

WVU BALLOON SATELLITE INSTRUMENTATION BOARD
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A. INTRODUCTION

In the fall of 2002 I was approached about helping with the first WVU Balloon Satellite course to be offered in the spring term. Being an amateur radio operator, interested in instrumentation, and micro-controllers the fit seemed too good to be true. In addition I was retiring as a full time faculty member at the start of 2003 and could dedicate nearly full time to the project.

The course was to be offered in the Mechanical and Aerospace Engineering Department but open to students from any discipline within the University. Since not all students would be from engineering it was decided to put the emphasis on the design, construction, and testing of a balloon package to make “measurements” during flight. To this end we would use “off the shelf” instrumentation packages such as the HOBO data logger as well as packages we would design and build for this project. The WVU Balloon Satellite Instrumentation Board shown here is the result of this in house development. We are now flying the second and third generations of this board and will report here on the second-generation board (Version 2.2 board) only. The Version 3 board is more specialized for higher speed applications (e.g. accelerometers at 50 Hz sampling rate).

B. DESIGN - HARDWARE

The design criteria for the hardware included the following considerations:

- Low power consumption
- Operation from 1 or 2 cells (1.5 or 3 Volts)
- Bell 202 packet radio MODEM (APRS and telemetry)
- Radio interface for APRS transmission
- Serial I/O for GPS receiver and configuration
- Multi-channel 12 bit ADC (single ended or differential input)
- Timer for resistive (thermistor) and capacitive transducers
- Timed pulse outputs
- Period/frequency input
- SPI interfaces for SPI transducers and devices
- LED output for diagnostic and operational status
- Onboard memory to allow recording data for the flight duration
- Small size and weight
- Low cost

These design criteria have been met or exceeded in the Version 2.2 board.

POWER SUPPLY

The board contains two independent power supplies that deliver +5 Volts to the board and to attached transducers/devices. One power supply uses a standard linear regulator and consists of diode D1, capacitors C1 and C2, and 5 Volt regulator VR1 (See Appendix B for schematic diagram). This supply is connected to the 5 Volt buss on the board via jumper block JU1-B and is intended for use in the laboratory during testing. The input to this power supply can be in the 7 to 15 Volt via the 2.1mm power connector J1.

The second power supply uses a switching regulator in step-up mode and consists of diodes D2 and D3, resistor R18, inductor L1, capacitor C3, and integrated circuit U2 (LT1073-5). This power supply is connected to the 5 Volt buss via jumper block JU1-A and is intended for use in flight. The input voltage is from two cells (AAA or AA) via the 2 pin BAT connectors. The efficiency of this switching power supply is about 80 to 85%. In use only one of the power supplies would be connected to the 5 Volt buss at a time.

The 5 Volt current drain of the board is about 12 to 20ma depending on the number and type of IO devices connected. This translates in to an operational life of over 24 hours on two alkaline AAA (1100 ma-hr) cells when using the switching power supply. When using alkaline batteries they must be kept above 0°C to get the service life indicated. Better low temperature performance may be obtained by using two 1.5 Volt Lithium cells.

MODEM and RADIO INTERFACE

The Bell 202 modem consists of a MXCOM MX614 (U2) integrated circuit and associated components. The MX614 is connected to a radio via the 5-pin header J2 (RADIO). This header has pins for Receive audio, Transmit audio, PTT (Push To Talk) and Ground and is suitable for connection to most radios. Variable resistor R1 and jumper block JU2 are used to adjust MODEM transmit audio level into the radio. The audio input to the modem can vary of a wide range and still decode.

The digital side of the MODEM is connected to the board's processor (U3 PIC16F876A-I/SP). The digital signals are: transmit data, receive data, carrier detect, and M0 and M1 mode select lines. The PIC will encode (decode) the AX.25 frames.

SERIAL INTERFACE

A TTL level 4800-baud serial interface is provided at the 10-pin connector J3. The signals on this connector are: TXD, RXD, RTS, CTS, GND, and +5 Volts. This connector may be connected to a GPS receiver (with TTL levels) or to a TTL/RS-232 level connector. We have been using the Motorola Oncore GT PLUS 8-channel receiver that has TTL levels. If other GPS receivers are used provisions must be made for level conversion.

The serial interface is also used to communicate with the PC during configuration and data downloading. We use a level converter that converts between TTL level board signals and RS-232 level PC COM port signals. A photo and diagram of the level

converter we are using is given in Appendix E. Power for this level converter is provided via pin 10 of J3.

ANALOG to DIGITAL CONVERTER

An 8 channel multiplexed 12-bit analog to digital converter with an SPI interface provides inputs for analog transducers. The ADC uses a MCP3208 or MCP3304 (U8) and connects to transducers via the 16-pin SIP connector (J5). Even pins are inputs and odd pins are ground. The ADC reference voltage is provided by U5 and may be 5.000 Volts (REF195), 4.096 Volts (REF198), or 2.048 Volts (REF191). The MCP3208 will provide 8 single ended inputs and the MCP3304 may be configured for 4 differential inputs (13 bit conversion). All ADC inputs are unipolar.

The digital side of the ADC is connected to the PIC processor via the boards SPI buss and an additional chip select line.

TIMERS (RESISTIVE and CAPACITIVE TRANSDUCERS)

Two CMOS 7555 timers (U4 and U7) are included primarily for use with thermistors. These timers can be used in resistance mode by placing fixed capacitors on the board at C25 and C26 and connecting resistive transducers to the Rx1 and Rx2 headers or capacitive mode by placing fixed resistors on R12 and R14 and capacitive transducers on headers Cx1 and Cx2.

The outputs of the two Timers are connected to input pins on the PIC processor. The data is read in the form of the period count for the input square wave. For temperature measurements we have been using YSI 44003A $1000\Omega@25^{\circ}\text{C}$ on the timer inputs.

PULSE OUTPUTS and PERIOD/FREQUENCY INPUTS

There are two independent pulse outputs that are used for generating TTL output pulses at evenly spaced periods (multiples of 10 seconds) and of fixed widths (multiples of 10 milliseconds). One of these outputs will rest at low level and pulse to a high level and the other will rest at a high level and pulse to a low level. The two pulse output lines are connected to the 2-pin SIP headers at IO1 and IO2 on the board. These lines can sink about 20ma each and may be used to drive a 5 Volt DIP relay. The status of these lines will be recorded in the Flag byte data field.

DIGITAL and SPI INTERFACE

The PIC processor lines brought out to the two SIP headers J4A and J4B may be used for several functions and programmed independently on each interface. They may be programmed (via configuration program) as:

- Period measurement input waveform (square wave).
- Frequency measurement input wave form (square wave)
- SPI interface
- NO FUNCTION

The CS lines in the interface are used for period/frequency input. There will be magnitude limitations for period /frequency measurements.

When used as SPI interface the signals on these connectors J4A and J4B are DIN, DOUT, CLK, CS, VCC, and GND. The transducers and devices connected may get their power via the VCC/GND pins. We have used these connectors for a number of different devices. At the present time there is code in place to support the following:

- TC77 digital temperature transducers
- DALLAS (DS1306) Real Time Clock (RTC)
- MCP3201 ADC (single ended input)
- MCP3301 ADC (differential input)

The PIC code makes provisions for up to 7 different devices. To add a new device a device driver must be written and assembled into the PIC code.

LED OUTPUT

As we used the Balloon Board it became apparent there was need for an indication of the status of operational parameters. The LED output provided this function. The two pins of the LED header are used to connect a LED. A current limiting resistor of 860 Ohms (R11) is provided on the board. The LED functions as set by the configuration program are:

- Flash on starting data logging
- Flash on each data logging scan
- Flash on each radio transmission
- Flash on each GPS radio transmission
- Flash every 10 seconds during data logging

The duration of a “Flash” is one second. During most flights the LED mode is set to flash on entering data logging and on each data scan.

The LED is also used to indicate correct initialization and start of board firmware by giving three short flashes on power up, leaving data logging mode, and other firmware restarts. To confirm the correct connection of the LED to the LED connector it may be flashed by the “C” (calibrate) command from the configuration software.

DATA MEMORY and CONFIGURATION MEMORY

Data collected in data logging mode is stored in an ATMEL Data Flash card. A 2MB card will store up to 16,384 128 byte records (one per scan). Each record will contain the point number, data for 8 analog channels, data for two timers, data for two SPI devices, GPS altitude (if GPS receiver is connected), Flag byte, and the raw GPS data (\$GPGGA sentence). Using a data-logging period of 10 seconds the 2MB card will store data for over 45 hours.

Data stored in the Data Flash card may be down loaded to an ASCII or a Binary data file using the configuration program. The ASCII data will be presented as comma delimited data. Balloon Board configuration information is stored in the non-volatile EEPROM in the PIC processor.

SIZE, WEIGHT and FORM FACTOR

The Version 2 board is built on a 4.7 by 3.2 inches rectangular 1/16-inch thick FR-4 double-sided circuit board stock using conventional through-hole technology and has a weight of 65g when populated. All integrated circuits are placed in double wipe sockets to allow ease of replacement of any defective components, although this has not been necessary.

The through-hole form factor for this board was determined by our ability to produce the circuit boards in our facility. The size and weight of the board could be reduced by the use of SMT.

COST

The cost of components for the Version 2 board may be calculated using the Bill of Materials in Appendix D. The costs will vary as time changes. A current estimate of the cost of materials is about \$75 when buying components at smallest quantities. A list of vendors for components is also provided in Appendix D.

DUAL SIP HEADER CONNECTORS

We have used SIP headers freely on the board because of their low cost, small size, and ease of use. Many of our transducers and devices need to be connected via the mating 2 pin female SIP connectors. We have found a ready supply of these in old PCs that are being scrapped. Here you find cables with connectors and LED, cables with switches, and many other goodies.

C. SOFTWARE

The software for the Balloon Board consists of two parts: the firmware in the



PIC16F876A processor on the board and the PC configuration software. The PIC firmware is unchangeable by the user and will respond to user commands in “HOST” mode.

