Contents

Chapter 16 — Online Content

Articles
- A Simple Sensor Package for High Altitude Ballooning by John Post, KA5GSQ
- APRS Unveiled by Bob Simmons, WB6EYV
- APRS with a Smartphone by Pat Cain, KØPC
- ARRL Education and Technology Program Space/Sea Buoy by Mark Spencer, WA8SME
- Fox-1 Satellite Telemetry – Part 1: On the Satellite by Burns Fisher, W2BFJ
- Fox-1 Satellite Telemetry – Part 2: FoxTelem by Chris Thompson, AC2CZ
- Touching Near Space on a Budget by Paul Verhage, KD4STH
- High Altitude Platforms – folder with a collection of Powerpoint presentations and PDF articles by Paul Verhage, KD4STH

Chapter 16

Amateur Radio Data Platforms

This chapter addresses the increasing use of amateur communication as a key element of scientific experimentation. The use of amateur means to collect and track data focuses on high-altitude balloons, which are the most popular platform used for this purpose today. Other types of platforms, such as drones and rockets, are also used for experimenting and enjoying operating them. Amateur Radio plays an important role in supporting their use.

The chapter begins with a discussion of what types of sensors and transducers are used to collect data on these platforms. Navigation and telemetry streams are also fundamental to collecting data and operating the platform. Several types of telemetry and location data are covered here along with a review of how the information is transmitted from the platform. (See the **Digital Protocols and Modes** for descriptions of the modes themselves.)

Future editions will continue to expand coverage to additional technologies, platforms, and applications. Material in this edition was updated by Paul Verhage, KD4STH and Bill Brown, WB8ELK.

Amateurs conducting science experiments and operating mobile craft frequently use amateur radio for their data links and control signals, even as they cross continents and entire oceans! Such *platforms* include balloons and multi-rotor copters. Others are land-based (such as weather stations, animal tracking, or robots) or marine (ocean or river buoys or rovers). CubeSats (**www.cubesat.org**) also use Amateur Radio control and data links.

Building these platforms combines several technical fields: using sensors and data acquisition systems to measure events and phenomena, mechanical and electrical engineering to construct the platform, 3-dimensional navigation, and the data link and associated radio technologies. These hybrids are attracting the experimentalists and scientists to amateur radio, just as they were attracted at the dawn of the wireless age.

Support of scientific experimentation is hardly a new aspect of amateur radio — amateurs have supported science almost since the beginning when Tom Mix, 1TS, accompanied the explorer MacMillan to the Arctic aboard the *Bowdoin* in 1923. Amateurs assisted the Naval Laboratory in listening tests that helped establish the existence of the ionosphere. The story continued with Grote Reber, W9GFZ, and radio astronomy in the 1930s, broad participation by hams during the International Geophysical Year of 1957 – 1958, wildlife tracking, propagation reporting, satellite construction, and numerous other instances. Recently, hundreds of amateurs participated in the Solar Eclipse QSO Party (**hamsci.org**) to observe the effect of a total solar eclipse on HF propagation. There is no doubt that fulfillment of FCC Part 97.1 is thriving as hams continue to "improve the radio art" by adapting technology to new uses.

This chapter is organized in four parts: Platform Overview, Sensors, Telemetry and Navigation, and Platform Design. The goal is to cover the engineering necessary to assemble an effective platform. In recognition of the rapid innovation in these activities, this chapter will change in future editions. Expect to see new digital protocols and miniature telemetry and audio-image transmitters. Improvements will be forthcoming in portable-mobile power sources and antennas.

Although the *ARRL Handbook* strives to be complete, covering all aspects of these efforts is beyond the scope of this book. The referenced magazines and websites in the References and Bibliography section at the end of this chapter provide additional material and the latest updates on platforms and technology.

16.1 Platform Overview

Automated platforms are found in many locations carrying out a multitude of functions. They are often the solution to data collection in locations where it's not practical for humans to operate data collection devices for reasons such as safety or extensive time commitment requirements. Aside from data collection, automated platforms are also pressed into service as transponders, repeaters, and beacons. In instances such as these, automated platforms are well served by amateur radio because of the wireless communication requirements these platforms need to telemeter the data they generate, report their location and status, or forward analog and digital radio communications.

Although the primary platforms used today involve high-altitude balloon-borne experiments, similar considerations apply to other fixed and mobile terrestrial and marine experiment platforms.

16.1.1 Platform Structure

The generic structure of a remote sensing platform is shown in **Figure 16.1**. Along with the power source, there are five separate functions:

1) Sensor data or image acquisition — conversion of analog data into digital format and acquisition of still images or video

2) GPS or navigation data — acquisition of location data in digital form

3) Integration of sensor and location data — collection of all data to be stored and/or transmitted to the ground station

4) Protocol engine — packaging and encoding of data for transmission

5) Amateur transmitter — generates the digitally modulated RF signal

These functions can be implemented by separate modules, or everything can be performed by a single microcontroller-based module such as one of the APRS trackers. The choice is completely up to the platform designer and varies with the requirements for the particular mission. For example, **Figure 16.2** shows a two-module solution in which everything except GPS location is provided by the single MMT module. The ATV payload described later uses a separate controller to integrate the video and GPS data for transmission as part of the overall audio-video signal. The combinations are endless! The websites listed in the following section on high-altitude platforms (balloons) are good places to begin looking for the right subsystems for your mission.

DATALOGGERS

Dataloggers are standalone microprocessor-based devices that acquire or "log" digital and analog data on a pre-determined schedule, or when prompted by a pre-determined event. They can also acquire digital data from avionics and navigation equipment. The data is stored or transmitted for later analysis. Dataloggers are available as commercial products, or they can be home-built. Commercial dataloggers have the advantage of being durable and standardized. On the other hand, they may not be customizable to the extent desired for a science flight into the stratosphere. Popular microcontrollers such as the BASIC Stamp (Parallax), PICAXE, Arduino, and Raspberry Pi have made it much easier to create custom dataloggers that are also capable of operating experiments as well as just recording data.

TEMPERATURE RANGES AND HUMIDITY

The platforms discussed in this chapter are often used outdoors or in unprotected environments. As a result, the electronics and other sub-systems can be subjected to extreme temperatures for long periods of time. When selecting components, modules, or other equipment, make sure they are properly rated for the intended use.

The four most common temperature specifications for electronics and electro-mechanical systems are as follows:

Commercial: 0 °C to 85 °C
Industrial: –40 °C to 100 °C
Automotive: –40 °C to 125 °C
MIL-SPEC (or MIL-STD):
–55 °C to 125 °C

Components meeting Commercial Specifications will work well for fixed stations residing indoors. However, when designing outdoor fixed stations, the amateur must consider using components that at least meet industrial specifications.

A closely related specification is for relative humidity (RH), which is specified in percent and condensing or non-condensing. RH can range from 0% in the desert or upper atmosphere to 100% from rain or fog or in water-borne environments. "Condensing" means that liquid water forms on surfaces of the device or component directly from the air. If your platform will be subjected to condensing humidity or direct water spray or splash, consult the equipment manufacturer for the best methods of protecting the platform components.

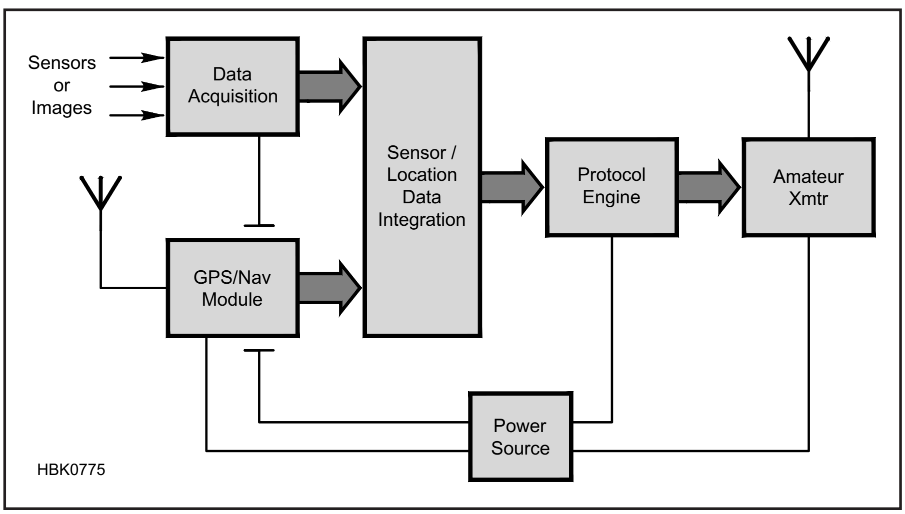

Figure 16.1 — The basic structure of a remote sensing platform using Amateur Radio for the telemetry link.

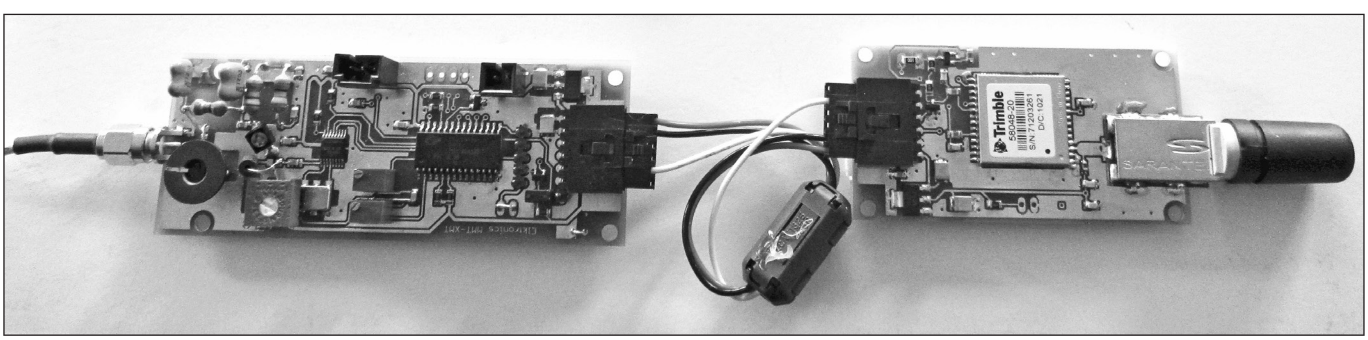

Figure 16.2 — A two-module payload consisting of a GPS receiver module (right) and WB8ELK's MMT (Multi-Mode Transmitter) on the left.

16.1.2 Types of Platforms

HIGH ALTITUDE BALLOONS

High altitude balloons are most frequently latex (mixed with neoprene) weather balloons designed to carry automated platforms weighing up to 12 pounds (heavier weights are possible) into near space. Altitudes above 60,000 feet (flight level 600) and below 328,000 feet are often referred to as *near space*. This region of the atmosphere has conditions that are closer to those found in Earth orbit than to Earth's surface.

Altitudes in excess of 100,000 feet are accessible using large weather balloons and lightweight platforms. Heavier platforms rely on polyethylene skinned balloons called *zero pressure balloons*. These balloons are vented to the atmosphere and do not develop an internal pressure above that of the surrounding atmosphere at any height (**www.eoss.org/faq/zero_pressure**).

