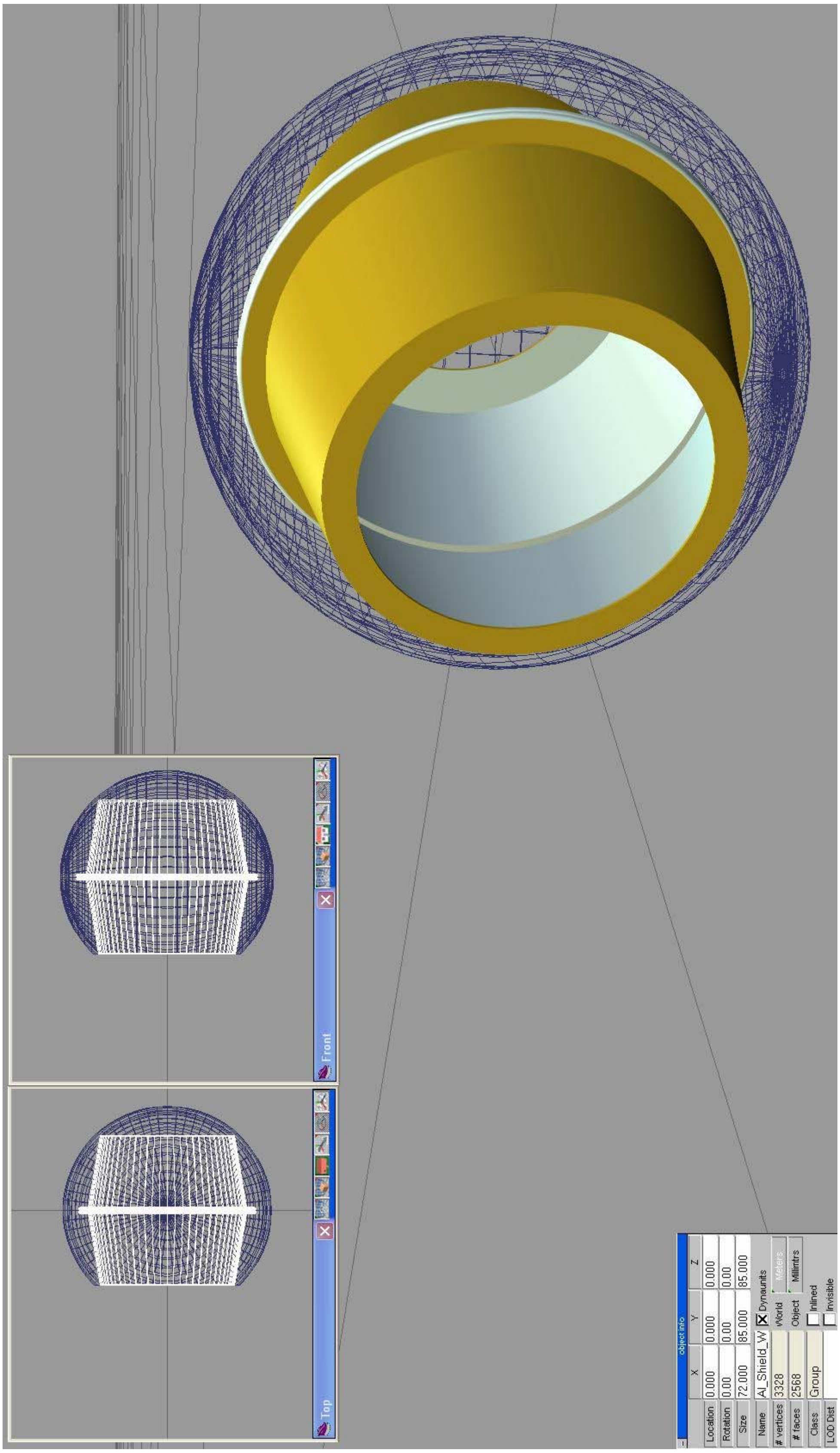
CORE ZONAL SUBSYSTEM

Subsystem	Component list	Size	Drawing
Solar Feeding	4 Solar cells		
Power Storing	2 Lithium Ion batteries		
Emergency Power Source	10 LiPo coin batteries		
Core Transferring	*Not applicable for Picorover1.3degrees*		
Core Heating	1 Thermoelectric cell		
Temperature Sensing	1 Temperature sensor *To be replaced by Z430-RF2500*	32x20x2 mm	 Z430-RF2500
Data Storing	1 USB pendrive - 1 Host USB Controller To be replaced by VDIP2	61x23x8 mm 14.2 grams 34x12x2 mm 1.7 grams	
Aligning	3 Sensors	44x29x13 mm D17.9 mm -	 T002A 94V-0
Processing	1 MCU Microcontroller *To be replaced by Z430-RF2500*	32x20x2 mm 1.8 grams	 Z430-RF2500
Referencing	1 IMU Inertial Measurement Unit		

