A NEW MODULAR SYSTEM FOR TELEMETRY-TELECOMMAND CONTINUUM LINK AND POWER SUPPLY IN LONG DURATION BALLOON FLIGHTS

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ABSTRACT

A fully integrated system, providing both up (Telecommand, TC) and down (Telemetry, TM) continuous link for Long Duration Balloon experiments has been developed and tested by using the Iridium® platform. The system uses two Iridium® channels, allowing up to 4.8 Kbit/sec, being 2.4 Kbit/sec the nominal maximum bit rate per channel. More modules can be used to attain higher bit rates. The basic unit also includes a power supply module, able to manage up to 10A at 24VDC, but the design allows extension up to 15 modules for higher power demands. When combined, the two units represent a reliable solution for managing Long Duration Balloon experiments, mainly in absence of distributed ground stations.

1. INTRODUCTION

Long Duration Balloon (LDB) flights may offer the opportunity for scientists to carry out experiments at stratospheric altitudes whose duration can last over one month. However, nowadays LDBs are mainly carried on from polar regions either Artic or Antarctic, where high altitude winds allow balloons to follow trajectories roughly around poles [1]. This is mandatory even for the constraints imposed by safety rules. Also, astrophysics experiments may benefit of high latitude to observe some target regions [2]. Unfortunately, for polar balloon trajectories the absence of ground stations prevents from balloon and payload control/monitoring, as usually done at mid latitudes. Moreover, since LDB last up to times of weeks, another major problem is managing electrical power to onboard equipments, which might also require hundred of watts. Astrophysics experiments as BaR-SPOrt [2] and OLIMPO [3] may be really complex systems requiring issuing telecommands as well as reliable telemetry data reception for quasi-real time on-ground monitoring. The onboard electronics can be designed to operate as independently as possible and to provide full data storage, but the main requirement still remains a continuum bi-directional link including a feedback action to the onboard equipments issued from the on-ground operator. The BaR-SPOrt scientific team, together with LEN s.r.l. and Telespazio S.p.A., has developed a package able to match the basic requirements. LDB packages design and performances, together with the basic user interface for quick-look data monitoring and in-flight management, will be described in some details in the following sections.

2. THE LDB PACKAGE

The LDB package (LDBPack) in the basic configuration includes two subsystems:

- The telemetry/telecommand module Multi Source Iridium Telemetry (MSITeL);
- The power management module or Solar Power System (SPSys).

Designed as independent modules, MSITel and SPSys can be used as stand alone units, even if they give the best performance when operating together. Several

MSITel and SPSys modules can be linked together to improve the TM/TC bit rates as well as for power supply requirements higher than that managed by a single module. Thus, the LDBPack is a modular system that can be expanded to fit with the demands of several balloon experiments. The LDBPack prototype includes both the operating hardware (h/w) modules and the software (s/w) packages, which allow the user to manage the experiment via the TM/TC link provided by the Iridium® satellite network. The Iridium® choice was dictated because of its capability to cover all the latitudes including the Poles, with the highest nominal (continuous) bit-rate available to date. Other satellite networks can be used as well following the user's requirements.

2.1 The MSITel module

MSITel (Fig. 1) is a Control Telemetry Unit conceived to interface one or more intelligent I/0 units, such as the SPSys module as well as several general purpose equipments and, in particular, modems and scientific instrumentation.

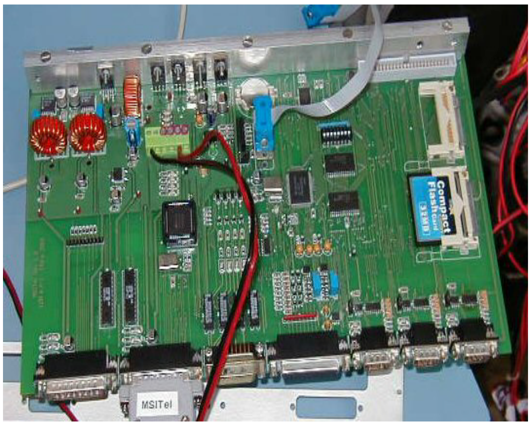

Fig. 1. MSITel Unit printed circuit board.

MSITel provides remote up-down data link control through a communication satellite system channel by using related data modems. MSITel is easily adaptable to any modem accepting AT compatible Commands, thus permitting data transmission with many available satellite systems (Iridium®, Inmarsat®, Globalstar®, etc) as well as any terrestrial system. Switching from a modem system to another simply requires s/w changes to match the AT Commands set for the specific unit. MSITel also provides several analog and digital I/O lines for a direct control of external instrumentation. Four digital outputs are implemented as 0.5A-actuators (1A optional) managed with a high security h/w and s/w logic and suitable for irreversible operations such as balloon-payload detachment, ballast release, etc. Any external equipment can communicate with MSITel through RS-232 or IEEE485 (Fig. 2).

