# CHAPTER FOUR

## Near Space Avionics, Part Three
## Electronics Supporting the Flight Computer

*"Let me get this straight: you can chase a balloon deep into uncharted territory in the middle of Missouri and recover it from thirty feet up in a tree, but you can't find a balloon that lands in your own backyard?"*
*- Jermone Tonneson (W0JRT),*
*in reference to an event in the NSBG Balloon Program.*

### Chapter Objectives

### 1.0    The Global Positioning System (GPS) Receiver

If you want your $500 near space capsule back, then you must launch a $100 to $150 GPS receiver with it. GPS receivers transmit a series of nationally defined text sentences. Each sentence contains standardized fields of data. You'll learn more about the GPS receiver in this chapter. Typically, the only sentences needed from the GPS receiver during a near space mission are the $GPGGA and $GPRMC sentences. A combination of these two sentences indicates much of the mission status, such as time of day (TOD), altitude, capsule speed, and capsule heading. Most GPS receivers send multiple GPS sentences every second or two. The MIM, Tiny Trak II, and BS2p in the CC/PS are programmed to ignore this stream of data until it is needed.

Before you purchase a GPS receiver and throw it into near space, you must be aware of some limitations.

### 1.1.    Near Space Limitations in GPS Receivers

There are three factors that I'm aware of that are capable of limiting a GPS receiver's use in near space. They include federal government Department of Defense (DoD) limits on GPS receivers,

software limitations in GPS receivers, and signal level limitations. Fortunately, several GPS receivers which do not have these limitations are available on the market.

### 1.1.1. DoD Limitations in GPS Receivers

To prevent GPS receivers from being used to guide terrorist missiles, the Department of Defense and the State Department require that GPS receivers stop transmitting their location in cases where the GPS antenna is at altitudes above 60,000 feet and moving at speeds greater than 999 knots. Notice that this is an AND function: the altitude greater than 60,000 feet AND the speed greater than 999 knots. There are some GPS manufacturers who have chosen to interpret this limitation as an OR function instead. These GPS receivers stop transmitting positional data once they are above 60,000 feet, regardless of the speed. This is a major problem for near space capsules as this altitude is below near space. It is not certain that these receivers will begin transmitting their position once they drop below 60,000 feet. So, it is possible that a receiver that stops giving position data below near space will refuse to give data during recovery, one of the most critical times.

### 1.1.2. Software Limitations in GPS Receivers

Another factor involves how the GPS is programmed. At least one GPS receiver is programmed with an altitude field that is defined too small. This limits the highest altitude the GPS can calculate and store in memory. This type of GPS will probably still function once the near space capsule descends low enough. While these GPS receivers meet the law as required, they are too severely limited by their programming to be used in a near space capsule.

### 1.1.3. Signal Level Limitations in GPS Receivers

Some serial devices expect to use true RS232 level signals, as opposed to inverted TTL (transistor-transistor logic) level signals. When TTL shows up in place of RS232, no communications are received, even though serial data is being sent. So what's the difference between TTL and RS232 voltage levels?

Both RS232 and TTL voltage levels are used to send serial data. Serial data just means the data bits are being sent over one wire and received on a second wire, one bit at a time, usually, but not always, in ASCII. A particular voltage represents each bit. When the higher voltage level represents a "1" and the lower voltage level represents a "0", then it is called true logic. Logic levels can be switched, where the higher voltage level represents a binary "0" and the lower voltage level represents a binary "1". This is referred to as inverted logic as opposed to true logic. TTL level signals use five-volts to represent logic 1 and zero-volts to represent logic 0. RS232 is an example of inverted logic. In RS232, a voltage of –12 volts represents logic 1 and +12 volts represents logic 0.

Most of the time in the real world, however, voltage levels never reach their intended highest or lowest levels. Often the voltage swings are lower than the ideal, and may give a weak, or mushy, signal. So in the real world, a binary "1" is represented by a voltage above a defined voltage level and a binary "0" is represented by a voltage below a defined voltage level. In the BASIC Stamp, the dividing point is 1.4 volts. Any voltage above 1.4 volts represents logic 1 and any voltage below 1.4 volts represents logic 0. The resistance, inductance, and capacitance of a cable increases as the length of the cable increases. As a result, the voltage swing of the serial signal becomes weaker.

To overcome voltage limitations of TTL, RS232 was designed with larger voltage swings. Since the serial signal for RS232 begins with a larger voltage swing (-12 volts to +12 volts), there is more room

for the voltage swing to weaken. In practice the voltage swings of RS232 seem to be more like -10 to +10 volts. RS232 generally accepts anything below -2 volts as a binary "1" and anything above +2 volts as a binary "0".

Some devices are true RS232 devices. As such, they demand to see a negative going signal to correctly interpret serial communications. If you ever get a communications device and know it is sending it inverted TTL signals but the receiver still does not respond, then the problem is most likely the magnitude of the voltage swing. Use the MAXIM MAX233 IC to convert TTL signals into RS232 signals. The MAX233 inverts the sense of the logic and also increases the voltage swing by using a charge pump. Because of its charge pump, the MAX223 does not require a negative power supply, which simplifies its use. I can't tell you many cracks my head made in my apartment walls trying to figure this out (but it sure felt good to stop banging my head against the wall).

## 1.2. GPS Recommendations

Taking these limitations into account, there are several GPS receivers I can recommend and some I cannot recommend. I'll explain my reasoning as to my recommendations since GPS specifications change and new receivers are being introduced all the time. Keep these points in mind when looking at a GPS receiver for use in near space.

### 1.2.1. Not Recommended

The GPS engines that I know do not work are the Garmin GPS20 and the DeLorme Tripmate. The Garmin GPS20 does not implement the DoD limitation properly. The Tripmate apparently has an altitude field that is defined too small. At an altitude of 32,000 meters, it has been seen to stop outputting altitude data.

### 1.2.2. Recommended

The GPS engines or receivers that I know work are the Garmin GPS25, Garmin Etrex, and the Motorola OnCore VP. I have flown all three on near space capsules in the past. The only problem encountered with the Etrex is that once it shuts off, it will not restart unless you press its power button, a very difficult task at 100,000 feet. One reason the Etrex will shut down is if its battery voltage drops too low. This happens when alkaline cells are used in the Etrex and the internal temperature of the near spacecraft drops too low. However, the Etrex is a very inexpensive GPS receiver and operates for 22 hours on three AA cells. If you decide to use an Etrex, keep the temperature inside the airframe around the GPS receiver warmer than 40 degrees Fahrenheit or use photo lithium cells.

## 1.3. Specific GPS Receivers

Below are notes on using the Garmin GPS35, the Etrex, and the Motorola OnCore VP.

### 1.3.1. Garmin GPS35

The GPS I recommend most is one of the Garmin GPS35-LV models, either LVS or LVC. Don't use the GPS35-HVS because of its higher voltage requirement. Also, there's no sense in using the GPS35PC as it has a ten foot cable terminated in a DB-9 connector. Near space applications require

shorter cable lengths and need to install their own DB-9.  The difference between the LVS and LVC models are:

| Model | Voltage | Output Signal |
| --- | --- | --- |
| LVS | 3.6 – 6.0 V | True RS232 |
| LVC | 3.6 – 6.0 V | CMOS |

The CMOS output of GPS35-LVC depends on the power voltage.  If supplied with 5.0V, the output signal is 0 – 5 V, inverted logic.

The RS232 voltage levels of the LVS can be sent to the BS2p, if a 22k resistor is wired in series with the line.  The next section explains how to wire up the cables for the GPS35.

In cases where the GPS continuously sends GPS sentences, like the Etrex or GPS35, put a timeout statement in the SERIN command.  This will make sure the BS2p doesn't hang should the GPS crash or the serial communication fail.

```
tnc_tx      con  3
gps_rx      con  7
i4800       con  16884        '4800 baud n81 inverted
GPSStat     var  Status.bit1  '0=good gps       1 = bad gps
alt_curr    var  word         'current gps alt (m)

serin gps_rx,I4800,10000,BadGPS,[wait ("$GPGGA"),skip 42, dec alt_curr]

BadGPS:
GPSStat = 1
serout tnc_tx,I4800,y"/No GPS"]
```

Note: this program assumes the TNC is connected to I/O pin three and the GPS receiver is connected to I/O pin seven.  Change the constant statments as needed.
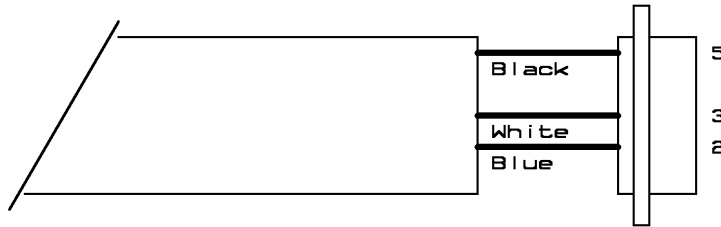
GPS35 Cable
The Garmin GPS35 LVS and LVC cables do not terminate in a DB-9 connector, so one has to be made.  I recommend you make your cable in the following way:

Materials
- Female DB-9 connector kit with solder cups
- DB-9 plastic housing kit
- 22k resistor with leads cut to ¼" long (needed for the LVS model, but not the LVC model)
- Two lengths (about six inches) of 22 AWG stranded wire, one red and the other black
- One pair of Powerpole® connectors
- Assorted lengths of heat shrink tubing with large enough diameter to cover the solder cups of the DB-9
- Hot glue
- Label with "GPS" printed on it
- Clear heat shrink tubing large enough to slide over the pair of Powerpole®s

Diagram

**GPS35 Cable** – Adding a DB-9 connector to the GPS35 cable.

Procedure

Strip back two inches of the outer jacket.  You'll see about ten wires inside the cable.  The wires you need for now are the following:

Blue      RXD1
White    TXD1
Black    GND
Red      Vin

Note that there are other useful lines in the GPS35 cable, like the pulse per second line and the power down line.  I do not discuss these lines in this book, but plan to cover them in my advanced projects book.

√    Strip ¼" of insulation from one end of the 22 AWG wires.
√    Strip back ¼" of insulation from the blue and black wires of the GPS35 cable.
√    Slide a short length of heat shrink tubing on the blue and black wires.
√    Solder the blue wire to pin #2 solder cup of the DB-9 connector.
√    Solder both the black GPS35 wire and the 22 AWG wire to pin #5 solder cup of the DB-9 connector.

If using an LVC model:
√    Slide a short length of heat shrink tubing over the end of the white wire.
√    Solder the white wire to pin #3 solder cup of the DB-9 connector.

If using the HVS or LVS models:
√    Slide a length of heat shrink tubing over the white wire.
        Note: The heat shrink tubing must have a diameter large enough to cover the resistor.
√    Solder the 22k resistor to pin #3 solder cup of the DB-9 connector.
√    Solder the white wire to the other end of the resistor.

√    Slide a short length of heat shrink tubing over the end of the red wire.
√    Solder the 22 AWG wire to the red GPS35 wire.

The red and black 22 AWG wires exit the DB-9 hood through the back end, where the data cable enters.

√    Slide the heat shrink tubing over all soldered connections and shrink them.
√    Squirt some hot glue over the solder cups of the DB-9.
√    Put a layer of hot glue in the bottom half of the DB-9 hood.
√    Place the DB-9 into the bottom half of the DB-9 hood, being careful not to ooze hot glue all over the place.
√    Squirt some more hot glue over the top of the wires in the hood to fill in gaps.

√    Put a layer of hot glue in the top half of the DB-9 hood.
√    Close the top over the bottom half, being careful to wipe up any excess hot glue.
√    Bolt the halves together.

√    Strip one inch of insulation from the exposed ends of the red and black 22 AWG wire.
√    Fold then in half to ½" in length.
√    Insert the bare wires into the crimps of the Powerpole® connectors and crimp.
√    Solder the interior of the crimps.
√    Insert the crimps into their red or black housings, being sure not to mix the housings and
√    wires.
√    Backfill the Powerpole® jackets with hot glue.
√    Slide the Powerpole® jackets together.
√    Wrap the Powerpole® jackets with the GPS label.
√    Cover the jackets and label with clear heat shrink tubing and heat it.
√    Fill in any gap in the back of the jacket with hot glue.
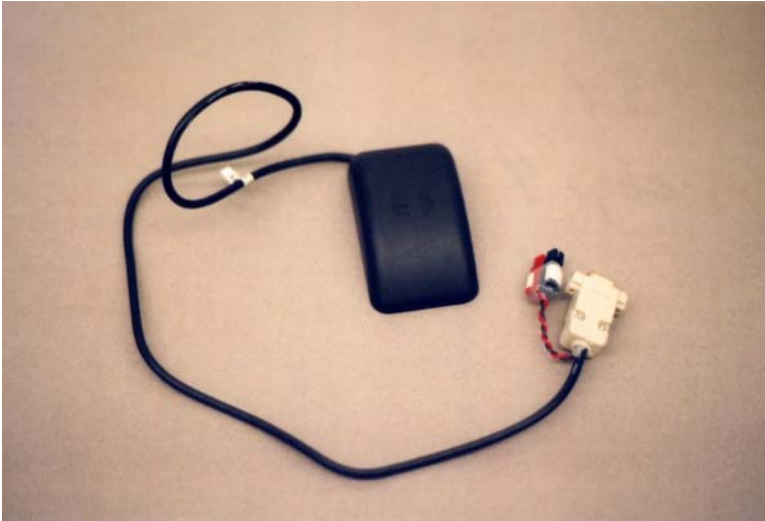


*The modified Garmin GPS35* - Note the receiver terminates in a DB-9 and PowerPole connector.

The GPS35 and The $PGRMV Sentence
$PGRMV is a Garmin proprietary sentence that reports the three-dimensional velocity of the GPS receiver.  The $PGRMV sentence has the following format:

$PGRMV,East,North,Vertical*Check CR LF

Where:
East is the true east velocity of the receiver in meters per second.
North is the true north velocity of the receiver in meters per second.
Vertical is the vertical velocity of the receiver in meters per second.
Check is the check sum of the sentence.
CR LF is the carriage return and line feed at the end of the sentence.

Both the east and north velocities range from –514.4 m/s to 514.4 m/s
The vertical velocity ranges from –999.9 m/s to 9999.9 m/s.