The need for long duration flights across continents, oceans, and even circumnavigating the planet has necessitated the development of *super-pressure balloons*. These balloons have skins of high-tech plastics and are sealed airtight. This prevents their lifting gas from escaping and shortening their flight times. While zero pressure and super pressure balloons are traditionally in the realm of professionals, amateurs have been making use of sealed Mylar foil party balloons as well as larger, custom-built, super-pressure envelopes using a special plastic film.

To be successful, the total weight of the payload should be a half-ounce or less. A handful of amateurs have developed incredibly lightweight payloads, and most are totally solar-powered. In one instance, a UK-launched Mylar party balloon remained aloft for months and circled the globe 9 times. More recently, a balloon launched from Atlanta, Georgia, has stayed aloft over a year and has circled the globe more than 20 times.

A number of conditions are commonly measured or monitored, with a microprocessor-based datalogging system to acquire the data and convert it to digital form. The data is stored in onboard memory for recovery or transmitted to ground stations as a telemetry stream. The sensor data can also be integrated with the GPS data for transmission via APRS. Some APRS trackers can acquire analog and digital sensor data and integrate it into the APRS data messages.

Standalone experiments can also be attached to the balloon, then located and recovered after landing. Data collected by sensors carried by the weather balloon can then be analyzed and correlated to the balloon's altitude. Thus, it is extremely important that the payload be able to transmit or store position and altitude data during the flight while collecting data.

You can find a considerable amount of information about balloons and experimental platforms suitable for balloons at **arhab.org**, **wb8elk.com**, **eoss.org**, **ansr.org**, and **nearsys.com**. See also the References and Bibliography section at the end of this chapter.

BalloonSats

BalloonSats are packages with standalone high-altitude experiments. They do not include a tracker, since it is assumed they will be carried by operational platforms that include trackers. BalloonSats are an excellent way to introduce school students to near space exploration. They are simple systems that permit students to perform experiments in the space-like environment of near space.

UNMANNED AERIAL VEHICLES (UAV)

UAV development goes back centuries. However, it was the development of lightweight electronic autopilots that turned the UAV into the practical and affordable platform of today. With the commercial marketing of the four-bladed quadcopter and the six-bladed hexacopter with rechargeable lithium-polymer batteries, amateurs gained access to practical UAVs. The UAV has severe altitude and weight limits that balloons do not. However, the UAV provides a platform for imaging and datalogging at higher resolutions, over more restricted regions, with higher data immediacy and quicker turnaround time. The popularity of this platform and the potential risks posed to conventional aviation have resulted in registration requirements and flight restrictions.

AMATEUR ROCKETRY

Experiments with amateur rocketry began in the late 1920s in Germany. By the 1950s, amateur rocketry had become a growing hobby for post-war America, especially after the launch of Sputnik 1 in 1957.

With the introduction of modern composite propellants and lightweight digital electronics, serious data collection is now possible. Unlike balloons and UAVs, rocket-based platforms must account for the rapid accelerations and tight dimensions inherent in rocketry. Because of their high accelerations, the rocket makes data collection possible at high altitudes but only over very short time frames.

ROBOTICS

Robots can be described as either *autonomous* or *semiautonomous*, depending on the amount of human input they require. Among the most famous robots are the series of rovers NASA has sent to explore the surface of Mars. Inexpensive microcontrollers, which are a form of programmable logic, have brought robotics to the amateur level. Robots often have fewer weight limits than balloons, rockets, or UAVs. They can also carry platforms to desired locations and remain on site while their platform performs its mission. Finally, robots usually place fewer power limits on their platforms than balloons, rockets, and UAVs. However, robots tend to cover the ground at slow speeds and limit their platforms to recording data from the ground level.

FIXED AND FLOATING PLATFORMS

Fixed platforms are any data collection stations that remain in one location. This can be due to their being mounted to a pole like a weather station or anchored to the seabed like a buoy. Typically, fixed platforms remain in place for long duration data collecting or imaging. As such, they require protection from the elements. They also require occasional maintenance from a human who goes onsite to service the fixed platform.

Some are floating buoys that may or may not be anchored. Anchored buoys can be treated as a fixed station. Free-floating buoys or marine rover-style platforms travel on the body of water either under self-contained power or by following the winds and currents.

16.2 Sensors

Inexpensive sensors and microcontrollers combined with amateur radio create opportunities for the amateur to perform experiments in environments that are otherwise inaccessible for one reason or another. Many interesting regions of the Earth, including extremely high altitudes in the atmosphere or the distant ocean, fall into this category. Hams can be instrumental in helping both amateurs and professionals explore these environments.

These platforms enable *remote sensing* — observing or measuring an object or event without a human being actually being in contact with the condition being measured. Data from the measurement is then stored on the platform for eventual collection after recovery or transmitted to a ground station for recording and analysis (telemetry). Examples of parameters that are measured by amateur remote sensing platforms include temperature, pressure (air and water/fluid), humidity, ozone and other gasses, acceleration, and light.

A sensor is a device that reacts to a specific condition of interest, such as temperature or pressure, and produces a predictable output in response. The first step is to select the appropriate sensor or sensors for the parameter of interest and a means of converting sensor outputs to digital data, usually by connecting the outputs to a microcontroller or analog to digital converter IC. Sensors and their associated *signal conditioning* circuits are the "front end" of remote sensing. Analogous to the speech and video circuits of traditional amateur transmitters, the same care in their design is required if quality results are to be obtained.

This section divides sensors into the following four types of outputs: *resistance-based, current-based, voltage-based,* and *digital*. In addition, four common types of sensor outputs are discussed here. Not all of these outputs are directly readable by a microcontroller. However, methods exist to convert the output of these sensors into a form that can be interfaced to a microcontroller. (See the Analog/Digital Conversion section of the **DSP and SDR Fundamentals** chapter.)

16.2.1 Resistance-Based Sensors

Resistance-based sensors change an internal resistance in response to the environmental variable they measure. An example includes the photocell, which is constructed of the chemical cadmium sulfide (CdS), a semiconductor that produces electrons and holes when irradiated by light. The production of free electrons and holes reduces the resistance of CdS when it is exposed to light.

In many cases, the change in resistance in response to changes in the measured condition is small. Therefore, sensor manufacturers often incorporate additional circuitry with the sensing element to convert this changing resistance into a more easily measured change in voltage. However, resistive-type sensors (without signal conditioning) are still available and quite useable.

Resistance-based sensors do not create a signal that a microcontroller can measure directly. Instead, the resistance of the sensor is used to vary the voltage from a regulated voltage source. A simple and popular circuit capable of converting a changing resistance into a changing voltage is the voltage divider as described in the **Electrical Fundamentals** chapter.

The voltage divider circuit of two resistors is shown in **Figure 16.3**. One resistor is fixed in resistance (R_F), and the other is the sensor and therefore variable in resistance (R_V). The current through the voltage divider circuit is variable. It increases as the resistance of the variable sensing element decreases and vice-versa. However, the sum of the two voltage drops is always equal to the supply voltage. The preferred arrangement of the two resistors depends on the response of the sensing resistor to the condition to which it responds — temperature, humidity, illumination, and so on.

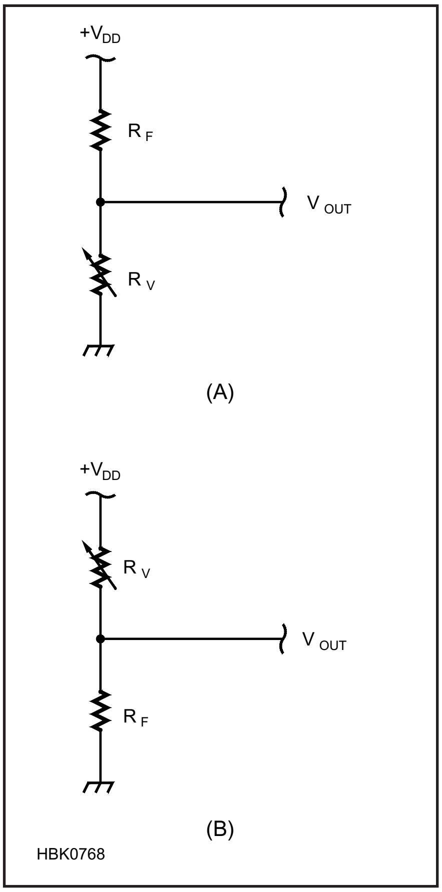

Figure 16.3 — The voltage divider circuit, a series circuit of two resistors. The orientation of resistors in A is preferable when the sensing resistor increases resistance in response to an increasing condition. Use B when the sensing resistor decreases resistance in response to an increasing condition. This results in the output voltage increasing with the increasing condition.

A microcontroller connected to the voltage divider circuit digitizes the voltage across the resistor connected to ground. This permits the design of resistance-based sensors into circuits that produce changing voltages which follow the change in the condition. For example, the resistance of photocells decreases as the light intensity increases. A microcontroller digitizing the voltage across a photocell connected as R_V in Figure 16.3A will observe V_{OUT} *increasing* as light intensity *decreases*. If however, the photocell is connected as R_V in Figure 16.3B, V_{OUT} *increases* as the light intensity *increases*. The latter case is easier to understand and work with than having output voltage and the sensed condition varying in opposite directions (or inversely proportional).

There are two equations that describe the output of the voltage divider circuit. The first describes the voltage drop across the variable resistor, and the second describes the voltage drop across the fixed resistor.

For Figure 16.3A:

$$V_{OUT} = +V\,(R_V/(R_F + R_V))$$

For Figure 16.3B:

$$V_{OUT} = +V\,(R_F/(R_F + R_V))$$

OPTIMIZING R_F

The equations above show that the value selected for R_F has a large impact on the range of output voltages created by the voltage divider circuit. The precision of the sensor output is greatest when the voltage range of V_{OUT} is maximized. The value of R_F that generates the maximum range is the geometric mean of the sensor's highest expected resistance (R_H) and lowest expected resistance (R_L). The equation for calculating the best fixed resistor value (R_F) in a voltage divider circuit is:

$$R_f = \sqrt{R_H R_L}$$

The maximum range for V_{OUT} of the voltage divider circuit is thus equal to 1/3 of the supply voltage, V_{DD}. Furthermore, the voltage range is centered at the midpoint of the supply voltage. The following three equations calculate the minimum voltage, maximum voltage, and voltage range of an optimized voltage divider.

$V_{MIN} = V_{DD}/3$

$V_{MAX} = 2V_{DD}/3$

$\text{Range} = V_{MIN} - V_{MAX} = V_{DD}/3$

16.2.2 Current-Based Sensors

Some types of sensors generate or change output current in response to the environmental condition they are measuring. Examples include the photodiode, solar cell, and light-emitting diode (LED). All three of these devices are similar, although not used in similar ways. When a photon of light is absorbed, its energy gives an electron in the device enough energy to jump across the PN junction. The electron creates a measurable current from the sensor.