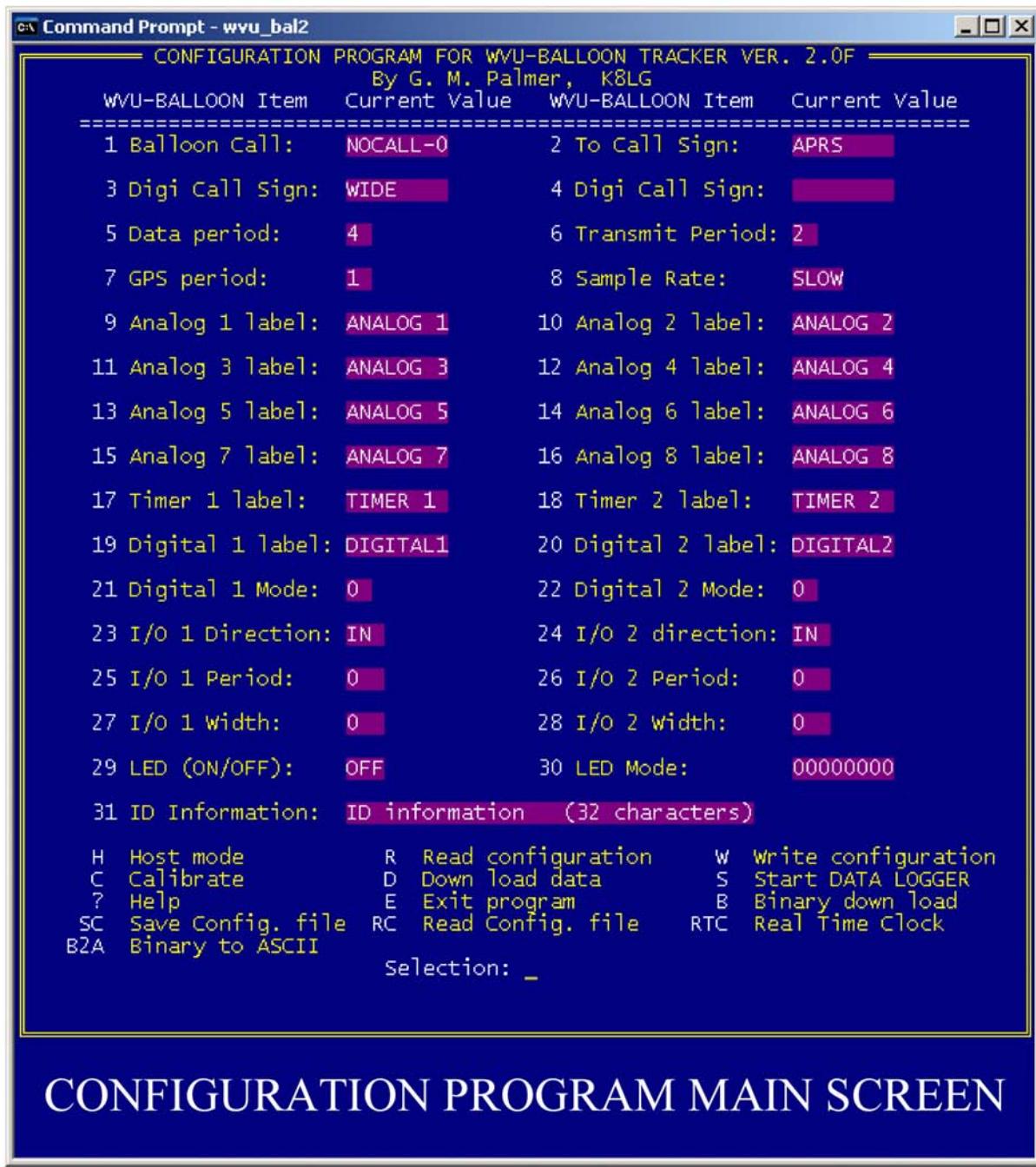
The configurations program communicates with the board via the serial interface using a host mode protocol. In host mode the user may set the board configuration and download data logger data from the board. Configuration information is stored in the PIC16F876A’s non-volatile EEPROM.

CONFIGURATION ITEMS

The configuration program allows the user to set 31 items and store them in the boards EEPROM. These items are:

- Amateur Radio call sign for board radio transmissions
- “TO” call sign for board radio transmissions
- First digipeater call sign for board radio transmission
- Second digipeater call sign for the board radio transmission
- Data logging period in units of 10 seconds
- Radio transmission period in units of data logging period
- Radio GPS transmission in units of Radio transmission period
- Data logging speed: Slow or Fast (Only SLOW speed covered)
- Analog channels 1 through 8 labels (8 character user defined title)
- Timer 1 and 2 labels (8 character user defined title)
- Digital 1 and 2 labels (8 character user defined title)
- Digital 1 and 2 MODE
- IO1 and IO2 data direction
- IO1 and IO2 period in units of 10 seconds
- IO1 and IO2 pulse width in units of 10 milliseconds
- LED on/off flag
- LED mode.
- ID Information a 32 character user defined field

Each of the 31 configuration items has “HELP” information available by typing the item number followed by a question mark (example: 3? for information about Digipeater 1 field.



Numbered items are configuration information and letter/letter groups are commands. Information may be entered into a text box after the configuration/command is entered or by typing the configuration number/command followed by a space and then the input information. "HELP" information may be found for most items by typing the item followed by a question mark (example: **30?** for information on LED Modes or **C?** for information on the Calibrate command).

COMMANDS

In addition to the 31 configuration items the program has the following commands:

- “H” Enter Host mode communications between board and PC
- “R” Read (and display) configuration data from the board’s EEPROM
- “W” Write current configuration information to the board’s EEPROM
- “C” Read data from analog channels, timers, and digital inputs and Display the values. Also flashes the LED.
- “D” Down load data stored in the memory card to a data file on the PC
- “S” Start the data logger
- “?” Display help screens
- “E” Exit configuration program
- “B” Binary down load data stored in the memory card to a PC file
- “SC” Save the current configuration to a PC file
- “RC” Read a configuration from a PC file and restore to the board’s EEPROM
- “RTC” Real Time Clock functions. If there is a DALLAS RTC Configured on Digital channel 1 this command will set or read it.
- “B2A” Binary to ASCII conversion function. Convert binary file to ASCII file.
- “V” Display Version of the board/software.
- “VI” Display Version information and options.

Many of the commands have “HELP” information available by typing the command followed by a question mark (example: D? for information about the Down Load command).

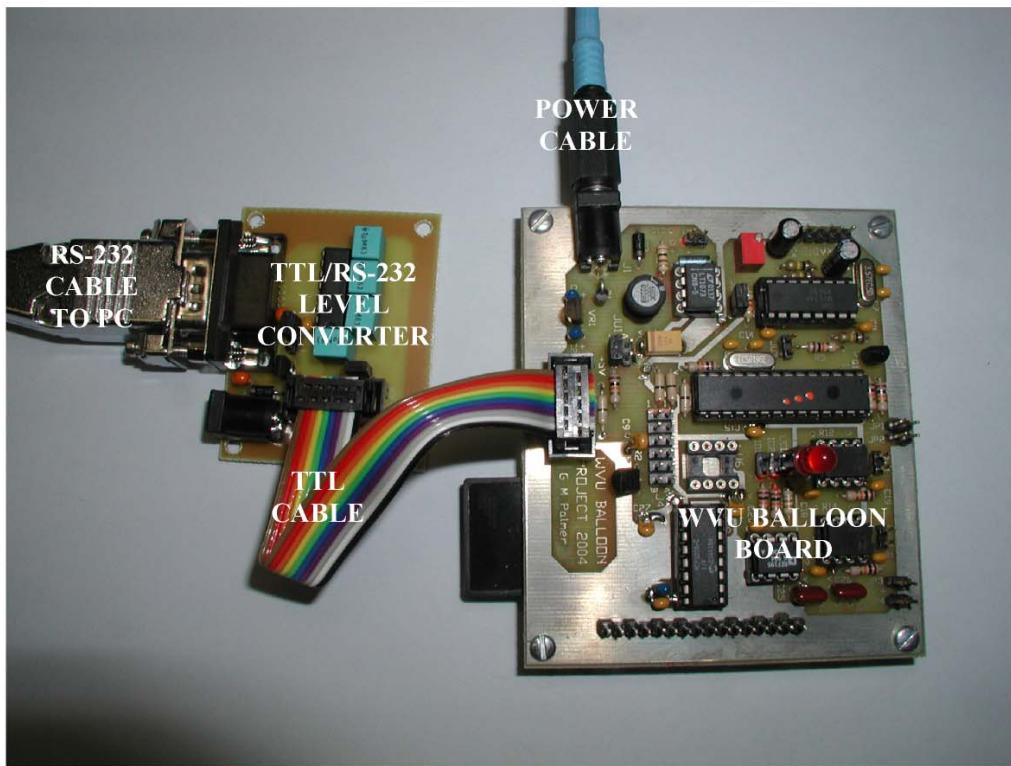
HOST MODE CONNECTION

The balloon board is connected to the PC’s serial port via the TTL/RS-232 Level Converter. A 10-conductor ribbon cable with 10 pin female IDC connectors on each end is used to connect the level converter to the board. A standard serial cable with female/male DB-9 connectors is used to connect the level converter to the PC’s serial port. The level converter is supplied with 5V via pin 10 of the ribbon cable.

After all the cables have been connected, power applied to the board, and the configuration program started communications can be established between the program and the board by the “H” (Host Mode) command. If the COM port has not been given on the DOS command line the user will be prompted to choose either COM1 or COM2. After issuing the “H” command the configuration stored in the board’s EEPROM will be down loaded and displayed. The number of data points stored in the memory card will also be displayed in the lower right corner of the screen.

Memory card data may be down loaded to a PC data file with either the “D” command that stores the data in ASCII format with columns separated by commas or the “B” command that stores the data in binary format. Since the serial communications data rate is 4800 baud, down load times may be quite long.