By default, the $PGRMV sentence is not actively reported by the GPS35.  To activate the $PGRMV sentence, send the following sentence to the GPS35:

$PGRMO,PGRMV,1,CR LF

Use the following BS2p program to send this command:

```
'***************************
'*   Enable $PGRMV Code    *
'***************************
gps_tx        con  5
gps_rx        con  7
n4800I        con  16884
gpsloop       var  byte
gpschar       var  byte

PGRMV:
debug "Enable RMV", cr
serout gps_tx,N4800I,["$PGRMO,PGRMV,1",cr,10]
pause 5000
debug "Get RMV", cr
serin gps_rx,N4800I,10000,NoRMV,[wait ("RMV"),spstr 20]
for gpsloop = 0 to 20
get gpsloop, gpschar
debug asc? gpschar
pause 500
next
goto Done

NoRMV:
debug "No PGRMV", cr

Done:
end
```

## 1.3.2. Garmin Etrex



**Garmin Etrex** – *This handheld GPS receiver makes an inexpensive GPS receiver that is near space capable. However, be sure to use photo lithium batteries to avoid power failure.*

Before using the Etrex, you must configure it to send NMEA data through its port. Follow these steps to enable NMEA output:
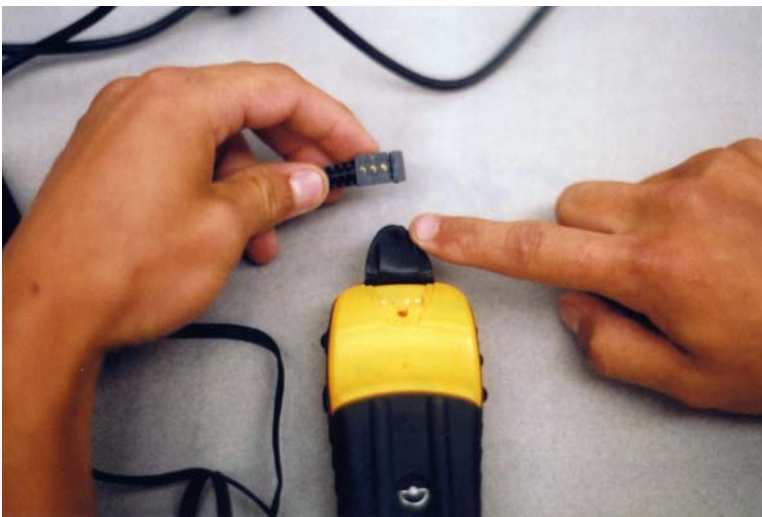
   √   Start the Etrex.
   √   Press the PAGE button twice to enter the menu.

√ Using the DOWN arrow, scroll down to SETUP and press the ENTER button.
√ Scroll down to INTERFACE and press ENTER.
√ Press ENTER again to display the options.
√ Scroll to NMEA and press ENTER.
√ PAGE out of the SETUP menu.

Reminder: be sure to use photo lithium batteries in the Etrex to prevent the cold temperatures of near space from shutting down the receiver.

Etrex Cable
Definitely go with the Pfranc cable. They're less expensive and plenty good. There's no sense in building an Etrex cable. Although the cable can provide a source of external power to the Etrex, the receiver cannot be switched on without physically pressing its power switch, so do not make this cable.



***Etrex Data Cable*** – *The data cable connects to the plug beneath the rubber boot. The connector slides on for a durable contact.*

Use the same code to read data from the Etrex as you do any other GPS receiver.

### 1.3.3. Motorola OnCore



***Motorola OnCore GPS*** – *There is no display or antenna.*

The Motorola OnCore VP is just a GPS board; there is no display or antenna. The antenna is purchased separately. A separate antenna has the benefit of letting a near space engineer mount the antenna outside the capsule while leaving the GPS engine inside. The OnCore VP does not have a built-in voltage regulator and therefore requires five volts (within 0.25 volts and with less than a 50 mVpp ripple). The OnCore antenna connects to the board through a SMA looking connector. There is a 2 X 5 pin header for power and data connections to the receiver. The OnCore VP draws 220 mA of current.

Some GPS receivers, like the OnCore, are easily commanded during a mission to send specific sentences. The sample code below instructs the OnCore to send the GPGGA sentence just once:

```
Ext_Comm      con 188                      'baud for TNC/GPS
GPS_In        con 3                        'data from GPS
GPS_Out       con 4                        'data to GPS

GPS_Lock      var Status.bit1              '0=no reply, 1=reply
alt_curr      var word                     'current GPS alt

serout GPS_Out,Ext_Comm,["$PMOTG,GGA,0",CR,10]
serin GPS_In,Ext_Comm,15000,badalt,[wait ("$GPGGA"), skip 45, dec alt_curr]

BadAlt:                                     'GPS did not respond in 10 sec
serout TNC_Out,Ext_Comm,[">NOGPS", cr]
pause 3000                                  'tell the world
GPS_Lock = 0                                'no GPS signal
```

Notes About the Program
The command $PMOTG is an instruction to the OnCore VP to send the following sentence at the rate indicated. The format for the command is as follows,

$PMOTG, sentence, rate
where;
sentence = a valid NMEA sentence
rate = frequency the sentence is sent in seconds (0 means send it just once)

So the command, $PMOTG,GGA,0 orders the OnCore to send the GPGGA sentence just once.

The valid sentences for the $PMOTG command are:
GGA
RMC
GLL
GSA
GSV
VTG
ZDA

The $PMOTG command must end with a CR and LF, hence the CR,10 in the SEROUT command.

OnCore Cable
Jumper J1 is the power and data interface to the OnCore VP. The pins have the following respective functions:*

| Pin | Signal Name | Description |
|-----|-------------|-------------|
| 1 | Battery | External Applied Backup |
| 2 | 5V PWR | +5Vdc Regulated |
| 3 | GROUND | Ground (Receiver) |
| 4 | VPP | Flash EPROM Programming |
| 5 | (Not Used) | |
| 6 | ONEPPS | 1 Pulse Per Second Output |
| 7 | ONEPPS-RTN | 1 Pulse Per Second Return |
| 8 | TTL-TXD | Transmit 5V Logic |
| 9 | TTL-RXD | Receive 5V Logic |
| 10 | TTL-RTN | Transmit/Receive Return |

\* OnCore Users Guide, May 1996, Motorola

J1 is located on the bottom of the OnCore VP and has pinouts as follows:

| 1 | 2 |
|---|----|
| 3 | 4 |
| 5 | 6 |
| 7 | 8 |
| 9 | 10 |

where Pin 1 is the pin closest to the corner of the GPS board.
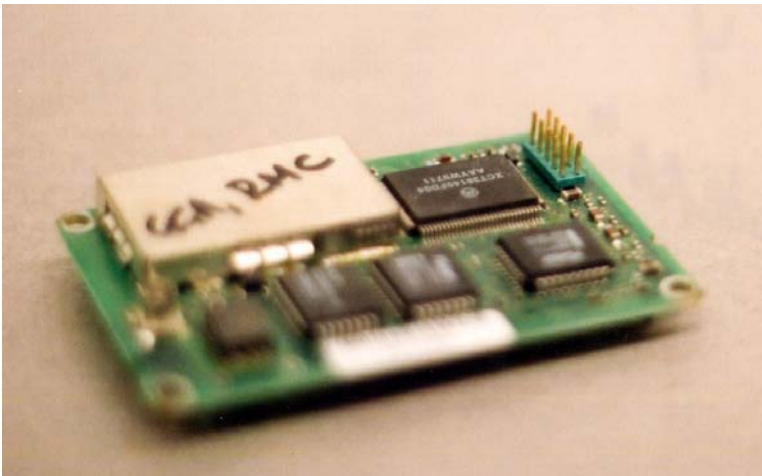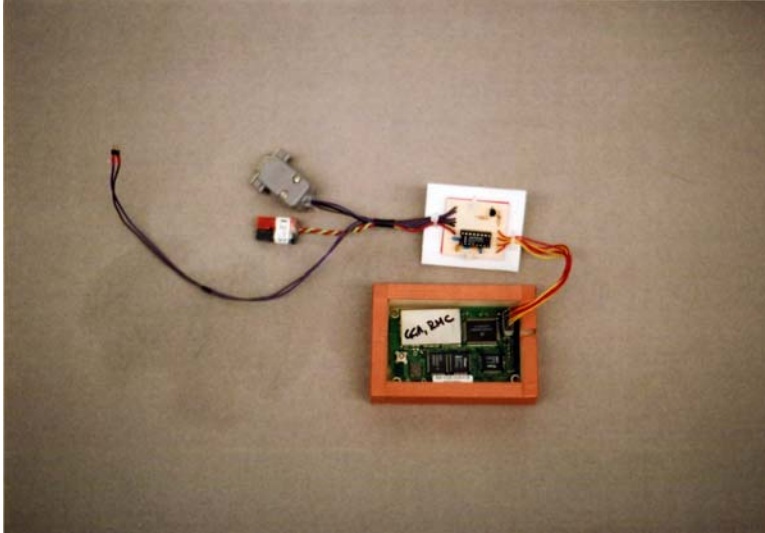


*J1* - Close-up photo of OnCore pins.

Of the pins, the ones required are:
2 and 3 for power
8 and 10 for receiving sentences
9 if the flight computer commands the OnCore VP

Making the OnCore VP Cable

***Completed OnCore*** *- The Motorola OnCore GPS board shown after completing and attaching the cables.*

Materials
- 2 by 5 plastic housing for 0.1" between center pins, 0.025" in diameter
and
- 10 female crimp pins
or just
- Thin heat shrink tubing to cover #24 AWG stranded wire

- Female DB-9 Connector (with solder cups)
- #24 AWG stranded wire, at least three colors (one red and one black)
- One pair of Powerpole® connectors
- Assorted lengths of heat shrink tubing with large enough diameter to cover the solder cups of the DB-9
- Assorted lengths of heat shrink tubing with large enough diameter to cover the wires making up the cable
- DB-9 plastic housing kit
- Hot glue
- Label with "GPS" printed on it
- Clear heat shrink tubing large enough to slide over the pair of Powerpole®s

Procedure
- √ Cut at least four wires to length (from GPS receiver to flight computer).
- √ Cut a fifth wire if the flight computer will command the OnCore VP.
- √ Strip ¼" of insulation from all ends of the wires, except for the red and black, where you strip 1" from one end of both wires.

Either:
- √ Crimp female pins on one end of each wire, and then insert the pins into the 2 X 5 housing in the positions indicated in the table below;

Or:
- √ Solder the wires directly to the OnCore pins, and then cover the soldered connection with heat shrink tubing.

| Wire | Socket Position |
|---|---|
| +5V (red) | 2 |
| Ground (black) | 3 |
| TXD | 8 |
| TXD/RXD Return | 10 |
| RXD (if used) | 9 |

- √ Strip ¼" of insulation from free ends of all the wires but the red and one black wire (these wires are for OnCore power).
- √ Separate the red and black wires from the rest.
- √ Slide several lengths of heat shrink tubing over the wires to form two wiring harnesses.
- √ Slide the heat shrink tubing over the RXD, TXD, and TXD/RXD wires.
- √ Solder the RXD wire to pin #2 solder cup of the DB-9 connector.
- √ Solder the TXD wire to pin #3 solder cup of the DB-9 connector.
- √ Solder the TXD/RXD Return (ground) wire to pin #5 solder cup of the DB-9 connector.
- √ Slide the heat shrink tubing over all soldered connections and shrink them.
- √ Squirt some hot glue over the solder cups of the DB-9.
- √ Put a layer of hot glue in the bottom half of the DB-9 hood.
- √ Place the DB-9 into the bottom half of the DB-9 hood, being careful not to ooze hot glue
- √ all over the place.
- √ Squirt some more hot glue over the top of the wires in the hood to fill in gaps.
- √ Put a layer of hot glue in the top half of the DB-9 hood.
- √ Close the top over the bottom half, being careful to wipe up any excess hot glue.
- √ Bolt the halves together.

- √ Strip one inch of insulation from the exposed ends of the red and black 22 AWG wire.
- √ Fold then in half to ½" in length.
- √ Insert the bare wires into the crimps of the Powerpole® connectors and crimp.
- √ Solder the interior of the crimps.
- √ Insert the crimps into their red or black housings, being sure not to mix the housings and
- √ wires.
- √ Backfill the pole power jackets with hot glue.
- √ Slide the Powerpole® jackets together.
- √ Wrap the Powerpole® jackets with the GPS label.
- √ Cover the jackets and label with clear heat shrink tubing and heat it.
- √ Fill in any gap in the back of the jacket with hot glue.

## 2.0 Radios

To transmit telemetry from the TNC, the near spacecraft requires a radio. Because of weight and space limitations, a handheld radio is the best choice. Unless powered from a 12-volt battery, most HT's output no more than a watt of power. Fortunately, transmissions of less than one watt are sufficient for line of sight communications. On the ground line of sight is limited to terrain features and a horizon about three miles away. In near space where there is no terrain or foliage to block a radio transmission, line-of-sight to the horizon is the ultimate limit. In near space, it's hundreds of miles to the horizon. To keep cost and weight low, use the Alinco DJ-S11 HT as the near spacecraft radio.

## 2.1.   A Tale of Caution: Two-Way Communications with TNCs

Let me tell you a short story about my first near space flight and why I'm currently hesitant to send commands to the near space capsule.  My first flight, KNSP 96A, was launched the first Saturday in November 1996.  Inside the near space capsule, both of the HT's MIC and SP lines were connected to the TNC.  At this point I hadn't planned to communicate with the near space capsule, but wired up the connection for future use.  The TNC was placed in transparent (TRANS) mode.  In this mode, as opposed to command mode, the TNC sends all data it receives from the CC/PS or GPS receiver.  Transmissions from the capsule where formatted as Unproto, so no connection was made with ground stations.  All transmissions were sent into the ether for everyone to receive.  Just after passing the 30,000-foot mark, a packet station operator in Kansas City saw my near spacecraft, the Isaac Asimov, as a new packet station and attempted connecting to it.  The connection placed the TNC into command mode.  In command mode, the TNC waits for further instruction and ignores all data sent to it from the GPS or CC/PS.  The BS-2IC in the CC/PS had no way of knowing that its data was not being transmitted.  The near space capsule was effectively "Lost In Near Space" (this sounds vaguely like a really bad science fiction movie).  I can't begin to explain how badly I felt at this time.  This was my first near space capsule, my baby, and the baby I had been building for over a year and now it was lost.  Fortunately one bright individual* in the KNSP chase crew determined he could connect with the TNC with his laptop.  Once the connection was made, the TNC transmitted data for 15 seconds before timing out.  As long as the connection was maintained, ground stations received data from the near space capsule.  So he kept hitting the ENTER key every ten seconds for the rest of the flight.  Because of this unsung hero, KNSP eventually recovered the near space capsule.  Believe me, there's no bummer like the bummer of losing your first flight.  Ever since then I have been hesitant to connect the center pin of MIC jack to the TNC in fear of a future repeat of this incident.

A little research shows several ways to prevent this occurrence.  First, the TNC can be left deaf to the world by not connecting the speaker output to the TNC.  The TNC still sends data, but cannot receive any commands.  Another way is to prevent connections to the TNC with the NOCOM command.  Of course if you do this, you should set up a remote login to your TNC in case you need to reprogram the TNC during a mission.

* I wish I recalled this individual's name.

## 2.2.   The Alinco DJ-S11 Handheld Two-Meter Radio

### 2.2.1. Theory of Operation

The Alinco DJ-S11 can operate with as little as 4.5 volts and has an output of 340 mW.  This is a sufficient amount of power if the antenna is replaced.  The antenna that comes with the DJ-S11 may be fine for ground use, but has a poor enough gain that it cannot be used reliably for critical near space telemetry.  Replacing the antenna with a simple dipole or J-pole improves its gain, letting its 340 mW do its magic.

