YES2 SpaceMail

Executive report – Part 1

Technical Summary

CE0001.1 - YES2-CDR-[M05] Part 1

Version: **2.0**

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Table of Contents

Document info

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Change record

Version	Rel	Date	# Pages	Changed pages	Description
1	0	19/11/2003	39	-	PDR (Phase I) overview
1	1	18/03/2005		all	Pre-CDR update
2	0	10/03/2006		all	CDR update

Acronyms

Other acronyms that may occur shall be retrieved from CP0301 - YES2-CDR - Abbrevations and Definitions

AIR	An Inflatable Re-entry capsule
BAS	Beacon Activation System (located on Fotino)
CDR	Critical Design Review
CPU	Central Processing Unit (YES2: PC104 board, part of FLOYD's OBC)
DC	Direct Current
DHU	Data Handling Unit (YES2: part of TSU that will store our data)
DLS	Data Logger System (part of payload for Fotino)
DOF	Degree Of Freedom
ESA	European Space Agency
FLOYD	Foton LOcated YES2 Deployer
FUSE	Future Space Exploration academia network
GPS	Global Positioning System
HIT	Foton Battery Pack (Russian acronym)
HK	HouseKeeping (most basic telemetry of system status)
H/W	Hardware
I/O	Input/Output (YES2: PC104 board of FLOYD's OBC)
IRDT	Inflatable Re-entry and Descent Technology
MASS	Mechanical and data Acquisition Support System (for Fotino)
MFD	MASS-Fotino Decoupling system (belt system supporting Fotino during launch, released by pyros)
TC	Telecommand
TM	Telemetry
TTTC	Time Tagged Telecommand (telecommand with predetermined delay of execution)
OBC	On-board computer (YES2: FLOYD CPU and I/O PC104 boards)
OLD	Optical Loop Detection (tether length measurement device)
PDR	Preliminary Design Review
PDU	Power Distribution Unit
ReCon	Releasable Connector (between FLOYD and MASS)
SPRInT	Small Payload Re-entry Inflatable Transporter
SRC	Space Research and Consultancy
SSETI	Student Space Exploration and Technology Initiative
StarTrack	Swinging Tether Assisted Re-entry Through Actively Controlled Kinetics
TBC	To Be Confirmed
TBD	To Be Determined
TSU/DHU	Telescience Support Unit, located in Foton capsule
YES2	Young Engineers' Satellite 2

Project terminology

Barberpole	Friction brake system of YES2, used for tether deployment control, the level of friction, thus indirectly the velocity of deployment is controlled by wrapping the unwinding tether around a small pole (like a barbershop's red spiral around a white pole)
Battery Pack	See Foton
FLOYD Attic	The compartment in top of the FLOYD tether container, supporting the ejection system and barberpole, and containing the stepper driver box.
Foton	Russian carrier vehicle, consisting of HIT/Battery Pack (on which YES2 is mounted), Foton capsule (recoverable, containing e.g. TSU), and service module
Fotino	The small spherical re-entry capsule of YES2 flight on Foton-M3
Loop, turn	A loop is a single winding of the tether on its spool. A turn is a 360 degree motion of the brake's barberpole with respect to null position.
MR YES	MIssion TEst Rig for YES2. Tether deployment test rig with real time tether simulator, TM/TC and EGSE breadboards in the loop.
Phase:	The deployment consists of 4 phases: • First stage: the phase in which the tether is deployed to the vertical • Hold phase: the phase in which the tether length is held constant (~ 3.5 km). Also called synchronization phase, because it is used to sync with the landing site, after which, the second stage of the deployment will start. • Second stage: after a short Transition Phase, the tether is deployed to a large angle and to its full length (~30 km). • Swing phase: swing back to the vertical, no deployment
Phase I:	The YES2 SpaceMail project is executed in two phases: Phase I: The Inspiration.
Phase II:	The YES2 SpaceMail project is executed in two phases: Phase II: The Mailing.
Stage:	Used for the two-stage tether deployment. The deployment consists of 4 phases (see Phase).
SpaceMail	The application of the frequent sample return capability for the International Space Station.
Unwinding rig	The tether will be subjected to extensive deployment tests. These tests will be performed in the mission test rig Mr. YES. The part of MR. YES that pulls the tether from the deployer with a velocity controlled by tether tension as if it were the AIR capsule subjected to inertia and space dynamics, is called Unwinding Rig. It includes also a rewinding facility for reuse of the tether.
Xbox	The electronic box of YES2, mounted to the FLOYD tether container, containing the OBC and PDU

YES2	YES2 is the second Young Engineers' Satellite. YES1 (YES) was launched in October 1997 on Ariane 502 (see www.delta-utec.com). YES2 is written without space (YES 2) or dash (YES-2).

1 Project Executive Summary

1.1 Scope

This document has three main purposes:

- To give a high level overview of the final YES2 design on Foton-M3 which is proposed for CDR. All systems are mentioned as well as the interrelationships and a brief mission overview. (This document – E0001 part 1).
- A system engineering overview is given in E0001 part 2
- To give an easy-access overview of the YES2 project, the management methodology, the teamwork and make at least a mention of all the educational design work done that did not end up in the CDR design of YES2. A major example is of course the extensive work on the inflatable capsule development. References to more info on such topics (e.g. YES2 website, YES2 reports collection CD-ROM) are to be found here as well. (E0001 part 3).

1.2 Objectives of YES2

1. To give European students a motivating technological & educational experience
2. To demonstrate SpaceMail: return a small capsule from space to Earth, using:
    - a 30 km 5 kg wire (tether) rather than a rocket engine, including scientific payload
    - a lightweight spherical capsule including scientific payload

1.3 Educational and Technical Approach

The YES2 SpaceMail is split into 2 phases:

Phase I: the Inspiration, May 2002-December 2003

Focus on educational return and setting up university network. Getting experienced with working inside student curricula. Design work performed by interns, volunteer work, group project, master thesis projects. International Summer School in Samara, Russia. Brainstorming on capsule design (including an inflatable re-entry capsule prototype development), build hardware and test set-up for tether, perform analysis and test to demonstrate mission and technical feasibility. Consistent concept presented at PDR.

Phase II: the Mailing, December 2003-September 2007

Focus on construction. Work packages are now defined based on required tasks, execution shifts to Centers of Expertise (particularly motivated universities from Phase I), supported by other universities through parallel studies or exchange students, internships in Delta-Utec or ESTEC. Partial critical design (review for acceptance on carrier): demonstrating schedule/financial feasibility. ESTEC workshops for intense co-operation between students. A second Summer School, focussed on preparation and execution of a variety of tests as well as on defining the interface with Foton in more detail. Prototyping, deployment tests, subsystem mock-up tests. Detailed design. Critical Design Review (decision about re-entry capsule and landing site), construction, test, flight, recovery, data processing. More outreach.

1.4 Mission and design summary

Two missions were planned related to YES2, on Foton-M2 and Foton-M3. The Foton-M2 precursor (Fotino re-entry and some technology demonstrations) was cancelled due to budgetary constraints.

1.4.1 Mission design changes since PDR

The major changes with respect to the PDR mission design are:

- Capsule is released from the tether and MASS, BEFORE the tether and MASS are released from Foton. This allows for a smooth, stable, gravity-gradient-assisted and well-defined capsule release compared to the pressure-sensor release in the atmosphere. The tether was originally planned to assist the re-entry of the capsule by providing initial pointing. However, this technology is rather experimental. In the current design, this interesting experiment is not lost (it lives on as MASS+tether will reenter and burn), but it avoids an interdependent combination of 2 experiments: re-entry capsule and re-entry assisted by tether drag tail.
- As a consequence of the new release timeline, it was decided the capsule is inserted into the re-entry orbit at a fixed time after ejection (since the primary release mechanism is no longer the tether cut at Foton, but is now located inside MASS, for which a timer solution is the simplest and most reliable). The release mechanism is called MFD. The new approach limits only slightly the mission flexibility and accuracy, it simplifies somewhat the mission and allows for a simpler redundancy in re-entry by tether cut. Finetuning of landing site can still be done with selection of the ejection time and second stage start time.
- The mission time is reduced to under 7 hours, and synchronization phase is reduced to 10 minutes, in order to minimize impact on Foton mission, as well as power budget. It is designed to be executed autonomously, although a few abort options remain.
- Landing is in Kazakhstan (or Southern Russia) rather than Sweden (imposed by ESA in April 2004)
- Inherently-safe concept (initially requested by W.J. Ockels) was deserted, the legal validity of the concept was questioned by ESA. Technological interest and budgets for inflatable re-entry capsules also disappeared. The capsule is now a small sphere, Fotino, landing with a parachute.

1.4.2 YES2 Mission on Foton-M3 September 2007

A detailed mission description can be found in CE0206 – YES2-CDR-[M05] YES2 Mission Summary.

YES2 is demonstrating the tethered SpaceMail technology, i.e. delivery of a small payload from space using a tethered re-entry capsule. For YES2, the Fotino capsule is a small very simple spherical construction equipped with science package and parachute. Some advantages are the compact storage ability, the lightweight structure, low cost accessible technology (students can build it), the use of a simple heat shield and the easy scalability to large payloads.

A final application for SpaceMail is foreseen to support the research done on stations such as the International Space Station (ISS) or other stations build in the future to deliver samples from space fast and close to the customer. Other applications are delivery of a capsule to planetary surface, launch assist, or insertion of constellation of small satellites (with multiple capsules released at intervals) for thermospheric research.

The Fotino capsule is a small demonstrator lightweight and flexible heatshield materials and with its simple spherical shape, low ballistic coefficient and scientific payload will serve as laboratory for re-entry (comparison flight results with CFD, plasma tests etc.). Fotino is planned to be re-entered by the YES2 tether.

The entire current YES2 system consists of 3 major components:

- FLOYD: Foton LOcated YES Deployer, including tether and brake on Foton battery-pack as well as control, data and power system inside the Foton capsule (~20 kg)
- Fotino: Re-entry capsule (~5 kg)
- MASS: Mechanical and data Acquisition Support System (~7 kg)

A 30 km, 5 kg tether is deployed from a passive spool into a swinging configuration within some hours time. MASS and Fotino are a unit at ejection from Foton and attached by a tether to FLOYD/Foton. After tether swing back to the vertical in the opposite of the flight direction, Fotino will be released from MASS at a fixed time after ejection from Foton, to

lower, through the momentum-transfer effect, the capsule’s perigee by more than 10 times the tether length, sufficient to induce a re-entry. This can be done with considerable accuracy and with simple low-cost hardware [see StarTrack report, EWP 1883].
The tether-MASS combination is then released at the carrier (Foton-M3) side after a short delay time of approx. 10 seconds. The tether is cut on Foton side first to minimize risk for it to remain attached to Foton, and because there is more direct and more reliable control of the cutter system available on Foton side. In this way, attitude & thermal control, as well as communication requirements are reduced on the Fotino side and the mission is kept simple.
So after cut, the tether will remain attached to MASS. MASS+Tether will burn up in the upper layers of the atmosphere.