The prototype version has been developed and tested for Iridium® platform by using modems (A3LA model) manufactured by NAL Research Corp.

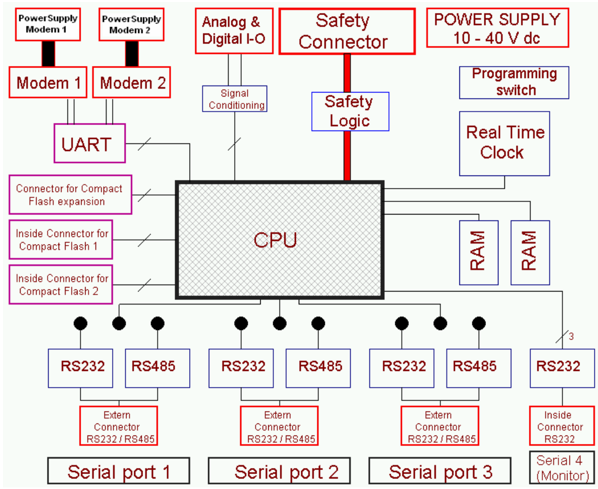

Fig. 2. MSITel block diagram with the main I/O devices set in evidence in the upper left corner.

MSITel performs the following main functions:

- management of two Iridium® modem devices;
- polling of external instrumentation with a special macro-language with both commands and user-defined priority. Any communication is carried out through a serial RS232 or IEEE485 standard link;
- data acquisition of the local I/O according to the macro-language;
- storage of the acquired data in non-volatile support (Compact Flash Card; one is wired on the right in Fig. 1);
- transmission of the acquired data to the ground station with a special protocol (data telemetry format) according to the macro-language (down-link telemetry);
- decoding and execution of commands received by the on-ground station (up-link telemetry);
- decision on the function set for the two modem units, i.e. both in use to double the bit-rate or just one with the other as backup item.

Raw data acquired by the system are stored in compact flash cards with up to 6-12 Gbytes total capacity. Prior to transmit data in the TM channel, raw data are processed with extensive checksum procedures in order to permit data recovery or error detection in presence of noisy channel. MSITel uses a *realtime clock* to provide absolute timing for the data storage which translates in a safe time correlation for any stored event.
Connection with the Iridium® modems (master and back-up unit) is provided by an RS-232 serial line with

hardware handshake. The power supply to the modem units is provided via a separate line.
The MSITel unit has also two more sensors for Power Supply Voltage and operating temperature monitoring.
The MSITel main specifications are:

- Power Supply Voltage range: (10÷40) VDC
- Operating Temperature range: -40°C to +50°C
- Operating pressure: tested down to 1mBar.

MSITel can work in two operative mode: stand-alone and main-board in an expanded system. In the first mode the unit operates as only telemetric unit, while in the second mode MSITel can works together with other MSITel partners to higher the bit-rate data telemetry. In expanded systems an a-priori hierarchy sets the master function for a particular MSITel and the slave function for the others, while a s/w priority chain takes care to change the functions in faulty event of the master.

2.2 The on-ground quick-look user interface

The MSITel provides near real-time communication between the on-board payload and the on-ground station, whereas TCs can be sent by the ground system to the on-board subsystems. MSITel generates a continuous bi-directional data link in real-time mode by maximizing the bit rate of the Iridium® channel. Any information, i.e. Housekeeping and Scientific data, are collected from the payload subsystems by MSITel and assembled in an appropriate pre-processed structure (Telemetry Packet) sent to ground station, decompressed in real time and visualized from the on-ground Quick-Look s/w. This s/w package permits a complete monitoring of the remote system as well as an interaction with the on-board equipment by issuing telecommands, which are on-board processed by MSITel. Both TM and TC data can be transmitted in the same Iridium® channel because of its actual full-duplex feature.

Fig. 3. Typical Control Panel display output of the on-ground quick-look PC.

The ground station simply consists of a personal computer (Master-PC) connected to an Iridium® modem via RS232. The use of the quick-look s/w installed on the PC makes possible to control all on-board subsystems. With a user-friendly interface (Fig. 3) it is possible to send command (Up-Link) and monitor all information (Down-Link), as GPS position, Temperature of the MSITel module, condition of all I/O on-board devices, etc.
Since the Master-PC distributes the TM data format over a local network (LAN), other client PCs' can share the graphical quick-look of the most important parameters of the on-board subsystems, while only the Master-PC is enabled to send remote commands to guarantee for safety operations.