SETUP FOR HOST MODE COMMUNICATIONS



CONFIGURATION

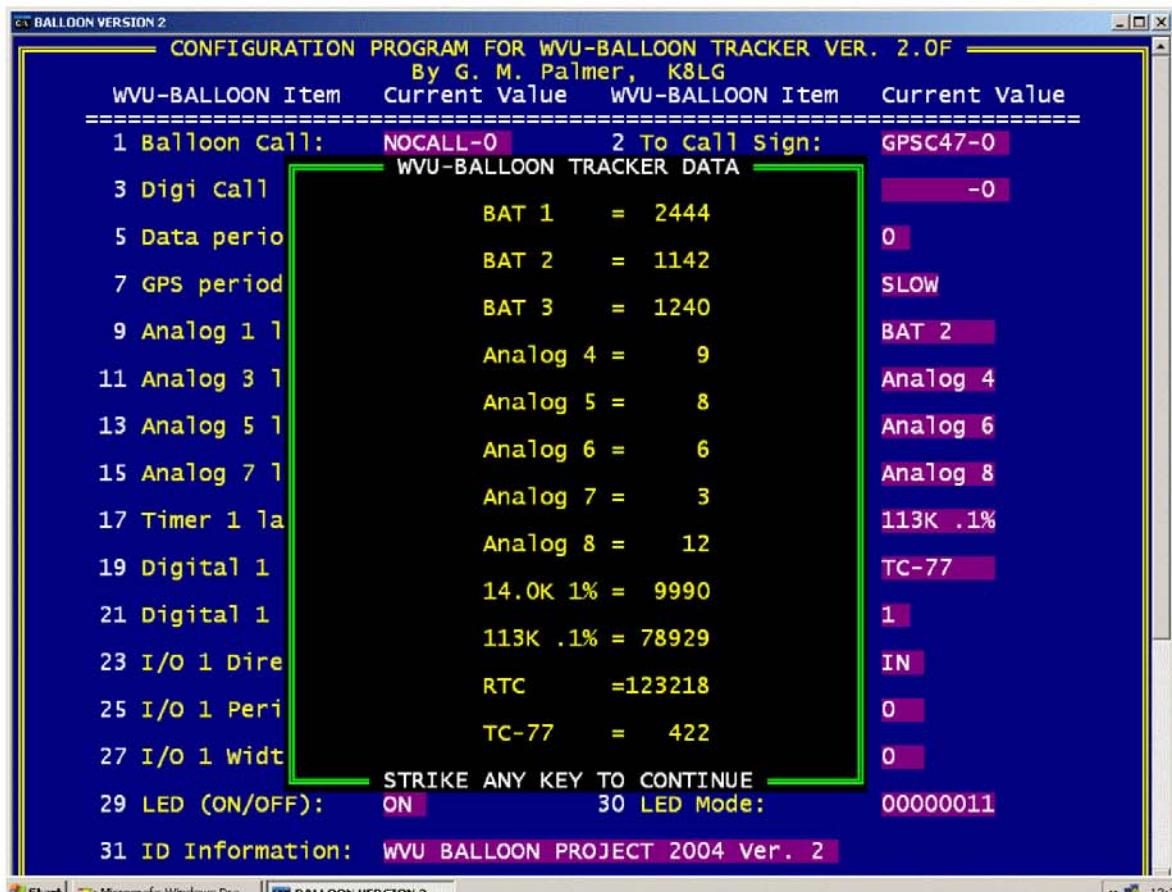
Initial configuration of the board is accomplished after entering host mode. Edit the configuration fields on the screen by typing the item number at the selection prompt and entering the data as needed. You may also type the number followed by a space and the parameter for the field, for example "3 WIDE2-2" to set digipeater 1 field. This will bypass the screen window for the item. After the edit of the configuration is complete the information is stored in the board's EEPROM via the "W" command. This command will do a "read after write" to insure the data is stored correctly. The configuration may also be stored as a PC file using the "SC" command. The file name should have an extension of ".CFG". To reconfigure or changing individual configuration items enter host mode, edit the item(s), and write the changed configuration using the "W" command.

CALIBRATION FUNCTION

The "C" command allows the user to display the values of the analog channels, the timers, and the digital inputs on the screen. In addition it will flash the LED allowing confirmation of the correct LED connection. Uses for the "C" command we have found are:

- Calibration of the timer channels using precision resistors
- Confirmation of correct LED operation
- Confirmation of correct temperature sensor operation
- Calibration of analog sensors
- Confirmation of data field names
- Overall view of flight data before launch
- Confirmation of wiggle-in/wiggle-out on data channels

EXAMPLE OF "C" CALIBRATION COMMAND SCREEN DISPLAY



Analog channels 1, 2, and 3 are connected to batteries with input voltages of 2.989, 1.396, and 1.516 V respectively (using FLUKE 175). Analog channels 4 through 8 are open and float to a few codes. The ADC voltage reference is a REF195GP (5.0 Volts +-0.2%) making the conversion from ADC code to Volts:

$$\text{Volts} = \text{ADC} * 1.22070 \text{ mV}$$

For more accurate work I would suggest using the REF195ES (5.0 Volts +-0.04%).

Timer 1 and Timer 2 have fixed resistors of 14.0 K and 113K respectively. The period values are in units of 20.345 ns per count and represent an average of 160 period measurements.

Digital 1 has the Dallas RTC attached and reads the time of 12:32:18 in hhmmss format and Digital 2 has a TC77 temperature sensor connected that is reading 16 times the temperature or 26.38 C (79.48 F).

START DATA LOGGING

Starting the data logging (and confirming start) is the most critical part of any flight. We have had more than one case of failure to go into data logging mode at launch time. Great care has been taken in this design to make it possible to get a positive indication of start.

While in host mode the data logging may be started or enabled by the "S" command. The result of the "S" command is determined by the status of jumper block JU3. If a jumper is NOT on JU3 data logging is started as soon as the command is issued. If the jumper is on JU3 data logging will not start until the jumper is removed even if the power is removed and reconnected.

Deferred start of data logging has the advantage of allowing the board to be completely setup for operation before starting logging. The board may have logging enabled with the jumper on JU3, powered down, moved into the flight package, re-powered, and then started by removing the jumper. Following this procedure eliminates the need for a connection to the configuration program at launch time.

Connecting JU3 to a switch on the outside of the package provides an easy way to start data logging at launch time. Adding an LED to the outside of the box (connected to the LED block) will provide a positive and clear indication of the data logging start. The photo at the right shows a switch and LED on the outside of a package.



ENDING DATA LOGGING

Data logging may be exited in several ways:

- Replacing the jumper on JU3 (requires 4 additional scans to stop)
- Connecting to a PC and entering host mode with "H" command
- Data memory card full (unlikely in SLOW mode)
- Loss of power (up to last 16 scans may be lost)

The loss of power exit is not recommended although we have had this happen more than once on "hard" landings. The loss of data occurs because the number of data scans is only updated in EEPROM every 16 data scans during normal operation. The other exit modes will store the number of data scans when closing out logging. Here again it is nice to have a switch on the lines from JU3 and an LED on the outside of the package that will terminate logging and provide a visual indication of end of logging.

DOWN LOADING DATA

After the balloon flight data collected may be moved from the memory card to a PC file. The “D” or the “B” commands may be used to move the data to the PC via the serial port.

The “D” command moves the data in ASCII column format to a data file. The file will contain a header with much of the information from the configuration, column headers and columns of data. The data in the columns is separated by commas and is specifically:

- One column of Point Number
- Eight (8) columns of ADC data
- Two (2) columns of Timer data
- Two (2) columns of Digital data
- One column of GPS altitude parsed from the GGA sentence
- One column of Flag data
- One field containing the raw GPS data

There will be a maximum of about 300 characters per line of data depending on the presence of the GPS field. Down loading with the “D” command will be a slow process as the serial port speed is only 4800 baud or 480 characters per second. A typical data file will be 1800 data points (data logging every 10 seconds for period of 5 hours) will require a down load time of about 20 minutes. The file extension for the ASCII file should be “.DAT”

The “B” command moves the data in binary format to a data file. This file will contain a 256-byte header containing all the configuration information plus one 128-byte record for each data point. The binary down load will be less than half that of the “D” command. Once data is received in binary format it may be converted to ASCII format using the “B2A” command. The file extension for the binary file should be “.BIN”.

D. TYPICAL TRANSDUCERS and INTERFACES

We have used a number of different transducers with this balloon board. Several of these will be given below as examples of the type of measurements that may be made.

TEMPERATURE

The inside and outside temperatures of our balloon packages have been measured using a variety of off the shelf transducers. Here we will discuss the following:

- Thermistor temperature transducers
- Solid state analog temperature transducers
- Solid state digital temperature transducers

We have not used thermocouples because of the complexity of the signal conditioning nor have we used RTDs because of cost.

THERMISTORS

Thermistors are devices that change resistance with temperature. We have used the NTC (negative temperature coefficient) devices made by YSI (Yellow Springs Instruments). The most useful have been the devices that have 1000 ohms at 25°C. YSI makes several others devices that are used by NASA in space flight but the cost becomes an issue. Data



on specific YSI thermistors may be found at their WEB site www.YSI.com. Here you will find Excel spread sheet data for their devices.

The thermistors are connected to the resistive input of the Timers and high quality 0.01µf capacitor is connected to the C25 and C26. The output of the timer will now be related to the resistance of the transducer (see data sheet for ICM7555 timer). To obtain accurate temperature data the raw data from the timer is processed through a two-step process. The raw data is first converted to resistance via a calibration curve for the Timer channel

and then the resistance value is converted to temperature by a look-up table technique using the YSI data for the specific thermistor being used.

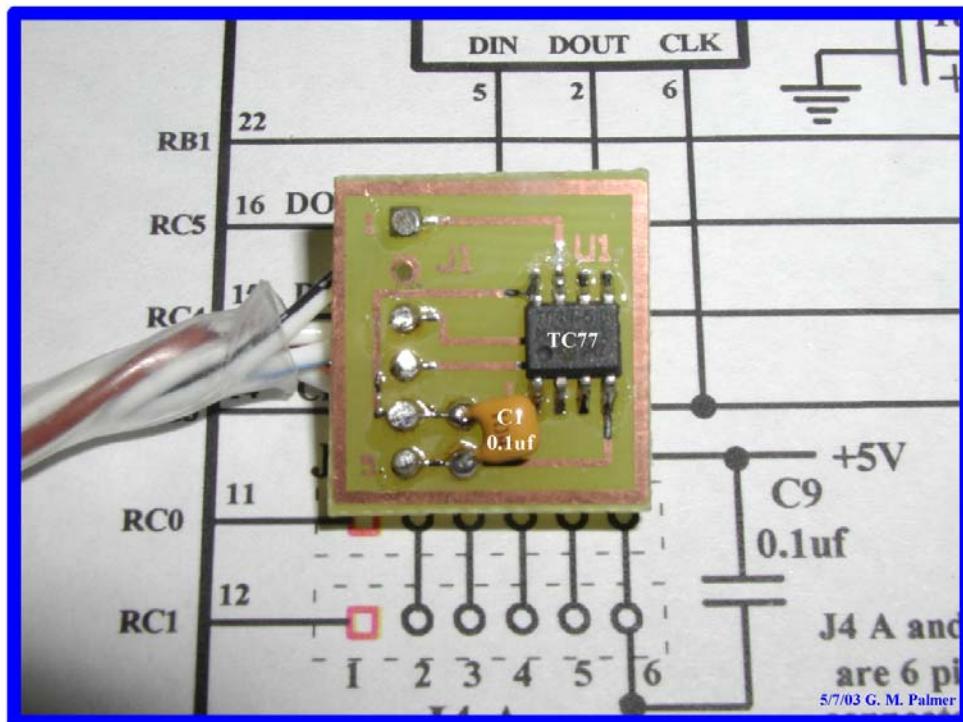
SOLID STATE ANALOG TEMPERATURE TRANSDUCERS

There are a number of solid state temperature transducers available. We have used the National Semiconductor LM34/LM35 on several flights. These devices have the advantage of providing a high level linear signal that is 10mV per degree ($^{\circ}\text{F}$ – LM34 or $^{\circ}\text{C}$ – LM35) over a wide temperature range. One has to be sure to obtain the higher quality units for outside temperature measurements. The biggest draw back to the use of these transducers is the need for differential input (or two inputs) when used from a single power supply. The data sheet for the LM34/LM35 describes how this may be done.