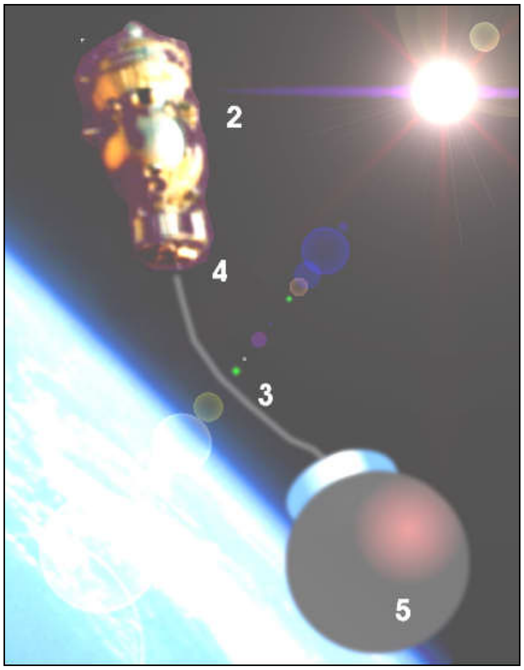
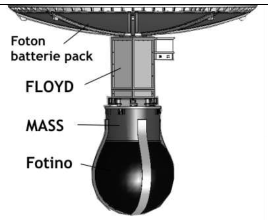
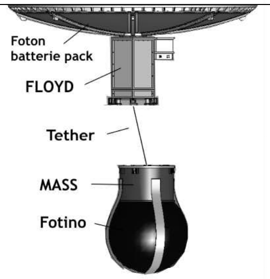
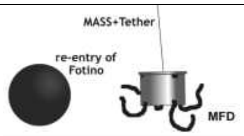
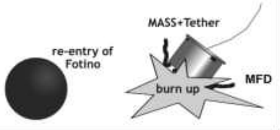


Figure 1: YES2 system during initial deployment. 2=Foton, 3=FLOYD, 4=tether, 5=MASS & Fotino

The total mission duration from YES switch ON till YES2 switch OFF is 6:45 hours.

1	FLOYD and MASS/Fotino on Foton battery pack	
2	Tether deployment(1ststage, holding phase, second stage)	
3	Fotino release from MASS and Coasting (tether cut off on Foton side)	
4	Fotino Re-entry (burn up of MASS+Tether+ MFD), landing of Fotino	

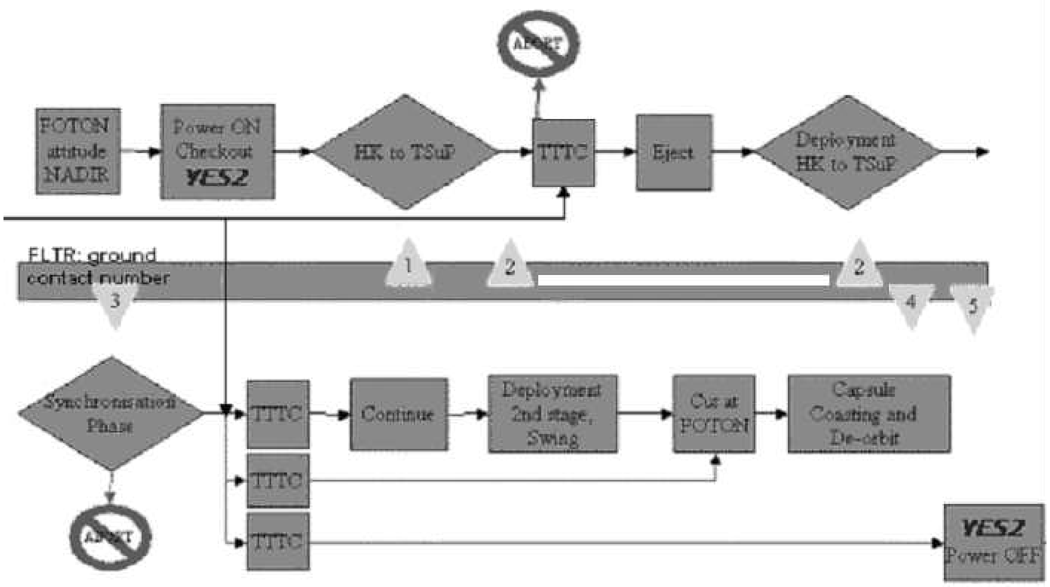


Figure 2. YES2 mission stages.

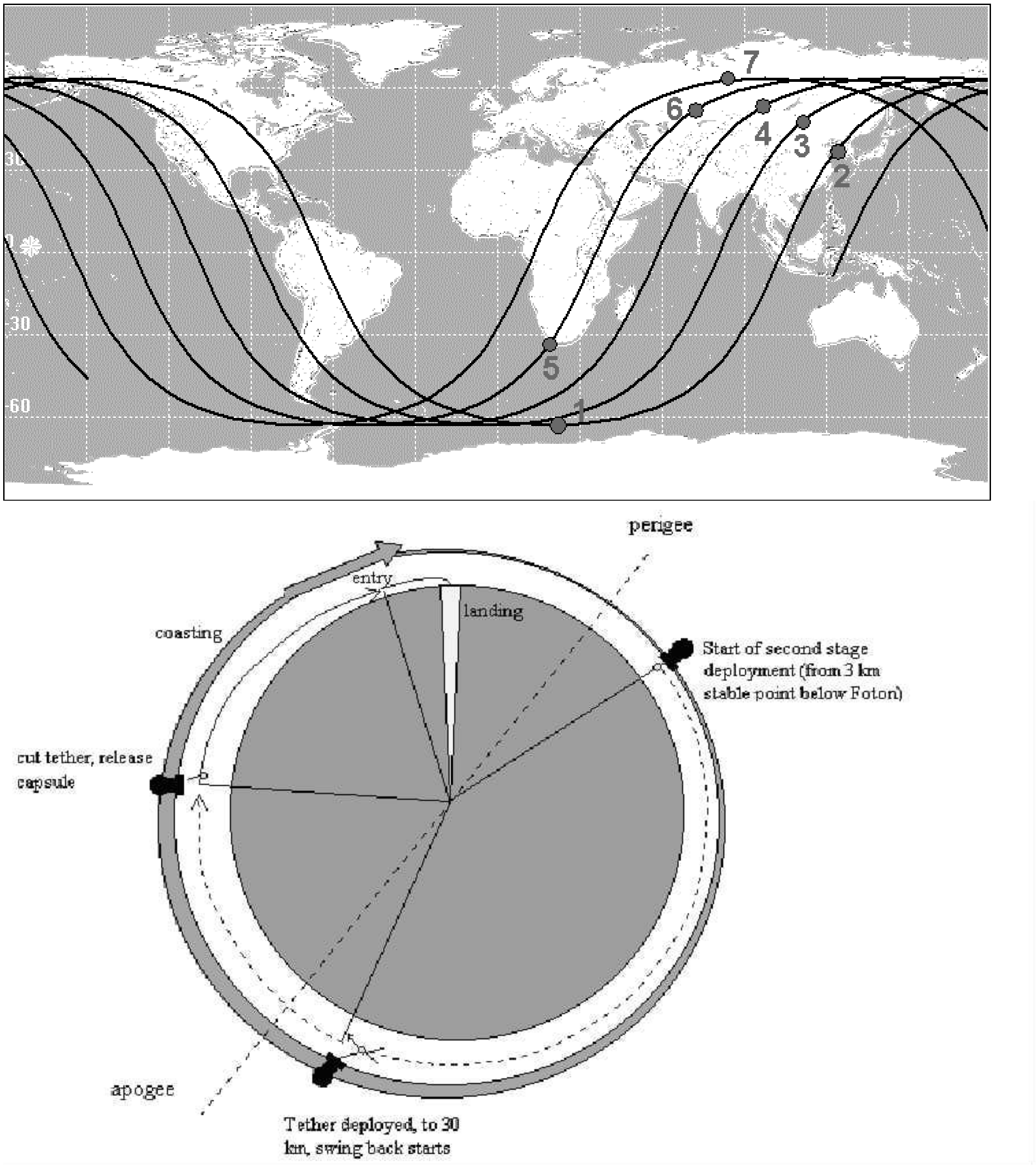


Figure 3: YES2 ground plot with major events, landing point Kasakhstan, orbital plane view.

1 – YES2 switch ON, start Foton attitude manouver to establish NADIR-orientation
2 – YES2 health and Foton attitude check [ground contact 1]
3 – MASS/Fotino ejection, start of 1st stage of tether deployment [ground contact 2]
4 - start of 2nd stage of deployment [ground contact 3]
5 – Fotino release, Tether cut on Foton side
6 – landing area Fotino [ground contact 4]
7 - YES2 switch OFF [ground contact 5]

1.4.3 Telecommands overview

YES2 TC number	Name	Purpose
YTK2	Eject	Fire ejection pyro, OBC starts deployment
YTK3	Cut Tether	Fire tether cutter pyro's to release tether from Foton
YTK4	Start Second Stage	OBC will put in motion second stage of deployment (from 3.5 to 30 km)
YTK8	MASS ON	FLOYD PDU switches on MASS and UHF receiver
TKTM	TM data	OBC will send all remaining stored mission data to TSU/DHU
YTK10	Arm pyros	Pyro arming latch set, OBC prepares for deployment or tether cut
YTK12	Disarm pyros (test only)	Disarms all pyros

Table 1. Overview of telecommands

1.4.4 YES2 Design changes since PDR

The major changes with respect to the PDR system design are:

- Mass reduced from 40 to 32 kg. The major trade-off here was mission reliability (larger deployment success rate) vs. mass, which has to be reduced to maximize the chances for the launch opportunity after YES2 was placed on the reserve list of Foton-M3, rather than on its primary payload list, in April 2004. The problem with low deployment mass is the reduced inertia that is required to overcome the friction in the first 500 m of deployment, after which gravity gradient can take over. It was found that with increased ejection velocity (same energy, less momentum), still acceptably robust deployment can be guaranteed, although the landing area is somewhat increased.
- All components are placed on top of the Foton spacecraft (battery pack or “HIT” container). In the PDR design, the on-board computer (OBC) was to be placed inside the recoverable Foton capsule. This exposes the electronics to the space environment and makes it more difficult to retrieve the mission data, but makes the system much simpler from an interfacing, integration and testing perspective. Also, no volume or mass in the re-entry capsule is required, which is an important asset for securing the launch opportunity.
- The TSU is only used for data storage, no longer for transmission, to simplify the interface and operations required. As a result a UHF link is used to communicate between MASS and FLOYD rather than S-band to the TSU. Because the OBC is no longer recoverable, the (non-critical mission) data which cannot be transmitted straight to the ground due to downlink bandwidth limitations (6 byte/s), can only be saved by using the TSU. A serial cable entering the Foton capsule from outside is foreseen and is judged as the most protruding interface requirement to the Foton spacecraft.
- Inflatable is dropped in favor of the smaller, simpler and lighter demonstrator of lightweight and flexible heatshield technologies, the 40 cm sphere, Fotino. Reasons: budget required for inflatable development could not be established. ESA has publicly withdrawn its interest in inflatable re-entry vehicles in favor of deployables. Stability issues and dynamics analysis requirements for Fotino have less uncertainties, precursor would be possible with Fotino.
- A connection between FLOYD and MASS is added, the ReCon, through which MASS is switched on by telecommand (rather than purely by a MASS microswitch). This is done to provide redundancy for the safe switch-on of the UHF transmitter and the activation of the MFD Fotino decoupling pyros.
- Additional safety is provided to guarantee tether cut (e.g. thermal element) and avoid recoil (ripstitching).
- Fotino is upgraded to a scientific re-entry laboratory and will be equipped with a parachute.
- The design is upgraded towards ECSS standards and inclusion of Quality Plan, traceability etc. More redundancy is implemented.

