THE MICRO-INSTRUMENTATION PACKAGE: A SOLUTION TO LIGHTWEIGHT BALLOONING

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INTRODUCTION

The Columbia Scientific Balloon Facility (CSBF), currently located in Palestine, Texas, launches scientific payloads on balloon vehicles. In its 40 years of existence, the CSBF has launched over 2,200 balloons for 124 different universities and technical institutes. The balloons, launched from various locations including Antarctica, Sweden, Australia, Brazil and the U.S., can be as large as 1.7 million cubic meters (60 million cubic feet), reach a float altitude of 48.8 kilometers (160,000 feet), carry a payload of up to 3600 kilograms (8,000 pounds), and stay at float for over a month. This service provided by CSBF offers the science community an option for their science experiments to reach near space altitudes with only a fraction of the cost of space shuttle or satellite based experiments.

Not only does the CSBF provide rigging and recovery support for the balloon launch and termination, it provides telemetry with the balloon payload. Telemetry with the balloon is obtained by integrating a CSBF telemetry package with the science payload. This telemetry package operates independently of the science payload with the purpose of transmitting science and housekeeping data, receiving commands sent from a ground station computer, executing commands received and terminating the balloon flight. In the early history of science ballooning, communications were possible through LOS only. This resulted in short duration balloon flights lasting from only a few hours to a few days. However, with the technology of satellite communications, also called Over the Horizon (OTH) communications, telemetry can now be achieved almost anywhere in the world. Consequently, OTH communications has dramatically increased science balloon flight durations. In fact, the record was set in 2005 with a science flight lasting 42 days over Antarctica.

Currently, CSBF offers two types of telemetry packages. One of the telemetry packages, called the Consolidated Instrumentation Package (CIP) is used for short duration flights where only LOS is needed. The CIP, including the termination equipment, weighs about 100 pounds with batteries. The other system, called the Support Instrumentation Package (SIP), consists of both LOS and OTH communications and is used for Long Duration Ballooning. To achieve OTH communications, the SIP uses NASA's Tracking Data and Relay Satellite System (TDRSS) and the Iridium satellite system. The TDRSS standard data rate is 6 kilobits and up to 150 kilobits with the use of the Wallops Flight Facility (WFF) developed High Gain Antenna (HGA). The Iridium system uses both Short Burst Data (SBD) and a direct dial-up mode. The SIP, including the termination equipment and necessary solar power system, weighs about 500 pounds.

Although the CIP and SIP provide high data rates with triple redundant systems necessary for high dollar payloads, the weight and cost associated with these systems can be limiting to certain science groups who may not need these full capabilities for their balloon experiment. These limitations create a need for a lightweight and inexpensive telemetry system. This system could be beneficial for various reasons. First, it would allow scientists to fly lightweight payloads on large balloons reaching even higher altitudes. Second, scientists could fly lightweight payloads on less expensive balloons such as meteorological balloons. Depending on the payload, these flights could be inexpensive and even disposable. Third, a compact telemetry system on any balloon will free up more room for the science portion of the payload. In response, CSBF is developing a compact telemetry system called the Micro-Instrumentation Package (MIP). The aim of the MIP is to provide a telemetry support package with all of the rudimentary functions for the safe operation of a balloon, yet weigh only 20 pounds including batteries lasting up to a few days.

OVERVIEW

Since the conception of the MIP in 2005, its development has been ongoing. From the beginning, certain guidelines were established. The MIP should be lightweight, cost effective, modular, low power, and reusable. Furthermore, the MIP should meet the FAA and NASA requirements on ballooning. In addition, it was very important to consider how a wide range of temperatures and a vacuum environment would affect the electronic and mechanical components of the system. Therefore, the MIP was designed to be able to withstand the same thermal extremes as that of the current CSBF support packages.