Attitude Controlling	1 Attitude Stepper Motor	67x15x15 mm D15x10.5 mm 15.4 grams	 PL15S-020
Mission Managing			
Thrust Controlling		44x29x13 mm D17.9 mm 19.4 grams	 T002A 94V-0
Shielding		D85/D76/D64x 26 mm 60.9 grams Window D54 mm Bearing D45 mm	 Al 0.1 mm

PAYLOAD ZONAL SUBSYSTEM

Subsystem	Component list	Size	Drawing
Downlink Transferring	1 Transceiver	32x20x2 mm	 Z430-RF2500
Recording	1 HD Camera 1 Cleared window	**Elphel Camera** 43.5x40.5x136.052 mm **Computar Lens** D41.6x48.8 mm **Window** D71.355x15 mm sphere96	 Elphel 353  FR2505S
Labeling	1 GLXP label 1 White LED		
Ranging	1 Transceiver	32x20x2 mm	 Z430-RF2500
Uplink Transferring	1 Transceiver	32x20x2 mm	 Z430-RF2500


Front
Top
object info
X
Y
Z
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Size 72.000 85.000 85.000
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Dynaunits
vertices 3328
faces 2568
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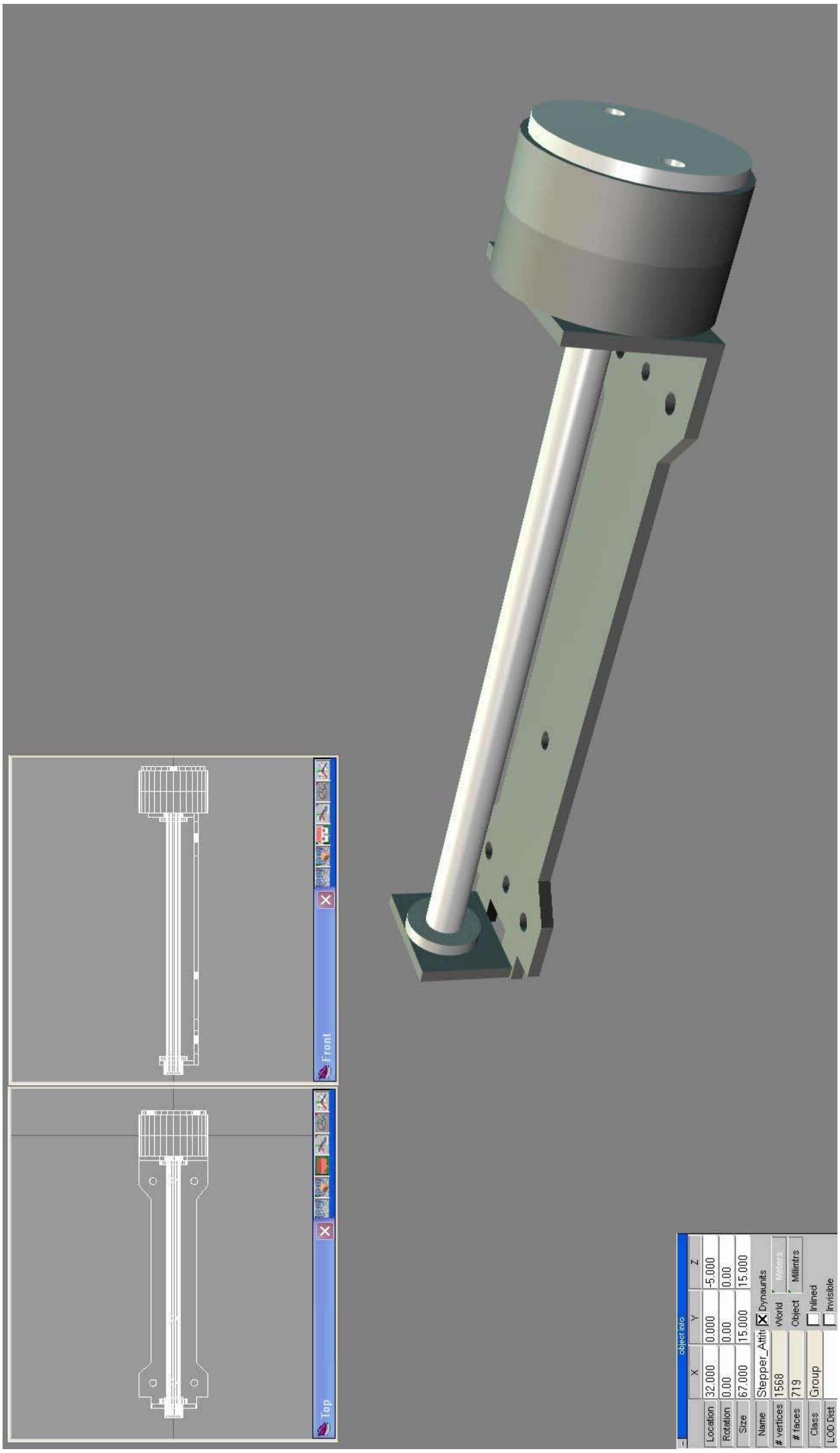
Object
Millimtrs
Class Group
Inlined
Invisible
LOD Dist