1.4.5 YES2 CDR Design

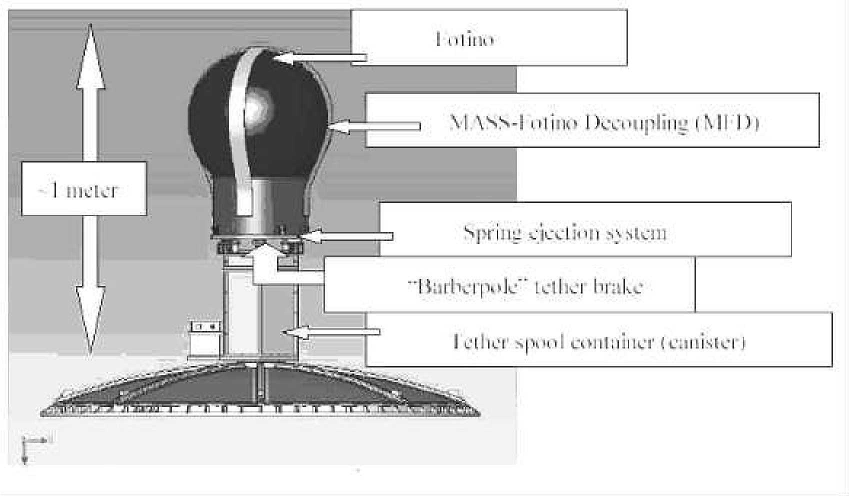


Figure 4. Mechanical design overview of YES2 on Foton battery pack.

Total mass is 32 kg. Power consumption is ~200 Wh.
The mechanical system contains:

- Fotino (4 kg, flexible re-entry capsule containing beacon, antenna and payload inside heatshield and foam core, parachute, scientific instrumentation & GPS, telemetry),
- MASS (8 kg, including sensors, GPS, UHF transmitter, DHS, PDU, the MFD retaining and decoupling system for Fotino)

The rest of the system is called FLOYD (20 kg):

- Tether spool container (including tether and OLD optical length detection electronics)
- FLOYD Attic (compartment containing stepper driver –stepper controller and amplifier-, relais box, UHF receiver and supporting the barberpole and ejection system)
- Ejection system
- Barberpole tether brake with stepper motor and tether cutters+thermal element (redundant system to melt tether)
- Microswitch (to sense ejection)
- Xbox (on side of canister) containing PDU (for electrical interface with Foton) and OBC (for deployment control and TM)
- Interface plate to Foton battery pack

MASS and FLOYD are connected by the ReCon releasable connector and by UHF link.
FLOYD and Foton are connected by 4 connectors:

- YK1 - Power (27 V)
- YK2 -Telecommand (7 time tagged pulse commands),
- YK3 - Telemetry (16 bit parallel 10 Hz data to Foton TM + 1 toggle bit),
- YK4 – Data (RS422 to ESA's TSU/DHU unit in Foton capsule for data storage).

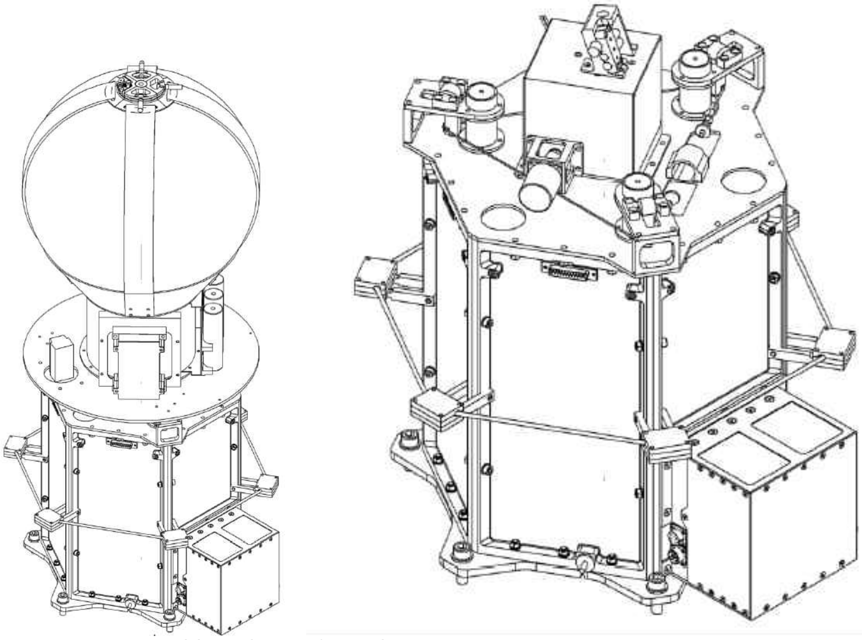


Figure 5. Fotino, MASS, FLOYD (left). FLOYD (right). Xbox is mounted on right bottom side. Barberpole box and ejection system can be seen on top. Large loop antenna around the hexagonical tether canister. UHF antenna and Stepper Driver are hidden in top of canister.

The mission is controlled by time-tagged pulse telecommands that are sent to Foton shortly before the experiment starts. The Stepper Driver and OBC contain S/W, so does the DHS on MASS and DLS on Fotino. This S/W and all its parameters are fixed before flight. Small pieces of code software, only oriented at hardware control is included in the UHF systems.
The grounding philosophy is that each physically separated system has its own zero level, a single grounding and is electrically isolated from the other systems via DC/DC converters, opto-couplers or RS422 drivers

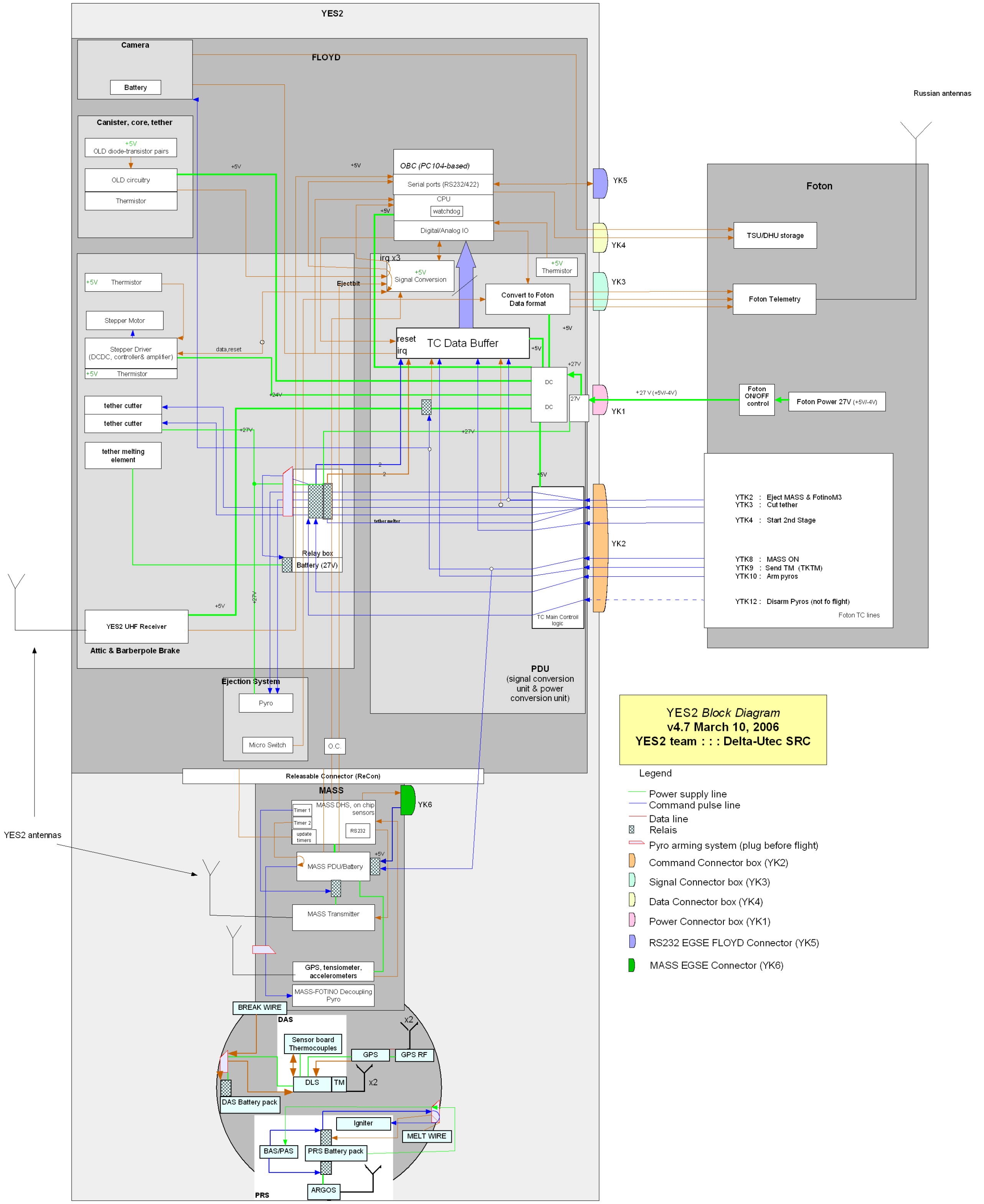


Figure 6. YES2 electrical overall layout

1.5 Feasibility and critical items

1.5.1 CDR design technical criticalities

Tether deployment tests and improved simulation capabilities have created sufficient confidence in the feasibility of the mission. Re-entry simulation in combination with plasma chamber tests suggest Fotino payload survival after entry and parachute landing (or impact). Independent validation by TsSKB sofar is in agreement with YES2 design work. Factors affecting safety for tether deployment to Foton have been eliminated by design choices. Mass of YES2 may be raised above 32 kg due to recent conceptual change by TsSKB in mechanical interface of Foton.
Critical remains the schedule. Most of 2005 has been spent on solving contractual issues and upgrade of the design to a formal CDR level. It is mandatory to be fully in line with the Foton-M3 schedule by June 2006, and remain there.

1.5.2 Major items to be demonstrated after CDR by mock-up/test

Focus for future testing is on the following critical topics:

- Design for radiation and S/W robustness
- Stepper motor and mechanism thermal and vibration performance
- Ejection system off-nominal performance (thermal gradients etc.)
- Capsule heatshield mechanical performance
- Capsule electronics thermal performance
- Parachute opening under unstable dynamical conditions

1.6 YES2 novelties

The novelties of this project promise to be, among others:

- 400 European, Russian students together built a satellite, largely within university curriculum (even student teams from Japan, Canada, Australia, USA were involved).
- First European/Russian tether deployment
- First tethered capsule delivery. Tether used for accurate deorbit and initial orientation of capsule.
- First student-built re-entry capsule
- Longest tether ever deployed in space (30 km. Current record is 20 km [SEDS1 & SEDS2])
- Low ballistic coefficient re-entry capsule validation
- First GPS on a tether deployment, so precise deployment data.