### 2.2.2. Materials

DJ-S11
- Three foot length of RG174/U 50 ohm cable*
- Small wire clamp **
- 3/16" heat shrink tubing

* Purchase this cable from Jameco.  Part number is 111472 and its cost is $3.25.  Cut a cable in half and you have enough coax to make the HT connection and an antenna.
** The wire clamp is called a 1/8" nylon strap at hardware stores.

Tools
- A small jeweler's Philips screwdriver
- Fine tipped soldering iron
- Thin solder

## 2.2.3. Procedure to Replace a DJ-S11 Antenna (with running commentary)
√   Cut the RG174/U cable in half.
  One half is used on the HT and the other half becomes part of the antenna.
√   Remove the back cover of the DJ-S11.
  There are three screws visible on the back cover of the DJ-S11.  There are four   additional screws hidden behind the batteries.  To remove them, you must first remove any batteries.  Beneath the batteries you'll see the four screws.  Remove all seven screws to remove the back cover of the DJ-S11.
√   Remove the folding whip antenna from the back cover.
  The folding antenna is mounted to the back cover where it makes a simple mechanical connection to the DJ-S11's PCB.  Remove the antenna by removing the retaining nut with a pair of pliers.  This leaves a hole in the back case of the HT, which will be used as an exit point for the coax.
√   Set the back of the cover aside.
√   Locate the male headers on the PCB.
  On the HT's PCB search for a pair of 0.025" males headers, with 0.1" between centers.  These two headers are mounted at a right angle to the PCB and located   near the top of the radio.  These two headers are connected to the antenna pads and are where the new antenna connection will be made.
√   Stick a small piece of tape beneath the headers.
  I do this to prevent an accident from damaging the HT.  Your mileage will vary.
√   Carefully tin both headers.
  Making sure you don't drop solder onto the PCB.
√   Cut a length of RG-174 (1/8" diameter coax) about eighteen inches long.
√   Strip about two inches of insulation from one end, exposing the braid.
  Use a #14 gauge stripper.
√   Spread the braid at the end closest to the insulation, forming a small hole.
√   Push the inner insulation through the opening.
√   Strip back ¾" of inner insulation to expose the center conductor of the coax.
  Use a #20 gauge stripper .
√   Tightly twist the braid and center conductor.
√   Tin both the braid and center conductor.

***Making the Antenna*** *- The cut and stripped RG-174 coax.*

√    Cut away the rubber cover over the HT's speaker and MIC jacks.
√    Notch the case where the rubber cover used to be.
     Use an Exacto knife and remove a small piece of plastic.  Make the hole large enough to let the coax pass through, but no larger than necessary.
√    Pass the coax through a cable restraint.
√    Loosely bolt the cable restraint to the back cover.
     Use the large bolt that comes with the hand strap and bolt the restraint to the threaded hole for the hand strap.
√    Slide on two pieces of heat shrink tubing.
    The tubing will increase the diameter of the coax so the cable restraint can tightly clamp onto the coax.
√    Slip the coax through the old antenna opening in the back cover.
√    Place the soldered coax ends up against the male headers on the HT's PCB and carefully solder the coax to the headers.
     Make sure no solder bridge is created.
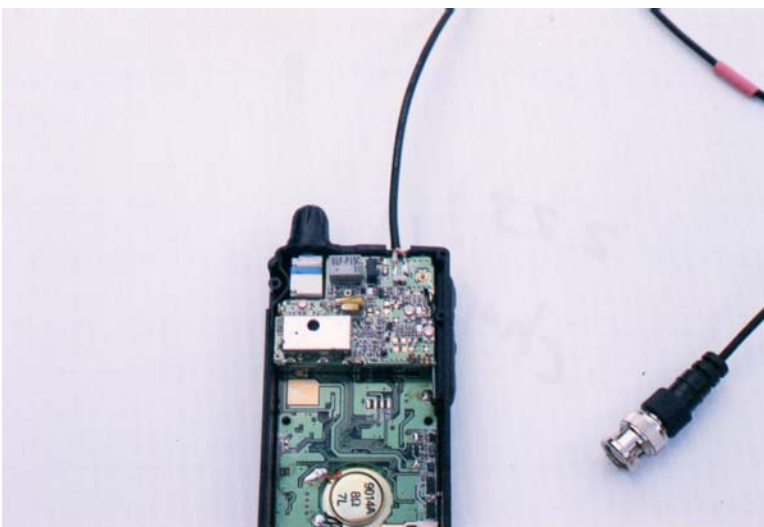


***Soldered RG-174*** *– The Alinco DJ-S11 (or DJ-S41) after the external antenna coax is soldered on to its two-pin header.*

√    Carefully pull coax out through the back cover as you close the back of the HT.
√    Screw the back cover into place.

Leave some slack in the coax as you thread it through the cable restraint.
√ Slide the heat shrink tubing into place and shrink it down.
√ Tighten the cable restraint.
Now the coax is tightly bound and strain relieved.



*Fully Modified Alinco DJ-S11 -*
*Sporting its new antenna.*

## 3.0    Antennae

Since everything within 300 miles or more is line of sight in near space, simple dipole antennas are all that are necessary for near space capsules.  A simple dipole antenna is excellent for a near spacecraft because of its uniform radiating pattern.  This is important because the balloon rotates and there is no control over the direction the antenna points.  There's enough gain with mag mount antennas that the chase crews will not need beam antennas, except perhaps for ATV (amateur television) where you need to squeeze out every milliwatt of signal.

A second type of antenna that has been used successfully in near space is the J-Pole.  Mark Conner's (NSTAR) capsule uses this antenna quite successfully.  The only real risk of a J-pole comes from the chance the near spacecraft may recover on a power line and the antenna lies across two or more power lines.  A minor nit pick is that the antenna hangs below the near spacecraft.  Any ground photographs taken during a mission include a dangling antenna in them.

Described here are two simple dipole antennae for near spacecraft.  The first is a rigid design while the second is uses flexible elements.

### 3.1.    A Dipole Antenna with Rigid Elements
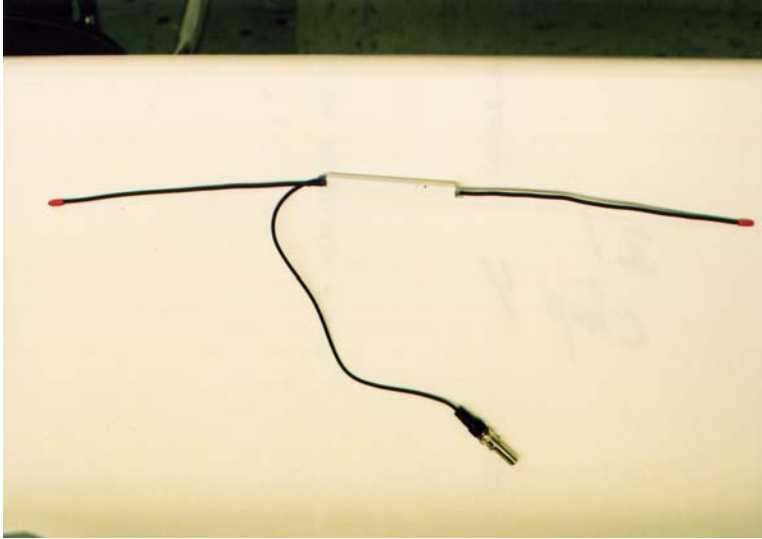
***Completed Dipole Antenna
with Rigid Elements***

Mount rigid dipole antennas to the end of an antenna boom.  Directions for making an antenna boom are in Chapter Five, Section Three.

### 3.1.1. Materials and Tools

The following materials are required to make a dipole antenna:

- Two pieces of #12 or #14 AWG insulated solid copper wire
- Half of a coax RG-174/U cable *
- Four inches of hollow 1/2" plastic square tubing**
- A BNC barrel connector
- Nylon zip wire ties
- Heat shrink tubing with diameter large enough to cover the solid wire
- Small diameter bolt thread protectors (select a bright color that closely fits the solid wire.)

* You should have half of this cable lying around, if you have modified the antenna of a DJ-S11. Purchase this cable from Jameco.  It is part number 111472 and costs $3.25.
** This material is available at hobby stores.

Collect the following tools:

- Wire strippers
- Small pick or pointy Exacto knife
- Soldering iron and solder
- Hot glue and a glue gun

### 3.1.2. Construction

***Stripped RG-174*** *- The coax cable with the center conductor pulled through the outer braided jacket.*

√  Cut two #12 or #14 AWG solid copper wires to a length of at least 20".
√  Strip 1" of insulation from one end of each wire.
√  Cut the coax cable in half if you have not already done so.
√  Strip back about three inches of outer jacket from the cut end, exposing the inner braid.  Use a sharp point and open up the braid near the insulation.
√  Through this hole in the braid, pass through the inner insulation and conductor.
√  Strip back the inner insulation by about 2.5 inches.
√  Open the braid to expose its hollow core.
√  Insert an end of one of the solid copper wire into the hollow braid.
√  Twist the braid tightly around the copper wire and solder them together.
√  Solder the wire to the braid (use a soldering gun as it takes a lot of heat).
√  Wrap the inner conductor around the second piece of solid wire.
√  Solder them together. This completes the electrical connection.
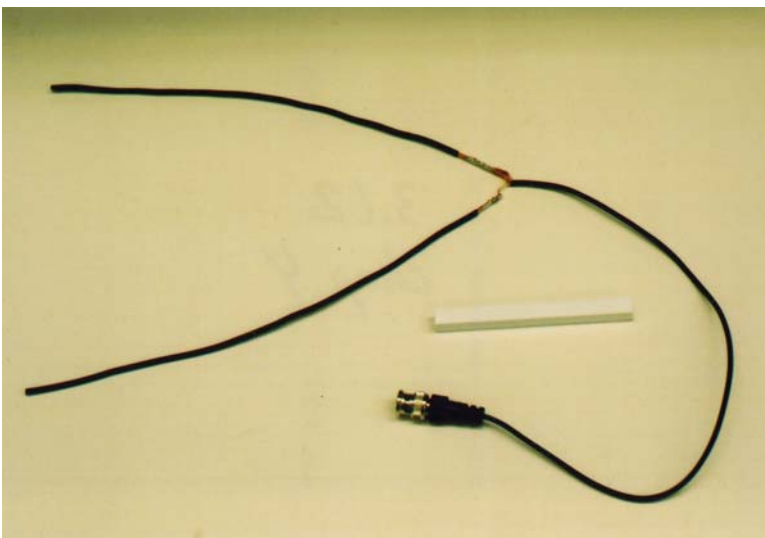


***The Soldered Dipole -*** *The antenna will be placed inside the square plastic tube and hot-glued into place.*

√  Cut each dipole element to a length of 19.5 inches, measured from their soldered
√  connection.
√  Fold the coax cable against the dipole elements in a short zigzag.

√    Wire tie the coax to the dipole elements
√    Insert the center of the dipole into the hollow plastic tubing.
√    Fill the interior space with hot glue.
√    Shrink enough layers of heat shrink tubing over the exposed ends of the elements to fit the thread protector snugly.
√    Twist the barrel connector onto the BNC end of the antenna cable.

## 3.2.  Dipoles with Flexible Elements

Dipoles with flexible elements are designed to let one element dangle below and the second to be tied to a link line.
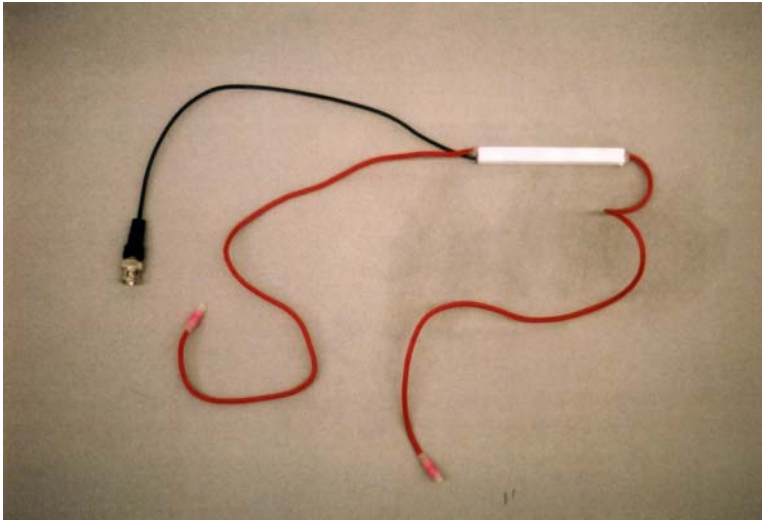


*Flexible Dipole Antenna* – A suitable antenna for missions where there is no antenna boom. The bottom element is left to dangle.  The top element is tied (loosely) to a link line.

### 3.2.1.  Materials and Tools

The following materials are required to make a dipole antenna:

√    Two pieces of 12 AWG stranded (flexible) copper wire*
√    Half of a coax RG-174/U cable from Jameco
√    Four inches of hollow 1/2" plastic square tubing
√    A BNC barrel connector
√    Nylon zip wire ties
√    Heat shrink tubing large enough to cover the solid wire
√    Bolt thread protectors (select a bright color that closely fits the solid wire.)

* A suitable cable is available at hobby shops that cater to RC racing car enthusiasts.  The wire is insulated in a silicon jacket and used for power cables.

Have the following tools at hand

- Wire strippers
- A small pick or pointy Exacto knife
- Soldering iron and solder
- Hot glue and glue gun

### 3.2.2. Construction

- √   Cut two # 12 or #14 AWG stranded copper wire to a length of at least 20".
- √   Strip 1" of insulation from one end of each wire.
- √   Cut the coax cable in half if you have not already done so.
- √   Strip back about three inches of outer jacket from the cut end, exposing the inner braid.  Use a sharp point and open up the braid near the insulation.
- √   Through this hole in the braid, pass through the inner insulation and conductor.
- √   Strip back the inner insulation by about 2.5 inches.
- √   Open the braid to expose its hollow core.
- √   Insert an end of one of the stranded copper wire into the hollow braid.
- √   Twist the braid tightly around the copper wire and solder them together.
- √   Solder the wire to the braid (use a soldering gun as it takes a lot of heat).
- √   Wrap the inner conductor around the second piece of stranded wire.
- √   Solder them together. This completes the electrical connection
- √   Cut each dipole element to a length of 19.5 inches, measured from their soldered connection.
- √   Fold the coax cable against the dipole elements in a short zigzag.
- √   Wire tie the coax to the dipole elements.
- √   Insert the center of the dipole into the hollow plastic tubing.
- √   Fill the interior space with hot glue.
- √   Shrink enough layers of heat shrink tubing over the exposed ends of the elements to fit the thread protector snugly.
- √   Twist the barrel connector onto the BNC end of the antenna cable.