Although we have not used them, there are other analog transducers that will provide a signal out that is 10mV per $^{\circ}\text{K}$ (LM135, AD590). These would appear to be a good choice for use as there would be no problem with a single voltage 5V power supply.

SOLID STATE DIGITAL TEMPERATURE TRANSDUCERS

A number of vendors make digital temperature sensors. We have limited our interest to those that conform to the SPI interface specification. The 13-bit Microchip TC77 digital temperature sensor is a good device and provides a two's complement 13-bit digital signal that is 16 times the temperature in $^{\circ}\text{C}$. We have used these for both inside and outside measurements. We are not recommending the TC77 for outside measurement.



TC77 SPI TEMPERATURE SENSOR

PRESSURE MEASUREMENTS

Atmospheric pressure may be measured using several off the shelf pressure transducers. We have used the All Sensors Corp. 0-15 PSIA transducers with high-level outputs. These units have a supply voltage in the 5V range and an output of 0 to 4.5V, which is a good match to the ADC inputs on the board.

We have also used the 0-15 PSIA 60-90 millivolt output sensors with bridge amplifiers. These are much more complicated to use because of the need for offset adjustment and differential input to accommodate the bridge power/output issues when using a single power supply.

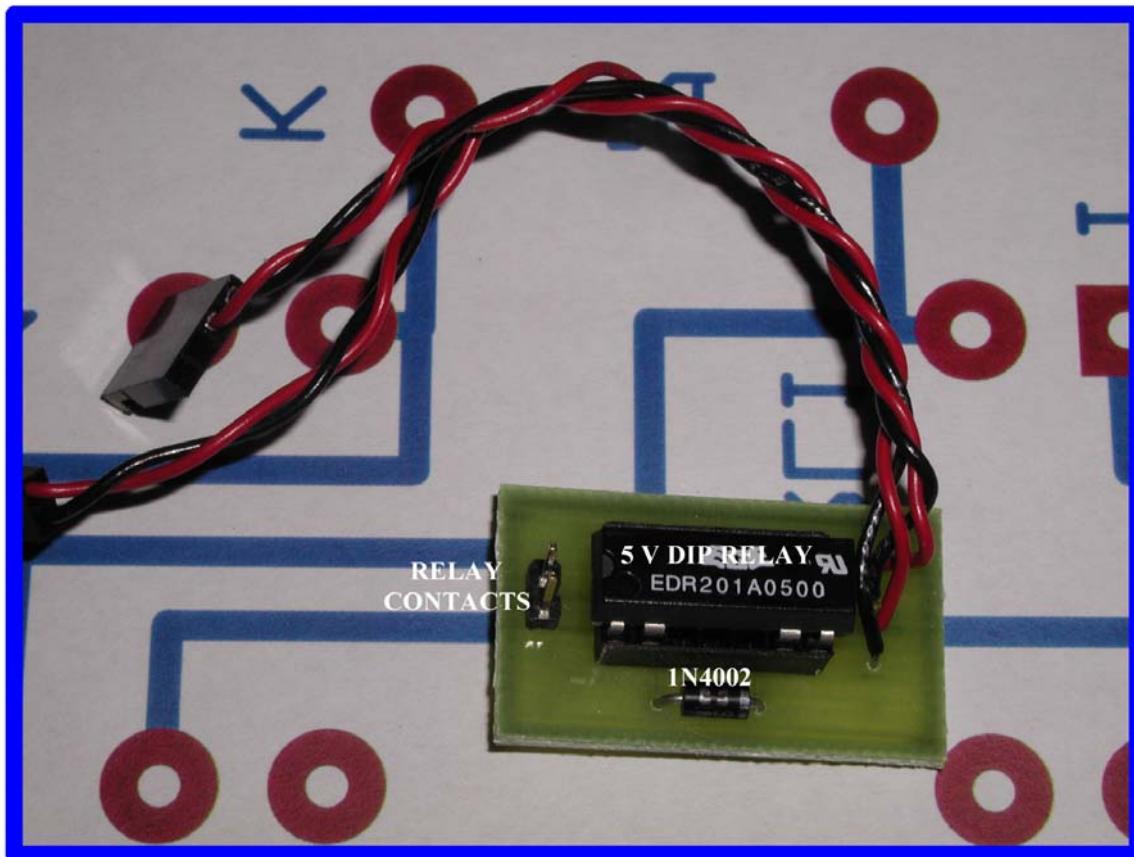
There are digital pressures sensors using the SPI interface that look good. We have not yet used any of these but hope to do so in the future. In order to get good data with any of the pressure sensors at high altitude it is necessary to calibrate them at low pressure.



15 PSIA PRESSURE TRANSDUCER. OUTPUT 0 to 4 VOLTS.

CAMERA INTERFACE

We have included digital cameras in many of our packages. The problem of triggering the camera periodically was solved by attaching wires across the camera's trip switch, bringing the wires out to a two-pin SIP connector, and using a relay to trip the shutter. A small 5V DIP relay is connected to the output of IO2, which rests at a high level and drops to ground. IO2 output is programmed to pulse at the interval desired and the width is set to a value that will trip the camera. The IO2 input will sink 20ma, which is more than that needed for the DIP relay. Five volt power for the relay is provided on one of the 4 JPx headers.

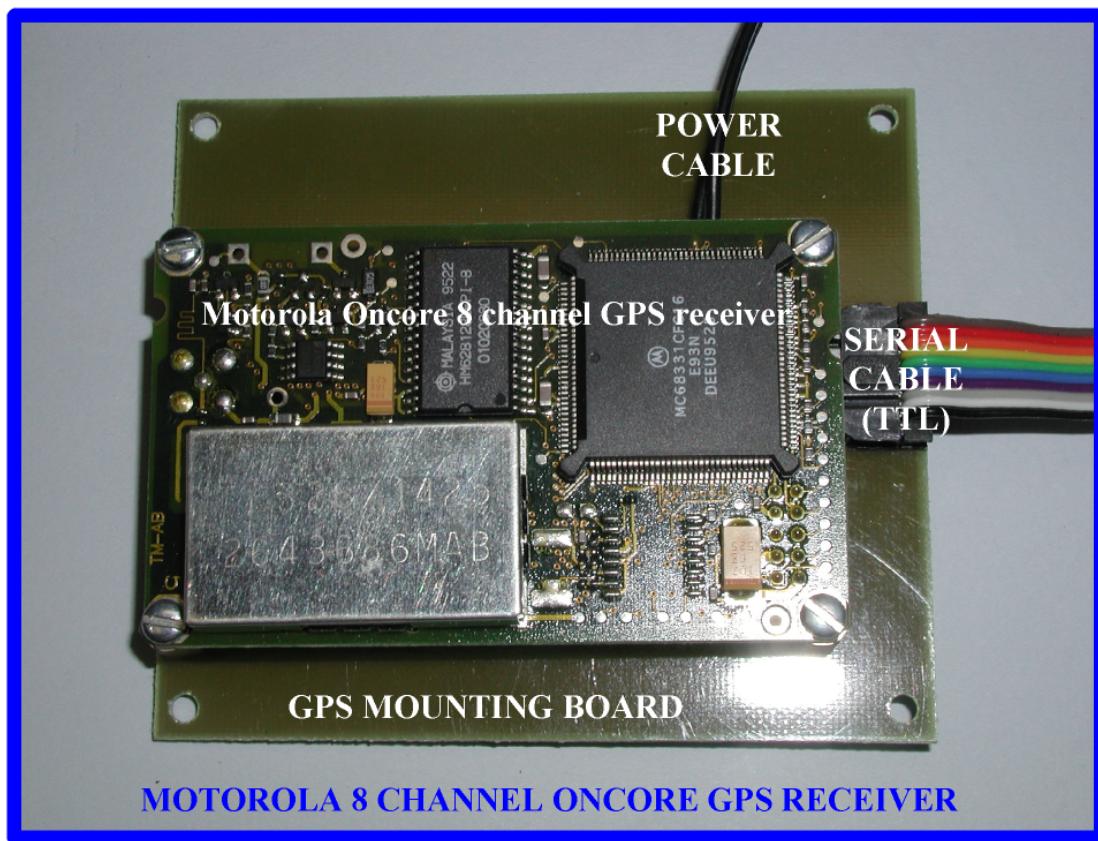


**RELAY BOARD USED TO TRIGGER THE DIGITAL CAMERAS.
THIS IS DRIVEN BY THE NEGATIVE PULSE OUTPUT.**

GPS MEASUREMENTS

The position and altitude of the balloon package may be recorded and broadcast via radio when a GPS receiver is connected to the serial port. The balloon board software is configured to use the Motorola Oncore series GPS receivers using the NMEA \$GPGGA sentence. This sentence is used because it has both longitude/latitude and altitude data. The period between GPS radio transmissions may be set with the radio transmit period and the GPS period in the configuration file. If the GPS is present and active GPS data will be recorded each data scan and stored in the memory card. The transmission period for APRS data is set to 1 minute for our balloon flights.

We have used both the Motorola Oncore M12 12 channel receiver and the Motorola Oncore GT Plus 8 channel receiver. Both of these receivers support a Motorola binary command format and the more standard NMEA format. Most of our flights use the 8-channel receiver because of its low cost (\$25-\$40 on Ebay and at flea markets) even though it has somewhat higher power consumption (5V @ 200ma). Both receivers will need to be set up initially using the Motorola Oncore setup program (available at www.oncore.motorola.com). If the receiver has no backup battery one may be attached on the supporting board. We use a Panasonic (ML1220/V1AE) 3 Volt rechargeable Lithium cell as recommended for the GT Plus receiver.