1.7 CDR Technical Documentation

1.7.1 Key to readers

The following documents are key to readers of the YES2 CDR documentation:

- **CE0001 - YES2-CDR-[M05] Part 1 - YES2 SpaceMail Technical Summary**
  This document

- **CE0PRD - YES2-CDR-[PDRD] Level 0 requirements**
  Project Requirement Document, YES2 Quality Plan

- **YES2 ICD** and **CE0803 - YES2-CDR-[E01] OID**
  External interface specification and outline installation drawing

- **CE0206 – YES2-CDR-[M05] YES2 Mission Summary**

Overview description of the YES2 mission

- CE0M04 - YES2-CDR-[M04] DRL and DRD
  Index of YES2 CDR documentation

- CP0301 - YES2-CDR - Abbrevations and Definitions
  Abbreviations

These documents can be found in the expert folder of the YES2 ftp site (see next section).

1.7.2 Documentation on the FTP site

Location: ftp.estec.esa.int, login via www.yes2.info, password spacemail
The ftp site has the following structure and contents.

Folder	Subfolder	Contents
Root		- CDR board composition - CP0301 : Abbreviations and definitions - Who writes what: YES2 CDR author index
expert		Released CDR documentation
	0 For Information	Documents released by the contractor for expert review, Technical Notes
	1 For Review	(Authorized) Documents authorized by the contractor for use in project and as contractual deliverable for acceptance by agency
	2 Agreed	Accepted by the Agency
	Applicable documents	
	Referenced documents	
Movies and pics		YES2 PR material
YES2 - CVS backups		Automated back-ups of YES2 software & version control
YES2 - Private Backups		YES2 work back-ups/document exchange
YES2 - Tests		Test plans and reports
YES2 - CDR documents - April 2006	1 For Information - Drafts	Working drafts of CDR documentation
	2 For approval	Released by DU for approval by CDR board
YES2 - Other docs	engineering	- Relevant engineering info - Datasheets - Standards - external documents - external requirements - system engineering
	Pre-CDR documents - April 2005	Latest consistent documentation set before 2006 CDR
	team communications	- team members - responsibilities - contacts - presentations - minutes of meetings - manual STEFI and Albatros system engineering tools
	templates	

Table 2. Documentation on the FTP site

1.7.3 Database for listing, budgeting and traceability

The product tree, CIDL, electrical interfaces, responsibilities, requirements & documentation traceability etc. are managed through the YES2 interactive online database, Albatros.
Location: albatros.yes2.info, login via www.yes2.info: yes2man spacemail

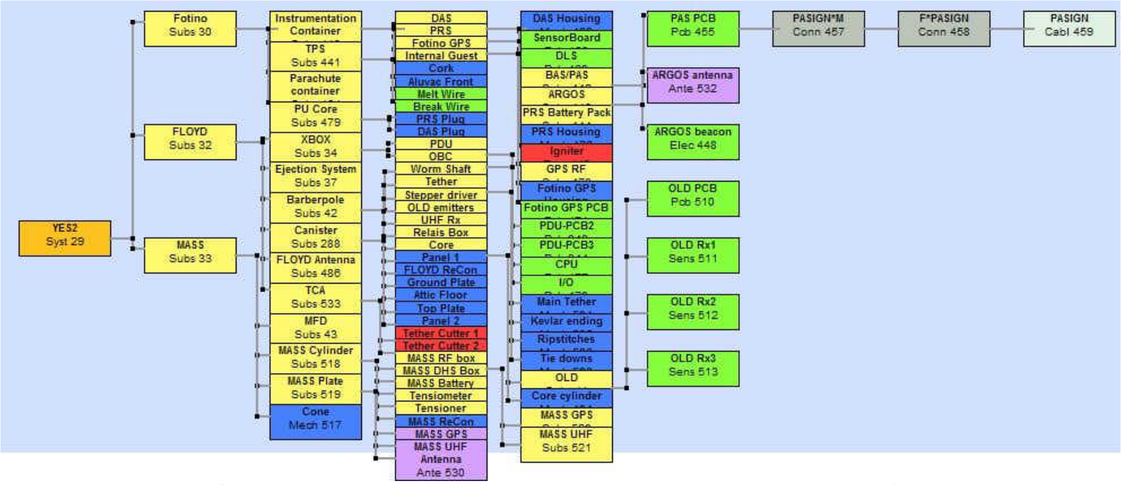
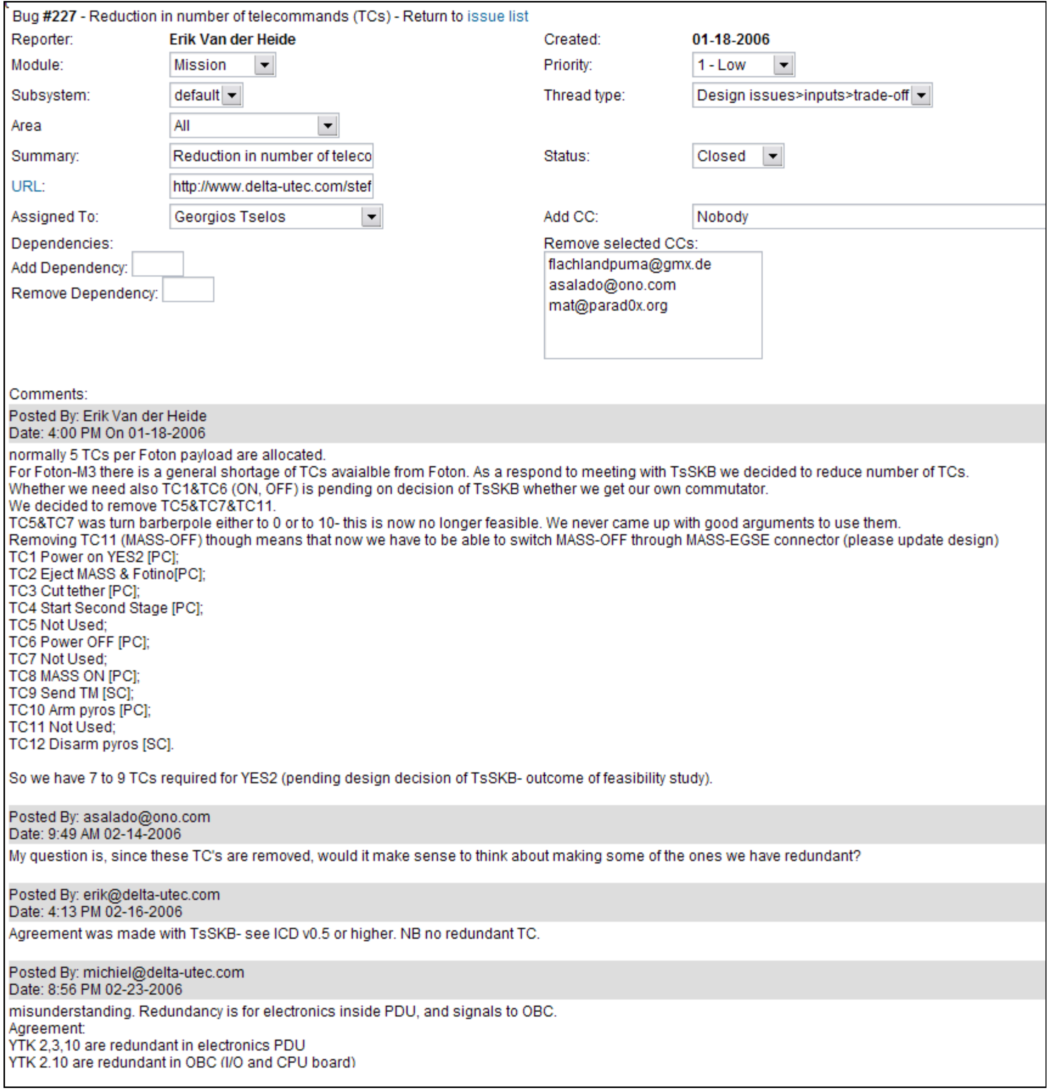


Figure 7. Albatros YES2 database: product tree, engineering lists, budgets, tracing, interfaces, contacts, requirements

1.7.4 Traceability of design trade-offs

Technical trade-offs and design changes are reported via STEFI.
Location: stefi.yes2.info, login via www.yes2.info, no password required.



Bug **#227** - Reduction in number of telecommands (TCs) - Return to issue list

Reporter:	**Erik Van der Heide**	Created:	**01-18-2006**
Module:	Mission	Priority:	1 - Low
Subsystem:	default	Thread type:	Design issues>inputs>trade-off
Area	All		
Summary:	Reduction in number of teleco	Status:	Closed
URL:	http://www.delta-utec.com/stef		
Assigned To:	Georgios Tselos	Add CC:	Nobody
Dependencies:		Remove selected CCs:	flachlandpuma@gmx.de asalado@ono.com mat@parad0x.org
Add Dependency:			
Remove Dependency:			

Comments:

Posted By: Erik Van der Heide
Date: 4:00 PM On 01-18-2006

normally 5 TCs per Foton payload are allocated.
For Foton-M3 there is a general shortage of TCs avaialble from Foton. As a respond to meeting with TsSKB we decided to reduce number of TCs.
Whether we need also TC1&TC6 (ON, OFF) is pending on decision of TsSKB whether we get our own commutator.
We decided to remove TC5&TC7&TC11.
TC5&TC7 was turn barberpole either to 0 or to 10- this is now no longer feasible. We never came up with good arguments to use them.
Removing TC11 (MASS-OFF) though means that now we have to be able to switch MASS-OFF through MASS-EGSE connector (please update design)
TC1 Power on YES2 [PC];
TC2 Eject MASS & Fotino[PC];
TC3 Cut tether [PC];
TC4 Start Second Stage [PC];
TC5 Not Used;
TC6 Power OFF [PC];
TC7 Not Used;
TC8 MASS ON [PC];
TC9 Send TM [SC];
TC10 Arm pyros [PC];
TC11 Not Used;
TC12 Disarm pyros [SC].

So we have 7 to 9 TCs required for YES2 (pending design decision of TsSKB- outcome of feasibility study).

Posted By: asalado@ono.com
Date: 9:49 AM 02-14-2006

My question is, since these TC's are removed, would it make sense to think about making some of the ones we have redundant?

Posted By: erik@delta-utec.com
Date: 4:13 PM 02-16-2006

Agreement was made with TsSKB- see ICD v0.5 or higher. NB no redundant TC.

Posted By: michiel@delta-utec.com
Date: 8:56 PM 02-23-2006

misunderstanding. Redundancy is for electronics inside PDU, and signals to OBC.
Agreement:
YTK 2,3,10 are redundant in electronics PDU
YTK 2.10 are redundant in OBC (I/O and CPU board)

Figure 8. STEFI database: traceability of design changes and trade-offs (called "bugs")

2 YES2 system overview

This section describes the system and main components in more detail.