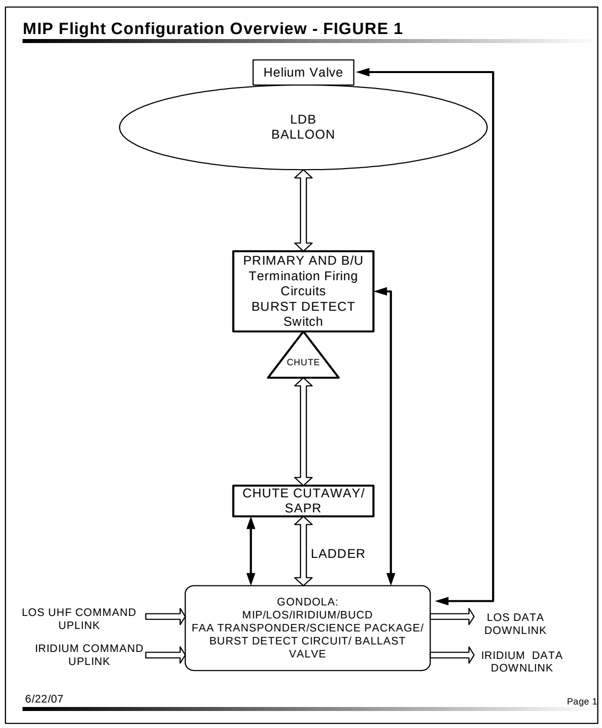
Along with these guidelines, additional functions were specified so that the Micro-Instrumentation Package could be an inclusive telemetry support package. These functions, which are necessary for the safe operation of a balloon flight, provide telemetry with the balloon, interface to other systems such as science, and redundant termination methods for the balloon.

Included in these functions are interfacing to science payloads through an RS232 serial port, transmitting data from the payload, and receiving command data from the ground station. In doing these tasks, the MIP will use both LOS and OTH communications. This allows the MIP to fly in any location with the capability to stay in the air for many days without a mobile ground station. The types of data transmitted will be both science data and MIP housekeeping data including Global Positioning System (GPS) data. Additionally, the MIP will be turning subsystems on and off including the science payload, redundantly providing termination of the balloon using the NASA approved capacitive discharge circuits for firing squibs, operating a valve to release helium from the balloon, releasing ballast, and cutting the parachute from the gondola to prevent payload dragging. Also, the MIP will have the function to terminate the flight system from the balloon if a balloon burst is detected.

An interface will be provided so that the MIP can communicate with CSBF's current systems such as Science Stacks, the Universal Terminate Package (UTP) and the Commandable Apex Package (CAP). A backup command system will also be provided to operate independently of the central unit of the MIP. Lastly, the MIP will include an FAA transponder if needed.

MIP HARDWARE

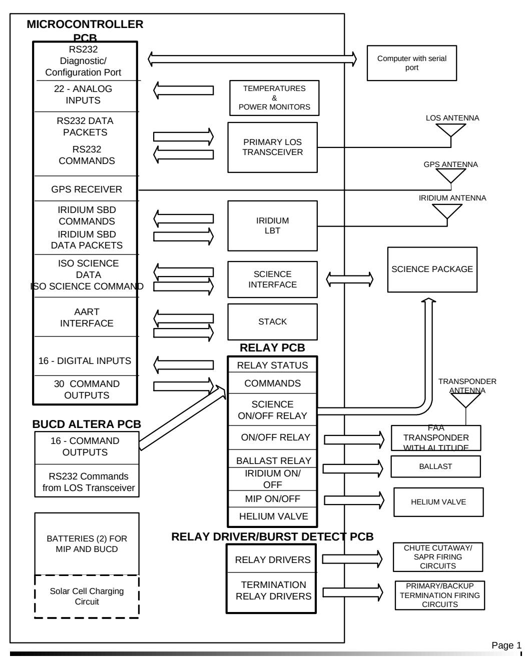
The MIP hardware is comprised of several components and is shown in Figure 1. Most of the components reside on the gondola next to the science package. These components are the Microcontroller PCB, GPS receiver, LOS and Iridium transceivers, Backup Command Decoder, Relay PCB and Command Driver/Burst Detect PCB. Next, located further up the flight train in between the gondola and the parachute is the Chute Cutaway system. Last, situated in between the parachute and balloon is the Primary and Backup Terminate systems.