The LED is one of the most surprising current-based sensors. While the photodiode is sensitive to a wide range of frequencies, the LED is most sensitive to light at the wavelength it emits when forward biased. This makes the LED a very inexpensive spectrally sensitive photometer. (See the References and Bibliography section entry for Mims for a description of the LED responses.)

A current-based sensor can provide useful data when connected to a digital multimeter (DMM) set to measure milliamps of current. However, this is not a suitable configuration for a microcontroller with the capability to digitize voltage. Therefore, it is necessary to find a way to convert changing current into a changing voltage. Two popular ways to accomplish this are to use a transimpedance amplifier or by measuring the charging time of a capacitor.

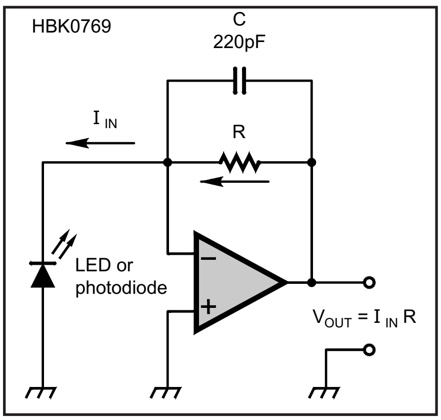

Figure 16.4 — The transimpedance amplifier converts current at its input to voltage at the output by balancing current through R with the input current.

THE TRANSIMPEDANCE AMPLIFIER

The transimpedance amplifier in **Figure 16.4** is a popular op amp circuit that converts input current into an output voltage. The feedback resistor, R, sets the gain of the transimpedance amplifier. The output voltage is given by the following equation:

$$V_{OUT} = I_{IN} \times R$$

The capacitor, C, reduces gain at high frequencies above 1/RC, acting as a low-pass filter to reduce noise. A generally useful value is 220 pF with the usual values of R for LED light-sensing. You will have to take the bandwidth of your measurement into account when choosing the value of C.

It is important that the value selected for the feedback resistor does not result in amplifier saturation for high sensor output levels. In those circumstances, data is lost when the sensor output is too high and the amplifier saturates.

USING CAPACITOR CHARGE TIME

A second method to digitize the current from a sensor is to measure the length of time required for a current to charge or discharge a capacitor to a certain voltage. One example can be found in the book *Earth Measurements* by Parallax (**www.parallax.com**, manufacturer of the BASIC Stamp microcontrollers). Here, the BASIC Stamp initially charges a capacitor. The Stamp then measures the length of time required for the capacitor to discharge due to the current entering it from the current-based sensor. The capacitor and resistor values are selected according to the expected current output of the sensor. The book uses the circuit in **Figure 16.5** to measure the current output of a photodiode or LED.

The program shown in **Table 16.1** (*Earth Measurements*, Program 4.2) was written to use the schematic in Figure 16.5. It assumes the circuit connects to the BASIC Stamp via I/O pin 6. Change the I/O reference to another pin as needed by your circuit.

The program reports the light intensity once per second. It begins by charging the capacitor to the same potential as the supply voltage through the use of the `HIGH 6` command. Afterward, the reverse current emitted by the LED, due to its exposure to light, discharges the capacitor. The changing potential of the capacitor makes the voltage drop across the LED appear to decrease from its start at +5 V. Any voltage above 1.4 V is treated as a logic high by the BASIC Stamp. Therefore, as reverse current from the LED brings the capacitor voltage lower, the voltage across the LED eventually becomes lower than 1.4 V and a logic low.

The `RCTime` command counts the time (in units of 2 μs) required for I/O pin 6 to change from a logic high (above 1.4 V) to a logic low (below 1.4 V). The result in units of 2 μs is stored in the variable `RCT`. The greater the

Table 16.1
BASIC Stamp Program

This BASIC Stamp program is used with the circuit of Figure 16.5 for measuring light intensity.

```
RCT VAR Word
Light VAR Word
HIGH 6

Loop:
      RCTIME 6,1,RCT
      HIGH 6
      Light = 65535/RCT
      DEBUG "Light Intensity: ", DEC Light
      PAUSE 1000
      GOTO Loop
```

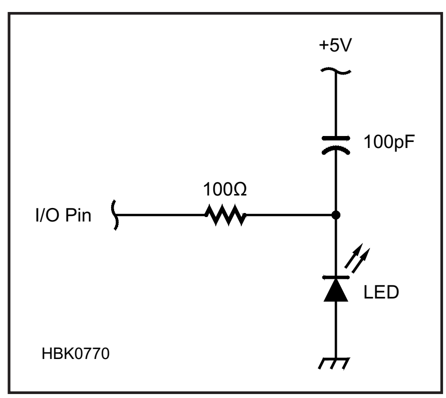

Figure 16.5 — The circuit recommended by Parallax for digitizing the current output of a photodiode or LED. See text for more information about using this circuit for current measurement.

intensity of the light shining on the LED, the faster the capacitor discharges and the smaller the value stored in the variable RCT. The value in RCT is then divided into 65535 to invert the relationship and is stored in the variable LIGHT, which contains a value directly proportional to light intensity.

16.2.3 Voltage-Based Sensors

Some types of sensors change their voltage output in response to the condition they are measuring. Examples include the LM355 temperature sensor, Honeywell's HIH-4000 relative humidity sensor, and Microdyne's MPS-3138 pressure sensor. These devices are typically current or resistance-based sensors along with circuitry to amplify and condition the output into a useable voltage change.

The voltage-based sensors easiest to interface are those that include signal amplification and correction on the chip. The result can be a ratiometric output that is linear and proportional to the supply voltage. The conversion factor for the sensor needed to convert its voltage into the environmental condition being measured is documented in the device's datasheet.

Pressure sensors can be used as altitude sensors for an airborne platform if a digital solution, such as GPS, is not available. Absolute pressure is preferred, although it must be calibrated against ground barometric pressure before launch and, if the flight covers long distance, requires additional corrections based on local pressure data.

16.2.4 Capacitance-Based Sensors

Capacitance-based sensors use changes in capacitance as their primary means of measurement. Capacitance between two electrodes of known area depends on the distance between the electrodes and the dielectric constant of the insulating material separating them. Any process that changes either separation or dielectric constant can be then be sensed as a change in the capacitance. Parameters that are sensed in this manner include motion, moisture, fluid and material level, chemical composition, and acceleration.

Sensors based on capacitance are rarely supplied without signal conditioning and linearization. Many have digital outputs that supply the measurement as a digital value. Another option is to have the sensor's capacitance control the frequency of an oscillator, which can then be read by a digital circuit. For more information on capacitive sensing, the excellent overview at **www.capsense.com/capsense-wp.pdf** is recommended.

16.2.5 Sensor Calibration

Sensors come in two basic configurations: *sensing elements* and *conditioned sensors*. The voltage divider discussed earlier is an example of a sensing element. There are no electronics associated with the divider — the package contains only the two resistors and the necessary connecting wires or terminals. Conditioned sensors contain electronic circuitry that operates on the signal from the sensing element before it is made available externally. The circuits usually regulate power applied to the sensor and also *linearize* the data so that a linear range of measurements is represented by a linear change in output voltage.

All sensing elements and some conditioned sensors require a calibration equation to convert the output signal into the parameter value the sensor is measuring. In some cases, the equation is simple and linear as in the LM335 temperature sensor. In other cases, the equation may be complicated, such as for the thermistor and photocell when used in a voltage divider circuit.

It is important to understand the range over which a sensor will be measuring a condition before attempting to calibrate it. The calibration equation is usually more accurate when based on the interpolation of measurements than when based on the extrapolation of measurements. There are exceptions to this rule. For example, the calibration equations of linear sensors can be just as accurate when extrapolated, as long as the maximum operating conditions of the sensor are not exceeded. Otherwise, is it best to expose the sensor to the entire range of expected environmental conditions while collecting measurements of its output to create the calibration equation.

The ham can easily create some of these conditions, such as temperature, on the bench top. High temperatures can be created with the use of heat lamps and low temperatures created with the use of dry ice packed in Styrofoam coolers. Other conditions might need to be simulated. For example, light intensity is easily changed by changing the distance between the sensor and a fixed light source. Recall however that light intensity decreases by a factor of $1/r^2$ when using this method to create the calibration curve of a sensor.

The spreadsheet is a powerful tool for creating calibration equations. To create the calibration equation, carefully measure the output of the sensor as the environmental condition is varied. Enter the readings and distance into a spreadsheet. In the next column, calculate the intensity of the source, based solely on its distance from the sensor. Graph the results so that the independent variable (X axis) is the distance and the dependent variable (Y axis) is the intensity. Then select the function to create a regression line from the data in the chart.

16.2.6 Digital Sensor Protocols

Some types of sensor outputs are in digital form. These sensors communicate their data as a serial protocol in which data is exchanged as a series of bits over one or more circuits. Data can be transmitted synchronized to an external timing signal (*synchronous protocol*) or synchronized to special signals embedded within the data being transmitted (*asynchronous protocol*).

Examples of synchronous serial data protocols include 1-Wire, Inter-Integrated Circuit (I2C), and Serial Peripheral Interface (SPI). Examples of asynchronous serial data transmission include USB and the RS-232 (COM) ports on PCs. These serial protocols can transfer measured data to a microprocessor without additional conditioning.

Another type of digital sensor is one in which an event's detection is signaled as a voltage pulse or as a switch closure. For example, the detection of ionizing radiation by Geiger counters is signaled by voltage pulses created when ionizing radiation passes through a Geiger-Muller tube. These signals require additional processing, such as by a counter or register circuit that is often implemented by a microprocessor.

SYNCHRONOUS SENSOR DATA PROTOCOLS

The following protocols are by no means the only ones used by sensors, but they are the ones amateurs are most likely to use or encounter. The manufacturer websites mentioned below have numerous resources to support design and development with devices that support these protocols.

1-Wire

1-Wire is a communication system developed by Dallas Semiconductor (now part of Maxim Electronics — **www.maximintegrated.com**) to enable communication between two or more integrated circuits. Devices on a 1-Wire network are daisy-chained together on a single-wire bus, called a *microlan*. (See **Figure 16.6**.) One device acts as the main device, and it controls communication between itself and the subnode devices connected to the microlan. Some available 1-Wire devices include:

- Temperature sensor: (MAX51826)
- EEPROM memory (DS24B33)
- Low voltage sensor (DS25LV02)

Since a microlan may not include a separate power wire, many devices attached to the microlan include a small capacitor in their design. The capacitor provides *parasitic*

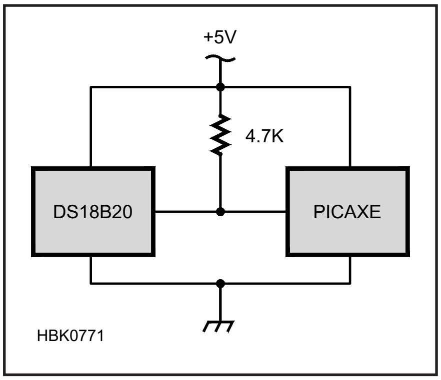

Figure 16.6 — The DS18B20 is a 1-Wire temperature sensor. In this circuit, the device does not use parasitic power and is connected to a 5 V source. A PICAXE microcontroller communicates with this device using the READTEMP or READTEMP12 command.