2.1 System overview and functionalities

The 32 kg of YES2 hardware will be attached on top of the Foton battery package. A minimal mechanical and thermal interface with the Russian battery pack is foreseen. Also, the interface plate can be easily replaced, leaving the remaining of the YES2 unchanged. A schematic of the YES2 hardware mounted on Foton is depicted in Figure 9. A more detailed view can be seen in Figure 4.

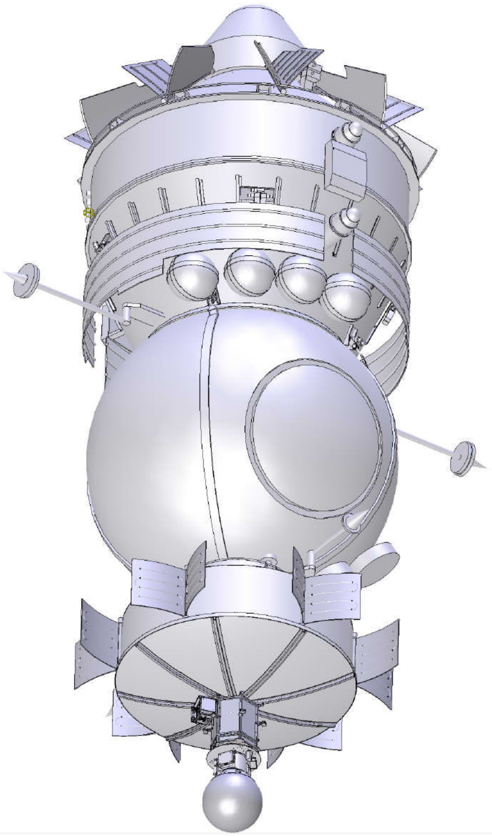


Figure 9: YES2 H/W configuration on Foton battery pack

2.1.1 Main components

The main components are the following:

FLOYD	Foton LOcated YES Deployer
MASS/Fotino	Mechanical & data Acquisition Support System, Fotino re-entry capsule

- Only FLOYD interfaces with Foton. There is a telecommand interface (7 time tagged pulse commands), a low bandwidth telemetry interface for important data during ground contacts (160 bit/s), and power (27 V), the link by serial cable for YES2 data storage on ESA’s recoverable “TSU” data recorder in the Foton capsule, and of course the single mechanical mounting plate described above.

FLOYD (~20 kg) contains the tether deployer system (tether spool, length sensors, friction brake), the On Board Computer (OBC), the Stepper Driver, the Power Distribution Unit (PDU) and the ejection system.

- MASS (~7 kg) is the instrumentation box and provides inertia to the deployment of the 40 cm spherical capsule Fotino. The sensors in the MASS instrumentation package are designed to measure the characteristics of tether deployment and MASS re-entry before its burn-up, including GPS/GLONASS. Furthermore, MASS retains and, at the right time, decouples Fotino to insert it into its re-entry orbit (Mass Fotino Decoupling system, MFD). MASS has a basic connection with FLOYD before ejection via the Releasable Connector (ReCon), and via a one-directional (MASS to FLOYD) UHF link starting some seconds after ejection. The data from MASS is not used by FLOYD, only forwarded to the TSU/DHU for storage and post-flight recovery.
- Fotino (~5 kg) contains an Argos beacon, which allows for recovery. It is switched on by a combination of a melt-wire (melting during re-entry) and the pressure-initiated Beacon Activation System (BAS) which also triggers the parachute opening at 5 km altitude (PAS). There is a datalogger not unlike that of MASS, which is switched on by a break wire at Fotino release from MASS and transmits it to the ground in UHF as well as stores its data on Flash, including GPS.

2.1.2 Overview table of YES2 subsystems and terminology

element/unit	acronym	purpose
Fotino		demonstrate lightweight re-entry technology
ARGOS Beacon	ARGOS	transmit signal from Fotino to ARGOS satellite by which landing point is calculated by ARGOS and published on internet, monopole antenna
TM (Fotino UHF)	FOTINO TM	transmit signal from space to ground and for close range location by triangulation, 4xmonopole antenna
Beacon & Parachute Activation System	BAS/PAS	make sure the Beacon & Parachute switches on based on air pressure at 5 km altitude (and not before)
Sensor board		Board including thermocouples and accelerometers, gyros, magnetometers, and connection to ESP to interface between sensors and DLS
Data Logger System	DLS	measure and store scientific data from sensor board and forward to TM
GPS+GPS RF	GPS/RF	[added 26-9-05] receive GPS data during descent, to reconstruct speed and location, patch antennas, amplifiers, combiner
Igniter & parachute system		[added 26-9-05] decelerate Fotino to 12.7 m/s, deployed by pyro-charge at 5 km (triggered by PAS)
Melt Wire & Break Wire		Simple mechanical initiation systems for PRS resp. DAS
DAS & PRS Battery Packs		Two separate battery packs plus simple electronics for power supply of resp. DAS & PRS
Structure		filler & impact damper (foam), heatshield (alumina blanket and shell) and ablator (silicon)
Terminology	SIP/TIP	Structure/TPS Intrusive Parts : thermocouple wiring, pressure sensor tubing, antennas etc.
Terminology	DAS	Data Acquisition System : DLS, Fotino TM, Sensor Board (incl. Thermocouples), ESP
Terminology	PRS	Primary Recovery System : BAS/PAS, Igniter, ARGOS, PRS Battery pack.
Mechanical and data Acquisition Support System	MASS	tethered subsatellite, holds Fotino and performs its release, transmits science to FLOYD
Tensiometer		measures tether tension (for science only)
Tether tensioning device		to connect tether to MASS and provide pretension
Data Handling System	DHS	collects data from on-chip sensors (accelerometers, gyroscopes, magnetometers), tensiometer, GPS and transmits to UHF. Controls switch-on of UHF. Controls time of Fotino release
Power Distribution Unit	MASS-PDU	provides local-battery power to the various components on MASS
UHF transmitter	MASS-UHF	transmits science data to FLOYD using a patch antenna
GPS	GPS	measures the tether deployment dynamics, the initial condition of Fotino coasting and the entry point of MASS+tether, using a patch antenna
Releasable Connector	ReCon	before ejection of MASS, the ReCon is used to switch on/off the MASS, and the opening of this connector notifies the DHS of the ejection event
MASS-Fotino Decoupling	MFD	4 belts holding Fotino in place, and release Fotino after firing of pyros on command of DHS
Structure		attach electronics and thermal blankets, interface to ejection system, Fotino and tether

Foton-LOcated Yes Deployer	FLOYD	single interface point to Foton (mechanical and electrical), deployment control of tether, receiving MASS data, sending Foton-TM, receiving Foton-TC
Tether		provide necessary deorbit and attitude stabilization to Fotino capsule, assist deorbit and orientation of MASS
Tie-downs		little cotton knots applied on the outer layer of the tether winding (spool) to keep the spool stable during launch
Ripstitching		stitched loops of tether in first meters of the tether, that will break in case of a jerk and thus absorb energy
Core		central cilinder on which the tether is wound
Optical Loop Detector	OLD	measure optically the deployment of each single loop of tether from the core, to allow for calculation of deployed length and speed
Length Milestone sensor	LM	optical sensor inside core that provide signal that tether is almost fully deployed
Power Distribution Unit	PDU	electrical interface to Foton (power, TM, TC) and TSU/DHU (TM), powers relays and FLOYD units
On-Board Computer	OBC	controls tether deployment and prepares TM data (interfaces to OLD, UHF, Stepper Driver, PDU)
UHF receiver	UHF	receives data from MASS and forwards to OBC
Ejection system		ejects MASS+Fotino at 2.6 m/s with low angular rate
Stepper Driver	SD	drives the stepper motor in the barberpole brake, controlled by OBC, contains amplifier and controller
UHF Antenna		receives signal from MASS-UHF
Structure		provides shielding, mechanical interface to Foton and FLOYD units
Barberpole Brake		provides controllable level of friction that affects deployment speed, position of pole controlled by SD
Tether Cutters		cut the tether to release it from Foton
Tether melting element		melts the tether to release it from Foton (back-up)
Microswitch		indicates ejection event MASS-Fotino
Terminology	IO	Input/Output board of OBC
Terminology	CPU	CPU board of OBC
Terminology	DHS	Acronym no longer in use (referred to combination of OBC and SD)

2.1.3 Functionality of the YES2 hardware

The FLOYD's purpose is to carry out and record properly the tether deployment and release the tether from Foton for safety purpose and to re-enter MASS.

The only measurements performed on the deployer are housekeeping signals (temperature) and 3 (+1) voltages of photo-diode/transistor pairs that are located within the tether deployer. These "optical" voltages are digitized and filtered in the "Optical Loop Detection" OLD electronics and serve as counter of the deployed number of tether loops.

At every control interval of 2 seconds, the OBC converts the loopcount into a deployed length. This data is the primary mission data since the tether dynamics can be reconstructed from it in post-processing. The data is piped through the serial housekeeping channel for real-time transmission using Foton's primary communication channel. It allows for high-level mission control (abort/tether cut). Through another serial link the data is also stored in ESA's TSU unit inside the Foton capsule to be retrieved after Foton recovery.

The tether deployed length data is used by the OBC S/W to control the tether friction brake on the deployer with a stepper motor. A feedback control is used to force the tether to follow a predetermined reference deployment profile (control of friction affects velocity, thus length is controlled vs. time. The capsule's in-plane angle follows as a result of orbital dynamics).

About one day before ejection, Foton orbital parameters are updated. By performing a tether deployment and re-entry simulation based on those parameters, as well as based on the predetermined reference deployment file, the start time of the second stage deployment (see below), as well as the time of tether cut, are being determined within a few second accuracy and sent to Foton as telecommands for delayed execution[1]. The FLOYD is then switched on by direct telecommand, and health status is checked.

MASS is switched on shortly before ejection and starts measuring right away (GPS positioning, magnetometer/gyroscope attitude, tether tension/accelerometer measurements). MASS and the capsule are jointly ejected by a delayed arm-and-fire telecommand via Foton from the Moscow ground control. Upon ejection, the loss of signal between FLOYD and MASS will initiate the MASS mission timer. This timer is used to, at a safe distance from Foton (some tens of meters) switch on the UHF transmitter for data uplink to FLOYD (which forwards it to the TSU inside the Foton capsule).

Fotino is fully isolated from MASS and FLOYD. Before or after ejection there is no data flow or telecommand capability to or from the Fotino capsule. Payload data on Fotino can be only retrieved through a well positioned groundstation or from FlashROM after recovery of the Fotino capsule itself.

There is a two-way connection between FLOYD and MASS until ejection (signals go through, but no sensor data), though after ejection, the UHF data only flows from MASS to FLOYD. Data from MASS is only retrieved after recovery of the TSU inside the Foton capsule.