## 3.3.   The J-Pole Antenna
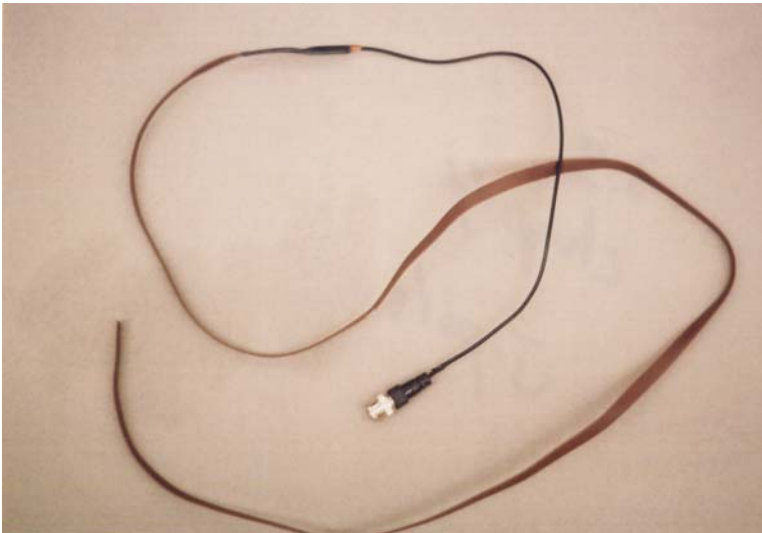


*Completed J-Pole Antenna*

I recommend using the J-Pole for only tracker flights; if used on science loaded missions, the antenna will intrude on the photographs.  A very good website demonstrating how to construct Dr. Carl Jelinek's roll-up J-Pole antenna from a TV twin lead is http://cvarc.org/jkpolescl.htm.

*J-Pole hanging out of capsule*

## 4.0    Near Space Power Systems
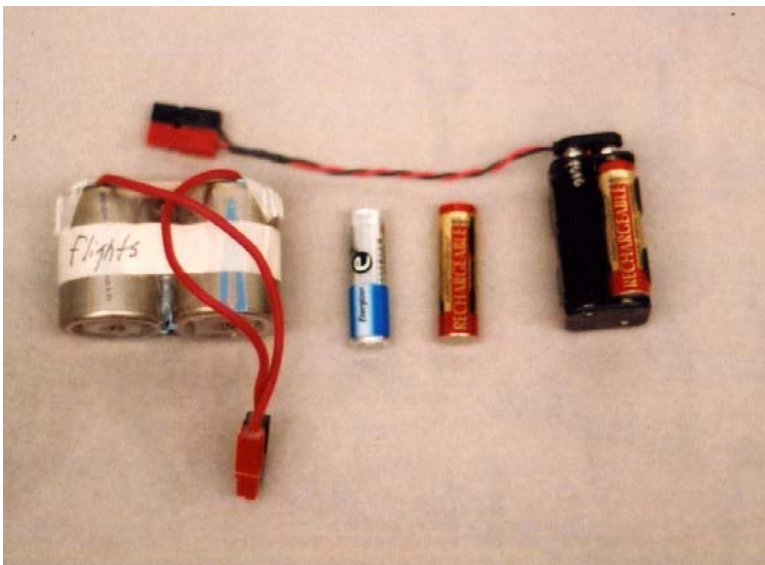


*Various Batteries* – *L to R – Military surplus lithium, photo lithium, rechargeable NiMH, rechargeable NiMHs in battery pack.*

## 4.1.    Batteries

Most people don't care, but being the professional amateurs that we are, being specific does matter. There's a difference between cells and batteries. A cell is a single unit that chemically produces a voltage potential. A battery is made up of several cells. While "AAA", "AA", "C", and "D" batteries are really cells, a 9V transistor battery is really a battery because it is made up of several cells stacked on top of each other (like Pez candies). Now that I've got that off my chest, let's continue with near spacecraft power systems. Cells have a characteristic voltage that depends on their chemistry. The voltage (a potential or force) produces a current (the flow of charge carriers, usually electrons) when the two terminals of the cell are connected to each other with conducting material. A cell uses energy to create the voltage potential that pushes the electrons that form the current. As the stored chemical energy in the cell is used up, the voltage on the cell terminals decreases. Long before the cell reaches zero volts, it is considered discharged. In fact, if a rechargeable cell is discharged to near zero volts, it has been damaged. Do not use such a cell in a near space application.

The characteristics of a cell that are important for near space are:
- Weight
- Voltage per cell
- Capacity
- Cold sensitivity
- Discharge curve profile
- Primary or secondary cell
- Cost

Note: The ratio of capacity to weight is referred to as the specific energy of the cell.

The near spacecraft is weight constrained. The more weight required for power systems, the less weight available for experiments, or the lower the altitude the stack will reach.

The higher the voltage per cell, then the fewer cells required building a battery pack for the avionics. This also reduces the total weight required for the power system.

The higher the capacity of the cell, the longer the cell can source current, and therefore the fewer the cells needed. Higher capacities allow longer missions (slower ascents which usually imply higher altitudes) and more time for the recovery crew to reach the near spacecraft before it shuts down. Cell capacity depends strongly on the discharge rate of the cell. When a load draws too much of a current the useful capacity of the cell is reduced.

Near space is cold. Really cold. As cells cool, their voltage and capacity drops. Some cell chemistries are more sensitive to the cold than others. The interior temperature of an near spacecraft needs to be characterized before using cells with lower cold tolerances. The most critical time for a power system is during descent when the interior temperature is at its lowest. It's very important the GPS receiver does not stop operating due to reduced battery voltage.

A battery discharge profile is a graph of a cell's voltage over time as the cell is discharged. If cells with a flat discharge curve are used, then battery telemetry reports constant battery voltages until they die. If a battery with a sloped discharge curve is used, then battery telemetry reports a continuous drop in voltage during the mission and gives sufficient warning of battery death.

Primary cells are not rechargeable, while secondary cells are. Primary cells can be discharged to a lower voltage, as you're not worried about damaging them. Secondary cells have a discharge level below which the life expectancy may be degraded.

The cost of batteries is not large compared to the cost of the balloon and helium. For primary cells, the cost of the batteries is a cost added to each flight like the cost of film. For secondary cells, the cost is a one-time cost like the HT or GPS receiver. Rechargeable cells that are not well cared for become an expensive power system, but rechargeable cells could lower the cost of each flight if they can be used enough times.

## 4.1.1. Cell Chemistries In Detail

Information about batteries in this section was found from several different sources. Primarily, websites of the following manufacturers was used:

Ultralife        www.utralifebatteries.com

    Duracell        www.duracell.com
    Panasonic     www.panasonic.com
    Energizer     www.energizer.com

Costs are those at my local Wal-Mart and HobbyTown. Weights are for an "AA" cell form factor. Discharge curves and capacities are determined for a cell that provides enough current to power the CC/PS and GPS receiver. At a voltage of 6.0 V and a current of 125 mA, cells must provide 750 mW for the entire mission. Assuming missions require three hours, plus 30 minutes before launch and an hour after recovery, cells must provide power for a minimum of 4.5 hours to be a viable power source. In addition to having the capacity to operate an near spacecraft, the flight batteries must have a minimum voltage greater than 5.25 volts to keep the voltage regulator operating. Even if the cells in a battery have excess capacity, once their collective voltage drops below the dropout voltage of the LM2940, they can't operate the near spacecraft avionics. Cells having lower operating temperature ranges anywhere near the minimum temperature expected during the descent of the near spacecraft are excluded from critical near spacecraft systems.

Each cell report includes the following statistics:

| Cell Statistics | |
|---|---|
| Weight of cell | in grams |
| Voltage per cell | in volts |
| Weight of a 6V system | total weight required creating a 6-volt pack |
| Capacity | in mAh |
| Temperature range | in degrees F |
| Cost | Wal-Mart or hobby store's prices |
| Discharge curve profile | voltage vs. time for a 750 mW power or 125 mA current drain |

Alkalines
Alkaline cells use manganese dioxide chemistry and an alkaline electrolyte. They are superior to the old dry cell.

| Alkalines | |
|---|---|
| Weight of cell | 24.4 g |
| Voltage per cell | 1.5 V |
| Voltage when discharged | 0.8 V |
| Weight of a 6V system | 97.6 g |
| Capacity | 780 mAh |
| Temperature range | -4 to 130 degrees F |
| Cost | $3.25 |
| Discharge curve profile | The voltage of an alkaline cell drops off immediately after use. There is no leveling off. For a 750 mW requirement, the voltage drops at a roughly constant rate of about 0.083V/hr. |

Nicads
Nickel Cadmium cells are secondary cells, that is, they are rechargeable. As long as they are not discharged too far, they are not damaged and can be recharged.

| Nicads | |
|---|---|
| Weight of cell | 21 g |
| Voltage per cell | 1.2 V |
| Voltage when discharged | 0.9 V |
| Weight of a 6V system | 105 g |
| Capacity | 700 mAh |
| Temperature range | -4 to 149 degrees F |
| Cost | $11.45 |
| Discharge curve profile | The voltage of a NiCd cell quickly drops by about 22% then holds at a near constant level voltage until it's close to fully discharged. |

NiMH
Nickel Metal Hydride cells are similar to nickel cadmium cells.

| NiMH | |
|---|---|
| Weight of cell | 27 g |
| Voltage per cell | 1.2 V |
| Voltage when discharged | 1.0 V |
| Weight of a 6V system | 135 g |
| Capacity | 1200 mAh |
| Temperature range | -4 to 122 degrees F |
| Cost | $22.45 |
| Discharge curve profile | The voltage of a NiMH cell changes near identically to that of a NiCd cell. |

Lithiums
Lithiums use lithium-manganese chemistry. The cells described here are equivalent to 2/3 of a "D" cell. These military surplus (part # BA-5598-U) cells come in five to a plastic box, which must be opened carefully to avoid cutting the batteries. Cut the box lid seam at one corner only and pry open. The batteries come wired together; you may leave two attached for use as a pair.

| Lithiums | |
|---|---|
| Weight of cell | 98 g |
| Voltage per cell | 3.0 V |
| Voltage when discharged | 1.7 V |
| Weight of a 6V system | 196 g |
| Capacity | 8000 mAh |
| Temperature range | -40 to 160 degrees F |
| Cost | less than $1.00 |
| Discharge curve profile | The voltage of a lithium cells drops off at a near constant rate until the cell is discharged. |

Note: Surplus batteries need to be tested under a load for 5 to 10 minutes before using them on a mission. The goal is to get them to fail on the workbench, rather than at 100,000 feet (I have had this sort of thing happen). Test them for a draw of 500mA, which exceeds near spacecraft requirements. At 6V, a resistance of 12 ohms is required to create a current of 500mA; at 6V and 500 mA, a total of 3W is generated. So, a power resistor of 12 ohms and 3W is required to load the batteries, but for safety use a 12 ohm, 5W power resistor (Digi-Key part # 12W-5-ND sells for $0.41). To test the

battery, connect the power resistor across the battery along with a digital multimeter (DMM) set for DC voltage and watch the voltage for 5 to 10 minutes.  It should drop under the load, but not below the 5.3 volt minimum needed to run the voltage regulator I recommend (LM2940T-5).  After the load is removed, the voltage should spring back up to what it was originally.

Photo Lithiums
Photo lithium batteries use lithium-iron disulfide chemistry.  This reduces their voltage per cell to that of an alkaline cell, letting them be used in equipment designed for alkalines.

| Photo Lithiums | |
|---|---|
| Weight of cell | 14.5 g |
| Voltage per cell | 1.5 V |
| Voltage when discharged | 0.8 V |
| Weight of a 6V system | 58 g |
| Capacity | 2900 mAh |
| Temperature range | -40 to 140 degrees F |
| Cost | $10.00 |
| Discharge curve profile | The voltage of a photo lithium drops off steeply and never levels out. |

## 4.1.2. The LM2940T-5 Five-Volt Voltage Regulator

This section addresses the issues regarding the LM2940 series of low-dropout voltage regulators, since it is the only voltage regulator used in this book.  Take a look at the data sheet in Appendix A as you read through this section. The LM2940T-5 voltage regulator produces a 5.0 (within 5%) volt output as long as its supplied voltage is greater than 5.25 volts.  Therefore the greatest amount of battery capacity is used if the battery pack produces 5.3 volts when fully discharged.  The greater the voltage supplied to the LM2940, the more energy wasted by the regulator and the lower its efficiency.  So another concern becomes, how great is the voltage of the fully charged battery pack?  A fully charged battery pack with a lower voltage wastes less energy than a fully charged battery pack with a higher voltage.

For example:

| CHARGED BATTERY PACK APPROACH | | | | |
|---|---|---|---|---|
| Chemistry | Discharged Voltage | Under Voltage | Full Charge Voltage | Over Voltage |
| Alkaline | 3.2 | 1.00 | 6.0 | 0.75 |
| NiCd | 4.5 | 0.75 | 6.0 | 0.75 |
| NiMH | 5.0 | 0.25 | 6.0 | 0.75 |
| Lithium | 3.4 | 1.85 | 6.0 | 0.75 |
| Photo lithium | 3.2 | 2.05 | 6.0 | 0.75 |

| DISCHARGED BATTERY PACK APPROACH | | | | |
|---|---|---|---|---|
| Chemistry | Discharged Voltage | Under Voltage | Full Charge Voltage | Over Voltage |
| Alkaline | 5.6 | 0.3 | 10.5 | 5.25 |
| NiCd | 5.4 | 0.1 | 7.2 | 1.95 |

| | | | | |
|---|---|---|---|---|
| NiMH | 6.0 | 0.7 | 7.2 | 1.95 |
| Lithium | 5.1 | -0.1 | 9.0 | 3.75 |
| Photo lithium | 5.6 | 0.3 | 10.5 | 5.25 |

Efficiency

Data supplied by Ralph Wallio (W0RPK) indicates the following efficiencies for the LM2940T-5 for a supplied current of 186 mA:

| Input | Efficiency |
|---|---|
| 7.5V | 63.8% |
| 7.0V | 68.3% |
| 6.5V | 72.8% |
| 6.0V | 78.6% |
| 5.5V | 85.5% |

When supplied with the lowest possible voltage, the LM2940 operates at its highest efficiency. So as the flight battery discharges, the voltage regulator generates less waste heat. If you use the minimum number of cells to operate the avionics, then the avionics never get the full capacity of the cells. If you use enough cells to get their full capacity, the voltage regulator initially doesn't operate at very high efficiency, wasting the battery capacity.

### 4.1.3. Some Recommendations

The best cell chemistry to use depends on your greatest concern. Ideally, the cell chemistry selected has a flat discharge curve for the majority of the time and a full charge not higher than 6.0V. At the same time its voltage begins to gently drop near the end of its charge, giving a warning that they are about to die. The ideal cell is inexpensive and light weight. They will have a high capacity, so they provide power for extended recoveries. However, no cell chemistry provides its ideal total capacity at the currents needed to operate a near spacecraft. Below are two examples illustrating this.