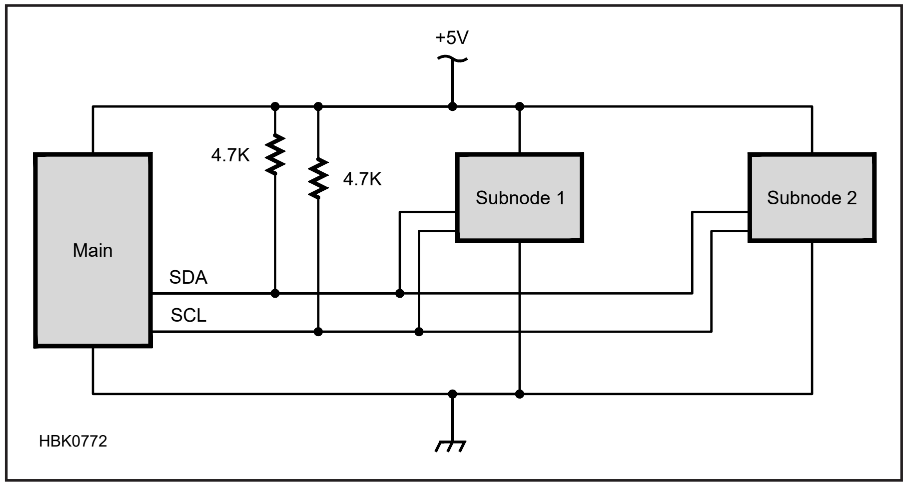

Figure 16.8 — An example of a main and two subnode ICs connected via an I2C network.

Figure 16.7 — A comparison between an iButton and a nickel.

power to the device while communications are taking place. The capacitor is necessary because communication requires the voltage on the single wire to alternate between power and ground. Without some temporary power source, devices would lose power during communications.

The main device communicates with each subnode device by transmitting the subnode's address over the microlan prior to other commands. Because multiple devices can be connected to a microlan, each device must have a unique address to avoid confusion. Subnode addresses are laser etched into 1-Wire devices. Alternatively, if a single 1-Wire device is attached to a microlan, communication on the network can ignore addressing altogether.

1-Wire is a two-way communication protocol. The main device begins communication by sending the subnode device's address and then commands over the network. Only the device with the address in the message will respond to the commands.

iButtons

An iButton is a sealed 1-Wire device resembling a thick watch battery (see **Figure 16.7**). iButtons include memory and a lithium battery. The memory contains the ID of the device and can often be used to store data. The battery permits an iButton to operate independently of a microlan.

iButton devices download their stored data when connected to a microlan. The microlan connection is made by pressing the iButton device against a 1-Wire receptor. 1-Wire receptors are available for integration into microcontroller projects. Some available iButton devices include the following:

• Time and temperature loggers (DS1920 Thermochron)

• Time, temperature, and humidity data loggers (DS1923 Hygrochron)

The amateur may be interested in the ongoing development of a 1-Wire weather station. Consult Maxim Integrated (**www.maximintegrated.com**) for the latest information concerning 1-Wire devices, including iButtons.

I2C

Inter-Integrated Circuit or I2C is a communication method developed by Phillips to enable communication between two or more ICs. Devices on an I2C network are daisy-chained together on a two-wire bus as in **Figure 16.8**. One device acts as the main device and controls communications between itself and the subnode devices connected to the network. The I2C network is described in detail at **www.i2c-bus.org** and in the application notes supplied by manufacturers of devices that use it.

The first connection in the I2C network is the serial data (SDA) line. This line carries subnode device addresses, data, and instructions between devices. The second line is the serial clock (SCL) line. This connection provides timing pulses to synchronize the data sent from the sending IC (main) to the receiving IC (subnode). In an I2C network, the SDA and SCL lines are pulled up to +5 V by pull-up resistors. A value of 4.7 kΩ works well.

The main device communicates with each subnode device by transmitting an address over the I2C bus prior to other commands. Because multiple devices can be connected to an I2C network, each device must have a unique address to avoid confusion. Subnode addresses may be designed into the IC or may be externally configured for an IC by connecting a combination of address pins to +5 V and ground.

I2C is a two-way communication protocol. The main device begins communication by sending the subnode device's address and then commands over the network. Only the device receiving its address in the message will respond to the commands. Serial data can be sent in either in fast (400 kHz) or slow (100 kHz) mode. The main device sends commands and memory addresses in either one byte or one word (two bytes) long commands. Some available I2C devices include the following:

• Memory: the 24LCxxx series of I2C memory.

• Real-time clocks: DS1307

• Analog to digital converters: LTC2903 (12 bit), AD7991 (12 bit), and MCP3421 (18 bit)

SPI and Microwire

Serial Peripheral Interface or SPI is a communication method developed by Motorola (now Freescale) to enable communication between two or more ICs. Devices on a SPI network are daisy-chained together on a two- or three-wire bus. (See **Figure 16.9**.) Like I2C, one device is the main that controls communications between it and the subnodes connected to the network. The Microwire network originally developed by National Semiconductor (now Texas Instruments) is essentially a subset of SPI. Microchip (manufacturer of the PIC processor family) has published an overview and tutorial about SPI at **ww1.microchip.com/downloads/en/DeviceDoc/spi.pdf**.

Two lines of the SPI bus are used to trans-

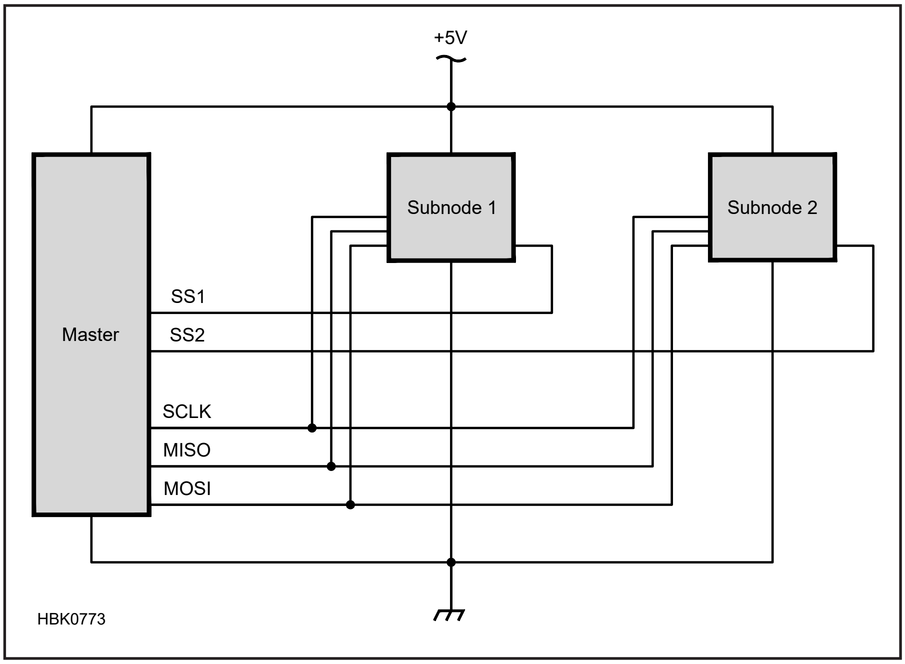

Figure 16.9 — An example of a main and two subnode ICs connected via an SPI network.

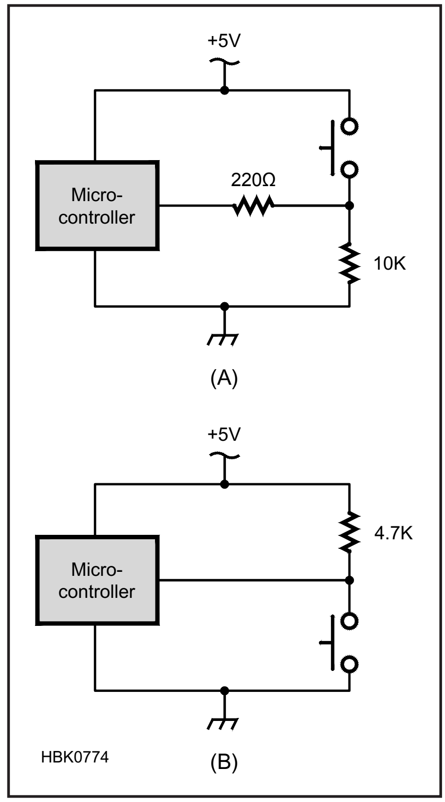

Figure 16.10 — (A) This circuit produces a logic high signal, typically 5 V, when an event is detected, represented as a switch closure. (B) This circuit produces a logic low signal, typically ground or 0 V, when an event is detected.

mit data and instructions: MOSI (main out/subnode in) and MISO (main in/subnode out). In some cases, the MISO and MOSI lines can be combined into a single shared line. The third line of the bus is the serial timing clock line (SCLK), which provides timing pulses to synchronize the data sent between the main device and the subnode. None of these lines requires being pulled high by a resistor.

The main device communicates with the subnodes by activating each device's Subnode Select (SS) line. To avoid confusion, each subnode must have a unique connection to the main device. This is a major difference between I2C and SPI. An I2C network requires only two communication lines between devices, while an SPI network requires two or three communication lines in addition to an SS line between the main and each subnode. A large number of subnodes require a large number of dedicated SS lines between the main device and the subnodes.

SPI is also a two-way communication protocol. The main device begins communications by activating the subnode device's SS line. Only the device with the activated SS line will respond to the commands. Serial data is sent as fast as the main device pulses the SCLK line. The number of bytes in each transmission between the main device and the subnode is limited by the design of the subnode rather than to eight or 16 bits. Some available SPI devices include the following:

- Analog to digital converters: MAX186 (12 bit resolution)
- Temperature sensor: LM74
- Hall effect sensor: MLX90363
- Pressure sensor: MPL115A1
- Memory: AT25010B

Note that the popular Dallas Semiconductor DS1620 Temperature Sensor uses a three-wire interface similar to SPI.

ASYNCHRONOUS SENSOR DATA PROTOCOLS

Asynchronous communication is any form of communication that does not use a clock signal to maintain timing between the sender and the receiver. A message begins with a start signal that allows the receiver to synchronize with the transmitter's message. The rest of the communication follows at a predefined rate in bits of data per second or baud. (See the **Digital Protocols and Modes** chapter for a discussion of data rate.) As long as the sender and receiver use equally accurate clocks, they will transmit and receive the same bits of data.

Some sensors supply their output data using RS-232 and USB ports. The data is transmitted as a stream of characters controlled by a protocol developed by the manufacturer. USB devices often conform to certain classes of data objects so that generic device drivers can be used to acquire data from the sensor. Control and configuration protocols that allow the user to interact with the sensor are usually proprietary.

Time-independent serial devices produce a change in output voltage only at the detection of an event. The primary example is the *event counter*. The simplest event counters detect the closure of a switch, which can be useful for detecting the presence of wildlife. Game cameras use switches in this way to trigger a camera to record an image of wildlife. Thermostats and thermal switches are another example.