The central unit of the MIP is the microcontroller PCB. This board, designed at CSBF, consists of a microcontroller, 22 analog inputs, 16 digital inputs, 30 command outputs and 6 serial ports. Chosen over a microprocessor, a microcontroller is low cost, low power consumption and easily programmed. In fact, the microcontroller chosen costs less than 10 dollars and nominally operates less than 0.5 watts. A microcontroller also has many different types of internal peripherals that are applicable to the MIP needs such as internal RS232 serial ports, SPI ports, input and output (I/O) pins, an analog-to-digital (A/D) converter and timers. The 22 analog inputs located on the microcontroller board collects battery voltages and currents, temperatures of subsystems, and other sensors such as sun sensors or load cell sensors. The 30 command outputs will toggle the relays used for power and termination. The 16 digital inputs will collect the statuses of relays. Lastly, the six serial ports will communicate with the LOS transceiver, Iridium transceiver, GPS receiver, Science interface, AART interface, and the Diagnostics interface. The AART interface is an RS232 serial port that can communicate with other CSBF systems such as the Science Stack, UTP, and the CAP. Since the microcontroller only has two internal serial ports, the other four serial ports are possible with two dual UART chips that communicate with the microcontroller through the SPI bus. A complete block diagram is shown in Figure 2.

The microcontroller will carry out scheduled tasks with the use of the microcontroller's internal timers. The first task is to collect the housekeeping data packet that includes GPS data, analog inputs, digital inputs and error messages. In order to collect the GPS data, the microcontroller communicates through a serial port to request specific data packets from the GPS receiver. Once GPS data collection is complete, the microcontroller uses its internal A/D converter to collect each analog input. Finally, the housekeeping packet is completed by reading the digital inputs. The second task is to collect the science data packet through the science RS232 serial port interface. The microcontroller sends a message to the science payload requesting a data packet to start this process. The science payload then responds with its data packet in which the MIP stores in its buffer. Once the microcontroller has the MIP housekeeping packet and the science data packet, the third task is transmitting the packets collected through the LOS and Iridium transceivers. The LOS packets are easily sent out of the LOS RS232 interface. However, in order to send out the Iridium packets, the microcontroller must communicate with the Iridium unit and initiate a session with the Iridium network. Along with transmitting data packets, the fourth task for the microcontroller is to use these two lines of communications to receive commands transmitted from the ground station computer. The MIP can receive LOS commands at any time executing them in a timely manner. However, similar to transmitting the data packets, the only way for the microcontroller to receive commands through the Iridium unit is request that the unit initialize a session with the Iridium network. Once, received and decoded, a command is executed by either toggling a relay through one of the MIP's 30 command outputs or routing the command to the appropriate location such as the Science or AART interface. There are also commands intended for the microcontroller itself such as the commands directed to change the timers for the frequency of transmitting LOS or Iridium packets. The last task of the microcontroller is to send diagnostic messages out of the Diagnostic RS232 interface. These messages tell the user what task the microcontroller is currently working on. It also informs the user of any errors that the microcontroller is encountering. Although not used in flight, the diagnostic port is very helpful for testing on the bench.

MIP Block Diagram - FIGURE 2



The next component of the MIP is the GPS receiver. Its function is to provide the balloon payload position and altitude and a timestamp for the data packets. The MIP uses the Trimble Lassen IQ GPS receiver. The Lassen IQ can track up to 12 satellites, costs around $70, interfaces through two serial ports, and is the width of a U.S. quarter. It is small enough to mount in a corner on the bottom of the Microcontroller PCB.