Mark Conner's (N9XTN) near spacecraft draws a current of 400 mA (this includes the TNC, GPS, and radio). When operated from 4000mAh NiMH, it operates for eight hours before failing. Mark gets 3200 mAh out of a 4000mAh flight battery, or 80% of their rated capacity.

My (KD4STH) near spacecraft draws a current of 160 mA (this includes the GPS and CC/PS). When operated from 2900 mAh photo lithiums, it operates for 12 hours before failing. I get 1900 mAh out of a 2900 mAh flight battery, or 65.5% of their rated capacity.

The reason for the greater percentage of rated capacity in the NiMH cells is that their discharge curve is flatter than the discharge curve of the photo lithiums. NiMH and NiCd cells self-discharge at a rate of 1% of their total charge daily. Lithium cells self–discharge at such a low a rate that they can be stored for up to ten years before use. Lithium cells are lighter in weight and have the larger specific energy. For a three to four hour flight, most cells will provide sufficient power, as long as they are not affected by the cold of near space.

If your primary concern is to have a guaranteed, fully charged flight battery, then using fresh, non-rechargeable cells is your best option. If the airframe interior stays warm enough (no lower than about 40 degrees F), then alkalines are the least expensive route. Photo lithiums are second best as far as cost. If using non-rechargeable cells, do not open their package until the morning of the

mission. This ensures they do not accidentally discharge before the launch. Charging rechargeable cells just before launch warms them up and delays their cooling during the flight.

If your primary concern is to have cells that operate regardless of the temperature, then using lithiums is your only option. Photo lithiums are the least expensive and most available option.

If cost is your primary concern, then using a rechargeable cell is your best option. NiMH is a much better chemistry than NiCd, for both rated capacity and lack of memory effect. While the low capacity of NiCds doesn't prevent their use, the risk of a memory effect is enough to recommend against using NiCds. Be sure to top off the NiMH cells the night before a launch.

An near spacecraft can be stored at the launch site the night before a launch. However, the flight battery should be stored indoors where it stays warmer. Leaving them out all night where they chill lowers their capacity before the launch.

## 4.2. Building Warm Boxes
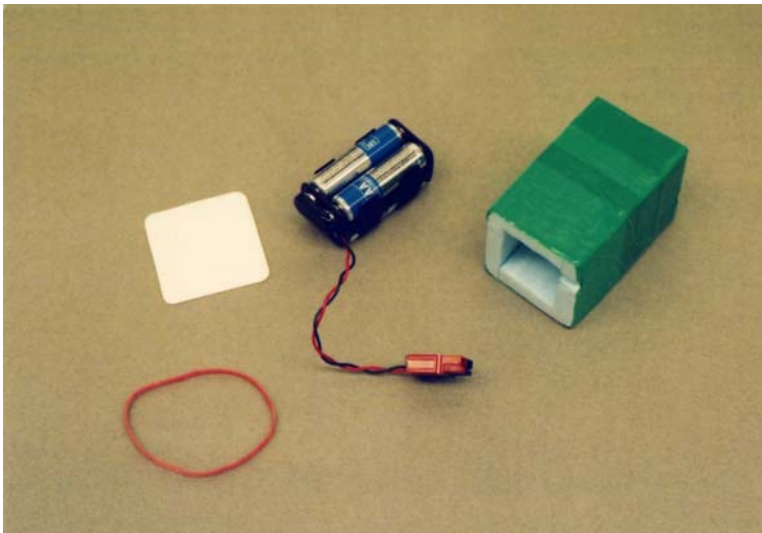


***A battery box*** - *The battery pack fits tightly inside the taped Styrofoam box and is sealed with a lid of polystyrene plastic and a rubber band.*

The warm box is a Styrofoam box containing temperature sensitive items like the flight cells. The warm box helps keep cells warm during the mission, keeps them within their cell holder during the flight, and prevents cells from shorting out if they make contact with metal. Locate warm boxes near the toasty warm GPS receiver*. This way the battery is stored in a warm location and can easily be loaded into the airframe just before launch.

* The GPS receiver is toasty warm compared to the decidedly chilly –60 degree temperatures outside the near spacecraft.

### 4.2.1. Materials
- ¾" or ½" Styrofoam sheet
- Hot glue
- One 4 "AA" cell holder
- A nine-volt battery snap
- One pair of Powerpole® connectors
- Uline tape

## 4.2.2. Construction

Electrical

√ Strip 1" of insulation from the bare ends of the nine-volt battery snap.
√ Double over the bare ends and crimp with Powerpole® crimps.
√ Insert crimps into the proper colored housings.
√ Backfill the Powerpole® housings with hot glue.
√ Slide housings together.


Mechanical

These directions are specifically for the flight cells, but can be modified for HTs and other temperature-sensitive devices.

√ Snap nine-volt battery snap onto the 4 "AA" cell holder.
√ Load a set of cells into a 4 "AA" cell holder.
√ Measure the dimension of the cell holder and cells.
√ Cut four sides and a bottom from Styrofoam to size so that a tight fitting box can be built
√ to house the cell holder and cells. Note: Trim the Styrofoam a little larger than necessary as the box is trimmed to the proper size after construction.
√ Glue the Styrofoam sides into a box form with hot glue. Note: Built the warm box around the battery holder to get to a tight fit.
√ Flatten the bottom of the warm box with a sharp Exacto knife or Exacto saw.
√ Glue the base to the warm box.
√ Smooth the cut edges and sides with a sander.
√ Place the battery holder back into the warm box and trim the warm box to be flush with
√ the top of the battery holder.
√ Cut any necessary notches into the top of the warm box to pass the battery cable.
√ Cover the warm box in Uline tape (this just makes it look better).
√ Cut another piece of Styrofoam to cover the top of the warm box. Note: Often I used a 0.04" thick sheet of polystyrene in place of foam.
√ Cover the top in Uline tape.
√ Optional: Make a label for the warm box indicating what item is inside.
√ After the battery holder (or other temperature-sensitive device) is installed inside the warm box, rubber band the cover over the top

1−1/8''

1−1/8''
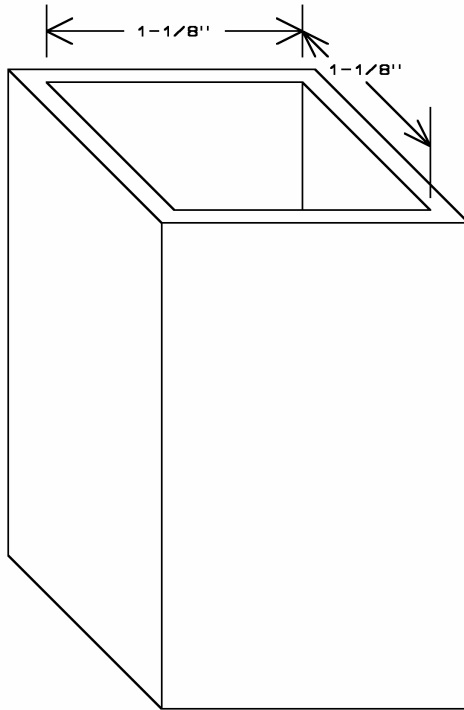
**AA Cell Battery Box** – *These are inside dimensions. The outside dimensions depend on the thickness of the Styrofoam, which can be sanded down.*

## 5.0    Data Flight Recorder
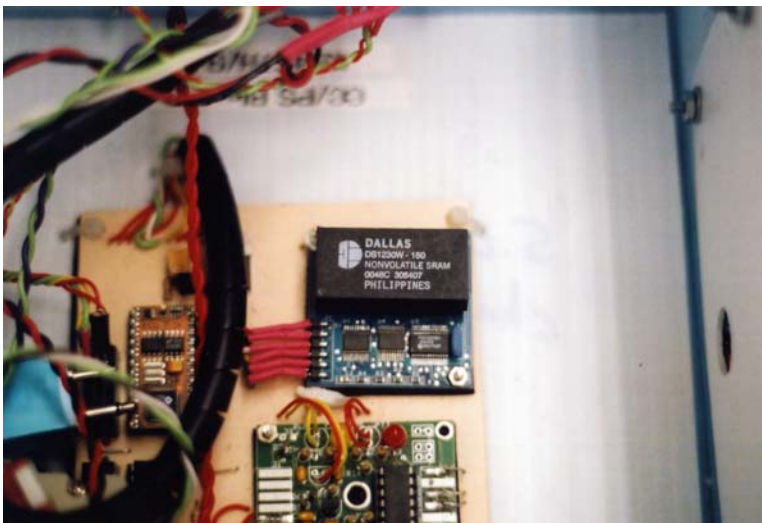


**Flight Data Recorder** *(FDR) – The completed FDR shown inside the near space capsule.*

Transmitting data (telemetry) to ground stations allows ground crews to "see" the data collected during the mission. This telemetry must be recorded in a log file during the flight, so ground crews must begin logging APRS telemetry before lift-off. This is so important that it should be in the mission's checklist. Invariably, some packets are not recorded and therefore logs are never complete. Even if all the telemetry is recorded, it's a major pain to clean up a 50 kB log after a mission by removing the 75% of other people's communications (junk, after you've been cleaning logs for two hours). So instead of transmitting science data to ground stations, record it onboard the near

spacecraft instead.  Now science data is recorded in the format you design, making it easier to load into a spreadsheet.  And best of all, the data is just your data, not the position reports of every vehicle in the Recovery Crew.

## 5.1.    Theory of Operation

The company Solutions Cubed makes a great device for logging data.  The RAM Pack B is a microcontroller module designed to accept inputted data and store it on a RAM chip.

At the start of a mission, the flight computer puts the RAM Pack B into FIFO mode.  FIFO (first in, first out) mode allows the flight computer to send data to the RAM Pack B without having to keep track of the current address.  Once the RAM Pack B is in FIFO mode, the flight computer sends it telemetry data sequentially one byte at a time.  After the mission, a program to read the data from the RAM Pack B is downloaded into the flight computer.  An adapter cable plugs into the P3 of the near spacecraft and the data is read into an open file under the control of a terminal program.  The file is saved as a text file.  Minor modifications are made to the text before the file is imported into a spreadsheet for further processing.  This process takes a fraction of the time required to clean up an APRS log.  It really is a slick process.

### 5.1.1. Materials

For the Data Logger:
- DS1230W – 150 32kX8 nonvolatile RAM (NVRAM)*
- A RAM Pack B from Solutions Cubed (come with 8kX8 RAM)
- Six #24 AWG stranded wires.  Use different colors, with at least one red and black.
- 12 pieces of 1/8" heat shrink tubing, cut 3/8" long
- One or two thin nylon wire ties or
- One or two pieces of 3/8" diameter heat shrink tubing, cut ½" long
- Depending how you made your I/O ports, either
- Double row male header, cut five pins long (10 pins total)
  Or
- Crimp pins and plastic housings

For the Download Cable:
- 9-Position Male, D-Subminiature Connector          RS# 276-1537C
- 9-Position Female, D-Subminiature Connector        RS# 276-1538C
- Two #24 AWG stranded wire (black and white)
- 1/8" heat shrink tubing
- D-Subminiature Connector Hood          RS# 276-1539D
- Hot Glue
- Three Resistor leads
- Two Labels marked Downloading
- Clear heat shrink tubing to fit assembled hood

*Available from Dallas Semiconductor.  Order it as a free sample.

### 5.1.2. Procedure

Switching RAM Chips

*Flight Data Recorder with Replaced RAM* - The RAM Pack B with a NVRAM makes the ideal data recorder. A lot of science data can be recorded in 32 Kbytes.

The RAM Pack B arrives with an 8kX8 bytes volatile RAM. Note that the X8 refers to the fact that each byte is eight bits wide, which is the standard for the BASIC Stamp. Unfortunately the standard RAM does not meet our needs. First, we need a NVRAM (non-volatile RAM) so that data isn't lost when main power is shut down. Second, 8 kB of RAM is too limited for a near space mission. It's better to have too much memory than too little.

The RAM chip is switched out for a NVRAM, following the advice of the RAM Pack manual. To get the replacement chip, obtain a DS1230W – 150 nonvolatile RAM from Dallas Semiconductor. Carefully remove the old chip and insert the new one in its place. You may need to use a lead straightener on the NVRAM chip first.

Cabling RAM Pack B
The RAM Pack B comes with a six pin male header. The pins functions are:

| Pin Name | Function |
|---|---|
| MODE | Switches between FIFO and addressable modes |
| READ/WRITE | Determines if the nodule should read or write data |
| FM | Data is sent to the module on this pin |
| TM | Data is sent from the module on this pin |
| GND | Signal and power ground |
| Vcc | +5V |

To interface the module, wires are soldered to the RAM Pack's I/O pins. The other ends of these wires are soldered to a connector for the flight computer's I/O port.

- √ Strip ¼" of insulation from both ends of all six wires.
- √ Quickly tin the headers on the RAM Pack and the short ends of the double row male
- √ headers.
- √ Put two pieces of heat shrink tubing on each wire.
- √ Keep the heat shrink tubing near the center of the wires.
- √ Solder one end of each wire to the RAMPack header, the red connects to the Vcc pin and the black connects to the GND pin. The other colors are your choice.
- √ If you're using heat shrink tubing for bundling the cable, slide it on now.

Depending how you made your I/O ports, either:

- √ Solder the FM and TM wires to the I/O pins of the double row male headers.
- √ Solder the Mode wire to the CLK pin of the double male header.
- √ Solder the Read/Write wire to the DATA pin of the double row male header.
- √ Slide the heat shrink tubes over the soldered connections and shrink them down.

Or:

- √ Crimp a header pin on the FM and TM wires and slide them into sockets for the I/O pins of the I/O port.
- √ Crimp a header pin on the Mode wire and slide into a socket for the CLK pin of the I/O port.
- √ Crimp a header pin on the Read/Write wire and slide into a socket for the DATA pin of the I/O port.

- √ Shrink the bundling heat shrink tubing,  tie on the nylon ties to bundle the cable.

I recommend making a warm box for the RAMPack at this point.  Cover it with red Uline tape and label it as Flight Data Recorder, so it will stand out inside the near spacecraft.
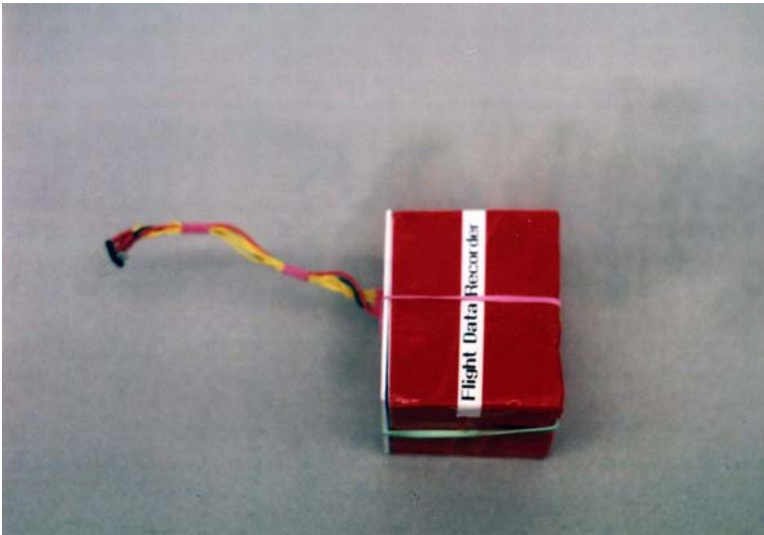


*Flight Data Recorder* - The enclosed flight data recorder (black box).  Make it a bright color so it stands out in the debris field left by your near spacecraft!!