Switches can be used to signal a microcontroller by two different methods. In the first, called *active low*, the switch connects a microcontroller I/O pin to ground at the detection of an event. When the event is not present, the I/O pin is connected to positive voltage or pulled up to a positive voltage by a pull-up resistor. In the second method, called *active high*, the switch connects a microcontroller I/O pin to positive voltage at the detection of an event. When the event is not present, the I/O pin is connected to ground. Schematics for both of these switch circuits are shown in **Figure 16.10**.

An example of a sensor that produces asynchronous output is the Geiger counter. The output of the RM-60 Geiger counter from Aware Electronics' RM-60 (**www.aw-el.com**) maintains a 5 V level until ionizing radiation is detected. Then the output voltage drops to 0 V for 20 µs. The amount of radiation detected by a RM-60 Geiger counter is measured by counting the number of pulses emitted by the sensor over a fixed period.

Other event counters can be modified for microcontroller use if they use an LED indicator or piezoelectric annunciator. When an

LED is illuminated, greater than 1.4 V appears across its terminals. Wires soldered to the LED can be connected to ground and one of a microcontroller's I/O pins to permit the microcontroller to count the number of LED flashes. Care in counting the number of flashes is necessary, since some inexpensive sensors may output several pulses each time the event is detected or in the case of contact bounce for a switch closure.

16.2.7 Powering Sensors

The output of sensing element sensors is typically very sensitive to power supply voltage and noise. Any changes in power supply voltage on the voltage divider also appear, proportionally reduced, at the output of the voltage divider. This includes noise, transients, slowly dropping battery voltage — any change in the sensing element's supply voltage. The sensing element user must provide clean, filtered, regulated power to the sensor to avoid contaminating the sensor output voltage.

Loading of the sensing element is also an issue for the designer to deal with. A high-impedance sensing element will output erroneous voltages if connected to a load impedance that is too low. Be sure you know what the sensing element's ratings are!

Conditioned sensors are far less sensitive to noise and power supply variations. Some kind of voltage regulator circuit is included to make sure the electronics operate with a "clean" supply. The conditioning electronics, which often include laser-trimmed calibration circuitry, assume clean, well-regulated dc voltage from a power supply. They are much less sensitive to the effects of output loading, although there are usually limits as to the amount of capacitance they can tolerate at the output, such as from a long run of wire.

In portable or mobile platforms, power is usually supplied by a battery pack. Make sure you have fresh, fully charged batteries before heading out to launch the platform for the experiment. Take into account the gradual reduction in voltage from the battery pack as its charge is consumed — it's awfully hard to swap out batteries with a balloon that is in flight! In the quest to save weight in these platforms, make sure you still have enough capacity in the battery pack voltage (see the **Power Sources** chapter) so that the experiment won't run out of power during its mission.

16.3 Navigation Data and Telemetry

Navigation data allows the sensor measurements to be combined with geographical data, which is important for correlating data to location (including altitude). A final step involves using amateur radio to either transmit the collected data to a ground station as telemetry or to track and recover a remote sensing payload for later data extraction. Since the most common use of this data is for weather balloons and other near-space missions, that context will be used.

It is important to note that transmitting data as ASCII characters (7- or 8-bit) is preferred to more compact binary formats. ASCII characters have the advantage of being human-readable so that even raw data can be inspected and used. At the low data rates of most amateur remote sensing, little overall throughput is lost by using ASCII characters. The ability to read the raw data stream directly is often invaluable during troubleshooting, as well.

16.3.1 Dead Reckoning

If a digital navigation data source such as GPS is not available, it is also possible to estimate platform position, including altitude, by the process of dead reckoning. In dead reckoning, navigation (or tracking) depends on determining a known position — called a *fix* — and then calculating subsequent positions from the platform speed and direction.

Direction data can be obtained from compass sensors that output direction as an analog voltage or digitally encoded signal. Altitude can be calculated based on ground barometric pressure and absolute pressure readings from the platform.

Obtaining accurate ground speed data is difficult for mobile platforms such as balloons or water-borne instruments, which move with the wind or current. If some other form of position tracking is available, it is possible to infer ground speed, although rarely accurately.

16.3.2 GPS Data

As currently practiced, a GPS (Global Positioning System) module is the usual means of acquiring navigation data, which is then transmitted as a telemetry stream using the Automatic Packet Reporting System (APRS). Thus, the two are combined in this section.

Depending on the model, GPS receivers produce a number of *navigation sentences*, such as the GPGGA and GPRMC sentences described below. GPS sentences are human-readable text with information in fields separated by commas. Below is a brief description of the two more important GPS sentences (when it comes to high altitude ballooning) and their fields.

THE GPGGA SENTENCE

The GPGGA sentence is the Global Positioning System Fixed Data sentence. A typical GPGGA sentence from a balloon-based GPS looks like this.

```
$GPGGA,153919.00,4332.2076,N,
11608.6666,W,1,08,1.1,13497.1
,M,18.3,M,,*78
```

There are 13 fields in the GPGGA sentence following the sentence identifier, "$GPGGA."

The fields from left to right are as follows.

1) Time in UTC (hours, minutes, seconds)

2) Latitude North (degrees and decimal minutes — note that there is no separator between degrees and minutes)

3) N (north)

4) Longitude West (degrees and decimal minutes — note that there is no separator between degrees and minutes)

5) W (west)

6) GPS Quality Indicator (0 = no GPS fix, 1 = GPS fix, and 2 = differential GPS fix)

7) Number of Satellites (number of satellites detected — not all of them may be used in determining the position)

8) Dilution of Horizontal Position (or DOHP, which is an indication of how precise the fix is — the closer to 1.0 the better)

9) Altitude (in meters)

10) M (meters)

11) Geoidal Separation (the difference in the actual height and a mathematic description of the height of an idealized Earth's surface in meters)

12) M (meters)

13) Checksum (result of exclusive OR-ing the sentence and used to verify that the text is not corrupted)

THE GPRMC SENTENCE

The GPRMC sentence is the Recommended Minimum Specific GPS/Transit Data sentence. A typical GPRMC sentence from a balloon-based GPS looks like this.

```
$GPRMC,153924.00,A,4332.2317,
N,11608.6330,W,24.4,46.3,2310
99,16.1,E*7E
```

There are 12 fields in the GPRMC sentence following the sentence identifier, "$GPRMC." The fields from left to right are as follows:

1) Time in UTC (hours, minutes, seconds)
2) Navigation warning (A = okay and V = warning)
3) Latitude North (degrees and decimal minutes — note that there is no separator between degrees and minutes)
4) N (north)
5) Longitude West (degrees and decimal minutes — note that there is no separator between degrees and minutes)
6) W (west)
7) Speed (in knots)
8) Heading (in degrees true north)
9) Date (day, month, and year — note that there is no separation between them)
10) Magnetic Variation (number of degrees)
11) Direction of magnetic variation (E = east and W = west)
12) Checksum (result of exclusive ORing the sentence and used to verify that the text is not corrupted)

16.3.3 Automatic Packet Reporting System (APRS)

Most mobile platforms include an APRS station in order to follow the platform's position and altitude throughout a mission to the edge of space. The APRS position reports, usually containing GPS data as described above, can be used directly to locate the position of the platform for recovery or tracking. (For more details about APRS, see the **Digital Protocols and Modes** chapter.)

There is a large network of dedicated ground stations and digipeater and Internet gateway stations operating on the US national APRS frequency of 144.390 MHz (144.800 and other frequencies are used elsewhere in the world). Thanks to this network, the platform's position will be plotted onto a map in near real-time. Two popular websites to view the maps are at **aprs.fi** and **findu.com**. These sites are databases of APRS packets received and routed through APRS Internet gateways.

Chase crews collect a platform's APRS data directly over amateur radio or over the Internet using the APRS maps. The platform or payload can then be recovered based on this position data. Later the data is correlated with other sensor data and images that are stored in on-board memory.

There are a number of APRS "trackers" that combine a low-power GPS module with a VHF transmitter and microprocessor that creates the APRS message packets. For example, Byonics (**www.byonics.com**) makes a number of APRS tracking and telemetry products, including the Micro-Trak RTG FA High Altitude Combo, which contains an altitude-certified GPS for balloon payloads. The RPC-Electronics (**www.rpc-electronics.com**) RTrak-HAB - High Altitude APRS Tracker Payload is specially made for high-altitude ballooning, as well.

The tracker combination built by WB8ELK is shown in Figure 16.2. On the right is a GPS module that creates the GPS sentences discussed previously. On the left is the MMT (Multi-Mode Transmitter) that creates and transmits the APRS packets.

APRS POSITION DATA

A simple APRS tracker can generate a stream of useful navigation data for a mission. The data begins at the GPS receiver where two navigation sentences are generated. The sentences are then combined to create a position report in the required APRS format. Like GPS sentences, the raw APRS packets are also readable text that is easily interpreted.

An APRS position report uses a combination of commas and slashes as field delimiters. An example of an APRS report from a balloon mission looks like this:

```
13:37:23 UTC: KD4STH-8>APT311,WIDE1-2,qAS,KC0QBU,133721h3836.39N/09500.51W>160/031/A=049114
```

There are 12 fields in the APRS report. The fields from left to right are as follows:

1) Time in UTC (hours, minutes, seconds)
2) Call sign and SSID
3) Routing Information
4) GPS Time (time in UTC — note there is no separator between hours, minutes, and seconds)
5) h (hours)
6) Latitude North (degrees and decimal minutes — note that there is no separator between degrees and minutes)
7) N/ (north)
8) Longitude West (degrees and decimal minutes — note that there is no separator between degrees and minutes)
9) W> (west)
10) Heading (in degrees from true north)
11) Speed (in knots)
12) A= (altitude equals)
13) Altitude (feet)

There are other formats and fields that may be present. Additional telemetry fields can be added in a variety of formats following the altitude data. For more information about the APRS reports, see "APRS Formats Used in Edge of Space Sciences," at **www.eoss.org/aprs/aprs_formats_eoss**.

APRS CONFIGURATION

High altitude APRS trackers should be programmed to provide altitude data and not to use Smart Beaconing. Altitude data is a fascinating datum and useful for determining when a platform has landed. Smart Beaconing prevents APRS trackers from transmitting their position while the tracker is not changing its speed or direction. At landing, it's important that the tracker continue to announce its position on a regular schedule. This is particularly important if the tracker was out of range of the chase crew at the time of landing.

The horizon for high altitude balloons and larger rockets can be hundreds of miles away. Therefore, their transmission footprint can cover tens of thousands of square miles. To prevent high altitude APRS trackers from interfering with orderly use of APRS, the high-altitude ballooning community recommends programming an APRS tracker with the following settings if a frequency of 144.390 MHz is used. (Thanks, Jerry Gable, KF7MVY)

1. Path Recommendations: Use no Path or set Path to WIDE2-1. Never use a two-part path such as the common WIDE2-1, WIDE-1 nor use WIDE2-2 or WIDE3-3.
2. Transmit Rate: Limit the transmit rate to once per 60 seconds during ascent and no less than 30 seconds during descent.