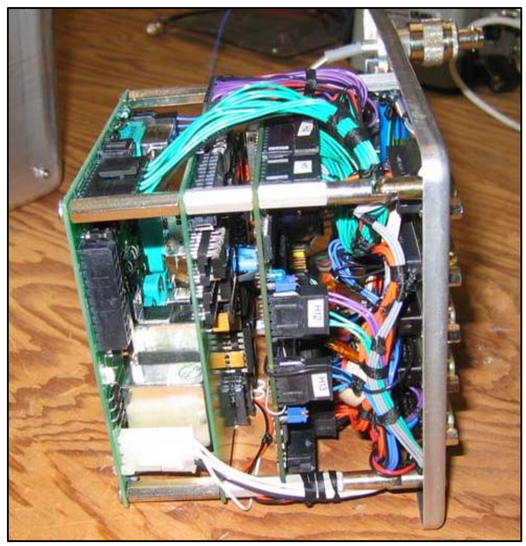
The LOS transceiver provides a method of transmitting data packets and receiving commands from the ground station. For LOS transmission and reception, CSBF's CIP and SIP uses separate units for each function. This means that there is a LOS transmitter with the function of only transmitting data packets and a separate LOS receiver with the function of only receiving transmitted commands. However, in order to save on power and weight, the MIP makes use of one LOS transceiver that does the function of both transmitting data and receiving commands. The downside to this is that if simultaneously a command is transmitting from the ground station and a packet is transmitting from the MIP then a collision occurs causing a loss of data on both ends. Therefore, to send commands to the MIP using only one LOS transceiver, the microcontroller's LOS data packet timer is set to an interval of every 20 to 30 seconds. If this data rate is not adequate for the science payload, then CSBF can provide a separate LOS transmitter dedicated for the science payload. However, this solution adds more weight in batteries due to increased power consumption.

The MIP also uses an Iridium transceiver for the OTH communications. Currently, the Iridium uses Short Burst Data (SBD) sessions to send and receive data. Basically, this is a store and forward type system using email messages through the Iridium network.

Using an FPGA Altera chip and powered separately from the microcontroller PCB, the Backup Command Decoder (BUCD) PCB decodes commands from an RS232 input and executes command outputs. The RS232 input will be shared with the microcontroller's receive line from the LOS transceiver. This means that both the microcontroller and the BUCD will receive LOS commands sent from the ground station. However, in order to prevent dual execution of commands, the BUCD will have a separate routing address from the microcontroller. The BUCD's command outputs will be able toggle the same relays as the MIP creating a redundant method for terminating the balloon. This backup system ensures the execution of termination commands in case of a microcontroller failure.

The MIP's Relay PCB consists of Darlington pair command drivers, one momentary relay and six latching relays. Some of the relays provide a way to toggle power to other components including power to the Iridium unit, LOS transceiver, and the microcontroller PCB. There is also a relay designated to toggle power to the science payload. The other relays are for dropping ballast and opening the helium valve. For redundant paths, every relay can be commanded from either the microcontroller PCB or the BUCD.

The MIP's Command Driver Burst Detect PCB serves two purposes as the name implies. Using power mosfets, one purpose is to drive terminate relays that are located outside of the MIP's main package and up the flight train. Similar to the Relay PCB, the microcontroller PCB and the BUCD can command each output. The other purpose of this PCB is to house the Burst Detect circuit. If there is a balloon burst, this circuit will send the necessary commands to terminate the balloon.



MIP ENCLOSURE - FIGURE 3

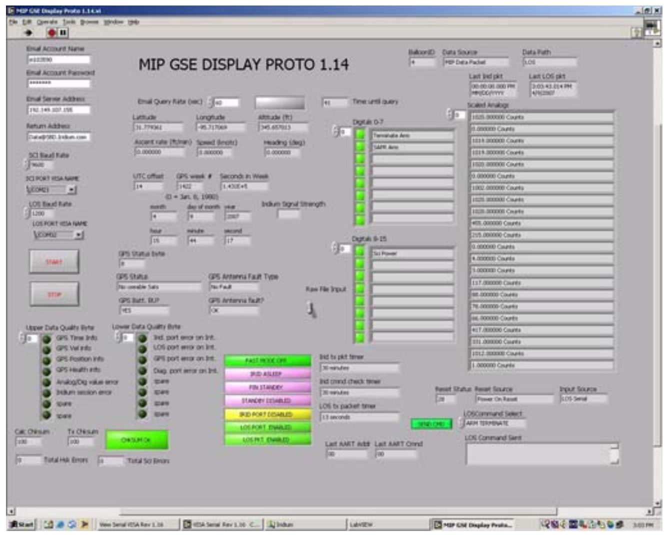
The MIP's chute cutaway system is located in between the gondola and the parachute. The purpose of this system is to separate the parachute from the gondola once the payload has landed on the ground preventing the parachute from dragging the payload in windy conditions. First activated by sending a command to arm the system, the chute cutaway system uses tilt sensors to detect when the parachute has landed on the ground. This event causes a squib to fire separating the parachute from the gondola. This system is most important in locations such as Antarctica and northern Canada where there exists windy conditions without vegetation making payload dragging possible.