2.3 The SPSys module

SPSys has been designed taking into account the following requirements:

- matching with power sources as rechargeable batteries, photovoltaic panels, fuel cells;
- management of power budgets of the order of some hundreds of Watt and distribution of the electrical power to the user from the most efficient power source available;
- capability to operate both in stand-alone-mode (automatic or local) and in telecommand-mode (remote);
- communication capability with a TM/TC module for monitoring (e.g. housekeeping) and for telecommand receiving (via up-link from ground);
- capability to operate in stratospheric environment.

The SPSys main specifications are the following:

- Input Supply Voltage: 10÷40 VDC
- Operating Temperature range: -40°C +70°C
- Operating pressure: tested down to 1mbar

Most of LDB flights are powered by batteries fed by photovoltaic arrays. Even if the SPSys module has been conceived by taking into account photovoltaic arrays as primary power source, other power sources can be used if available, e.g. fuel cells.
SPSys has to manage the electrical current provided by the Solar Panel (SP) and to optimise the charging process of the floating batteries.
A single SPSys unit manages 10A@24VDC and charges up to 3 batteries. The modular design permits a grouping up to a maximum of 15 boards operating at the same time through an IEEE485 communication link: when several SPSys are used in multiple configuration, it is possible to manage up to 3.6kW@24VDC electrical power, being one of the unit appointed as the master and the others as slaves. If the

master fails, one of the remaining slaves can become the master by defining a s/w priority procedure. SPSys is built around a microcontroller which continuously monitors the operating parameters of the power sources (voltage and current) and establishes the optimum charging-up procedure for the batteries. The "optimisation procedure" consists both in delivering power to the user from the actually more powerful source and in adjusting the charge current to the batteries depending on their actual temperature; this reduces the power losses since in normal conditions the batteries are always ready and charged to provide power to the load without any power dispersion. Furthermore, the SPSys CPU will watch for the availability to operate any power source by monitoring the I-V parameters and deciding to exclude any bad possible faulty power source. Housekeeping data from SPSys can be fed to MSITel for remote control by an RS232 protocol. Fig. 4 shows the SPSys block-diagram.

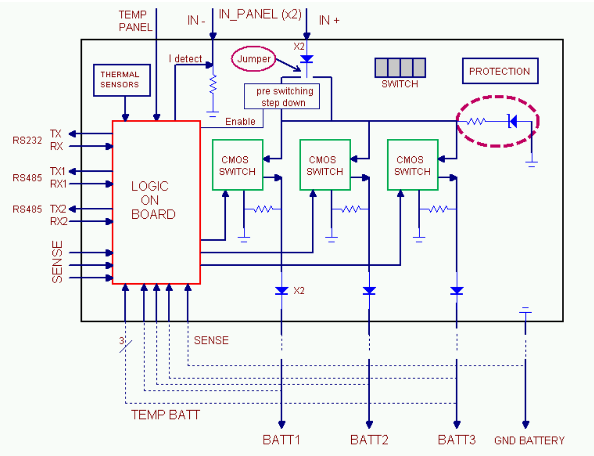

Fig. 4. SPSys functional block diagram.

3. THE SOLAR PANEL PROTOTYPE

To test SPSys an SP prototype has been designed and built (Fig. 5) able to operate in an LDB flight.
An SP internal frame with a 2 mm thick double layer of LEXAN embedding the mono crystal silicon cells (POWER MAX®) is mechanically integrated in an external aluminium frame. Each cell is locked between the LEXAN layers by four-point silicone glue drops providing elasticity during the frame contraction or expansion due to thermal inputs. Mono crystal silicon cells were chosen for high efficiency in solar-to-electric power conversion (~ 15 %). Despite LEXAN is featured by a good transparency in the visible region (~ 90 %), but it is opaque in infrared, the layers in correspondence to the cell are opened to reduce light reflection and to enhance the cell thermal emission, in front and rear, due to heating by solar illumination. LEXAN was chosen for its mechanical hardness able to

Fig. 5. The solar panel (SP) prototype during test connected to the rechargeable batteries (white-circled in the right down corner).

sustain strong and sudden thermal gradients.
The SP prototype, with an area of ~1.5x0.6 = 0.9 m^2, has 7 modules each of which contains 10 individual cells. The SP can provide ~120W electrical power when exposed to daily-standard on-ground solar illumination.