Making Download Cable

*Download Cable*

After each mission, data onboard the near spacecraft is recovered from the flight data recorder. First the flight data read program is downloaded into the BASIC Stamp. Then a download cable connects the flight computer (through the program jack) to a PC running the Windows Terminal program.
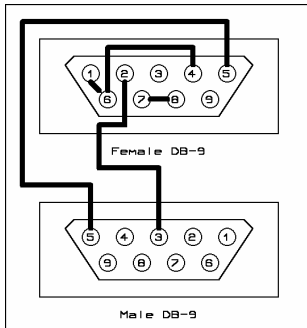


**Schematic of Download Cable** – *Note: Pins 1, 4, & 6 of the female DB-9 are connected together.*

- √ Cut ½" lengths of heat shrink tubing and slide onto wires, keeping them in the center and away from the heat of the soldering iron.
- √ Cut ½" lengths of clear heat shrink tubing.
- √ Slide on large clear heat shrink bands over all wires.
- √ Make the following solder connections:
  Black wire to pin 5 on both connectors.
  White wire to pin 2 on female connector and pin 3 on male connector.
  On female, use resistor leads to connect the following pins:
  > 7 to 8, solder both ends of wire.
  > 1….6, solder only pin 6.
  > 1…4, solder only pin 4.
  > Solder pin 1.
- √ Check carefully that no short circuits were created.
- √ Slide heat shrink tubing over wires in the solder cups and shrink.
- √ Cover ends in hot glue.
- √ Squirt in a layer of hot glue into base of hood.
- √ Place connector in (won't need the attaching screws.)
- √ Finish gluing and close top.
- √ Bolt hood together.

√    Back-fill the opening.
√    Twist wires in cable.

## 5.1.3.  Software

The following three program listings are required to use the RAM Pack B as a Flight Data Recorder (FDR, the near space black box).  The first program is loaded into the flight computer before a mission and overwrites data before a mission.  The second program is a part of the flight code.  First it prepares the RAM Pack for FIFO mode so that data can be stored.  Then the program stores important flight (GPS altitude, time, and velocities) and science data (particular to the mission) to the RAM Pack during this mission.  The last program is downloaded to the flight computer to read the data in the RAM Pack and send it to an opened file under the terminal program.  There's no reason each of these routines can't be stored in their own program slots and run at the appropriate times.  I developed this software from the App Notes that Solutions Cubed sent with the RAM Pack B.

Clearing out the RAM Pack B before a Mission
The following program clears out memory in the RAM Pack B.  Every memory location is overwritten with a *#*.  When downloading the data from the data flight recorder, RAM Read program looks for a *#* to determine the end of the flight data.

```
'***********************
'*     Setup RAMPack    *
'* Write # In FIFO Mode *
'***********************
mode          con  13
rw            con  14
fm            con  15
tm            con  15
addr          var  word
n1200         con  2063    '1200 baud n81


input 15
output 14

debug "Setting Up RAM Pack", cr
SetRAMP:
high fm
high rw
high mode                 'not in fifo mode
pause 3000
serout fm,n1200,[$55,$04]  'set baud rate for fifo
pause 1000
serout fm,n1200,[$55,$03]  'use expanded memory
pause 100

debug "Overwriting RAM Pack", cr
low rw                    'put into fifo write mode
low mode                  'put into fifo mode
for addr = 0 to 32767
serout fm,n1200,["#"]      'overwrite all memory locations
next

debug "Finished Overwriting RAM Pack", cr
end
```

Storing Data during a Mission
A data record to be stored in the Flight Data Recorder is built up in the BS2p's SPRAM.  At the end of a mission cycle, the data record is read from SPRAM and loaded into the Flight Data Recorder.  In

the BS2p the SPRAM is 128 bytes in size. During a mission, GPS sentences are stored in the first 65 bytes of SPRAM. Since the last byte of SPRAM can't be used, there are only 62 bytes free for a data record. I recommend storing a data record into SPRAM, starting with the last available byte and working forward. After an entire data record is created and stored, the data record is read into the Flight Data Recorder (FDR). Afterwards the cycle begins all over again, and a new data record is created.

The following BS2p routines prepare records in SPRAM and load them into the FDR.

The first routine puts the RAM Pack B into FIFO mode. This routine is performed at the start up of the capsule.

```
'***************************
'*      Set Up RAMPack     *
'***************************
RAMPack:
high fm
high rw
high mode                   'not in fifo mode
pause 3000
serout fm,n1200,[$55,$04]    'set baud rate for fifo
pause 1000
serout fm,n1200,[$55,$03]    'use expanded ram
pause 100
low rw                       'put into fifo write mode
low mode                     'put into fifo mode
return
```

The first record to be loaded into SPRAM for eventual downloading into the RAM Pack B is the data rep, or the number of the data record to be stored.

```
'***************************
'*  Put DataRep Into SPRAM  *
'***************************
SaveDataRep:
Workspace = DataRep
Digitbyte = WorkSpace/100
Digitbyte = Digitbyte + $30
put 125,Digitbyte
Digitbyte = Digitbyte - $30
WorkSpace = WorkSpace - (Digitbyte*100)
DigitByte = WorkSpace/10
Digitbyte = Digitbyte + $30
put 124,Digitbyte
Digitbyte = Digitbyte - $30
DigitByte = WorkSpace - (DigitByte * 10)
Digitbyte = Digitbyte + $30
put 123,DigitByte
put 122,","
return
```

GPS data is then loaded into SPRAM with this routine.

```
'***************************
'*    Get GPGGA Sentence    *
'***************************
GPGGA:
```

```
serin gps_rx,I4800,10000,NoGPS,[wait ("GGA"),spstr 56]

UTCgga:
for gpsloop = 3 to 6
get gpsloop,gpschar
'SPRAMAddr = 122 - gpsloop
SPRAMAddr = 124 - gpsloop
put SPRAMAddr,gpschar
next
put 117,","                      'SPRAMAddr = 117



ALTITUDE:
for gpsloop = 42 to 46
get gpsloop,gpschar
SPRAMAddr = 158 - gpsloop
put SPRAMAddr,gpschar
next
put 111,","                      'SPRAMAddr = 111

'**************************
'*    Get PGRMV Sentence    *
'**************************
PGRMV:
for gpsloop = 1 to 20
put gpsloop,"X"
next

serin gps_rx,I4800,10000,NoGPS,[wait ("RMV"),spstr 20]

RMV:
for gpsloop = 1 to 20                '$pgrmv varies in length
get gpsloop,gpschar
if gpschar = "*" then EndRMV
SPRAMAddr = 111 - gpsloop
put SPRAMAddr,gpschar
next
EndRMV:
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,","                    'SPRAMAddr = end of pgrmv
goto EndGPS
```

Every time science data is collected, it is stored into SPRAM with the following routine.  In this routine, the value of the data to be stored is saved in the variable, Exp_Value.  The number of digits in the data is stored in the variable n

```
n = 4
WorkSpace = Exp_Value
gosub SaveData
```

The routine to save the data uses the following code.

```
'**************************
'*  Convert Data Into Bytes *
'**************************
SaveData:

if n < 5 then N4
N5:
digitbyte = workspace/10000
workspace = workspace - (digitbyte*10000)
```

```
digitbyte = digitbyte + $30
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,digitbyte
n = 4

N4:
if n < 4 then N3
digitbyte = workspace/1000
workspace = workspace - (digitbyte*1000)
digitbyte = digitbyte + $30
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,digitbyte
n = 3

N3:
if n < 3 then N2
digitbyte = workspace/100
workspace = workspace - (digitbyte*100)
digitbyte = digitbyte + $30
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,digitbyte
n = 2

N2:
if n = 1 then N1
digitbyte = workspace/10
workspace = workspace - (digitbyte*10)
digitbyte = digitbyte + $30
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,digitbyte

N1:
digitbyte = workspace + $30
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,digitbyte
SPRAMAddr = SPRAMAddr - 1
put SPRAMAddr,","
return
```

At the end of a flight cycle, the following routine is called to copy the data record currently in SPRAM to the FDR.

```
'***************************
'*   Send Data To RAM Pack  *
'***************************
TellRAMP:
SPRAMAddr = 125
LoopRAMP:
get SPRAMAddr,digitbyte
serout fm,n1200,[digitbyte]
SPRAMAddr = SPRAMAddr - 1
if SPRAMAddr < 20 then EndTellRAMP
if digitbyte = "*" then EndTellRAMP
goto LoopRAMP
EndTellRAMP:
return
```

Notice that for the data rep and GPS data, the BS2p keeps track of the SPRAM address currently open. These routines are fixed and never change from mission to mission. However, the experiments flown on each mission does change. So the SaveData routine takes full advantage of the FIFO capabilities of the RAM Pack B.

Downloading Data after a Mission

After recovery, download the following program into the flight computer and then switch off the capsule.

```
'*********************
'* Read RAM Pack Data *
'*********************

value    var byte
addr     var word
highaddr var addr.highbyte
lowaddr  var addr.lowbyte
n1200    con 2063
b1200i   con 18447
mode     con 13
rw       con 14
fm       con 15
tm       con 15

Begin:
input 15
output 14
pause 5000

high fm                          'read in non-fifo mode
high mode                        'get out of fifo mode
pause 2
high rw                          'not in write fifo mode

'serout fm,n1200,[$55,$04]
'pause 100
serout fm,n1200,[$55,$03]
pause 100
serout fm,n1200,[$55,$05,$00,$00]  'reset pointer
serout 16,b1200i,["start", cr,10]
'debug "Start", cr
pause 2000
GetData:
if Addr = 32767 then EOF
serout fm,n1200,[$55,$01,highaddr,lowaddr]
serin tm,n1200,[value]
serout 16,b1200i,[value]
'debug value
Addr = Addr + 1
if value = "*" then EOR
if value = "#" then EOF
goto GetData
EOR:
serout 16,b1200i,[cr,10]
'debug CR
goto GetData

EOF:
high mode
end
```

After connecting the capsule to the PC with the downloading cable, start the Windows terminal program (HyperTerminal) and give it the following settings:

N81
1200 baud

Save these settings and create an icon for the HyperTerminal.

Start HyperTerminal and open a download file.  Next power up the capsule and watch the data get sent to the HyperTerminal.  After the data is downloaded, close the download file, save the file under a meaningful name (one related to the flight designation), and close HyperTerminal.  Start Notepad and open the download file.  Edit any fields requiring changes.  There are three changes I recommend.  The first is to fix the altitude field for very low altitudes.  The second is to add commas in the time field to separate hours, minutes, and seconds, and the third is to add commas in the latitude and longitude fields to separate degrees from minutes.  After saving the modified file it is ready to import the data log into a spreadsheet as a comma delimited file.

## 6.0    Module Umbilical
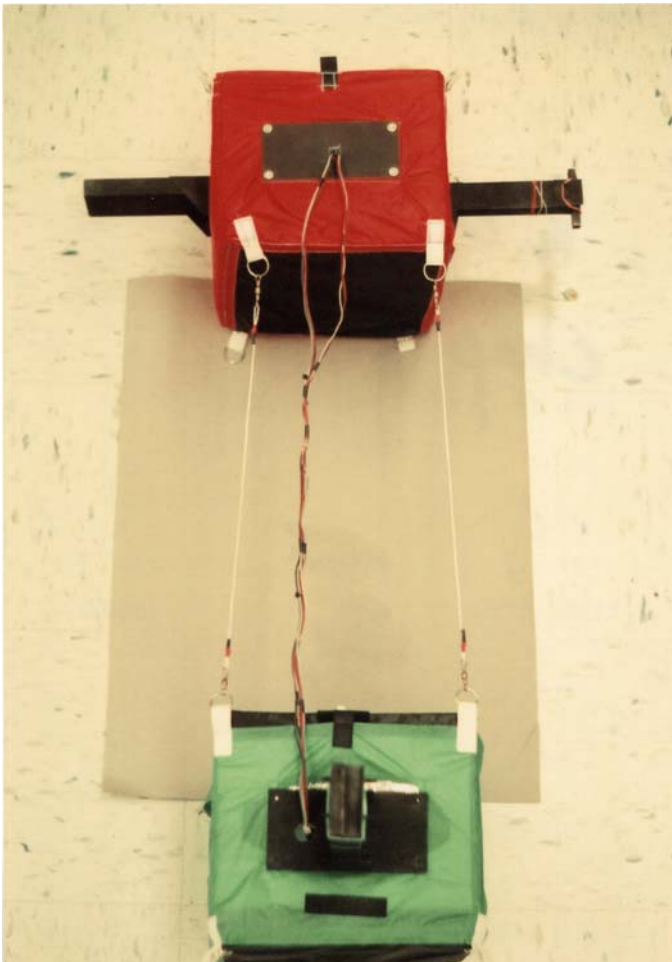


*Module Umbilical* – The umbilical cable typically consists of cables for servos and data.

To meet the simple weight requirements of FAR 101, there may be missions when experiments controlled by the flight computer are mounted to the other module.  When this is necessary, an umbilical must connect the flight computer on the first module to the experiments on the second module.  The umbilical typically consists of cables for servos and data.

Materials
- #24 AWG stranded wire
- Male headers, 0.1" between centers
- Crimp pins
- Crimp housings
- Crimper
- Several diameters of thin heat shrink tubing
- Hot glue

Procedure

This procedure describes the construction of cables that make up an umbilical. A cable is constructed for each experiment mounted to a module not containing the flight computer. Make a couple sets of cables and set them aside for later use. By far, most cables are either two- or three-wire cables. Two wire cables are used for power or signals and three wire cables are used on servo connections.

Cables
√ Cut two or three lengths of #24 AWG wire to a length of four feet. * Note: Make the wire colors red for power, black for ground, and white for signal.
√ Cut several one-inch long pieces of thin heat shrink tubing with a diameter large enough to slide over all the wires in the cable.
√ Slide the tubing evenly over the wires, but several inches from the end, and shrink them to keep the wires in a neat bundle.
√ Strip ¼" of insulation from the ends of the wires on one end of the cable.
√ Crimp pins on the wires and solder.
√ Cut a crimp housing wide enough for the wires in the cable and trim the cut edges.
√ Insert the crimped wires into the housing. Note: Watch the order of the wires in the cable.
√ Cut a length of 0.1" male headers three pins wide.
√ Slide one-inch lengths of thin heat shrink tubing over the open ends of the wires.
√ Strip ¼" of insulation from each of the wires in the open ends of the three wires.
√ Twist and tin the ends of the exposed wires.
√ Tin the short side of the pins in the male header.
√ Solder the wires to the headers. Note: Watch the correct placement of the wires in the cable.
√ Slide the heat shrink tubing over the soldered connections and shrink.
√ Apply a small amount of hot glue between the pins on the male header.
√ Slide a two-inch length of heat shrink tubing over the open ends of the wires.
√ Position and shrink the tubing so that the long end of the pins are exposed but the soldered short end of the pins is not.