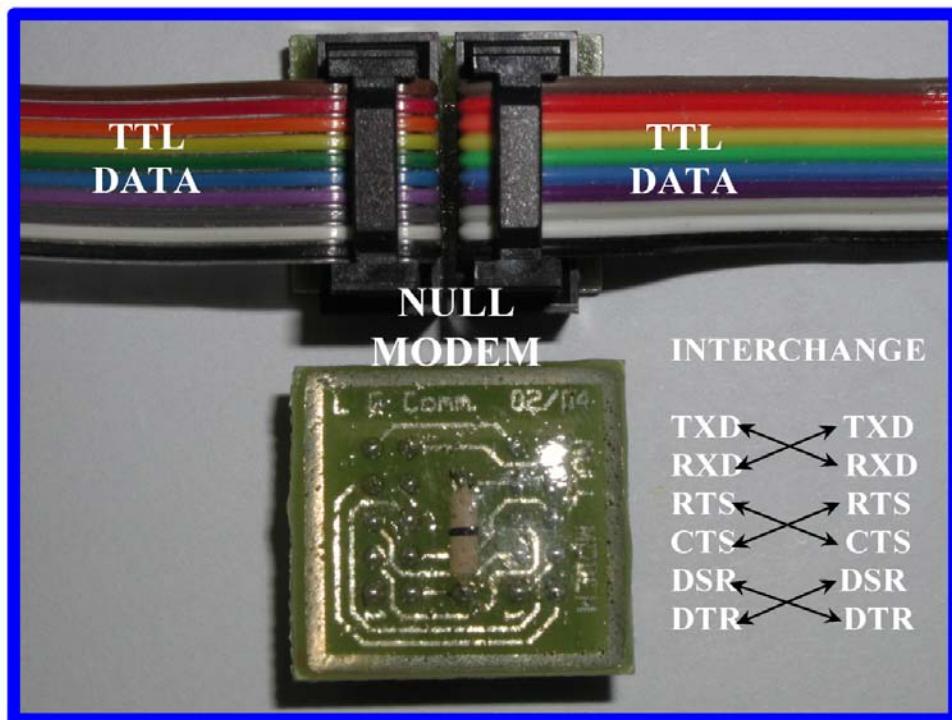
When using the Motorola Oncore program to setup the GPS receiver you will need to Place a jumper on JU1 of the Level Converter board and power it from an external source. A null-modem will be needed between the output of the GPS receiver and the

input to the Level Converter board. Once the board is configured and in the 4800 baud NMEA mode the back up battery will hold the setting for several months.

The bottom of the GPS board is shown below. This board is designed to stack under the main Balloon Board.



The Null Modem placed in line with the data cable from the Oncore GPS receiver is shown below. This cable crosses the TTL signal lines: TXD/RXD, RTS/CTS, and DSR/DTR from the GPS receiver to the Level Converter.



E MORE INFORMATION

This project has been very satisfying and a great deal of fun for all involved in the balloon project at West Virginia University. We have been lucky with our launches over the more than three years we have been doing this project and recovered all the packages in good condition. A number of the local amateurs have been very helpful in the tracking and recovery effort.

The first year (2003) we really didn't know what we were doing but managed to track the APRS signal to the balloon but were totally unprepared for removing the packages from the tops of 80 feet trees. We came back one week later with a tree climber and recovered the packages! Even though the packages hung in the trees for a week in the rain all the data was intact and photos (the ones that took) were fine.

The second year (2004) we went prepared with a tree climber among the crew. Sure enough the packages were even higher in the trees but were recovered in fine shape with all their data.

The most disastrous launch was on Halloween day 2004. This was a launch sponsored by several graduate students and faculty. We had two APRS tracking packages on the balloon but neither worked! The first package (mine) was a simple radio, GPS receiver, and PIC based tracker (unit developed in house). I had made the software too polite and it could not find clear air to transmit once at altitude. The second was part of an instrumentation package using a Version 2 board. At launch we had to do a restart of the firmware and failed to plug the GPS serial cable into the Balloon Board. It would transmit telemetry but no GPS data. The good news: one of the crew had done a very good job with the landing prediction software. We were able to drive to the predicted landing location and hear my package after it landed. Needless to say I fixed the tracker firmware to do unrestricted transmission when in balloon service.

Our two launches in the spring of 2005 went off with hitches. One required a tree climber to recover the packages and the other landed in a meadow.

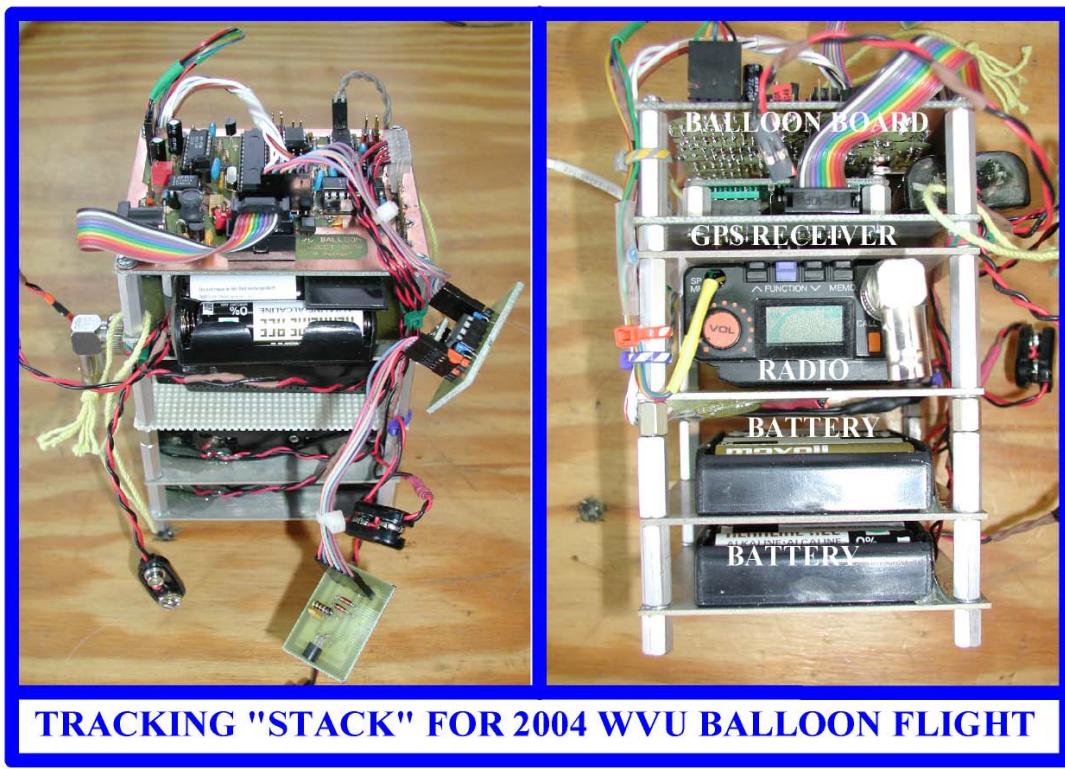
We are willing to share information on our hardware, software, and experiences with any one interested in academic Balloon Satellite launches. Please feel free to contact me at:

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Morgantown, WV 26505-2940

APPENDIX A WVU BALLOON TRACKING STACK

Tracking for the 2004 WVU balloon flight was tracked using the Version 2.2 balloon board. The stack used is shown in the photo below. This package had the Balloon board on the top of the stack with a Motorola Oncore GT Plus GPS receiver under it. An Alinco Model DJ-120 2 meter radio is mounted under the GPS receiver. On the bottom of the stack are two 6 AA cell battery packs, one for the radio and one for the GPS receiver. A third battery pack contains two AA cells that power the Main board. This stack was mounted inside a foam box with one-inch thick walls. The GPS antenna was glued to the top of the box and the 2-meter radio antenna was connected to the bottom of the box. There were temperature sensors both inside and outside the box. All battery voltages were monitored on analog channels.

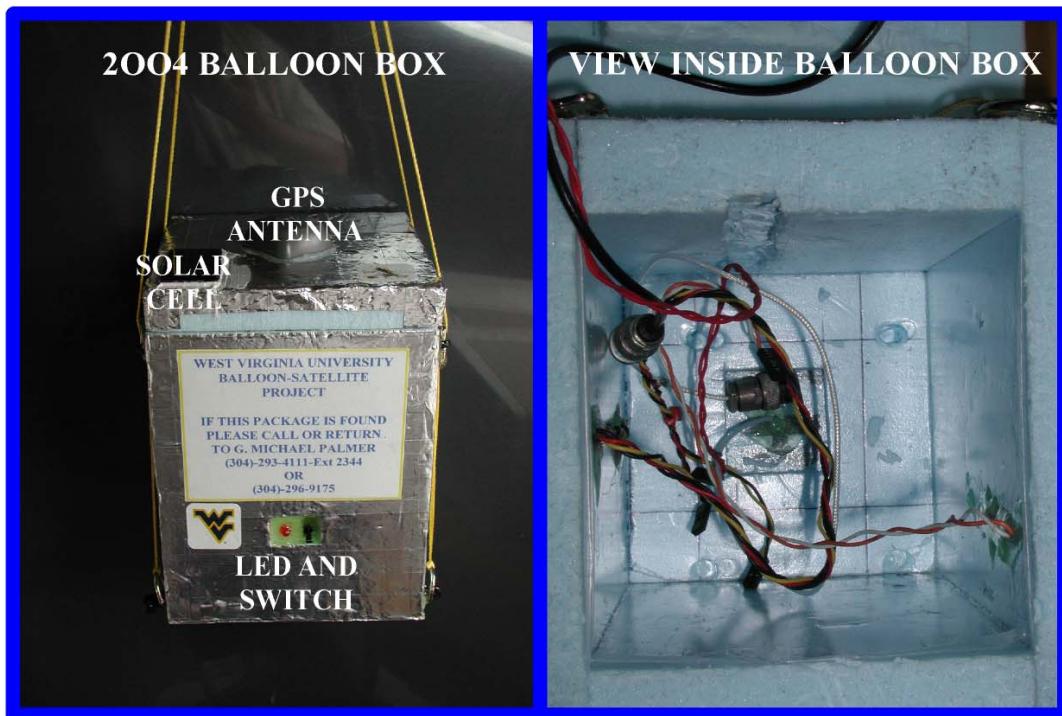


This package is heavier than needed for a simple four-hour flight (one hour before launch, two hours in the air, and one hour on the ground) because the operational duration here is designed for 10 hours. This longer period will keep the GPS receiver active even after landing allowing the recovery team to find the packages by its position. One of the features of the Oncore GPS receiver is it will continue to send its last good fix until turned off. This will insure a good fix when the signal is heard even if the GPS antenna can't see the satellites.