Front
Top
object info
X Y Z
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Rotation 0.00 0.00 0.00
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Dynaunits
vertices 1568
World
faces 719
Object
Millimtrs
Class Group
Inlined
LOD Dist
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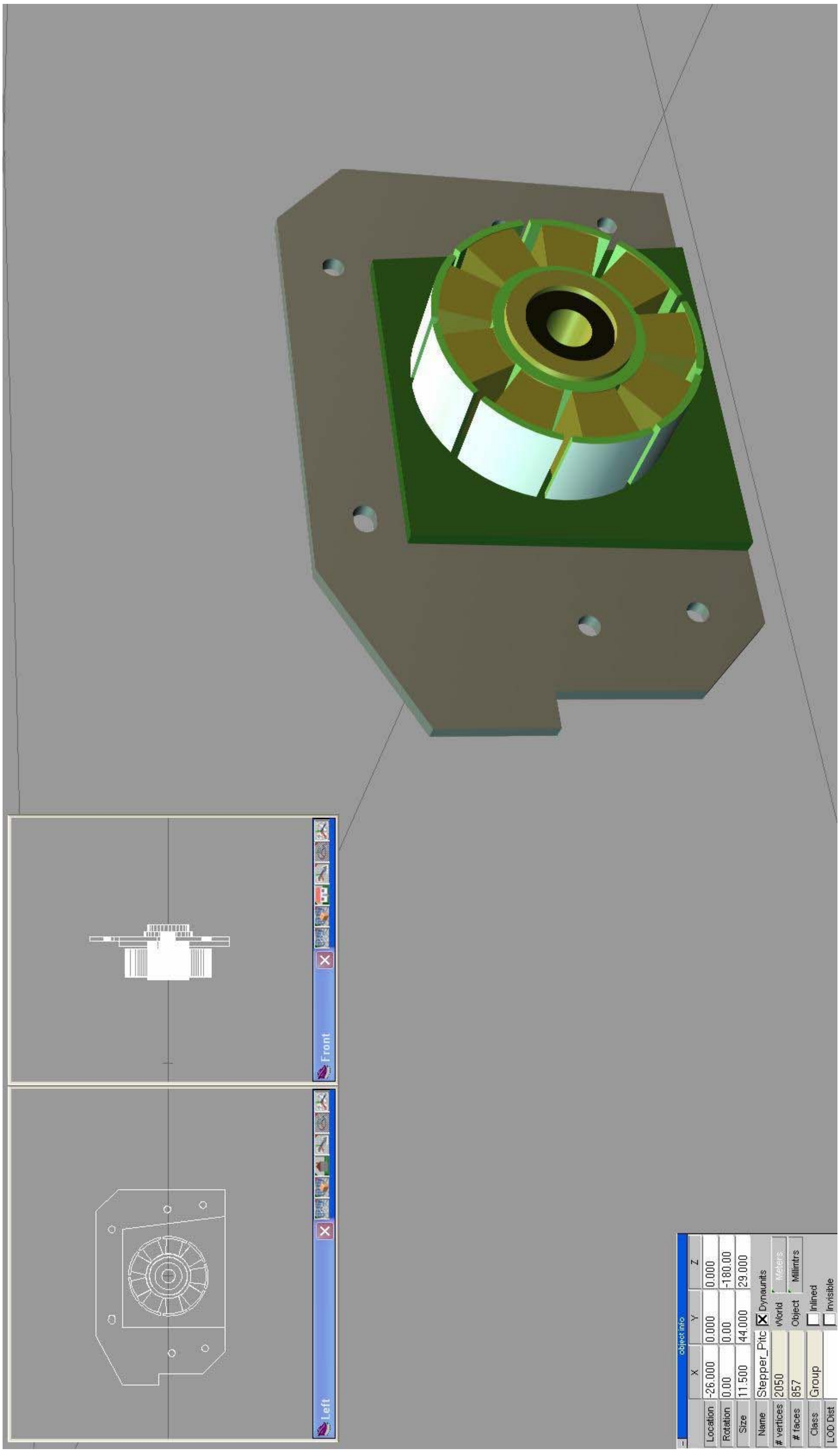
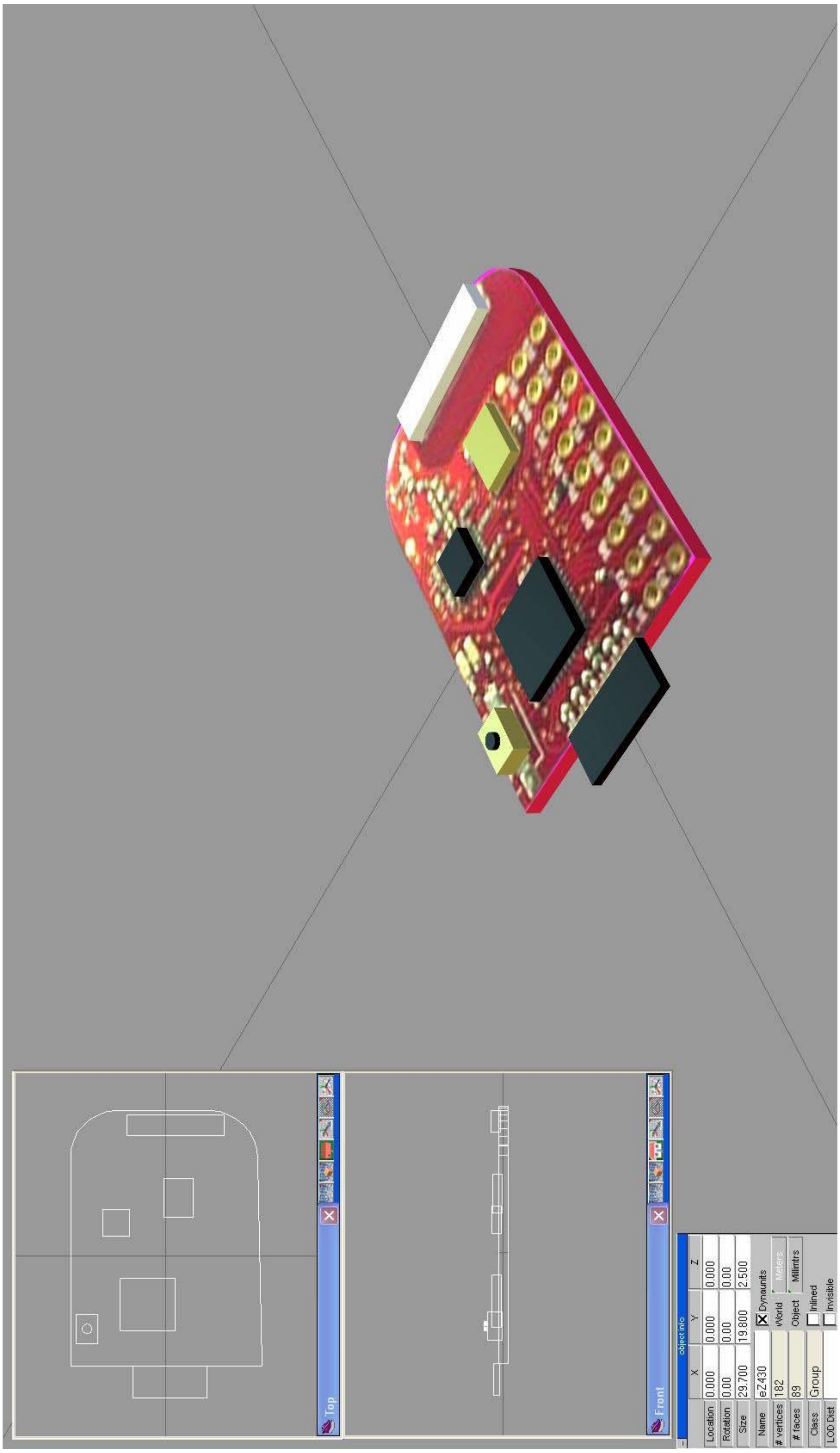
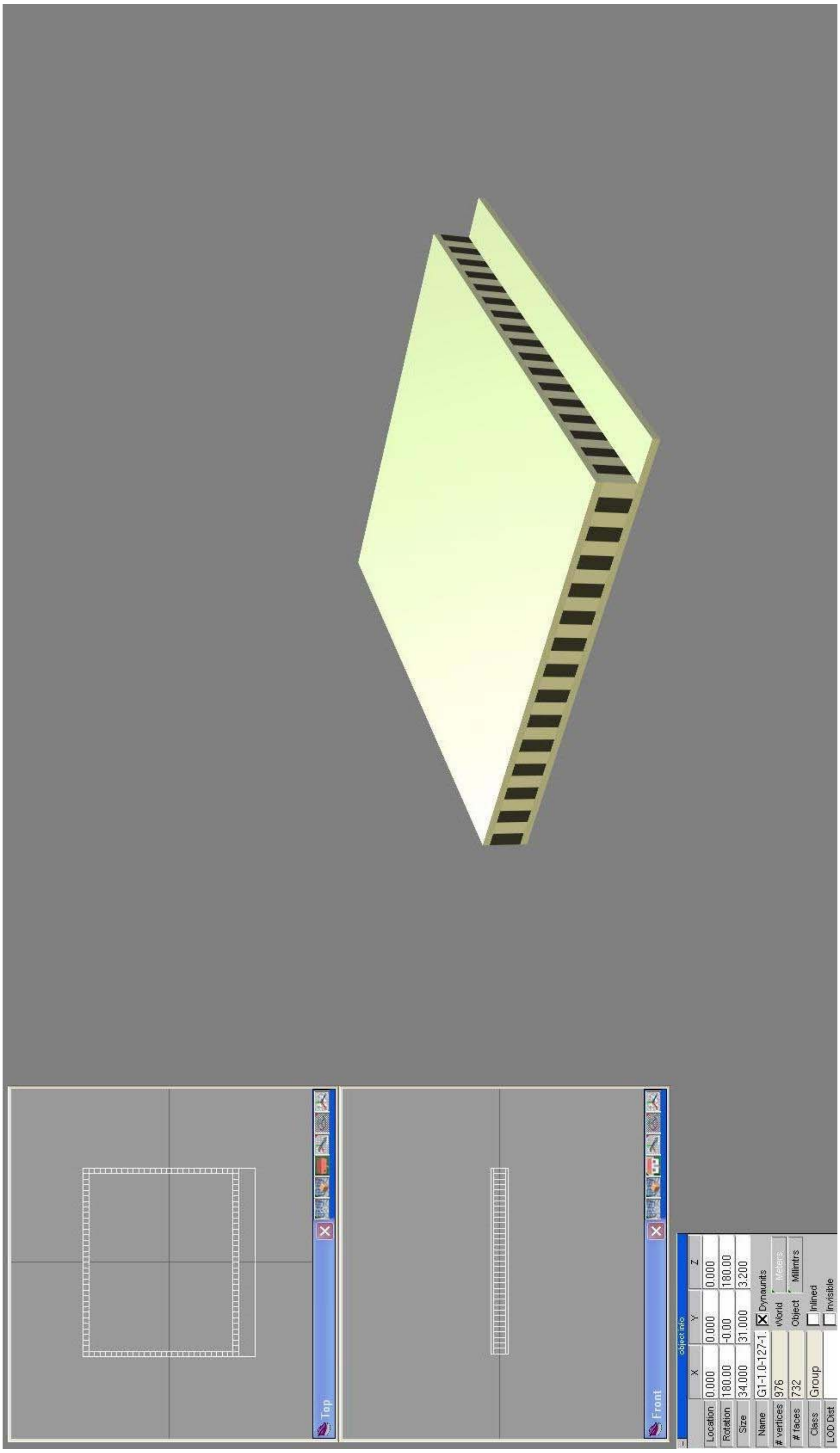
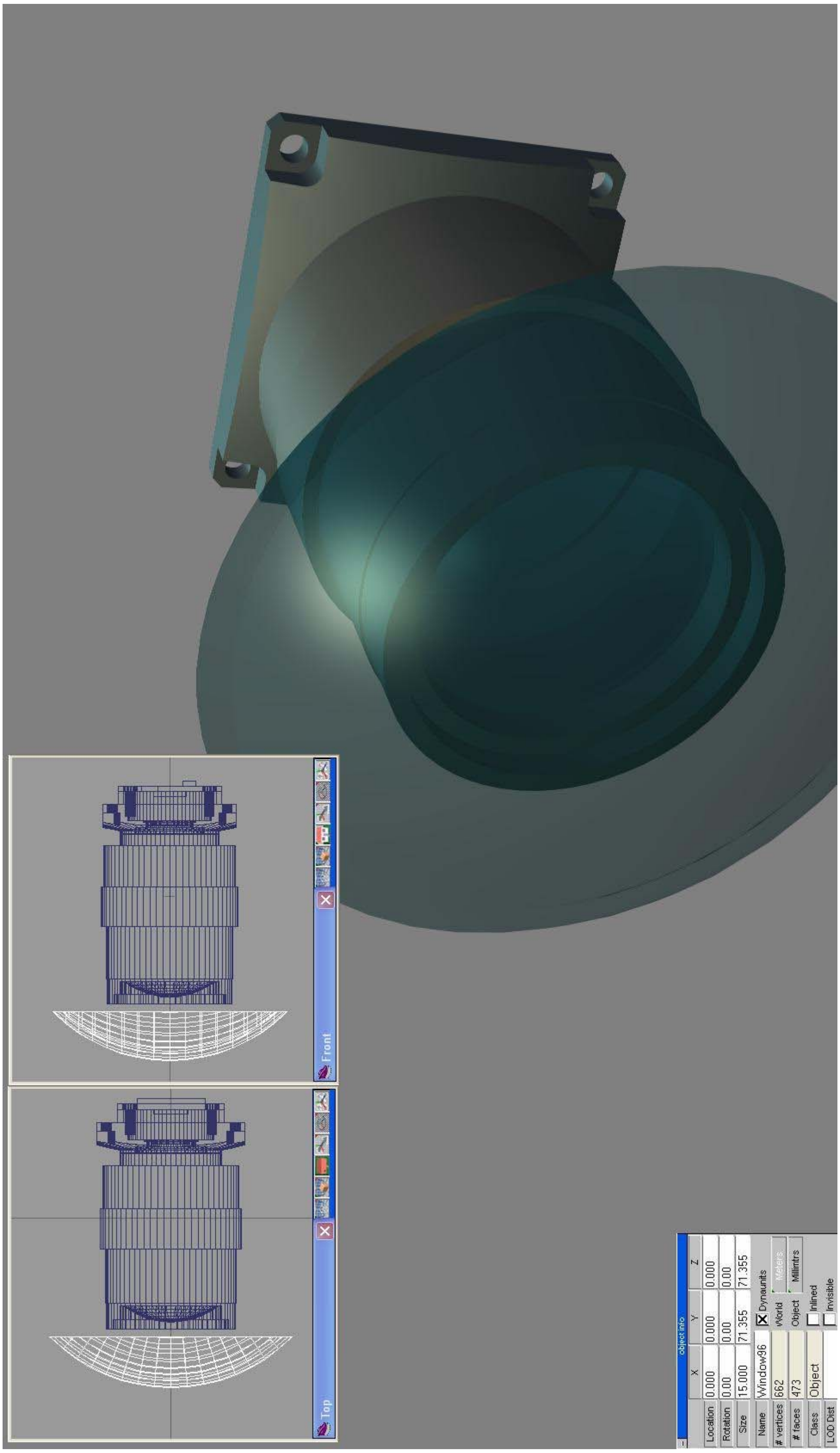