* Depending on the length of the link lines, the lengths of the wires will change. Each wire must connect one end to the flight computer and the other end near the umbilical opening of the second module. My experience is that four feet is long enough to do this. In all cases, make sure the cables are long enough that the link lines are under tension, and the cables are not.

Alternative Cables

An alternative to the above procedures is to make an umbilical from ribbon cables. I cannot stand working with ribbon cable because of the fineness of the wires in it. Perhaps you will have better luck that me.

## 6.1. <u>Directions for Use</u>

### 6.1.1. Materials Needed to Incorporate an Umbilical
- Duct tape
- Twister seals
- Masking tape

### 6.1.2. Procedure
Preplanning
- √ Determine which modules are to contain the flight computer and experiments.
- √ Determine an orientation for the modules, that is, determine which faces of the modules line up with each other.
- √ Note: Take into account the position of experiments and Quad panels with openings to pass cables through.

In the Primary Module
- √ Connect the necessary cables to the flight computer.
- √ Extend the cables through the opening in the proper Quad panel. Note: Select a Quad panel where the cable(s) will not interfere with the mission, like get in the way of a camera.
- √ Label the function of each cable with a small piece of masking tape near the open end of the cable.
- √ Consolidate the cables into a single umbilical with twister seals. Note: Apply twister seals about every six inches, with each twister seal bundling every cable into a single umbilical.

In The Secondary Module
- √ Label the free end of each experiment cable with a piece of masking tape.
- √ Extend all cables from experiments in the secondary module through an opening in the proper Quad panel.
- √ Combine the cables into a single umbilical with a twister seal after the cable exits the airframe.

During Capsule Closeout (at the launch site)
- √ Link the modules of the capsule together with link lines.
- √ Connect like-labeled cables in the umbilical together.
- √ Separate modules to verify that the umbilical is long enough.
- √ Remove masking tape labels.
- √ Apply a small strip of duct tape around each connected cable housing.
- √ Twist tie the umbilical together around the connections.
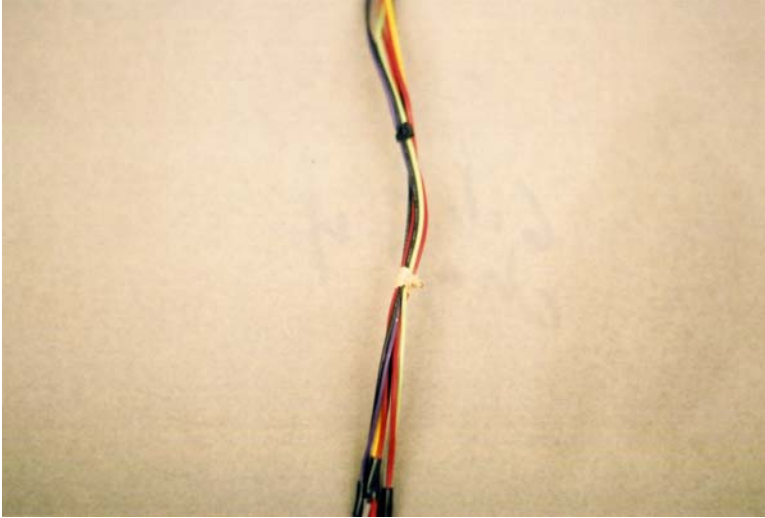
*The taped umbilical cable.*

## Good to Know

The Global Positioning System



**Got GPS?** *Once the near spacecraft is recovered, everyone brings out their GPS receiver.*

How the GPS Works
One of the most important components on board the near space capsule is the GPS receiver. Without it, it is difficult to both locate the capsule and analyze the returned science. While you can achieve successful results without understanding the GPS receiver, you will be even more successful with an understanding of it.

There are three parts (called segments) making up the GPS system: a space segment made up of satellites, a control segment made up of ground stations that monitor and update the satellites, and a user segment made up of all the GPS receivers currently in use. We are users of the third segment and depend on the proper functioning and the accuracy of the space control and ground segments.
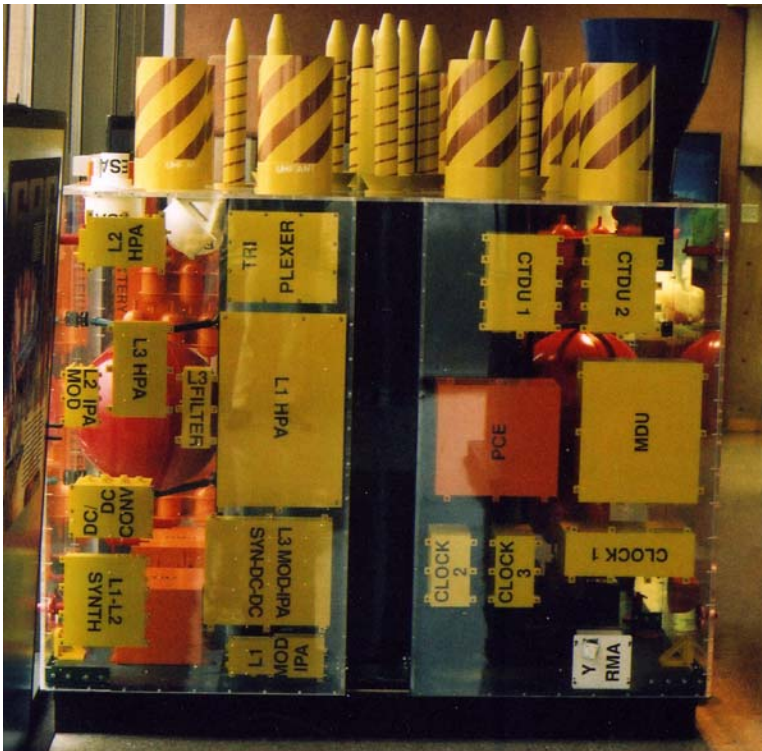
The Space Segment

The NAVSTAR (NAVigation, Satellite Timing And Ranging) satellites are a constellation of 24 satellites orbiting the Earth in twelve-hour orbits at an altitude of 13,000 statute miles.
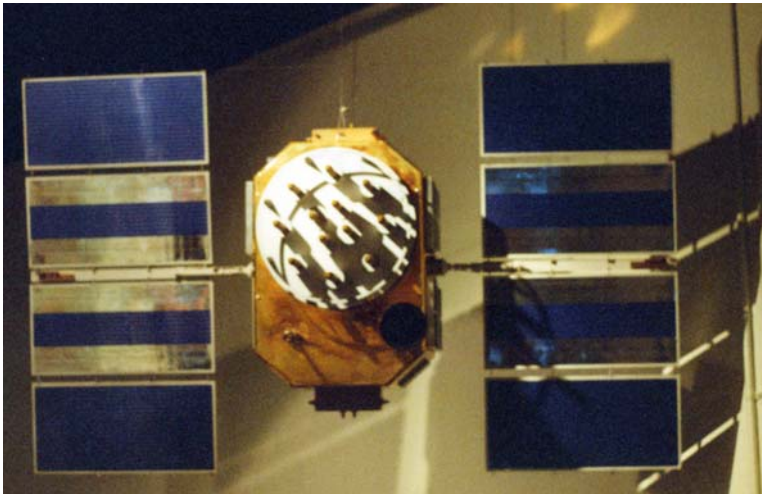


*Cool Satellite –A Navstar satellite on display in a museum. This is the space element of the GPS system.*

Four satellites evenly occupy each of the six orbits of the constellation. Each orbit is inclined 55 degrees to Earth's equator and equally spaced out. In this way, there is always more than the minimum of four visible satellites needed by a GPS receiver to determine an accurate position.



*Interior of Transparent GPS Satellite – Almost 6 feet tall. From the Space History Museum in Alamogordo, New Mexico.*

Each satellite contains a synchronized atomic clock and transmits data to both the user and the ground control segments. The user segment receives two separate channels, L1 and L2, of navigation data.

L1 (1575.42 MHz)

The L1 channel broadcasts C/A Code, P Code, and NAV messages.

L2 (1227.60 MHz)
The L2 channel broadcasts P Code (no C/A Code) and NAV messages.

C/A Code
(Course/Acquisition Code) consists of a short series of pseudorandom bits. C/A Code does not provide the accuracy that P Code does and is the only code that civilian GPS receivers receive. Being pseudorandom, the C/A code for each NAVSTAR is unique. A unique pseudorandom code from each satellite is necessary for identification, as all NAVSTAR satellites transmit on the same frequency using CDMA (Code Division, Multiple Access). The unique pseudorandom code prevents NAVSTARs from jamming one another so a GPS receiver can determine which NAVSTARs are heard. C/A Code is amazingly accurate. With Selective Availability (SA) turned off, your GPS receiver determines a position within less than 100 feet most of the time. Watch the amount a stationary GPS position jumps around to see this accuracy. If someday you suddenly notice a drop in accuracy, then there is probably trouble some place in the world.
The alternative to using pseudorandom codes on the same frequency is to do what Glonass (the Russian version of GPS) does. Satellites in the Glonass system transmit on one of 25 separate frequencies, instead of all sharing the same frequency. This use of separate frequencies by FDMA (Frequency Division Multiple Access) adds to the complexity of the Glonass User Segment.

P Code
P Code is Precise Code and consists of a very long series of pseudorandom bits that is modulated at a higher frequency than C/A Code. The P Code is encrypted, making it available to only military GPS receivers.

NAV Messages
NAV Messages are broadcast over both channels (by modulating the C/A and P Codes at 50 bits per second) and contains the following information:

System Time (from atomic clocks)
Corrections to the clock
Data on how the ionosphere delays L1 and L2 channels from the NAVSTAR
Satellite ephemeris (describes the orbits of the NAVSTARs)
NAVSTAR health (who's working and who's not)

The Control Segment
The Control Segment maintains the health and accuracy of the NAVSTAR constellation. Several monitoring stations spread over the world and under the centralized control of the Master Control Station in Colorado Springs, Colorado makes up the Control Segment. In addition to transmitting L1 and L2 channels to the User Segment, each NAVSTAR satellite also transmits its clock time and ephemeris to monitoring stations in the Control Segment. The Master Control Station computes corrections for each satellite and has those corrections sent back up to each NAVSTAR. Updates are necessary as atomic clocks and satellite orbits drift. Some health and status reports of NAVSTARs can be heard over the WWV radio station, the Atomic Clock broadcaster in Boulder, Colorado.

The User Segment
Once our GPS receiver identifies the C/A Code for each satellite it can hear, it retrieves the following information from the NAV data:
System Time
Clock Corrections

Propagation Delays
Satellite (Vehicle) Ephemeris
Satellite Health

Determining a three-dimensional fix requires the GPS receiver to lock onto four satellites. Locking on a satellite means the GPS receiver claims it has identified a satellite (by its C/A Code) and understands the satellite's transmissions. The two factors impacting a receiver's ability to lock in a satellite are how close the satellite is to the horizon and the obstacles on the ground blocking its transmissions. While in near space there are no obstacles blocking satellite transmissions, a low satellite is still a problem. The antenna of a GPS receiver is designed to give very good coverage over most of the sky, with antenna gain dropping off only near the horizon (recall that the horizon is depressed in near space, giving the near spacecraft a larger sky to see NAVSTARs).

A good way to visualize how a GPS receiver determines its position is to picture what kinds of positions can be determined with one, two, three, and four satellites. But first, remember that light travels at a known and (ideally) fixed speed. The further the GPS receiver is from a NAVSTAR satellite, the greater the difference between the GPS receiver's clock time and the satellite's clock time.
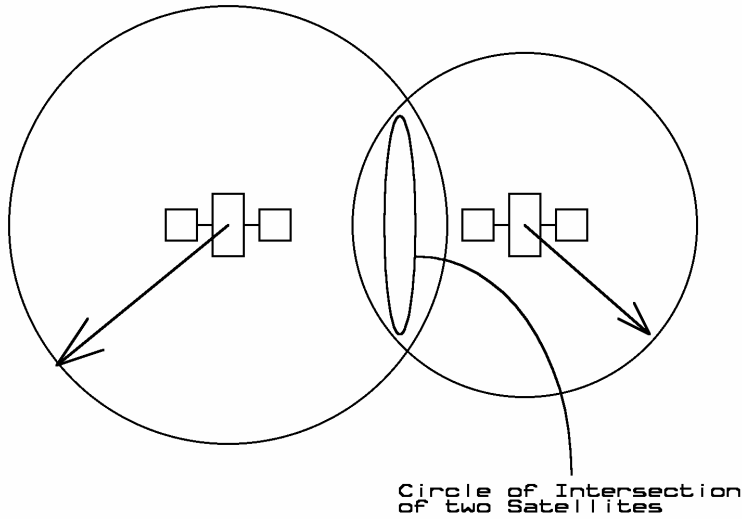
One Satellite Case
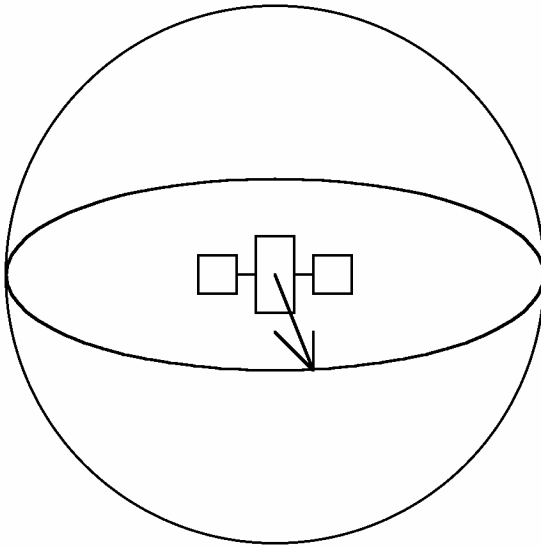


**One satellite diagram** – If you know your distance from one satellite, then you are located somewhere on the surface of this sphere.