After deployment of the first stage of 3.5 km (~one orbit), a short hold phase will start. There will be opportunity of monitoring of deployed length data, as well as optical viewing of the deployed tether if weather and time of day permits.[2]

Upon reception of the continuation command, the OBC will release the brake to continue full deployment (second stage), the MASS timer will cause the MFD to fire and release the Fotino at a fixed interval since ejection, about 3000 s after second stage start. The release of Fotino, through a break wire, starts up any payload inside, as well as a timer for the recovery beacon. 10 Seconds later (based on a programmable telecommand that was sent to FLOYD via Foton) the tether will be cut on the Foton side, releasing the MASS and tether into its own re-entry trajectory and leaving Foton free. About 1200-1300 s later Fotino will re-enter. Its payload will register, store and transmit dynamic and aerothermodynamic characteristics of the re-entry. The ARGOS beacon is switched on by a pressure sensor, or

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[1] Note: release of Fotino from the tether (the actual re-entry orbit insertion) occurs at a preprogrammed time since ejection and cannot be altered (control of landing site is done by eject and second stage start time).

[2] Note: as additional flexibility, but not planned for the nominal mission: during this hold phase an update of the delayed continuation (second stage) command could be sent to the OBC or any of the abort or contingency commands.

alternatively, some 10 minutes after the breakwire breaks or melts, and at the same time, at about 5 km, the parachute will be deployed (Beacon and Parachute Activation System, BAS/PAS).

The tether remains attached to MASS and will burn around 110 km. By this time, MASS will still be measuring and transmitting to Foton. Foton will still be in line of sight. The tether will apply considerable torque to MASS and the measurements at this point will tell us about the airdrag on the tether at such altitudes, which is an interesting tertiary experiment. Within a minute after the tether melts, MASS will disintegrate.

Around this time, the FLOYD will finish its data transmission to the TSU and switch off. Foton will reorient itself for its own re-entry, 24 hours later.

Eventually, the Foton battery package with YES2 deployer is jettisoned from the Foton capsule. At this time, the cables for thermistor and optical sensor data, power and telecommand, that link the Foton capsule and FLOYD are separated. Whereas Foton and thus the YES2 data on the TSU will re-enter and be recovered, the deployer on the Foton battery package will eventually burn-up in the atmosphere.

2.2 Tether experiment

The principle of tethered momentum transfer is remarkably elegant and deterministic. A tethered system is governed by the gravity gradient force in the sense that it will drive deployment and provides tension when deployment is finished. When two masses are connected by a vertical tether in space, they are forced by the tension in the tether to orbit Earth at equal angular rate. However, orbital dynamics for point masses (or ordinary satellites) demand that objects in a low circular orbit encircle the Earth at higher rate than objects at greater altitude. When the tether is cut, the lower mass (in our case, the capsule) is no longer pulled ahead by the tether, and is left in orbit with a velocity too low to maintain a circular trajectory. The capsule will thus be inserted into an elliptical trajectory, with a perigee significantly below its original circular altitude (about 7 times the tether length). If this new perigee is located within the Earth's atmosphere, a re-entry is initiated. Similarly, the upper mass (the Foton or ISS) will be smoothly inserted into a slightly higher orbit.

The strategy proposed for the YES2 SpaceMail mission is in origin based on StarTrack, proposed by Ockels, Heide & Kruijff (EWP 1883, IAF-95-T.4.10) and employs a swinging rather than a hanging tether and thus reduces required tether length and mission time. The additional gain in momentum transfer from the backward swinging motion of the tether almost doubles deorbit effectiveness compared to a hanging tether (altitude loss of perigee upto 13 times the tether length). A 6 kg tether will be sufficient for deorbit of masses from ISS in the range of about ten up to several hundreds of kilos (thickness and mass, for a simple single wire is determined by meteorite survival probability).

Read about tethered SpaceMail on www.yes2.info/downloads.html.

2.2.1 Success and failure of space tether missions in the past

The below table shows that most tether mission conducted sofar have been successfully (contradictionary to common belief), only 2 out of 14 deployment attempts failed. All passive spool deployments, the category to which YES2 belongs, have been successful so far. The longest tethers deployed were SEDS-1 and SEDS-2, each 20 km. YES2 would add 10 km to that record. However it should be said that the two-stage deployment and high accuracy requirement of YES2 are challenges not yet attempted before. Also visible is the recent susceptibility of tether missions to safety concernts (YES, ProSEDS). For this reason, YES2 has been developed for Foton-M3 and deploys downward, guaranteeing a safe, low-altitude operation.

Year	Experiment	Length	Orbit	Technology	Objective	Agency	Success	Remark
2007	**YES2**	**30 km**	**LEO**	**Mechanical, passive spool+barberpole**	**Accurate re-entry of a scientific capsule**	**ESA**		**Two stage deployment**
1967 1967	Gemini 11 Gemini 12	30 m	LEO	Mechanical link between Gemini and Athena upper stage	Artificial gravity	NASA	YES YES	Spin stable 0.15rpm Local vertical, stable swing
1983 1984 1992	Charge-1 Charge-2 Charge-2B	500 m	Sub-orbital	Conductive	Electrodynamic	ISAS/USA	YES YES YES	
1989 1995	Oedipus-A Oedipus-C	959 m 1 km	Sub-orbital	Conductive	Electrodynamic	CSA	YES YES	
1992 1996	TSS-1 TSS-1R	268 m of 19.6 km 19.6 km	LEO	Conductive, active reel deployment	Electrodynamic	NASA	NO PARTIAL	Tether jammed Tether broke after science success
1993 1994	SEDS-1 SEDS-2	20 km 20 km	LEO	Mechanical, passive spool+barberpole	Swing & cut Controlled deployment	NASA	YES YES	SEDS-2 probably cut by meteorite after mission completion
1996	TiPS	4 km	LEO	Mechanical, passive spool	Study survival and stability	NRL	YES	1 decade in orbit without cut
	PMG	1 km	LEO	Conductive, passive spool	Power and thrust		YES	
1997	YES	0 of 35 km	GTO	Mechanical, passive spool + barberpole	Rotation, re-entry	ESA	N/A	Not deployed due to unsafe orbit
1998	ATEx	6 km	LEO	Mechanical, reel, active	Stability & control	NRL	NO	S/W stopped deployment
-	METS	5 km	LEO	Conductive/Mechanical, passive reel	Thrust (MIR station)	Mirspace	N/A	Cancelled for political reasons
-	ProSEDS	20 km	LEO	Conductive, passive spool+barberpole	Thrust	NASA	N/A	Cancelled for ISS safety

Table 3. Overview of tether missions to date

2.2.2 Design steps

The tether hardware design is inherited from the ESA TSE project and from flight proven SEDS & YES hardware, but has been fully re-analyzed, characterized and modeled. In addition, all design trade-offs have been redone. Based on the TSE design and the recommendations from this project the tether hardware and electronics was redesigned in an early phase of the project (Summer 2002, improvements on tether sliding behavior, thermal conductivity etc.). The brake was redesigned for maximum learning possibilities and a mathematical model was developed. An extensive test campaign was performed to develop and then demonstrate the maturity of the developed hardware. For this purpose a tether test rig has been manufactured by students in late 2002. First tests have been performed during the parabolic flight campaign in the summer of 2003. A high precision winding capability has been developed in parallel. “On-board” control S/W has been developed and the control computer was breadboarded. Test control S/W & EGSE has been developed, as well as a wireless communication capability. Also a low drag (helium) container has been built. The feedback controlled deployment tests with a real-time tether simulator in the loop were performed and lead to final recommendations for the flight brake system and tether canister. The spool manufacturing (winding) technology itself, has been demonstrated to have reached sufficient level and further quality improvements may be made without affecting the design of the YES2 hardware.

2.2.3 Tether hardware

The total available mass budget is assumed to be around 32 kg. The hardware that will be installed on Foton has a total mass of about 20 kg, which leaves about 12 kg for the ejectable subsatellite.

The hardware consists of:

- Tether canister including Optical Loop Detection (OLD) circuitry ;
- 30 km of Dyneema tether on spool ;
- Barberpole brake, stepper motor and tether cutters;
- Ejection system, including pyros and microswitch;
- OBC and stepper driver; OBC contains CPU and I/O board
- PDU (primary interface between Foton, telemetry, telecommand, power and most FLOYD electrical components);
- UHF receiver and antenna.
- Support structure: Xbox, interface plate, “attic”, UHF antenna brackets. The OBC and PDU are in the so called Xbox, as well as the Russian connector interface panel. The attic houses the stepper driver and UHF and functions to separate the barberpole and ejection system from the tether exit guide.

The tether hardware is based on a tether spool contained in a hexagon canister and a friction brake system. The brake is the only device that actively controls the tether deployment. The friction surface is controlled by turning the tether several times around a pole. Each additional turn amplifies the incoming tension by a factor ~3 more. A single stepper motor drives the turning pole. The brake is low-cost and extremely simple. It is not precise but reliable.

The tether is 0.5 mm wide and made of braided Dyneema (high density poly-ethylene), it is a mechanical tether. This type of tether should not be confused with electrodynamic or conductive tethers, that are designed to interact with the Earth’s magnetic field and are e.g. used for the TSS mission and the ProSEDS mission.

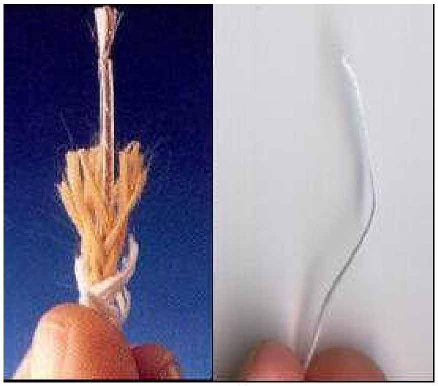


Figure 10: Two different tethers
[Left: TSS electrodynamic tether (8.2 kg/km),
right: YES2 tether (0.2 kg/km)]

2.3 The MASS/Fotino subsatellite

Fotino is a small spherical capsule (40cm, 5 kg), which has been designed as a minimal design for a capsule that could bring a payload from space to Earth, with (or in some cases without) parachute, and be retrieved by means of a beacon. It contains dynamic sensors, pressure sensors and thermocouples, GPS, data storage and telemetry.

The Fotino can be seen as a technology demonstrator and science laboratory, it is a lightweight capsule decelerating in rarefied/slip flow regime, a yet untried regime where useful lessons about the atmosphere can be learnt, thanks also to its simple spherical shape. It tests low-cost and light-weight flexible heat shield materials.

MASS is a dedicated piece of support hardware for:
- the tether deployment science characterization, as well as for
- accurately timed release of Fotino into its re-entry trajectory.
- finally MASS itself becomes an experiment of great interest as it will enter the atmosphere with tether still attached. The air drag effect on the tether in the rarefied regime at ~110 km altitude can be measured with the on-board instrumentation set and will tell us about heat transfer, drag and air density at this altitude

2.3.1 Design steps of Fotino

In the early phases of YES2, students brainstormed on concepts and then worked in groups through a first iteration of a variety of concept design, including mock-ups, simulations, drop-test and windtunnel tests. The design of the groups were eventually merged into a final design, an inflatable sphere-cone, which was worked out in more detail (AIR). An inflatable sphere concept was finally rejected because of mass constraints and manufacturing cost, so AIR became the baseline. In Phase II the students continued to work on optimizing the final design, did stability analysis, heat shield and windtunnel tests, FEM and CFD analysis, and started building the inflatable AIR capsule prototype.
Design and manufacture of a number of promising simpler, smaller capsules (1-4 kg range) was pursued in parallel (Steel dish, Fotino, Self-unfoldable parachute, Lepton). For those, a piggy-back flight on Foton-M2, or a sounding rocket was kept an option.
Finally AIR was cancelled due to budget constraints and loss of interest within ESA in inflatables, which made it impossible to find sponsors. Fotino was chosen to replace AIR, because of its expected low impact on the YES2 design and schedule.