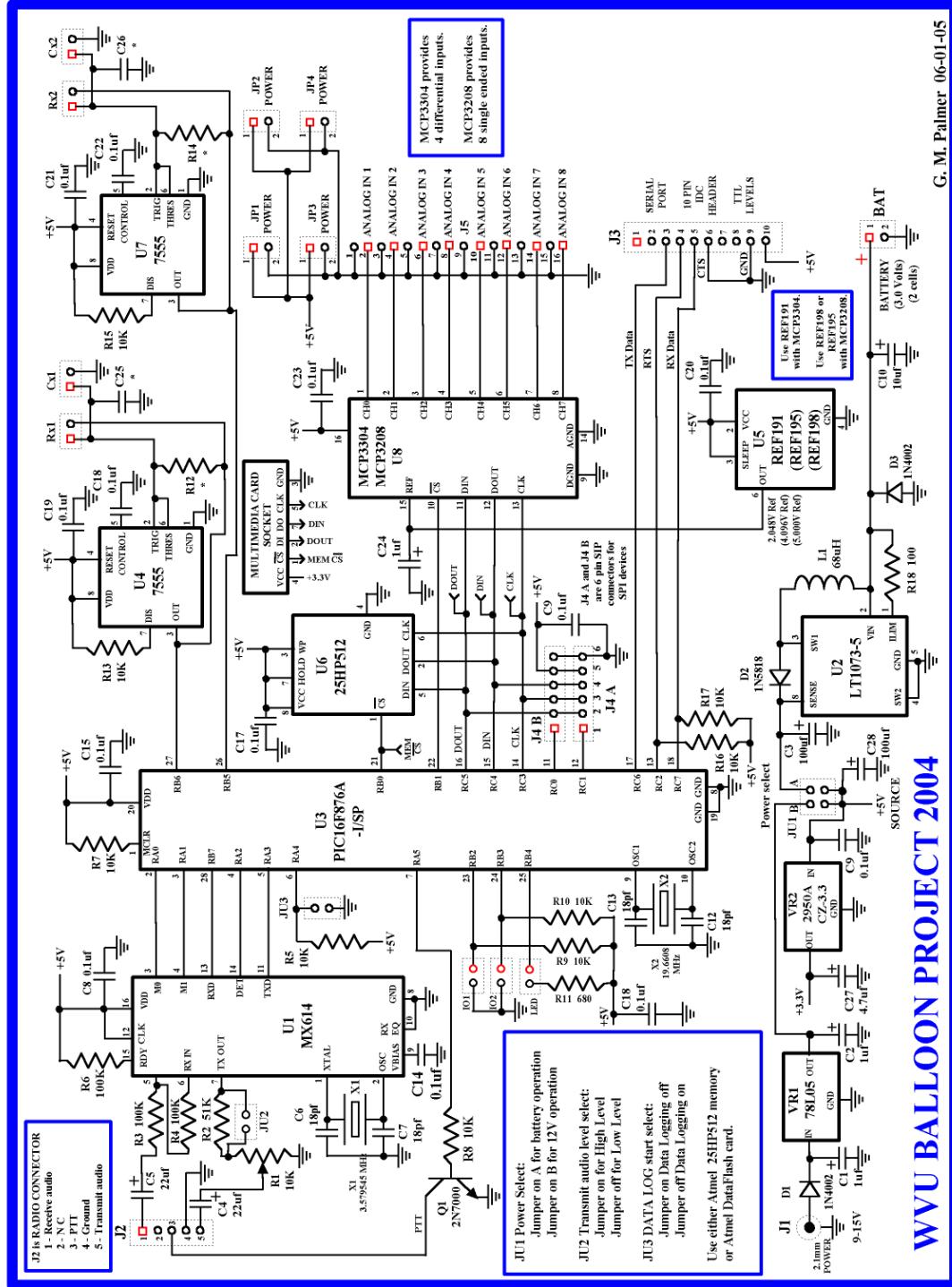
We fly out of a small air-strip near Jackson's Mill, West Virginia and the prevailing winds carry us on a path about 30° South of East. This puts our landings in or near the national forest in southern West Virginia or northern Virginia. It is typical for our



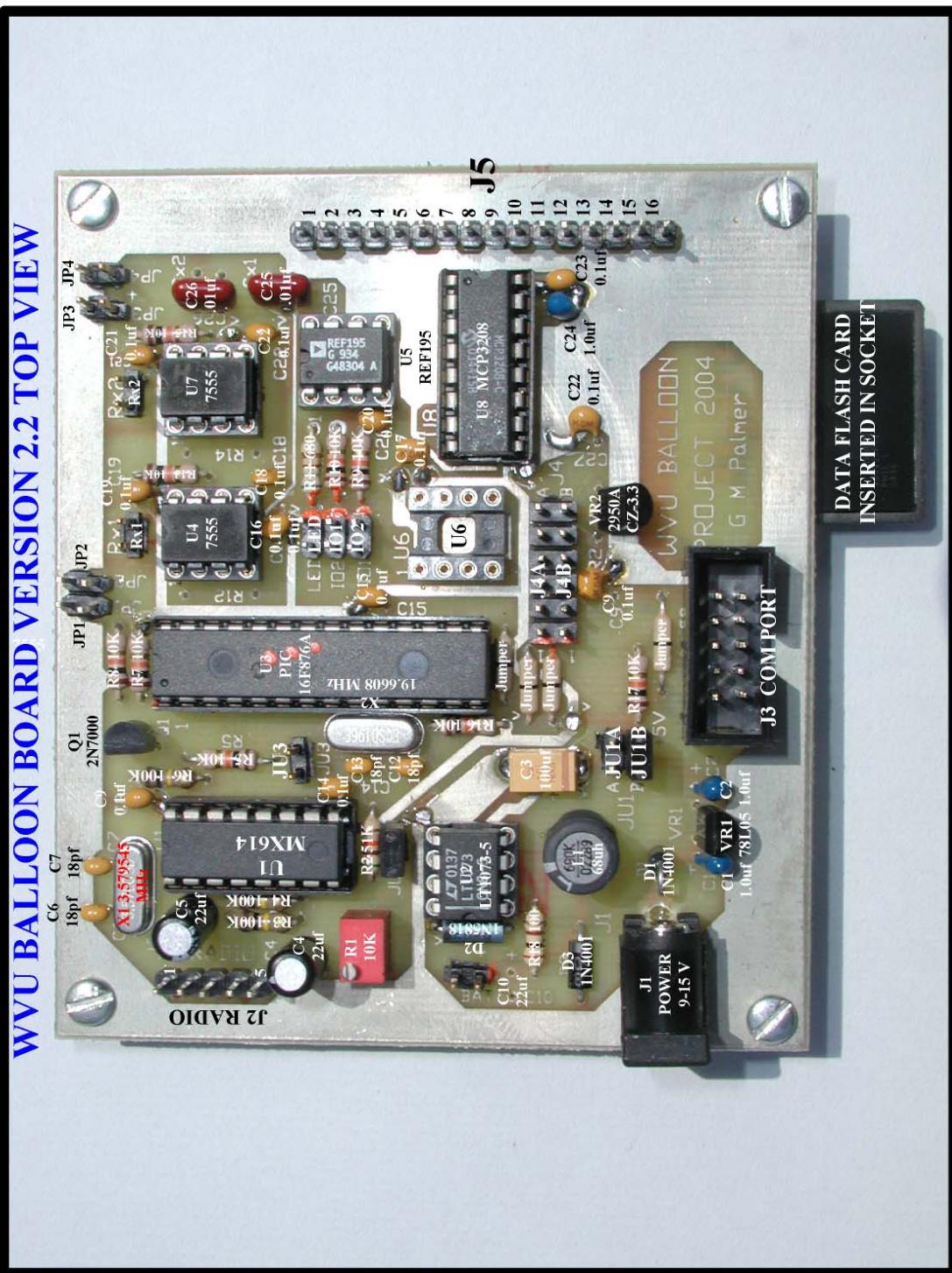
packages to land in the tops of 80 feet trees well away from roads and require an overland hike to reach.