The last components of the MIP are the primary and backup terminate systems. These two items, housed in one box, are located in between the parachute and the balloon. Their function is to provide two methods for terminating the balloon. In each system, toggling the arming and firing relays causes a squib to fire cutting the cable that connects the balloon to the parachute. Also, to ensure redundancy, each terminate system has its own battery pack and can be commanded from both the microcontroller PCB and the BUCD.

MIP GROUND STATION EQUIPMENT (GSE)

The MIP GSE's design makes it possible so that only one laptop, antenna with an RS232 LOS transceiver and an internet connection is required to communicate with the MIP. Theoretically, a user could follow the balloon in a car or plane and receive data packets or send commands to the MIP. Another possibility is that through Iridium data transmission, the MIP can be launched from another continent and operated from Palestine, Texas. The MIP prototype GSE display, shown in Figure 3, uses Labview software to receive data packets transmitted from the MIP, transmit commands to the MIP, route data to the science ground station and log the data to a hard drive.

The Labview user interface program displays the received and decoded data packets. An RS232 LOS receiver receives the transmitted MIP data packets. These packets can be received anywhere in the range of LOS with the payload. In order to receive the Iridium data packets, the ground station software must check an email account specific to the Iridium unit used on the MIP. The incoming messages contain an attachment of the Iridium data packet. The software reads the attachment and displays the decoded data on the user interface. MIP Iridium packets can be received in any location where there is an internet connection.



The Labview interface also sends commands to the payload through both LOS and Iridium paths. For LOS, the commands are transmitted through an RS232 command transmitter. As with the data packets, LOS commands can be sent anywhere in the range of LOS with the payload. The Iridium commands are sent in an email to the Iridium network. The commands are transferred to the Iridium unit on the MIP when the microcontroller initiates a session with the Iridium network.

The Labview ground station software routes the science data packets received from the MIP to the science GSE. The MIP microcontroller places a special header on the science packet so that the Ground Station software can distinguish the science packet from the MIP housekeeping packet. The software also logs both the science data packets and the MIP data packets onto a hard drive.

TESTING

Initial test flights with the MIP have been successful. Three of the test flights used small rubber balloons that reached a height of 105000 feet before bursting. These were short flights lasting around two hours. The fourth test flight was flown as a piggyback to one of CSBF's science flights launched out of Palestine, Texas. This flight lasted around 8 hours. During all four of these flights, the tested functions included the LOS and Iridium uplink and downlink, GPS tracking and collection of data packets, and the ground station software. One of the test flights also used the termination system to fire a squib which terminated the balloon from the parachute. Integration of the MIP to a science payload is currently being conducted for a test flight. Future test flights are also planned to further test the MIP as a full up telemetry/termination system.

MIP TEST FLIGHT #3

CONCLUSION

In conclusion, the MIP offers the science community a lightweight approach to ballooning. The goal of an inclusive telemetry/termination package weighing less than 20 pounds for a 24 hour flight was reached. With a few tradeoffs, it provides a basic cost effective telemetry support package with both LOS and OTH capability and weighs significantly less than the traditional support systems. The MIP is ideal for science groups interested in light weight ballooning that can afford lower data rates than that of the CIP and SIP.

Future capabilities of the MIP will include Iridium dial-up, a dedicated science LOS transmitter and data logging. This will help increase the speed of data transmission and commanding. Also planned for future capability is the use of a solar panel power system. For longer flights, instead of flying numerous batteries, a solar power system will be used to save weight.