The approach with Fotino has been very pragmatic, i.e. by building prototypes of the actual materials. Supported by the heat shield test and re-entry simulations, AIR materials were reused and requirements were put up: the largest capsule possible with full use of the (reduced) mass budget was recommended. The spherical shape (not optimzal from heat flux point of view) was intended to simplify CFD, drag coefficient and stability analysis, due to time constraints, but at the same time was highly interesting from a scientific point of view (easy to compare to CFD and plasma tests). It was decided to place the payload off-center, so the capsule would have a known front-side, since relying on some kind of barbecue mode for keeping the temperature low was considered too risky. The heat flux on Fotino is considerably higher than prospected for AIR but still low compared to most current re-entry vehicles. The challenge for Fotino has been to give it structural rigidity with only 5 kg to use. Drawing on the database of the inflatable capsule’s materials, a foam core surrounded by a flexible insulating layer and a minimal thickness heat shield (vacuum-molded hollow sphere) was finally selected.

2.3.2 Subsystems

It is foreseen to have the following subsystems on MASS and Fotino:

MASS

- *Mechanical interface*

Interface to ejection system (FLOYD), (cylindrical/conical) support for retention fixture and release of Fotino capsule (MFD), including support structure for instrumentation, tether attachment and tether pretensioning. MLI for thermal insulation. Boxes for electronics protection.

- *Power distribution unit (PDU).*

Switched on by latch controlled by the signal from FLOYD PDU. Including voltage convertors and cabling, switch for UHF receiver and driver for power pulse to the MFD.

- *Data handling system (DHS)*

for reception of MASS GPS/GLONASS (serial) & instrument data (incl. thermal/voltage info), A/D conversion and transmission, programming of time of Fotino/MASS release from ejection.

- *Timer system (part of DHS)*

A timer and alarm system (triple, median time is used) and counter is used to keep mission time (since switch on and afterwards since ejection) that will be included in the sensor data packets. More importantly, they are used for delayed switch-on of UHF after ejection (to guarantee safe distance to Foton) and MASS-Fotino Decoupling. They are programmed by the MASS-DHS right after it is switched on (based on predetermined hardcoded times). When the alarms go off, their signals are sent directly to the PDU, with a copy to the DHS.

- *Mass Fotino Decoupling (MFD)*

A crossed-belt system with the purpose to restrain Fotino during launch and deployment. The belts are held together with a Dyneema cable on top of Fotino. The 3 cable cutters secure its release, and are fired by the PDU.

- *3 Pyrotechnic cable cutters (part of MFD)*

For release of Fotino.

- *Releasable Connector (ReCon) to FLOYD*

MASS PDU sends a signal through ReCon, which is looped back to MASS Data Handling System so it can determine the moment of ejection. Through this link also the FLOYD Power Distribution Unit can send the signal that switches on (or off) the MASS Power Distribution Unit. A health status bit from the MASS DHS and PDU is sent back to FLOYD, the latter functions as redundant confirmation of ejection. MASS is switched on by telecommand and not by the event of ejection for safety purposes.

- *Antennas*

1 GPS antenna, 1 UHF antenna, located near ejection system interface

- *Power supply*

3 Batteries for all systems.

- *Selection of sensors*

To measure the dynamic behavior of the sub-satellite and the tether (GPS, tensiometer -integrated in tether attachment-, magnetometer, accelerometers, gyroscopes, thermistors)

- *Telemetry unit*

UHF transmitter, on serial link with DHS. Transmit power follows an optimized timeline since switch-on.

Fotino

- *Beacon and Parachute Activation System (BAS/PAS)*

Switches on beacon at about 5 km altitude, using a pressure sensor (direct measurement) and a melt wire (melting at entry) plus timer in OR logic configuration. In AND configuration these switches initiate the parachute.

- *ARGOS recovery beacon plus antenna*

Plus battery, switched on by BAS.

- *Data Acquisition System: DLS and TM*

Switched on at MASS Fotino Decoupling with a break wire, melting of the same wire in the atmosphere is the redundancy. Data logger system (DLS) plus battery, stores all data from the payload (impact-robust). Data is transmitted (TM) to ground (optimal ground station location about 100 km down range of nominal landing point) at 10x measurement rate for maximum probability of reception.

- *Measurement Payload: Sensor Board and GPS*

The following sensors are connected to the DLS: sensor board: 21 K-type and S-type thermocouples assess the thermal environment during re-entry. 12 On-chip pressure sensors measure the pressure distribution and capsule attitude. On-chip accelerometers, gyroscopes and magnetometers measure the dynamics of and around center of mass.

- *Other payload*

A small passive team item, sponsored object or payload will possibly be taken along inside Fotino.

2.4 Electrical design

An overview layout is given in Figure 6.
The following detailed schematics give a more detailed but still introductory idea of the YES2 electronics design.

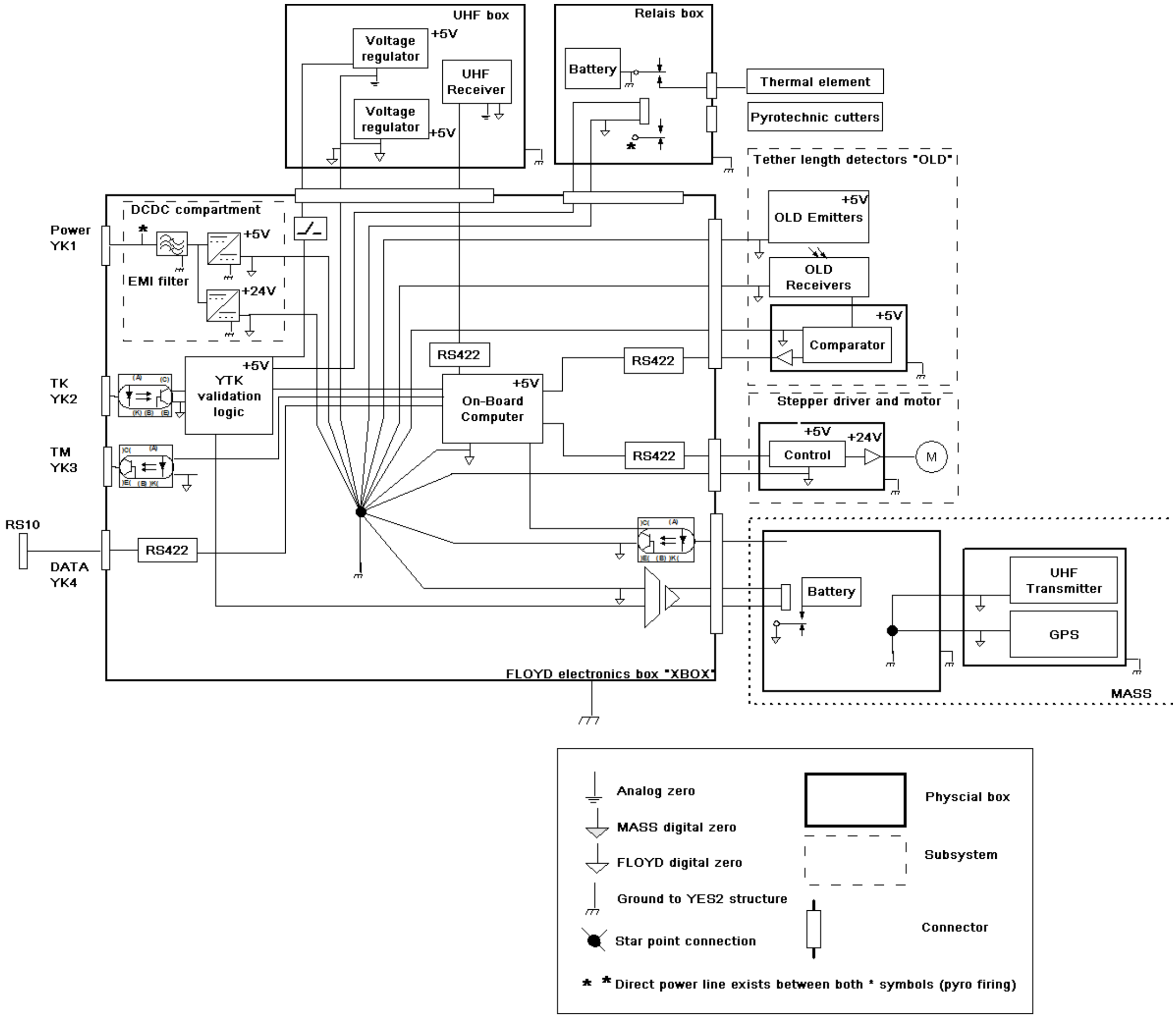


Figure 11. YES2 grounding scheme.

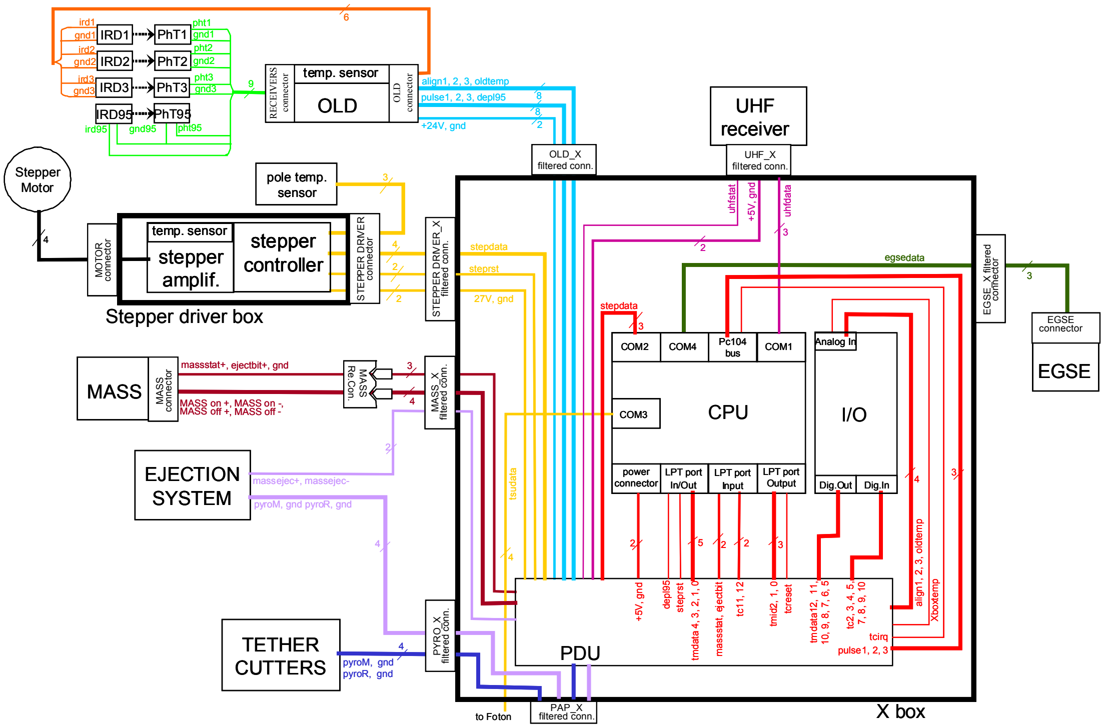


Figure 12. FLOYD signals, cables and connectors (TBD). ***Outdated, do not use for design purposes.***

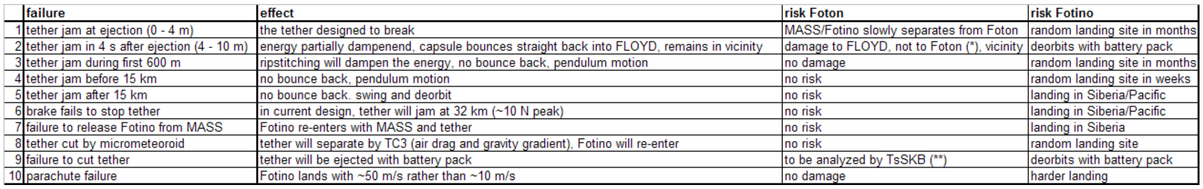
2.5 Safety

2.5.1 Approach

The YES2 safety requirements are defined in CE0PRD - YES2-CDR-[PDRD] Level 0 requirements.