4. QUALIFICATION TESTS

Since 2003, the MSITel and SPSys boards, the NAL modem, the SP and gel-batteries have been extensively tested in laboratory to qualify for an LDB flight.
Anyone of the above subsystem was tested in a thermo-vacuum chamber both separately and wired together in order to make them work in a simulated balloon environment. The telemetry system (MSITel board and NAL modem), has been tested to inspect for possible variations on performances due to the bias voltage and drain current variations. The tests were performed keeping active the Iridium® link and sending/receiving data and telecommands respectively. The temperature of the heat sink and the modem have been continuously monitored. Fig. 6 shows the set-up of the telemetry system inside the vacuum-chamber.

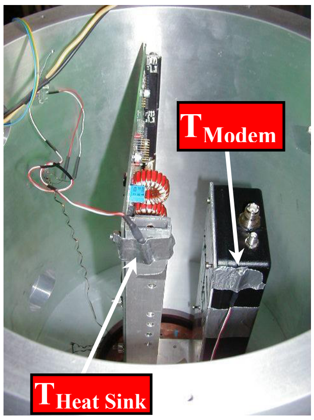

Fig. 6. MSITel and NAL modem in the test vacuum-chamber. The Pt100 temperature sensors are also shown.

Forcing the pressure inside the chamber at ~ 1 mbar for a time of about 3 hours led to the results reported in Fig. 7. The temperatures of the modem and the heat sink rise with respect to the environment until thermal stabilization of the whole TM system is attained after three hours in vacuum.
The final temperature of the TM system is higher than that of the environment (~ 23 °C) of about 20 °C, which implies that the heating of MSITel board and the modem is satisfactory considering that no particular care has been adopted to dissipate the heat produced. No variation due to the electric features of the PC-board and the TM/TC-communication through Iridium® has been observed.

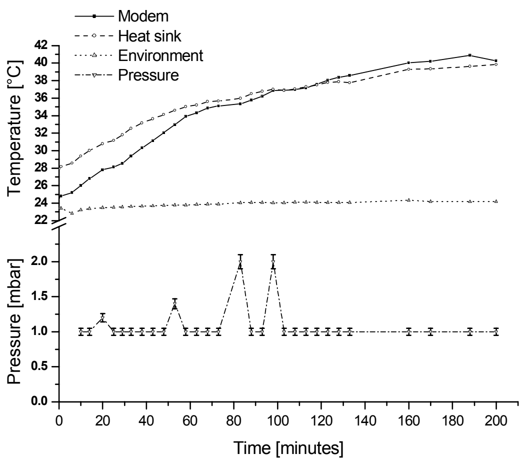

Fig. 7. Thermal behaviour of the monitored points. Temperature errors are < 1 ‰.

The individual components of the SP have been separately tested before the construction. The LEXAN has been adopted for its thermal behaviour particularly suited to the application. It has been shock-tested by applying several strong thermal gradients from ~ -200 °C (liquid nitrogen) up to 200 °C (thermal gun) without showing any crumble or crack.
The sun cell [4] has been cooled down by means of the cryocooler inserted in the small vacuum chamber used for the MSITel test (see Fig. 8-left side).
This test had to analyse the electric behaviour of the cell and inspect for possible breaks by simulating the balloon ascension phase with particular reference to the thermal-inversion layer where the temperature of the atmosphere suddenly falls down to its minimum, i.e. ~ –70°C@100mbar. The cell has been illuminated by a 100W Tungsten electric lamp and connected to a 2.35Ω ohmic load. No crumble or crack effect due to the thermal shock down to –50°C has been observed while an output voltage drift of ~ –2mV/°C has been detected.

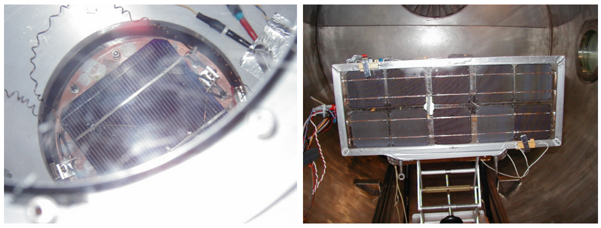

Fig. 8. The sun cell as seen outside the chamber (left). Housing of the photovoltaic module inside the chamber (right).

A module of the assembled SP prototype (see Fig. 8) has been inserted inside the thermo-vacuum chamber (Mod. TY 7000/D-ACS s.p.a. Italia), which is a facility (L=2m, Φ=2m) able to simulate stratospheric environment for laboratory qualification of the payloads.