If possible or practical, you may want to use a frequency other than 144.390 MHz.

16.3.4 Satellite Telemetry

Amateur satellites use a variety of modulation methods and data encoding to construct and transmit the stream of data coming from the satellite. Bit rates vary from 1200 to 9600 bps and modulation types of CW, PSK, BPSK, FSK, and AFSK are common. Each satellite also uses a custom scheme to encode the data, often using the AX.25 packet radio protocol.

Decoding satellite data would be very challenging except that the team building the satellite usually publishes a description of the telemetry stream and provides software for receiving and decoding the data. In this way, individual amateurs can collect telemetry data for the satellite's operational team.

Information on particular satellites is often available at one of the AMSAT websites such as **www.amsat.org** (AMSAT North America) or **amsat-uk.org/satellites/telemetry/** (AMSAT UK). Satellite status, including whether telemetry decoder software is available, can be found at DK3WN's website (**www.dk3wn.info/p/?page_id=29535**). Additional information for CubeSats launched by universities or other private groups is usually available on a web page provided by the satellite's sponsor.

To decode satellite telemetry reliably at the higher bit rates, particularly 9600 bps, you will need to provide the full bandwidth audio from the receiver or use packet radio TNCs that are rated for 9600 baud operation.

The Fox-1 satellite (AO-85, see **www.amsat.org/status** for the satellite's current status) has both a low-speed 200 bps DUV (data under voice) and a high-performance 9600 bps FSK telemetry stream. *FoxTelem* software is available for decoding the information. As an example of current best practices for satellite data, a two-part article from *AMSAT Journal* on the Fox-1 telemetry system is available as a PDF on the downloadable supplemental information. (See the reference listings for Burns Fisher, W2BFJ, and Chris Thompson, AC2CZ.) Numerous other satellites use the same or similar telemetry formats and modulations.

16.3.5 Non-Licensed Telemetry Transmissions

There are many low-power data links operating in the unlicensed 915 MHz and 2.4 GHz bands. Typically, these are intended to be used for short-range applications but with the balloon payload at great altitude, the range of these devices is much longer, particularly if a high-gain Yagi antenna is used to track the payload. (See the **Antennas** chapter for information on VHF and UHF beams.)

Many of the data link modules use a standard two-way protocol such as Zigbee and have direct analog and digital inputs and outputs. Some modules support Ethernet and Bluetooth interfaces, offering even more options for modules that can be assembled into the payload.

It is also important to note that unlicensed transmitters operating under FCC Part 15 rules are also subject to certain restrictions such as field strength. In addition, the type of antenna may be fixed and even required to be attached to the transmitter permanently. These and other restrictions are required in order to limit the range of these devices. Amateurs are used to modifying and adjusting their equipment, and this may not be allowed for some of these devices! Be sure to obtain the full documentation for any unlicensed device you plan on using and be sure you can use it in the way you expect.

16.3.6 Other Telemetry Digital Modes

The usual method of communication from airborne and other remotely located platforms is via the APRS network. APRS messages are packaged in X.25 packets and usually transmitted as FSK or PSK modulation on FM transmissions. This works well and takes advantage of the extensive ground network of APRS digipeaters and servers.

Along with APRS, other subsystems are popular in the amateur balloon community. These include Weak Signal Propagation Reporter (WSPR), Hellschreiber, DominoEX, Contestia, JT9, PSK31, RTTY, CW (especially for fox hunting a lost near space balloon), FM for voice repeaters, and imagery through ATV and SSTV. (All of these digital modes are described in detail in the **Digital Protocols and Modes** chapter.)

WSPR

WSPR, part of the *WSJT-X* software suite (see the **Digital Protocols and Modes** chapter), is a simple location reporting method using HF and therefore a practical tracking data system for long duration balloon flights. WSPR takes a bit less than two minutes for one transmission.

The format of a WSPR report specified in the protocol definition is limited to: call sign, transmitter location (using the Maidenhead grid locator system), and transmitter power (in dBm). To send telemetry, amateurs have developed a way to encode altitude, voltage, temperature, and a six-digit grid locator by sending a second WSPR transmission that uses a call sign beginning with a "0" or a "Q," which are prefixes not used in Amateur Radio. The telemetry is embedded in the call sign field and power levels, and one method also uses the grid square. There are several protocols in use and undergoing development as of early 2018. You can find information on them by doing an Internet search for "wspr telemetry."

Figure 16.11 shows the track of WB8ELK's ballon that took six trips around the world in 75 days. The track is based on WSPR.net reports and displayed on the UK High Altitude Society's (UKHAS) **tracker.habhub.org** website, which features tracking of many balloons that are flying at any given time.

WSPR has a similar advantage to APRS in that there is a distributed network of ground stations around the world that relay reports to a centralized web server, which can be viewed on the **wsprnet.org** website. The data from a long duration balloon can be picked up from many thousands of miles away using a very low power HF transmitter in the 10 to 25-mW range.

JT9

JT9, part of the *WSJT-X* software suite (see the **Digital Protocols and Modes** chapter), is also very effective for low-power HF telemetry and has been used for long duration, high altitude balloon platforms. It takes less than a minute to send a transmission. It does allow a free-form transmission in which telemetry can be embedded, however the amount of information is very limited. There is no distributed worldwide ground station network that exists, as there is for the APRS and WSPR modes.

HELLSCHREIBER

Hellschreiber ("light writer" in German) is an HF transmission method that can send balloon location and other data as a fax image. The characters are formed with an accurately timed sequence of on/off keying that forms an image of the data in a received waterfall-style display. This makes it an ideal mode for poor reception conditions, since human eyes are very good at retrieving information from a noisy image.

ASCII RTTY

ASCII RTTY is very easy to implement with a small microcontroller. It uses two tones and speeds similar to Baudot RTTY but uses the full ASCII character set to send telemetry. Speeds range from 45 baud for HF systems. VHF and UHF FM transmitters can send RTTY at 100 to 300 baud.

CONTESTIA AND OLIVIA

Contestia and Olivia are MFSK modes with excellent FEC correction. They can be used for HF, VHF, and UHF payloads. Information about these modes and how to encode them in a microcontroller can be found here: **ukhas.org.uk/guides:olivia_and_contestia**

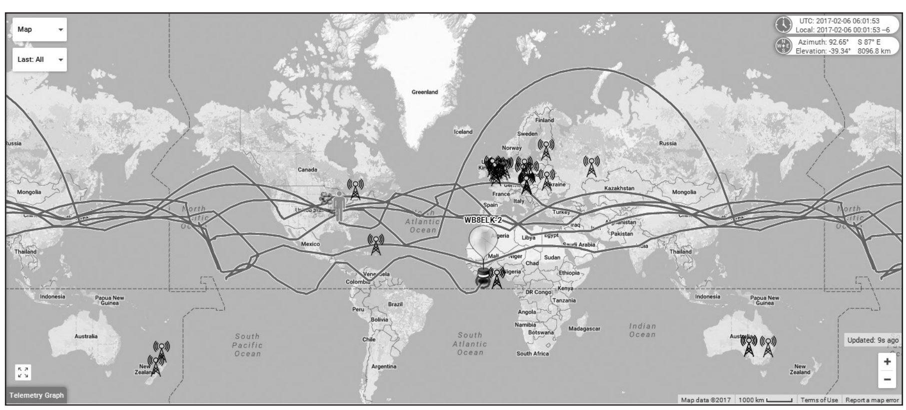

Figure 16.11 — The track of a balloon launched by WB8ELK that managed 6 trips around the world in 75 days. The image was generated from WSPR reports collected by the UKHAS website (tracker.habhub.org).

DOMINOEX

DominoEX is designed for very weak signals using an 18-tone sequence that can send balloon data using a low power signal on either HF, VHF, or UHF. It uses Offset Incremental Frequency Keying (IFK+), which uses the frequency difference between tones rather than the absolute frequency of each tone. As a result, it is very tolerant of frequency drift.

PSK31

PSK31 is a phased shift keyed mode primarily for HF payloads that requires a stable transmitter and can provide a 31.25 baud data rate.

CW (MORSE CODE)

CW is likely the easiest mode to implement with a small microcontroller performing On/Off Keying or OOK. It is primarily used as a backup transmitter for direction-finding a lost balloon payload. With the addition of a small GPS, some balloon groups actually send the position and altitude via Morse code so that the chase crew can decode the position without using a decoding program on a laptop computer.

SATELLITE COMMUNICATION

Some missions use satellite communications as a backup and telemetry-message system. These are unlicensed communication methods that charge a subscription fee. The two satellite communications services used today are Spot (for position tracking below 20,000 feet altitude — **www.findmespot.com**) and Iridium modems (for sending messages —such asthe RockBlock Mk2 modem (**www.sparkfun.com/products/13745**). There are no format standards for data transmitted using satellite or mobile phone systems.

16.3.7 Receiving and Relaying Telemetry

Most digital modes can be readily received by a modified version of the free software package *FLdigi* called *dl-FLdigi* which can be downloaded from **ukhas.org.uk/projects:dl-fldigi**. This software receives and decodes the telemetry, uses a checksum to ensure the accuracy of the received data and sends that data to a server. The position report can then be viewed at: **tracker.habhub.org** which is maintained by the UK High Altitude Society (UKHAS). The site can display telemetry from any platform but has a number of features specifically designed for high altitude balloon platforms, both Amateur Radio and license-free transmitters.

The format for generating telemetry for use with **tracker.habhub.org** is comma-separated values (CSV) of ASCII characters as follows:

$$CALLSIGN,
sentence_id,
time,latitude,
longitude,
altitude,
speed (optional),
bearing (optional),
internal temperature (optional),
*CHECKSUM\n

Although these parameters can be changed with the exception of $$ to start and a checksum at the end. More information on the telemetry formats can be found at **ukhas.org.uk/communication:protocol**.

16.4 Payloads

16.4.1 VHF/UHF/Microwave Payloads

NEAR SPACE TRACKER

A very popular configuration for high-altitude payloads is the Near Space Tracker, consisting of avionics to acquire and record or transmit data, an APRS tracker module coupled with a GPS receiver for position data, and a simple dipole or omnidirectional antenna. **Figure 16.12** shows a typical physical layout for such a package. The APRS tracker module consists of a *terminal node controller* (TNC), and a transceiver module. It is advisable to use a complete APRS tracker for balloons rather than a separate TNC and radio. Using a combined system reduces the complexity, weight, and battery needs of the tracker.

A complete construction article is included in this book's downloadable supplemental content, titled "Touching Near Space on a Budget," by Paul Verhage, KD4STH. The assembled tracker is shown in **Figure 16.13**. It uses an inexpensive insulated lunch cooler to hold the electronics, battery, and antenna.