APPENDIX B WVU BALLOON BOARD DIAGRAM

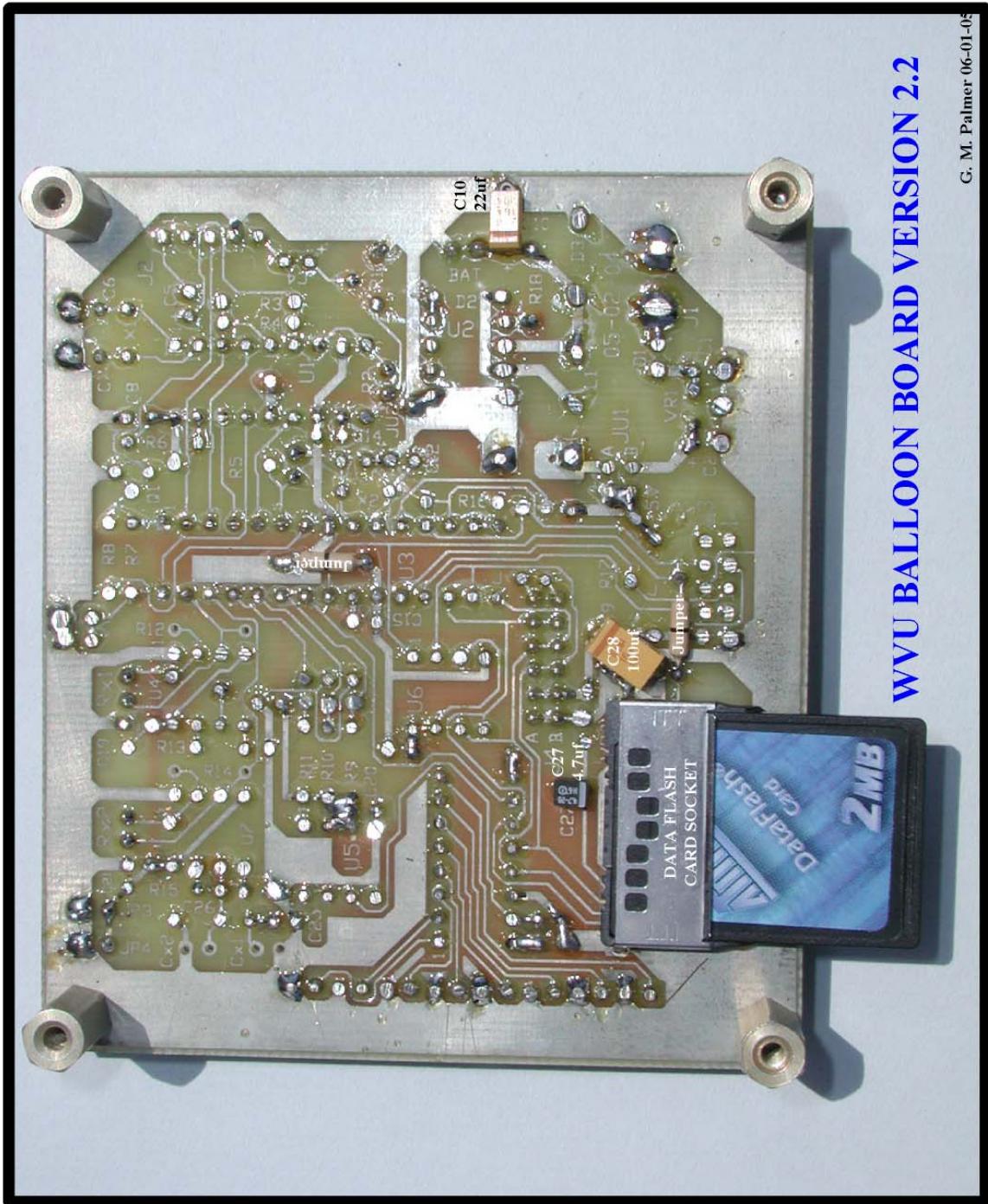


APPENDIX C WVU BALLOON BOARD LAYOUT



WVU BALLOON BOARD VERSION 2.2

G. M. Palmer 06-01-05



APPENDIX D WVU BALLOON BOARD BILL OF MATERIAL

ITEM	Description	Price
C1,C2,C24	1.0 μ f Tan.	1.00
C3	100 μ f Tan. Low ESR	5.00
C4,C5	22 μ f Elec.	0.15
C6,C7,C12,C13	18pf 5%	1.00
C8,C9,C14-C23	0.1 μ f Cer.	1.04
C10	22 μ f Tan.	0.50
C24,C26	User defined	0.00
C27	4.7 μ f Tan.	0.50
C28	100 μ f Tan.	0.50
Cx1,Cx2	2 Pin SIP header	0.40
D1,D3	1N4001	0.12
D2	1N5818	0.12
J1	2.1mm Power connector	0.59
J2	5 Pin SIP header (RADIO)	0.20
J3	10 Pin Header (COM PORT)	0.40
J4A,J4B	6 Pin SIP header (SPI device)	0.20
J5	16 Pin SIP header (ADC)	0.20
JP1-JP4,JU1A,JU1B	2 Pin SIP header (5V Power)	0.60
JU1A,JU1B	2 Pin SIP header (Power select)	0.20
JU2,JU3	2 Pin SIP header	0.20
LED,IO1,IO2	2 Pin SIP header	0.30
L1	68 μ H Inductor	2.60
Q1	2N7000	0.25
R1	10K Pot.	0.60
R2	51K	0.01
R3-R6	100K	0.04
R7-R10,R13,R15-R17	10K	0.08
R11	680	0.01
R12,R14	User defined	----
R18	1000	0.01
U1	MX614 (MODEM)	7.50
U2	LT1073CN8-5(5V switching regulator)	5.50
U2	PIC16F876A-I/SP	6.05
U4,U7	ICM7555IPA (CMOS Timer)	5.00
U5	REF198	2.50
U6	25HP512 (Not used)	----
U8	MCP3208-CI/P	3.95
VR1	78L05	0.25
VR2	LM2950ACZ-3.3	1.05
Memory Card	AT45DCB002	9.70
Card Socket	CCM05-5501	1.50
Socket (4)	4 Pin IC socket	0.40
Socket (2)	16 Pin IC socket	0.30
Socket (1)	28 Pin IC Socket (.3)	0.25
X1	3.579545 MHz crystal (18pf)	0.85
X2	19.6608 MHz crystal (18pf)	0.85
PC Board		7.00
Hardware	Spacers, screws, etc.	2.50

Total hardware cost exclusive any transducers or external wiring is about \$75.00 for a single board.

All Resistors are 0.25W 5%. Components are “I” (Industrial) temperature range even where not marked as so. Costs are listed on the conservative side (high). Buying in larger quantities will reduce cost.

Places to buy components:

Digi-Key Corp.
www.digikey.com

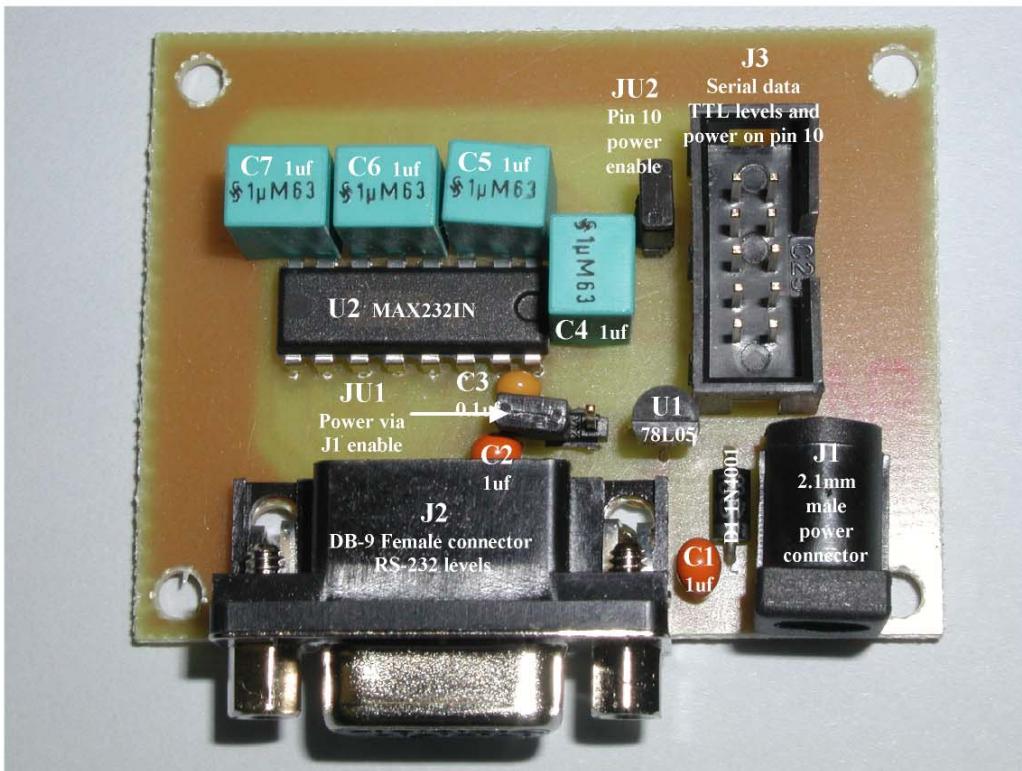
Randy Jones
www.glitchbuster.com

Jameco Electronics
www.jameco.com

MOUSER Electronics
www.mouser.com

APPENDIX E LEVEL CONVERTER

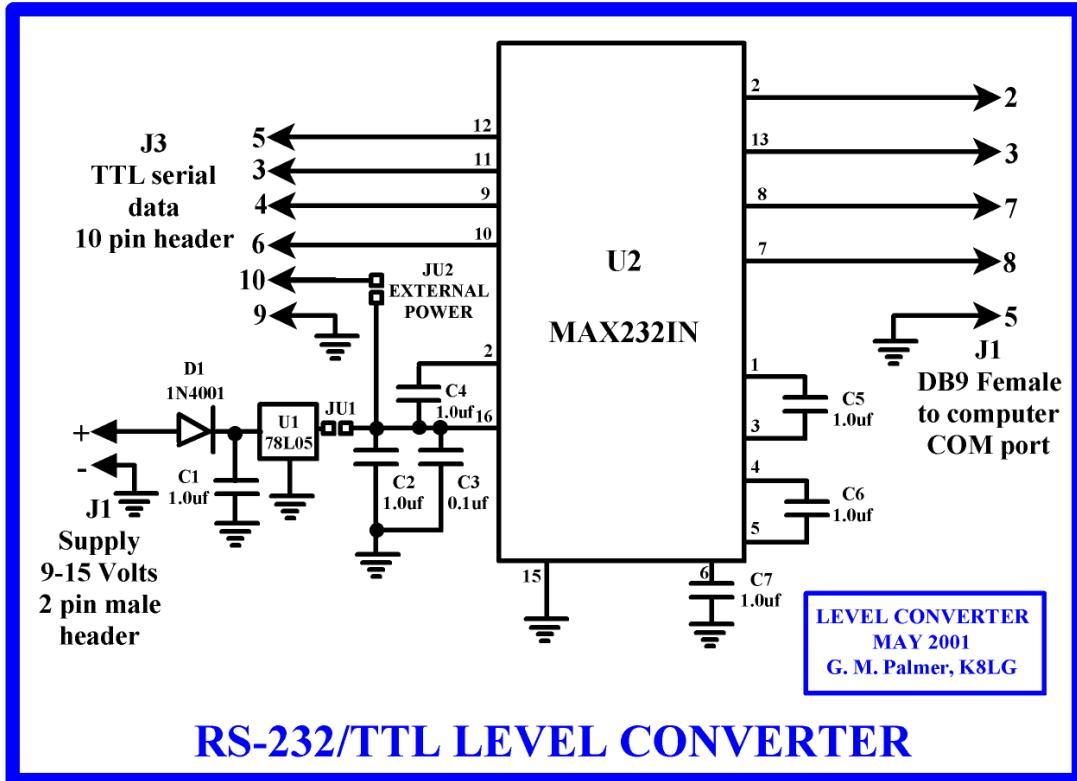
TTL/RS-232 LEVEL CONVERTER



PARTS LIST

C1,C2	1.0uf Tan.
C3	0.1uf Cer.
C4-C7	1.0uf Elec.
D1	1N4001
J1	2.1mm male power connector
J2	9 Pin DB Female connector
J3	10 Pin Header for IDC connector
JU1, JU2	2 Pin header with shorting block
U1	78L05 5 volt regulator
U2	MAX232IN RS232 to TTL converter

Wiring diagram for the level converter is given below. The 10-conductor ribbon cable may be connected to the female 10 pin IDC or to a nine pin DB-9 IDC connector. When doing so the 10th conductor is not used. When pin 1 of both connectors is connected to



the brown conductor the translation of the pins is:

10 Pin header	9 Pin DB-9
1 Brown	DCD 1 Data Carrier Detect
3 Red	RD 2 Receive Data
5 Orange	TD 3 Transmit Data
7 Yellow	DTR 4 Data Terminal Ready
9 Green	GND 5 Signal Ground
2 Blue	DSR 6 Data Set Ready
4 Violet	RTS 7 Request To Send
6 Gray	CTS 8 Clear To Send
8 White	RI 9 Ring Indicator
10 Black	NC

Pin 10 on the Level Converter is used for power.