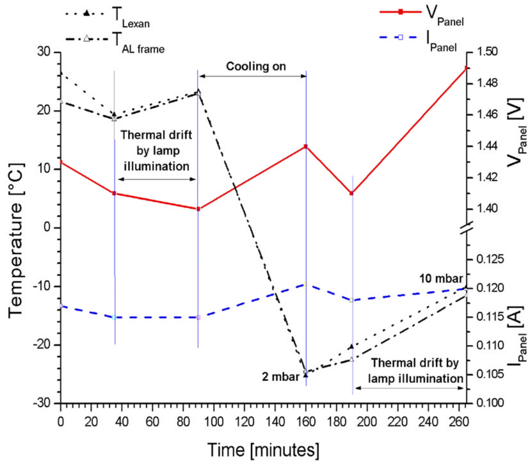

Fig. 9. SP-module temperatures' and electric parameters' (VPANEL, IPANEL). Some details about the environment pressure are also shown.

Monitoring of the electrical main parameters of the SP module was performed by connecting to a 12 Ω ohmic load and illuminated from *outside* the chamber by a 32000 lumen lamp. During the test, the temperatures of the aluminium frame and the LEXAN rear panel were also monitored. Fig. 9 shows the results for a typical run. The thermal variation induced, *50°C/60min...0.8°C/min*, is comparable with respect to that expected during the balloon ascension at the thermal-inversion layer. The temperatures of the SP aluminium frame and the LEXAN show the same trend, while the variations induced on the electric parameters are restricted to less than 5% at standard on-ground conditions.
Fig. 10 shows the set-up for the vacuum test of the SPSys PCB powered by 2 batteries. The PCB temperature has been monitored from –20°C to + 45°C and no criticality has been observed.

Fig. 10. The SPSys PCB in the vacuum chamber. The heat sink for the active components is also shown.

5. THE FLIGHT PROTOTYPE

The Agenzia Spaziale Italiana (ASI) has planned a test flight for the LDBpack prototype. A possible flight configuration is shown in the block diagram of Fig. 11.

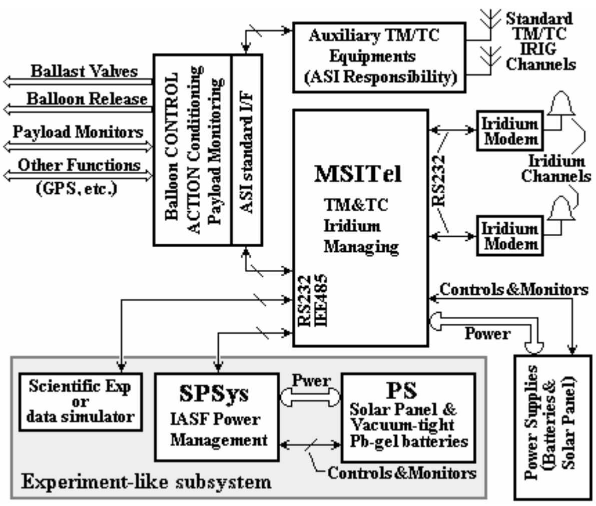

Fig. 11. Possible payload configuration for the test flight. The links connecting the different subsystems are set in evidence as they are described in the text.

The flight prototype payload is under construction and will allow qualification of the LDB TM package. The MSITel unit shall be mainly tested for flight parameter management (ballast release, balloon position, flight termination, balloon housekeeping, etc.) as well for scientific data collection. Since this should be the first test flight, MSITel shall work in conjunction with the standard subsystems used by ASI team to control the payload parameters (auxiliary TM/TC equipments and Balloon Control in Fig. 11) so as to guarantee for both redundancy and safe operations. A dedicated supply subsystem will provide power to MSITel.

The SPSys module will be linked to the SP prototype and two batteries, to verify its capability to manage the charging procedure of the batteries supplying the bias voltage to a dummy-load. At the same time also the SP efficiency and its thermal and mechanical frame will be tested for future scientific users.

6. CONCLUSIONS

An LDBpack has now been presented. The detailed design and the laboratory qualification tests have been described. The TM package can provide both the remote control of the gondola and of the scientific payload. The on-board power management can be optimized (and controlled) by using SPSys modules in combination with MSITel unit. The complete laboratory tests show that this system is now ready to fly on a balloon platform for full experimental qualification. After that the LDBpack will be available to the LDB community, both agencies and experimenters. The intrinsic features of the MSITeL makes it able to match even the requirements for real-time control of any instrumentation remotely located.

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7. REFERENCES

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