Front
Left







Front
Top

Intentionally empty

Revision control

Date: 2009-Feb-13	Revision: 1.0	Prepared by: Joshua Tristancho	Revised by: Andres Petilo
Date: 2009-Apr-23	Revision: 2.0	Prepared by: Joshua Tristancho	Revised by: TO BE VALIDATED

1 Team FREDNET Mission Analysis

Scope

Due to Pico-Rover Design implements Critical Design and Quality Assurance, Team FREDNET (also referred as community) may be also compliance with these requirements. This document qualifies Team FREDNET whole mission in order to be compliance.

Mission Analysis Approach

This mission analysis implements a Top-Down approach which may change with time due to iteration process.

In progress

1.1 STEP 0. Mission Statement

- The ultimate goal of Team FREDNET program is the development and construction of an open space technology available to the community in order to have a TRULY OPEN SPACE

In progress

1.2 STEP 1. Objectives Definition

- Broad Objectives and Constrains
  - The goal is win the GLXP as an example of viability and public effort
  - The following goal is to establish partners for Moon's resources exploitation based in this open space technology
  - At least GLXP constrains or better
- Quantitative Needs and Requirements
  - Enter the moon under the GLXP requirements
  - Target launcher cost lower than US$40M provided by non public partner or lower than 10% of total cost
  - Target launch weight lower than 500 kg

- Target development cost lower than US$4M

In progress

1.3 STEP 2. Mission Characterization

In progress

1.3.1 Alternative Mission Concept

- Launched inside a partner payload will be

In progress

1.3.2 Alternative Mission Architectures

OPTION 1. Basic configuration

1.3.2.1 User Segment: GLXP Provider

In progress

1.3.2.2 Ground Segment: Mission Support

In progress

Following AlexC Post: There are two preferred communications partners for the Google Lunar X PRIZE. One is Universal Space Network who offer 50% discount. The other is the SETI institute who offer free services using the ATA array for 7 Earth days I think. See all preferred GLXP partners at http://www.googlelunarxprize.org/lunar/about-the-prize/preferred-partners
1.3.2.3 Ground Segment: Mission Control Center

In progress

1.3.2.4 Ground Segment: Ground Stations

In progress

1.3.2.5 Space Segment: Launcher

Assuming Launch cost per kilogram like gold price in US$35,273.96 per kilogram.

Parameter	Launch with WRV1	Launch with Jaluro	Launch with Picorover
Weight	37.1 kg	371.2 kg	29.7 kg
Lease Launch Cost	US$1.15M	US$11.5M	US$0.9M

We have considered Team FREDNET specifications only for Jaluro

1.3.2.6 Space Segment: Lunar Bus

The Lunar Bus is also called TLI.

Parameter	Lunar Bus with WRV1	Lunar Bus with Jaluro	Lunar Bus with Picorover
Weight	37.0 kg	371.0 kg	30.0 kg
Width	0.7 m	0.8 m	0.6 m
Height	1.0 m	1.0 m	1.0 m

Lunar Bus Specification Source. *Results are not completed*

Lunar Bus Orbit Consideration

$r^3 = G \cdot M \cdot T^2 / 39.48$

Where:

$39.48 = 4 \cdot PI^2$

G: $6.67 \cdot 10^{-11}$ $Nw \cdot m^2/kg^2$

M: $7.349 \cdot 10^{22}$ Kg

T: Angular rotation 27d 7h 43.7m = 2360622 seconds for a stationary orbit

Possible orbits:

$r_{stationary}$ **= 88,446.86 km** (h = 86,709 km)

r_{L2} **= 61,500 km** (h = 59,763 km)

Alex reports that a spacecraft at $r_{stationary}$ would fall back to Earth. This is also why using the lunar bus as relay would only provide intermittent comm link.