APPENDIX F FUTURE DEVELOPMENT

Ever on our mind is the reduction of weight and better power management tempered with cost constraints. The GPS tracking unit must be designed for a 10-hour duration to insure the chase team can find and recover the packages under the most severe conditions. To this end we are looking at several ideas:

REDUCTION OF GPS POWER AND WEIGHT

The Motorola GT Plus requires about 1Watt of power (5v @ 200ma with antenna) and the battery (6 Alkaline AA cells) weighs about 180g. Replacing the present linear voltage regulator with a high efficiency switching regulator could reduce weight.

As the price of the Motorola M12 GPS receiver drops on Ebay and other sources we may change to this receiver. The M12 requires about 0.3 Watts (3V @ 100ma) but comes with other problems including the need to have a 3V power supply and hardware to level shift between 5-Volt and 3-Volt logic. The power and weight savings may justify the use of the M12.

We have been also looking at the very new Motorola FS Oncore GPS receiver that needs only 70 mW (at three different voltages). The real advantage of this receiver is its size and its support of a SPI interface. This FS GPS receiver board uses SMT and could be made part of our main board and connect directly to the SPI buss. At this time we have not been able to get full information on its use although we have access to a FS board and its development system.

In all our flights we have been using active GPS antennas bought on the internet and other places. These come with cables much too long for use in our packages and are shortened and fit with BNC connectors. With the much shorter feed line (6 to 8 inches) we are looking at replacing the active antenna with passive units to save power and weight.

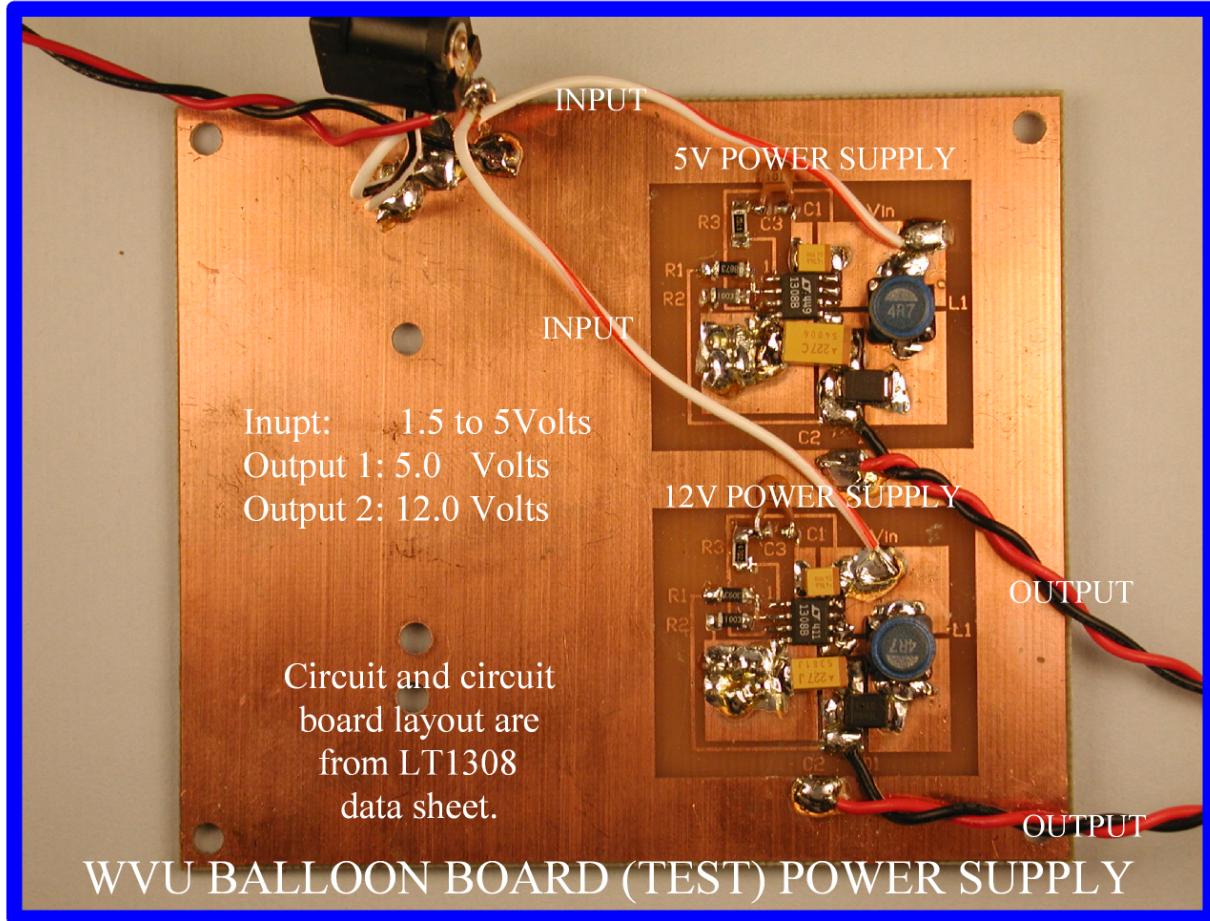
POWER SUPPLY EFFICIENCY

At the present time only the main board takes advantage of high efficiency switching power supply technology. The GPS and radio batteries currently fly using linear regulators (GPS) or connect directly (Radio) to the device. In the case of the GPS receiver we use six Alkaline AA cells in series connected to a 5 Volt (LM2931-AT5.0) low dropout regulator. This allows the batteries to run from 9 volts to the regulator drop out voltage (about 5.5 Volts or 0.9 Volts/cell) with duration of 12 to 13 hours (assuming 2700 ma-hr batteries). This is a good match but operates at an overall efficiency of about 65%. A well-designed switching power supply would operate in the 85% region.

Our Alinco radios are powered from a 6 cell alkaline AA battery. This is a poor match for this radio that is designed to operate on voltages from 7.2 to 12 Volts. We cannot extract the full energy from the batteries by taking them down to about 0.9 Volts/cell. In addition the current (weighted average of receive and transmit currents) drawn by the radio will vary with supply voltage from 85ma @ 9V to 75ma @ 9V which yields a

power extraction efficiency of below 50% and duration of about 15 hours. While the duration exceeds the design criteria we are only using half the battery energy – a big waste in weight.

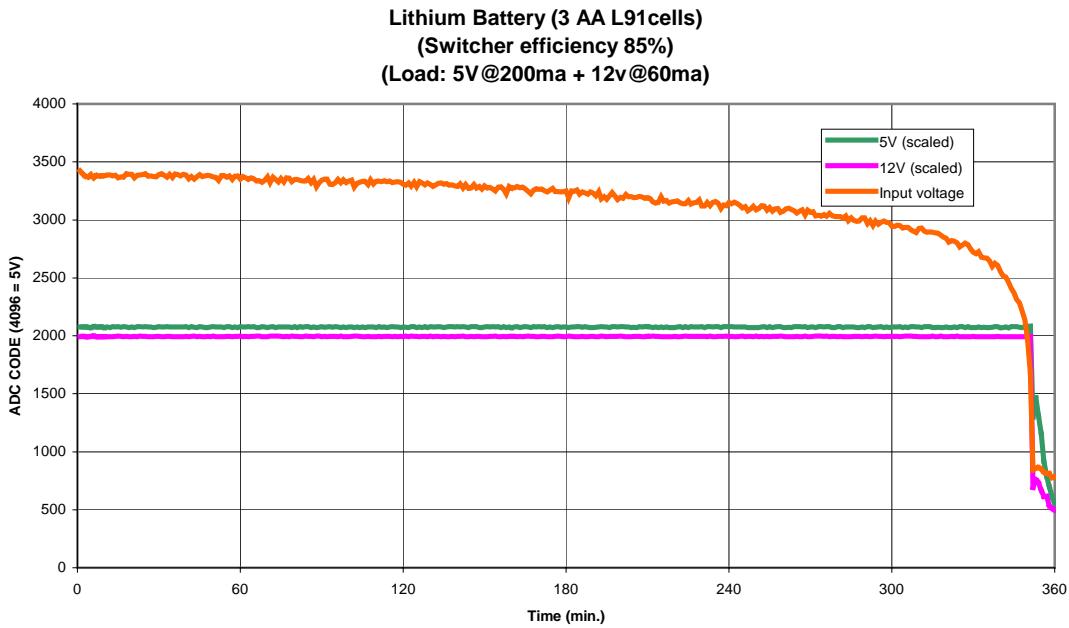
We have been bench testing step-up switching supplies based on the Linear Technology LT1308B chip. This chip is designed to operate from a single Li-Ion cell at near 90% efficiency. While I am always skeptical of manufacturers' specifications this one is true! In the photo below you will see a two power supplies (one 5V and one 12V) built around the LT1308B chips on a board designed to stack with our other boards.



I have done extensive testing of this dual power supply with an output load of 1720 mW (5V @ 200ma plus 12V @60ma) using Lithium-Ion cells and Energizer L91 Lithium cells. These tests were made powering both supplies from a single source. Three L91 cells in series provided a duration of 5.75 hours. We have also used Li-Ion cells scrapped from old laptop batteries. These work very well but are somewhat heavier than the L91 cells and require charging before use.

At this time the best configuration for our current main board/GPS/radio stack is two batteries each with three L91 cells each, one for each power supply. This should give the

10 hour required duration. Below is a typical test curve for the Energizer L91 battery tests.



Using the L91 cells and the switching power supplies a savings of 250g in battery weight plus another 50g in battery holder/hardware weight is possible. I hope to flight test this power supply in the fall of 2005.

Other available batteries (Ni-Cd, Ni-MH, and alkaline cells) cannot deliver the sustained high current the switchers require even though the capacity (ma-hr) is comparable to the Li-Ion/L91 Lithium cells.

FIRMWARE/HARDWARE CHANGES

The MX614 MODEM chip may be used for both transmission and reception of AX.25 packets but is only used for transmission in the application firmware described here. I have looked at the addition of command reception for in flight operations but as yet have not completed the firmware to this end. Since I already have PIC firmware for this purpose in my PIC-KISS TNC it would only be a matter of moving and integrating the reception code into the balloon board firmware. I would like to have the ability to “command” a sonic-alert or strobe light to help in locating the packages in the “tree tops”. I also looked at using this command path for “cut-down” but prefer a completely independent path for this function.

I would also like to “port” the current PIC code for the PIC16F876 to the PIC18F252 which has more code space, more data memory, expanded instruction set, “flat” memory, faster clock speed, and the same pin-out as the as the 16F876. This may get done in the summer of 2005.