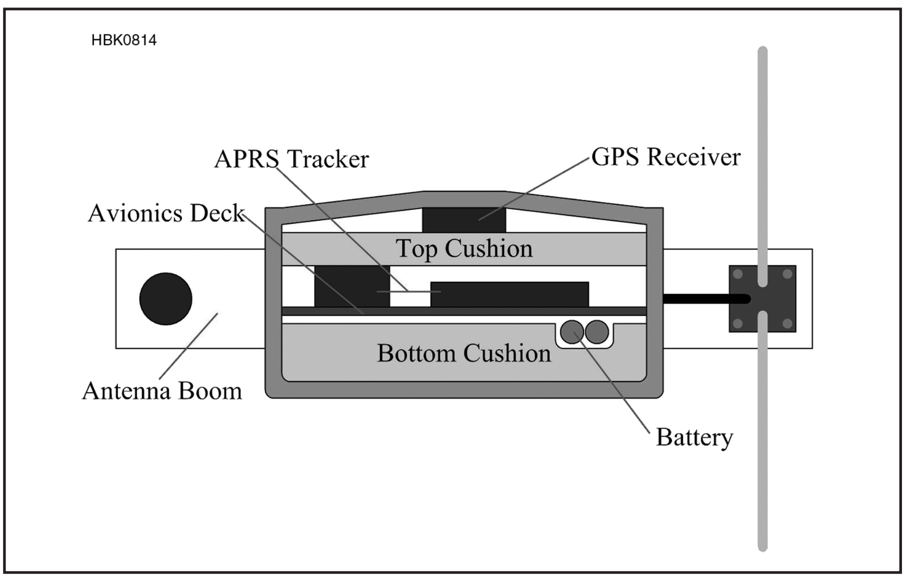

Figure 16.12 — A cut-away graphic showing an idealized Near Space Tracker including an APRS tracker, GPS receiver, an avionics package, batteries, and a dipole antenna.

Tracker packages such as this are excellent experiments not only for hams but for students and other groups when assisted by a licensed amateur to allow the use of the APRS module. Such experiments are a good way to introduce students to amateur radio and can often be supported by a local radio club.

Key considerations for trackers are their weight (less is better) and time of operation (or how long will they operate on a fully charged battery). The lighter the tracking system, the more available weight for science payloads. It also means a given balloon will reach a higher altitude before bursting (on account of the reduced initial volume of lifting gas). Since it can take an hour to fill a launch a balloon, ninety minutes to reach peak altitude, forty-five minutes to descend, and a few hours to recover, a tracker should be

Figure 16.13 — The complete Near Space Tracker assembled in an insulated fabric lunch cooler.

capable of running for at least six hours on a set of batteries.

APRS trackers such as the Byonic TinyTrak 3, Argent Data Systems Tracker3, Tracksoar, and others are software configurable. This means the tracker's behavior can be pre-programmed using configuration software provided for the tracker. An APRS tracker is configured for settings such as Callsign, SSID, Symbol, Smart Tracking, Transmit Times, Time Slotting, and Status Messages. (See the previous section on APRS.)

A tracker producing a 300 mW signal is adequate for a balloon flight. Even an APRS transmitter producing only 25 mW such as the Skytracker (**wb8elk.com**) can be used as a backup tracker. Even at this low power it is comparable to higher power transmitters down to about 1500 feet AGL (above ground level). This means a battery with a capacity of several hundred mAhrs will be sufficient for most balloon flights (a 2200 mAh is even better, since it permits an overnight recovery).

Since a 5-V LM2940T-5 voltage regulator has a drop-out of 0.5 V, a two-cell (2S) rechargeable LiPo battery can provide more than enough power for most avionics on a balloon flight. In addition, these batteries are commonly available from hobby stores where they are sold for RC racing cars.

A vertical dipole is the recommended antenna for near space tracking modules using APRS. They are simple to construct, light weight, and are not direction sensitive with respect to chase vehicle antennas (which tend to be mag-mounted vertical whips).

GPS RECEIVERS

GPS receivers are a vital component for APRS trackers. To prevent their use in guided missiles, the Coordinating Committee for Multilateral Export Controls requires GPS receivers to stop creating position data when they are moving faster than 1,000 knots at an altitude above 59,000 feet. Some companies have taken this as an OR condition and not an AND condition as it was meant. Therefore, amateurs must verify their selected GPS receiver will operate above 59,000 feet. Amateurs can find a list of appropriate receivers through an internet search.

GPS signals are weak signals. This means it can be easy to block the radio signals that GPS receivers depend upon. Experiments have shown that several inches of Styrofoam will not block a GPS signal, but that a layer of aluminized Mylar will. It's important that amateurs test their APRS tracker prior to launch after they have finished constructing their airframe.

SIMPLEX REPEATER

Readers should be aware that a high-altitude balloon at 100,000 feet has a radio line-of-sight horizon of more than 400 miles. The formula for radio signal line-of-sight in miles can be calculated as follows:

$$\text{Distance (in miles)} = 1.41 \times \sqrt{\text{height (in feet)}}$$

where H is the height in feet.

Since antenna height is so important for operating on VHF and UHF, imagine having an antenna that is 19 miles high. If you could fly a repeater to that altitude, two ground stations 800 miles apart could communicate with each other through the repeater. One simple way to do this is to fly a single handheld radio operating on 2 meters or the 70 cm band. Connecting a voice recorder and playback device to the handheld radio creates a *simplex repeater*. One such device is the Argent Data ADS-SR1. A discontinued Radio Shack simplex repeater module can be sometimes found online.

It takes some practice and patience to get the hang of a simplex repeater conversation, but this provides a very simple way to make some very exciting contacts over a multi-state region using minimal equipment on the ground.

CROSSBAND REPEATER

If you use two handheld radios, one on 2 meters and one on 70 cm, you can build a crossband repeater payload. (Some handheld radios can also operate as crossband repeaters by themselves.) You'll need to build an audio level control to adjust the audio between the two radios and also provide a PTT control.

Although more complicated, heavier, and more expensive than the simplex repeater, this does provide a real-time repeater without having to worry about flying large filters to prevent desense. The input is usually on the 2 meter band with the output on the 70 cm band. Although you can set it up the other way around, the 3rd harmonic of the 2 meter transmit can cause desense issues with the 70 cm receiver.

STILL IMAGES

A great addition to any balloon flight is the ability to actually receive live images during the flight. From 100,000 feet you can clearly see a spectacular view of the blackness of space and the curve of the Earth, since the balloon is above 99 percent of the atmosphere. **Figure 16.14** shows a photo taken from by a balloon-launched camera. Suitable lightweight cameras are available in thumb drive (USB) formats and helmet- or bike-cams designed to be used while being worn.

SSTV has been flown since at least 1998 and is still used with 2-meter FM transmitters by using a SSTV module such as SSTVcam by Argent Data (**www.argentdata.com**). The SSTV images are decoded using sound cards and software on a PC. The ability to use software means amateurs are free to use virtually any SSTV mode they prefer. The Argent system is configurable to produce images in the following four modes, Robot 36, Robot 72, Scottie 1, and Scottie 2. Scottie 2 will transmit one image in 71 seconds. Robot 36 is somewhat quicker although with some loss of

Figure 16.14 — A balloon carrying a camera payload was launched from the Dayton Hamvention in 2010 by Bill Brown, WB8ELK. This picture was obtained a few minutes later from an altitude of about 1000 feet.

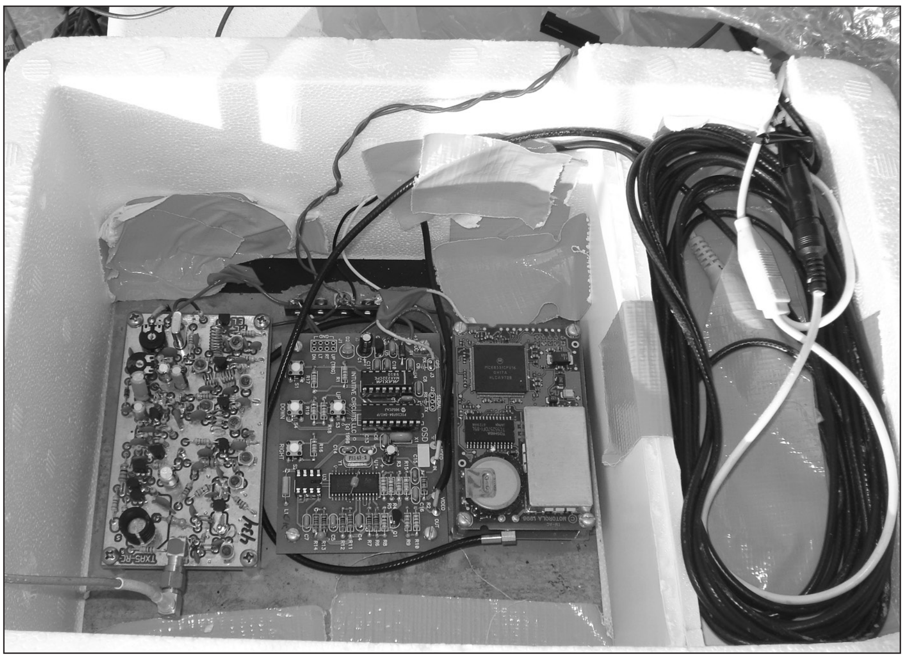

Figure 16.15 — This payload consists of a GPS receiver (right), payload controller (center), and an ATV transmitter (left). Batteries and cables are in the far-right compartment and the entire platform is contained in a Styrofoam enclosure.

resolution. The Scottie modes are most commonly used for balloon flights. (See the downloadable **Image Communications** chapter)

There are several programs to decode the SSTV audio signal and display the images on a computer screen. *MMSSTV*, *MixW*, *MultiPSK,* and *Ham Radio Deluxe* (DM780) are a few programs that can be used to capture and view SSTV images.

VIDEO

There is nothing like watching a live video camera view from a flight to the edge of space. Typically, a 1 W to 3 W AM-modulated ATV transmitter on either 434 or 439.25 MHz is used for best results. You can also use FM ATV transmitters on higher frequencies, such as the 23 cm and 13 cm bands, but the path loss will be much higher on those frequencies, which will limit your maximum downrange reception distance. There are many lightweight video cameras that can be used. (See the **Image Communications** chapter with the downloadable supplemental material for more information about analog and digital ATV.)

Analog and digital methods are used to transmit video. In digital mode, Raspberry Pi computers can produce the video, and 5.8 GHz modems are used to transmit the video. UHF can also be used to transmit digital video. By using video overlays, GPS data can be superimposed on images as a backup tracking method.

A variety of transmitters can be found at these websites: **www.hamtv.com**, **www.hamtv.com/videolynx.html#VM70X**, **kh6htv.com**, and **www.hides.com.tw/product_eng.html**.

Figure 16.15 shows a typical ATV payload in the insulating Styrofoam box enclosure. On the left is the low-power 70 cm transmitter. In the middle is the microprocessor-based controller. The GPS receiver module is on the right. The batteries and cables are placed in the separate compartment at the far right. Note that the three electronics boards are mounted over a common PCB ground-plane to provide mechanical stability and to minimize RFI from the transmitter. The antenna for the ATV link hangs below the package.

On UHF, Little Wheel or Big Wheel omnidirectional antennas have been a staple of high altitude weather balloons. The balloon group Project Traveler has a webpage on making a Little Wheel antenna for high altitude balloon flights at **www.projecttraveler.org/index.php/how-to-s/6-little-wheel-antenna-for-70cm-atv**. PC Electronics (**www.hamtv.com/wheel.html**) carries the Olde Antenna Labs line of "wheel" antennas for various bands as well as video camera modules, and ATV transmitters and receivers.