Precise Calculations For The Required Fuel (Rocketry)

To be removed

Rocket type: **Bipropellant liquid rocket**
Fuel. **Hydrogen**
Oxidizing. **Fluorine**
Adiabatic flame temperature. T_0 **= 4756 K**
Specific impulse. I_{sp} **= 390 s**
Average molecular weight. $mW_{average}$ **= 10** *(To be removed)*
Effective exhaust velocity. V_e **= 4400 m/s**
Energy per kilogram. E_w **= 9.7 MJ/kg**

Tsiolkovsky's rocket equation

$$V_{Delta} = V_e * \ln (M_i/M_f)$$

Where:
V_{Delta}: Speed (scalar) that measures the amount of "effort" needed to carry out an orbital maneuver [m/s]
$V_e = g_0 * I_{sp}$
g_0: Acceleration at the Earth's surface [m/s2]
I_{sp}: Specific impulse [s]
M_i: Initial mass [kg]
M_f: Final mass [kg]

In progress

1.3.2.7 Space Segment: Lunar Lander

Parameter	Lander with WRV1	Lander with Jaluro	Lander with Picorover
Weight	5.0 kg	50.4 kg	3.0 kg
Width	0.7 m	0.7 m	0.7 m
Height	0.5 m	0.5 m	0.5 m

Lunar Lander Specification Source. *Results are not completed.*

In progress

1.3.2.8 Space Segment: Lunar Rover

Parameter	WRV1	Jaluro	Picorover
Weight	1.5 kg	2.0 kg	0.5 kg
Width	0.2 m	0.2 m	0.1 m
Height	0.15 m	0.1 m	0.1 m

Lunar Rover Specification only applied for Jaluro.

In progress

OPTION 2. High risk configuration added to the basic configuration

1.3.2.9 Space Segment: Lunar Beacons

OPTION 3. High cost configuration added to the basic configuration

1.3.2.10 Space Segment: Lunar Bus with Stationary Orbit

In progress

1.3.2.11 Space Segment: Lunar Bus in the Lagrange Two point

In progress

1.3.3 System Drives Identification For Each Alternative

Detailed System Definition (What is and does)

- User Segment
  - GLXP Provider
- Ground Segment
  - Mission Support
  - Mission Control Center
  - Ground Stations
- Space Segment
  - Launcher
  - Lunar Bus
  - Lunar Lander
  - Lunar Rover

In progress

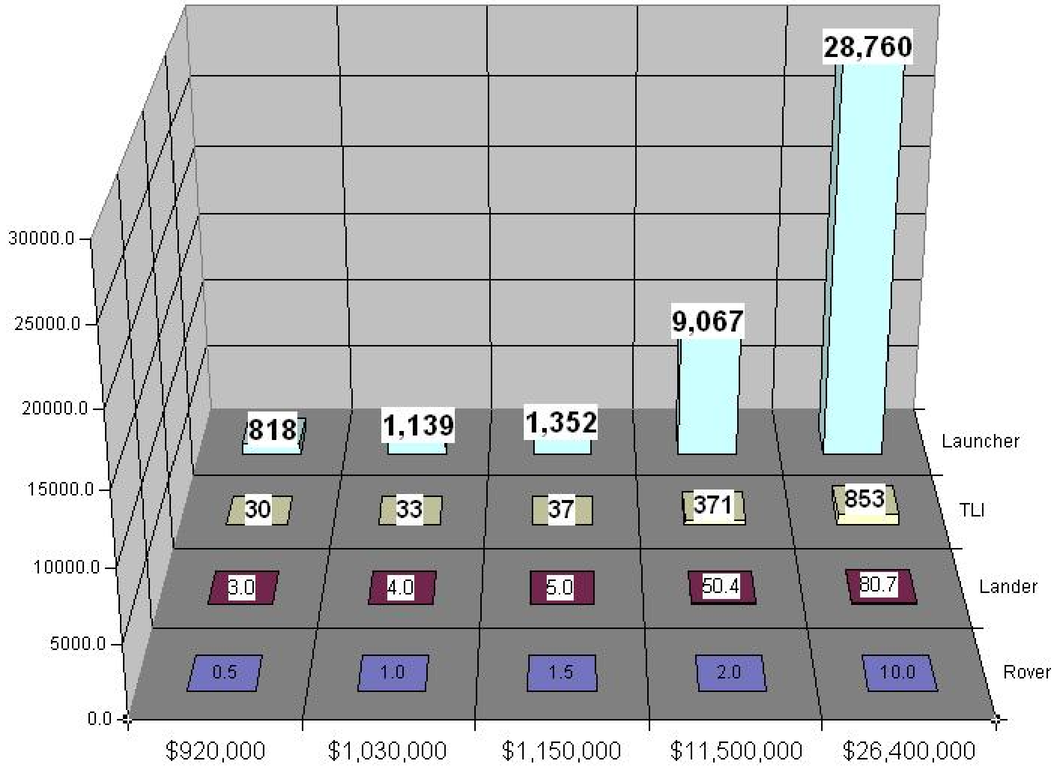
1.4 STEP 3. Mission Concepts Evaluation

- Critical Requirements for Each Mission Concept
- Mission Utility
- Baseline System Design Selection