Being the first European tether experiment, analysis and guarantee of safety to people and Foton takes a central place in the YES2 design. This includes passive solutions as solid system design with minimum tether guides and minimum moving parts, tether damping to avoid bouncing if the tether would get stuck, extensive deployment testing, as well as mission parameters and analysis (redundant design of critical systems, low orbit for fast contingency re-entry, landing area analysis in nominal and off-nominal cases, analysis of effects of premature tether cut and release failures). Analysis of critical states that the system can get into shows that risk is minimized. It is therefore possible to operate YES2 with a simple and basic contingency plan was set up. The only contingencies intended for use by Moscow ground control and are YES2 system tether cut plus switch off, and can be activated before ejection. After ejection it is recommended to complete the experiment, although if necessary, it can be aborted after the first stage deployment.
If despite the triple redundant tether cut system tether cut fails, it is recommended to postpone the Foton reorientation maneuver to the morning before re-entry, similar to the Foton-M2 mission operations, where the tether is disposed together with the battery pack, with minimal loss of fuel for attitude control.
Some flexibility is included in the design to allow for other actions, but these are not planned for use. No autonomy is included, to prevent unwanted actions in case of failure of the autonomous system. The data available on-ground (update once per orbit) for aborting the mission is the tether length and velocity, YES2 on-board computer and stepper driver condition.

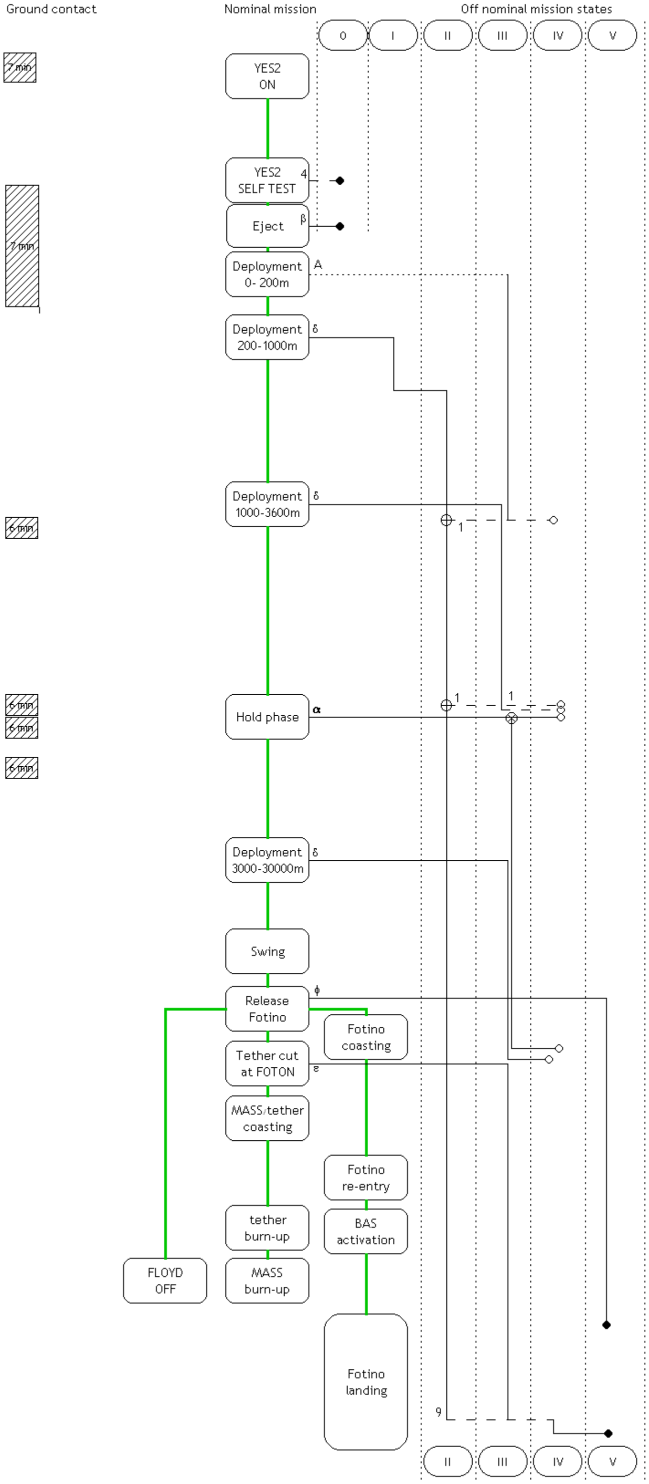
2.5.2 Overview of potential failures and criticality



	failure	effect	risk Foton	risk Fotino
1	tether jam at ejection (0 - 4 m)	the tether designed to break	MASS/Fotino slowly separates from Foton	random landing site in months
2	tether jam in 4 s after ejection (4 - 10 m)	energy partially dampenend, capsule bounces straight back into FLOYD, remains in vicinity	damage to FLOYD, not to Foton (*), vicinity	deorbits with battery pack
3	tether jam during first 600 m	ripstitching will dampen the energy, no bounce back, pendulum motion	no damage	random landing site in months
4	tether jam before 15 km	no bounce back, pendulum motion	no risk	random landing site in weeks
5	tether jam after 15 km	no bounce back. swing and deorbit	no risk	landing in Siberia/Pacific
6	brake fails to stop tether	in current design, tether will jam at 32 km (~10 N peak)	no risk	landing in Siberia/Pacific
7	failure to release Fotino from MASS	Fotino re-enters with MASS and tether	no risk	landing in Siberia
8	tether cut by micrometeoroid	tether will separate by TC3 (air drag and gravity gradient), Fotino will re-enter	no risk	random landing site
9	failure to cut tether	tether will be ejected with battery pack	to be analyzed by TsSKB (**)	deorbits with battery pack
10	parachute failure	Fotino lands with ~50 m/s rather than ~10 m/s	no damage	harder landing

Table 4. Potential failures and criticality

2.5.3 Contingency tree



State	Description
0	YES2 cancelled
I	MASS/Fotino orbits towards Foton
II	Tether collects on Foton
III	Hanging tether to Foton
IV	Orbiting MASS/Fotino & tether
V	Fotino off nominal landing

Action	Description
1	Cut Tether (TC3)
2	Try to stop deployment (TC5)
3	Try to restart deployment (TC7)
4	Not Eject (TC6, delete TC2)
5	MFD OFF (TC11)
6	Delay cut (TC3)
7	Delay 2nd stage (TC4)
8	Switch FLOYD OFF (TC6)
9	Jettison Foton battery pack

Measure	Description
A	Ripstitching

Event	Description
α	Tether cut by debris/meteoroid
β	Ejection system fails
δ	Deployment halts
ε	Tether pyro fails
ϕ	Off-nominal deployment

Style	Description
🟩	nominal flow
———	off-nominal flow
— —	flow due to action
....	flow due to passive measure
⊕	OR
⊗	AND
-○	intermediate state IV. Flows to state V after x orbits
-◆	end-state

YES2 Mission Safety Tree
v0.1 March 25th, 2005

***YES2* team : : Delta-Utec SRC**

Figure 13. YES2 contingency overview (TBD). ***Outdated (holding phase has been shortened from 100 to 10 minutes)***

2.6 Design standards, challenges and approach

ESA standards for small projects serve as guidelines for this project, and ESCC standards/PSS standards, as well as GPQ-MAN-01 Issue 2 (Documentation Standard for ESA MSM-G Projects) are followed where possible. A reduced QA (rather: PA) is followed, as defined in CE0PRD - YES2-CDR-[PDRD] Level 0 requirements, with focus on safety to people and other spacecraft, secondly to mission success, in which the landing and especially the subsatellite data take only a minor, non-critical role. Rather, the achievement of building a satellite and developing new technologies to flight hardware is seen as a major piece of pre-mission project success (as it is still an educational project). The tether deployment (FLOYD) and recovery of the capsule re-entry data (Fotino) are the primary focus for mission success.
The main challenges of the project are:

1. *To create a design with students, who are:*

- Mostly only in project for 3-6 months (investment, continuity, design transfer problem)
- Not under contract (so little absolute control possible),
- Little or not experienced (so long task accommodation/investment & educational effort required),
- Europe-wide, not co-located
- Their effort is based on motivation, which is always taken into account in the definition of the tasks, where generally great responsibility and freedom is given. Documentation turns out to be a task hard to motivate students for over prolonged times.

2. *Low budget*
   YES2 cost is no more than 10% of that of comparable technology development projects
3. *Challenge of building a satellite based on innovative technologies*, (rather than using common technology), so that the R&D and maturing of technologies has to be performed within the project (tether, capsule, simulations).
4. *Ever changing circumstances and unknowns*
   As part of the educational character and dependency on politics and dynamic funding situation the boundary conditions, such as project goals (inherent safety, inflatable, landing site, scientific objectives), budget, launch opportunity and launcher interface have been volatile throughout the project

The solution is great enthusiasm of all team members and quantity of students involved (and thus education). This way of dealing with problems does have a clear cost: extra time.

Contributing to the successes achieved sofar have furthermore been the following factors

- Colocation at ESTEC and Delta-Utec of a significant fraction of the students
- Extensive time for test & simulation
- Sponsoring, both in expertise and financially, from companies (e.g. Emxys, Active Space, Leonardo da Vinci, see www.yes2.info/sponsors)
- Motivational value of following professional approach
- Robust and sometimes non-optimal technical design choices (allowing for flexibility with respect to design changes). Start from simple design concepts for fast motivating results. Simple mission (few telecommands).
- Support from ESA and Delta-Utec experts
- Webbased project-wide accessible logging of design decisions, changes and trade-offs
- Allows to access and evaluate current design status at all time, with minimum of documentation/version control effort
- Webbased project-wide accessible document & contact info storage (ftp)
- Webbased system engineering and configuration item control
- Webchat