Assuming the GPS receiver's clock time is accurate, when a GPS receiver knows its distance from a single satellite, then the GPS receiver knows it is located somewhere on a sphere with a radius of that known distance, centered on the satellite. Note however that a GPS receiver does not know the precise time with only one NAVSTAR: it requires several NAVSTARs to determine the time accurately. So the one satellite solution is just a thought experiment.
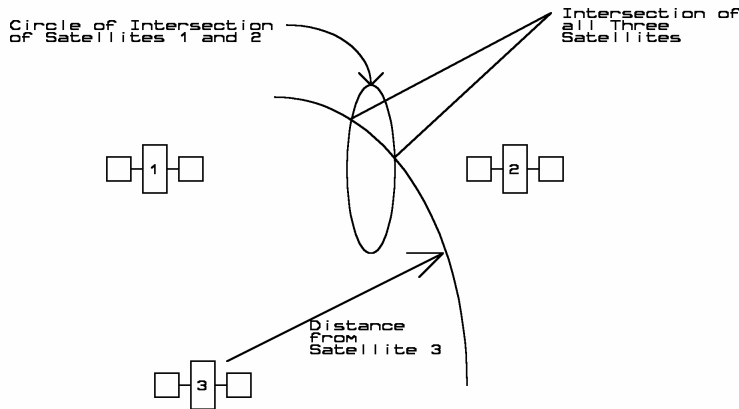
Two Satellite Case

**Circle of Intersection of two Satellites**

*Two Satellite Diagram* – *If you know your distance from two satellites, then you are located somewhere on the circle of the intersection of the two spheres.*

Since the intersection of two spheres creates a circle, knowing its distance from two satellites lets the GPS receiver determine its position along a ring in space.
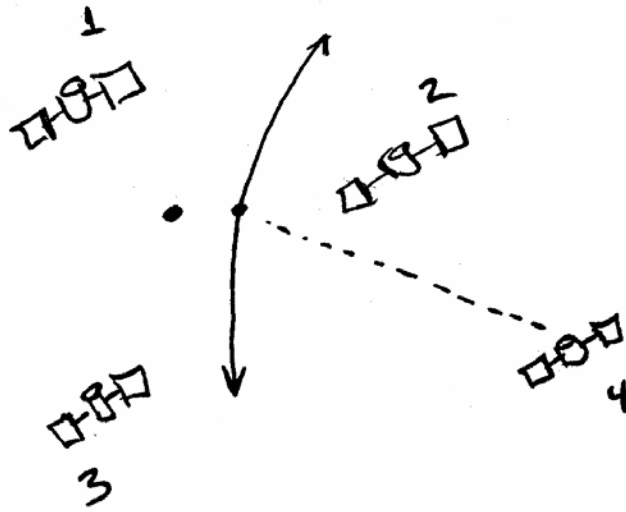
Three Satellite Case



Circle of Intersection of Satellites 1 and 2

Intersection of all Three Satellites

Distance from Satellite 3

*Three Satellite Diagram* – *If you know your distance from three satellites, then you are located at one of two points formed by the intersection of the last example's circle and the sphere from Satellite #3.*

The intersection between a circle (determined by the two satellite case) and a third, new sphere (determined by the third satellite), is two points.  Ideally then, when three satellite distances are known, the GPS receiver can determine two possible positions where it could be located.  One of the positions will make sense and other one won't (for instance, the Earth would block signals from a GPS receiver located at the second position).  Ideally a GPS receiver should be able to determine its altitude in this case.  Because of the GPS receiver's uncertainty about the time (brought on by things like propagation delays through the ionosphere) a GPS receiver does not attempt to determine the altitude of the receiver (the GPS only gives a 2-D fix).

Four Satellite Case

***Four Satellite Diagram*** – *When you know your distance from a fourth satellite, one of the points from the three satellite case can be thrown out. In actual use, the distance from a single NAVSTAR cannot be determined without the help of signals from other NAVSTARs.*

With an additional satellite, only one of the two points determined from the first three-satellite case intersects with the sphere around the fourth satellite. In addition, the extra satellite signal lets the GPS receiver determine the system time more accurately, leading to more accurate positions and an altitude determination. Note that the altitude is the least accurately determined position generated by a GPS receiver.

The NMEA Standard and the Two Most Important GPS Sentences for Near Space
GPS receivers output data following standards designed by the National Marine Electronics Association (NMEA). The particular specification followed is designated NMEA-0183. The NMEA-0183 specifications require GPS receivers to transmit data as RS232 (inverted logic) serial at 4800 baud N81. NMEA-0183 has designated several standard sentences, of which the two most important sentences for near space work are the GGA and RMC sentences. Here's an example of these two sentences:

$GPGGA,153919.00,4332.2076,N,11608.6666,W,1,08,1.1,13497.1,M,18.3,M,,*78
$GPRMC,153924.00,A,4332.2317,N,11608.6330,W,24.4, 46.3,231099,16.1,E*7E

Every NMEA-0183 sentence from a GPS receiver begins with $GP. The $ indicates the beginning of a sentence and GP indicates the sentence comes from a GPS receiver. The rest of the first field of each example identifies the type of sentence; in this example, either GGA or RMC.

The next field in both the GGA and RMC sentences is the time is in hours, minutes, and seconds in UTC, which is Coordinated Universal Time determined by the atomic clock and broadcast by WWV in Fort Collins, Colorado. UTC is synchronized with GMT, or Greenwich Mean Time, also called Zulu time, in London, England. A GPS displays a blank field here if it doesn't have a position fix. Indeed the GPS receiver cannot know the time accurately unless it has a position fix. If you see two commas after the sentence type, then the GPS is determining a position at the time the sentence was generated.

In both sentences, the fields following the time in UTC are the latitude in degrees and decimal minutes followed by the longitude in degrees and decimal minutes. A comma separates the latitude

and longitude. There is no separation between the degrees and minutes in both the latitude and longitude, but there is a decimal separating the whole minutes from the fractional minutes.

The other fields in these sentences are formatted as follows:

The GPGGA Sentence
$GPGGA, Time in UTC, Latitude North, Longitude West, GPS Quality Indicator, Number of Satellites, DOHP, Altitude in Meters, Geoidal Separation in Meters, Age of Differential Data, Differential Reference Station ID, Checksum.
The terminology in this sentence is explained below.

Where:
$GPGGA is the sentence type.
The time is in hours, minutes, and seconds
Latitude is in degrees and decimal minutes.
Longitude is in degrees and decimal minutes.
GPS Quality Indicator is 0 if the GPS hasn't calculated a position solution, 1 if the GPS has calculated a position solution, and 2 if the GPS is using differential data in its position solution.
The Number of Satellites indicates the number of satellites the GPS has a lock on.
DOHP is the Dilution of Horizontal Position, an indicator of the accuracy of the GPS receiver's position calculation. The closer to 1.0, the better.
Altitude is the GPS antenna's height above an ideally shaped Earth.
Geoidal Separation indicates a mathematical correction to the Earth's shape.
Differential data is left blank unless a differential receiver is sending data to the GPS receiver.
Checksum is a mathematically calculated hexadecimal number describing the total text of the sentence. It is used to detect data errors.

The GPRMC Sentence
$GPRMC, Time in UTC, Latitude North, Longitude West, Speed in Knots, Heading in Degrees, True North, The Date, Magnetic Variation, Checksum

Where:
$GPRMC is the sentence type.
The time is in hours, minutes, and seconds as determined by the Universal Time Clock.
Latitude is in degrees and decimal minutes.
Longitude is in degrees and decimal minutes.
Speed is given in nautical miles per hour (1 knot is equal to 1.2 mph).
The heading is the direction of travel and is not related to the direction the GPS is pointed.
Magnetic Variation is the difference between true north and magnetic north.
Checksum is a mathematically calculated hexadecimal number describing the total text of the sentence. It is used to detect data errors.

Sources for this report:
OnCore User's Guide Version 7.0, Motorola
http://www.trimble.com
JPL's satellite website, http://Leonardo.jpl.nasa.gov/msl/QuickLooks/

## Near Space Humor

## Eleven Places You Don't Want Your Near Space Capsule To Recover

1. In the exercise yard of the state penitentiary.
2. In front of the White House.
3. On top of the containment building of your local nuclear power plant.
4. On the property of an anti-government militia during their Saturday practices.
5. In the middle of the state's largest lake.
6. In an open railcar of an express train on its way to the other side of the country.
7. In automobile junkyard guarded by the biggest, meanest dog you've ever seen.
8. On the runway of a major airport.
9. In the bottom of the Grand Canyon.
10. On the top of the state's tallest mountain in the middle of winter.
11. On the north rim of the Grand Canyon, while you're on the South Rim.

## Appendix A – LM2940 Datasheet

*National Semiconductor*

January 2003

**LM2940/LM2940C 1A Low Dropout Regulator**

# LM2940/LM2940C
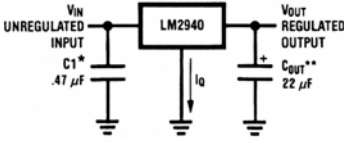# 1A Low Dropout Regulator

## General Description

The LM2940/LM2940C positive voltage regulator features the ability to source 1A of output current with a dropout voltage of typically 0.5V and a maximum of 1V over the entire temperature range. Furthermore, a quiescent current reduction circuit has been included which reduces the ground current when the differential between the input voltage and the output voltage exceeds approximately 3V. The quiescent current with 1A of output current and an input-output differential of 5V is therefore only 30 mA. Higher quiescent currents only exist when the regulator is in the dropout mode ($V_{IN} - V_{OUT} \leq 3V$).

Designed also for vehicular applications, the LM2940/LM2940C and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. During line transients, such as load dump when the input voltage can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both the internal circuits and the load. The LM2940/LM2940C cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

## Features

- Dropout voltage typically 0.5V @$I_O$ = 1A
- Output current in excess of 1A
- Output voltage trimmed before assembly
- Reverse battery protection
- Internal short circuit current limit
- Mirror image insertion protection
- P+ Product Enhancement tested

## Typical Application



*Required if regulator is located far from power supply filter.

**$C_{OUT}$ must be at least 22 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

## Ordering Information

| Temperature Range | Output Voltage | | | | | | Package |
|---|---|---|---|---|---|---|---|
| | 5.0 | 8.0 | 9.0 | 10 | 12 | 15 | |
| 0°C ≤ T$_J$ ≤ 125°C | LM2940CT-5.0 | | LM2940CT-9.0 | | LM2940CT-12 | LM2940CT-15 | TO-220 |
| | LM2940CS-5.0 | | LM2940CS-9.0 | | LM2940CS-12 | LM2940CS-15 | TO-263 |
| −40°C ≤ T$_J$ ≤ 125°C | LM2940LD-5.0 | LM2940LD-8.0 | LM2940LD-9.0 | LM2940LD-10 | LM2940LD-12 | LM2940LD-15 | LLP 1k Units Tape and Reel |
| | LM2940LDX-5.0 | LM2940LDX-8.0 | LM2940LDX-9.0 | LM2940LDX-10 | LM2940LDX-12 | LM2940LDX-15 | LLP 4.5k Units Tape and Reel |
| −40°C ≤ T$_J$ ≤ 125°C | LM2940T-5.0 | LM2940T-8.0 | LM2940T-9.0 | LM2940T-10 | LM2940T-12 | | TO-220 |
| | LM2940S-5.0 | LM2940S-8.0 | LM2940S-9.0 | LM2940S-10 | LM2940S-12 | | TO-263 |
| −40°C ≤ T$_J$ ≤ 85°C | LM2940IMP-5.0 | LM2940IMP-8.0 | LM2940IMP-9.0 | LM2940IMP-10 | LM2940IMP-12 | LM2940IMP-15 | SOT-223 |
| | LM2940IMPX-5.0 | LM2940IMPX-8.0 | LM2940IMPX-9.0 | LM2940IMPX-10 | LM2940IMPX-12 | LM2940IMPX-15 | SOT-223 in Tape and Reel |
| SOT-223 Package Marking | L53B | L54B | L0EB | L55B | L56B | L70B | |

The physical size of the SOT-223 is too small to contain the full device part number. The package markings indicated are what will appear on the actual device.

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LM2940/LM2940C

## Ordering Information (Continued)

| Temperature Range | Output Voltage | | | | Package |
|---|---|---|---|---|---|
| | 5.0 | 8.0 | 12 | 15 | |
| −55°C ≤ $T_J$ ≤ 125°C | LM2940J-5.0/883 5962-8958701EA | LM2940J-8.0/883 5962-9088301QEA | LM2940J-12/883 5962-9088401QEA | LM2940J-15/883 5962-9088501QEA | J16A |
| | LM2940WG5.0/883 5962-8958701XA | | | | WG16A |

For information on military temperature range products, please go to the Mil/Aero Web Site at http://www.national.com/appinfo/milaero/index.html.

## Connection Diagrams

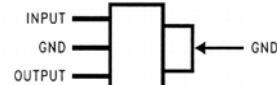### (TO-220) Plastic Package

GND
OUTPUT
GND
INPUT
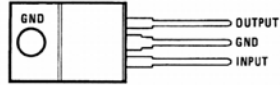
00882202

**Front View**
Order Number LM2940CT-5.0, LM2940CT-9.0,
LM2940CT-12, LM2940CT-15, LM2940T-5.0,
LM2940T-8.0, LM2940T-9.0,
LM2940T-10 or LM2940T-12
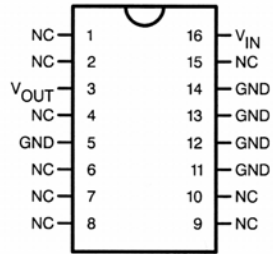See NS Package Number TO3B

### 3-Lead SOT-223

INPUT
GND
OUTPUT
GND

00882242

**Front View**
Order Part Number LM2940IMP-5.0,
LM2940IMP-8.0, LM2940IMP-9.0,
LM2940IMP-10, LM2940IMP-12 or LM2940IMP-15
See NS Package Number MP04A

### 16-Lead Dual-in-Line Package (J)

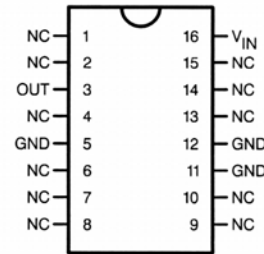| | | | | |
|---|---|---|---|---|
| NC | 1 | | 16 | $V_{IN}$ |
| NC | 2 | | 15 | NC |
| $V_{OUT}$ | 3 | | 14 | GND |
| NC | 4 | | 13 | GND |
| GND | 5 | | 12 | GND |
| NC | 6 | | 11 | GND |
| NC | 7 | | 10 | NC |
| NC | 8 | | 9 | NC |

00882243

**Top View**
Order Number LM2940J-5.0/883 (5962-8958701EA),
LM2940J-8.0/883 (5962-9088301QEA),
LM2940J-12/883 (5962-9088401QEA),
LM2940J-15/883 (5962-9088501QEA)
See NS Package Number J16A

### 16-Lead Ceramic Surface-Mount Package (WG)

| | | | | |
|---|---|---|---|---|
| NC | 1 | | 16 | $V_{IN}$ |
| NC | 2 | | 15 | NC |
| OUT | 3 | | 14 | NC |
| NC | 4 | | 13 | NC |
| GND | 5 | | 12 | GND |
| NC | 6 | | 11 | GND |
| NC | 7 | | 10 | NC |
| NC | 8 | | 9 | NC |

00882244

**Top View**
Order Number LM2940WG5.0/883 (5962-8958701XA)
See NS Package Number WG16A