In progress

1.5 STEP 4. Requirements

- System Requirements
- System Requirement Allocation
- Functional Requirements
    - Performance
    - Coverage: Ground visivility, Relay required
    - Responsiveness: Near real time
    - Duration: 6 month
    - Availability: FEC in acordance with CCSDS 131.0-B-1
    - Survivability: 6 month, Lunar night
    - Data Distribution
    - Data Content and Format
    - Environment: Disposal required
    - Cost and Schedule

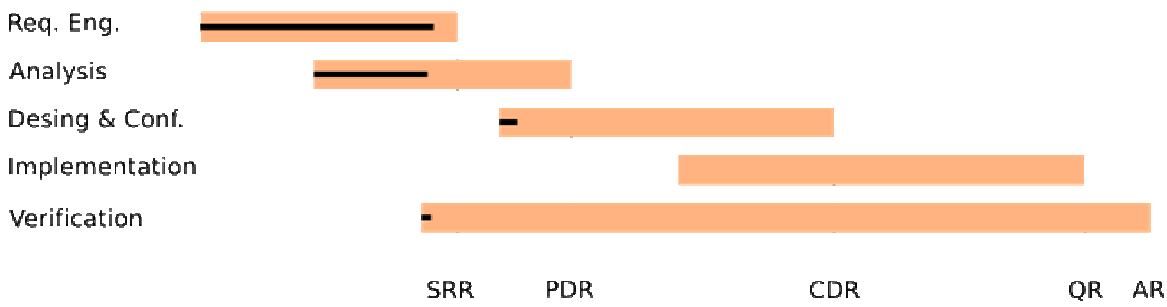


Cost *vs* Lunar Rover weight. Weight of associated Launcher, TLI and Lander are showed in kilograms

In progress

2 Planning

In progress
Also see Communication System Development Plan



3 Pico-Rover Group Roles

3.1 Group Leader

In charge of resources managing, with economical capability in order to ensure the research and development of the Pico-Rover project.

Assigned to: Joshua Tristancho

3.2 Quality Control

In charge of manage the quality of Pico-Rover organization and production, with quality skills in order to ensure the correctness of any process in accordance with **SAE ARP 4761** (*Safety Assessment Process), **SAE ARP 4754** (Certification Considerations for Highly-Integrated or Complex Aircraft Systems*) and **IEEE Standard 1362-1998** (*Concept Operations Document*).

Assigned to: Andres Petilo

3.3 System Manager

In charge of manage Pico-Rover's subsystem, with technological skills in order to ensure correct decisions about subsystem design and definition.

Assigned to: Joshua Tristancho

3.4 Software Manager

In charge of programming and coding any component of any Pico-Rover's subsystem, with multilanguage skills in critical software developer in accordance with **DO-178B** (*Software Development Life-Cycle*)

Assigned to: Raul Cuadrado

3.5 Hardware Manager

In charge of designing and building any component of any Pico-Rover's subsystem, with technological skills in critical hardware developer in accordance with **DO-254** (*Hardware Development Life-Cycle*)

Assigned to: Enric Fernandez

Revision control

Date: 2009-Feb-13	Revision: 1.0	Prepared by: Joshua Tristancho	Revised by: Andres Petilo
Date: 2009-Apr-23	Revision: 2.0	Prepared by: Joshua Tristancho	Revised by: TO BE VALIDATED

1 Pico-Rover Group

We are part of the Team FREDNET who is the owner of for our production. We are a subgroup of the *Rover Group*. Our target is design and build an open space rover called *Pico-Rover* as a part of the Team FREDNET rover competition.

2 Organization

We follow the rules defined by the Team FREDNET. We promote parallelism between rover groups. Our design, development and production are free accesses for the public domain. We use common materials and providers in order to let this technology accessible for everybody. We are not financed by any public organization or government. We procure our own financial viability.

3 Engineering Process

We emphasize a top-down approach, a life-cycle orientation, a major emphasis on initial definition of system requirements and an interdisciplinary team approach. We encourage coordination, communication and traceability. We prepare our group with an adequate training program.

4 Quality Assurance

We have a quality independent department for quality assurance regardless the criticism of the project.

5 People Register

Nick	Joined since	Member since	Real name
Tristancho	08 Jan 2009	17:47, 11 January 2009	Joshua Tristancho
Raulcs	02 Feb 2009	09:39, 10 February 2009	Raul Cuadrado
Enric	30 Jan 2009	12:27, 12 February 2009	Enric Fernandez
Petilo	05 Mar 2009	05:24, 10 March 2009	Andres Petilo