Analog video will produce P5 (high-quality) signals early in the flight while the balloon's altitude is relative low. At high altitudes, it's not uncommon to receive P1 (low-quality) signals on the ground, even from below the balloon.

Remember that the power requirements for a continually operating 1 W TV transmitter will be much higher than an APRS or audio repeater payload. You'll typically need at least 12 V with an Ah rating sufficient to allow for at least three hours of operating time. High capacity, four-cell, RC racing car batteries are a good option for powering ATV transmitters.

You will need a good antenna on the ground, an ATV downconverter, and an analog TV receiver. If you are flying in an area where horizontal polarization is used for local ATV activity, the Big Wheel antenna is a good option for the payload's ATV antenna. It provides good coverage at the horizon as well as underneath the payload. You can also use a vertical antenna, but there will be a null directly underneath a vertical radiator.

16.4.2 HF Payloads

The RF range of a high-altitude balloon at peak altitude is limited to about 450 miles when using VHF and UHF. Some balloon groups have flown transmitters on the HF bands with reception reports many thousands of miles away. It's a great way to include amateur radio operators far outside your local region.

There are several digital modes that can be programmed into a small microcontroller without having to invoke floating point math (see **www.elktronics.com** for an example of a multi-mode HF balloon transmitter). Morse code, RTTY, PSK31, DominoEX, and Hellschreiber have all been successfully flown as well.

Transmit power levels under 1 W will work well due to the weak signal advantage of some of these digital modes. DominoEX, Hellschreiber, and PSK31 are particularly good for very weak signal reception. WSPR will also provide tracking information.

RESTRICTIONS ON UNATTENDED OPERATION

Note that unattended "beacon" operation and stations making transmission on their own are restricted to the automatic control band segments when located in areas under FCC jurisdiction. There should be a way to turn the HF transmitter on or off under remote control. (Being able to turn the transmitter on and off does not constitute full control via the remote link, so the transmitter is still considered to be operating under automatic control.) There are a number of inexpensive and lightweight UHF handheld radios that can be used as a control receiver along with a DTMF decoder board.

Be sure to comply with the requirements of FCC Part 97.221 – Restricted Operation, which reads as follows:

§97.221 *Automatically controlled digital station.*

(a) This rule section does not apply to an auxiliary station, a beacon station, a repeater station, an earth station, a space station, or a space telecommand station.

(b) A station may be automatically controlled while transmitting a RTTY or data emission on the 6 m or shorter wavelength bands, and on the 28.120-28.189 MHz, 24.925-24.930 MHz, 21.090-21.100 MHz, 18.105-18.110 MHz, 14.0950-14.0995 MHz, 14.1005-14.112 MHz, 10.140-10.150 MHz, 7.100-7.105 MHz, or 3.585-3.600 MHz segments.

(c) Except for channels specified in §97.303(h), a station may be automatically controlled while transmitting a RTTY or data emission on any other frequency authorized for such emission types provided that:

(1) The station is responding to interrogation by a station under local or remote control, and

(2) No transmission from the automatically controlled station occupies a bandwidth of more than 500 Hz.

16.5 High Altitude Balloon Platforms

The reader will find plenty of near space information downloadable by using search terms such as "near space," "ARHAB," or "BalloonSats." Persons and organizations planning a near space event will find a series of papers and presentations on the **nearsys.com** website in its "Other People's Helium" section (**www.nearsys.com/arhab/ophe/ophe.htm**). The free e-book *BASIC Stamp Near Space* (see the References section) covers every aspect of high altitude ballooning. It is written for the amateur who wants to begin a near space program from scratch or who is looking for new ideas. Finally, the "Near Space" column in *Nuts and Volts* magazine contains articles on designing and using microcontrollers for high altitude balloon projects.

Here are a few websites with a great deal of information about amateur radio high altitude ballooning (ARHAB):

- Amateur Radio High Altitude Ballooning (ARHAB) — **www.arhab.org**
- Near Space — **nearsys.com**
- Edge of Space Sciences — **www.eoss.org**
- WB8ELK Balloons — **www.wb8elk.com**
- UK High Altitude Society — **www.habhub.org**
- Great Plains Super Launch — **www.superlaunch.org**

16.5.1 FAA Requirements

The regulating agency for unmanned free balloons is the Federal Aviation Administration (FAA). The applicable regulation for unmanned free balloons is the Federal Aviation Regulation Part 101 (FAR 101) or Title 14: Aeronautics and Space, 14 CFR 101.

FAR 101 Section 101.1 applies to any unmanned free balloon if it falls under one of these four conditions:

1. The unmanned free balloon carries a payload weighing more than four pounds and has a weight/size ratio greater than three ounces per square inch (this "surface density" is measured on the side of a payload with the smallest area).

2. The unmanned free balloon carries a single payload weighing more than six pounds.

3. The unmanned free balloon carries a payload of two or more packages weighing a combined 12 pounds.

4. The unmanned free balloon uses a rope or line to connect the payload to the balloon, which requires more than 50 pounds of force to separate the payload form the balloon.

Amateurs are strongly encouraged not to exceed the four limitations outlined above. When any of these limitations are exceeded, the balloon flight must meet additional requirements. These requirements are explained in Subpart D and include the following.

A) Limitations on launch site selection

B) Limitations regarding cloud cover at the time of launch

C) Requirement to add payload cutdown devices

D) Requirement to add balloon termination devices

E) Requirement to add a radar reflector to the balloon train

F) Requirement to increase the visibility of the balloon train

G) Additional pre-launch notification requirements

H) The requirement to regularly report the balloon's position

Section 101.3 states that one can request a waiver for a balloon flight that cannot meet the requirements of FAR 101. Anyone requiring a waiver must complete an FAA Form 7711-2, Application for Certificate of Wavier or Authorization.

Section 101.5 states that an unmanned free balloon cannot be launched from a restricted or prohibited area without permission from the controlling agency, or an agency that uses that restricted or prohibited area.

Section 101.7 states that you cannot operate a balloon in a manner that creates a hazard to people or their property. For example, a balloon cannot be launched if during its flight objects will be dropped in such a way that can harm or injure people or their property.

The maximum weight per payload is 6 pounds for a total of 12 pounds for the platform. Launching additional weight requires getting special permission from the FAA. This doesn't mean that you can fly 6-pound lead weights. You have to make sure that the density of your payload will not inflict damage to others, and you also need to protect all those expensive electronics that you have packed inside.

16.5.2 Balloon Platform Environment

The near space environment has environmental conditions that are in many ways closer to those found in outer space than Earth's surface, as **Table 16.2** illustrates (LEO stands for Low Earth Orbit).

HORIZONTAL DEPRESSION

For an observer at the Earth's surface, the visual horizon forms a horizontal line, 90 degrees from the zenith (the point overhead) for all azimuths (directions). As height increases, the horizon is determined by the point at which a line from the observer's eye is tangent to the Earth's surface. (The radio horizon is a bit more distant, as explained in the chapter on **Propagation of Radio Signals**.) As an observer's altitude increases, as shown in **Figure 16.16**, that tangent point becomes more distant due to the curvature of the Earth. The angle from the zenith to the tangent line also increases, therefore the horizon appears lower to the observer. This lowering of the horizon is called *horizontal depression*.

ATMOSPHERIC DENSITY AND PRESSURE

Air pressure, and therefore density, decreases as altitude increases because the weight of air still above that level decreases. The scientific way of specifying changes in atmospheric density is *scale height*. Similar to a capacitor discharging, scale height is the change in height by which the density of the atmosphere decreases by a factor of e (which equals 2.718). Scale height depends on factors such as acceleration of gravity, the average atomic mass of atmospheric gases, and temperature. Scale height is a characteristic of every planet's atmosphere and a useful measurement for astrodynamics and astronomy. The scale height of Earth's atmosphere is 4.9 miles. Therefore, for every 4.9-mile increase in height, Earth's atmosphere is 1/e or 37% as dense. A simple rule of thumb is that air pressure drops by 50% per 18,000-foot increase in altitude.

Air pressure (see **Figure 16.17**) is a concern in near space experiments for keeping organisms alive, high voltage electrical circuits that might arc over without the insulation provided by the air, and where contact with the air is a factor in keeping devices cool.

Table 16.2
Balloon Environment Summary

	Sea Level	*Near Space*	*LEO*
Pressure	1013 mb	60 mb to 5 mb	0 mb
Temperature	59 °F	–60 °F to 20 °F	undefined
Gravity	32.2 ft/sec^2	31.09 ft/s^2	28.9 ft/s^2
Distance to Horizon*	3 miles for 6' tall adult	300 miles to 400 miles	1260 miles
Horizontal Depression**	0 degrees	5 degrees	18 deg
Cosmic Rays	8 counts/min	800 counts/min	?
UV Radiation	UV-A, small amount UV-B	UV-A and UV-B	UV-A,B, & C

* Distance to horizon can be calculated by the formula distance (miles) = sqrt(height(feet) * 1.5)
** See text

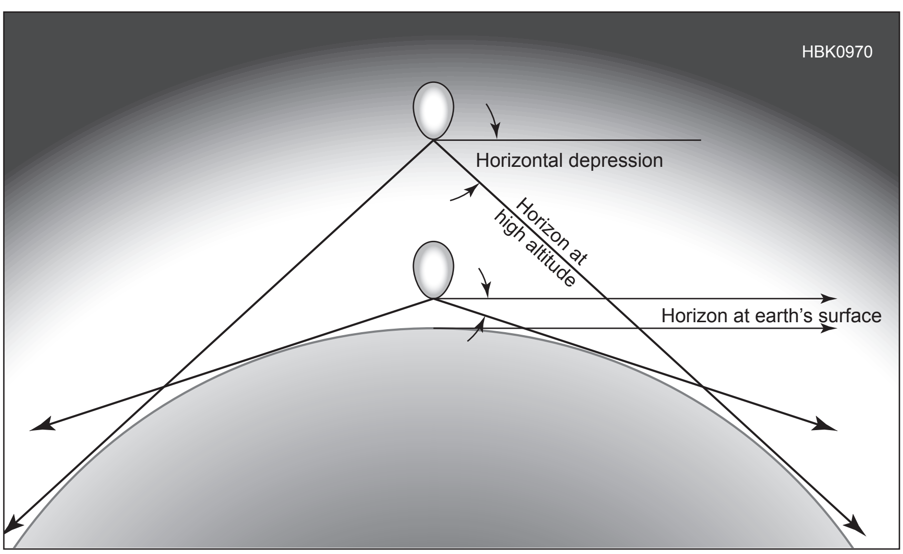

Figure 16.16 — In this highly exaggerated view, the higher balloon has a more distant horizon than at lower altitudes. This depresses the higher altitude balloon's horizon as altitude increases.

TEMPERATURE

The atmosphere consists of four layers, two of which are observable in the **Figure 16.18** chart. The lowest layer is the *troposphere*, which includes all our weather. It's heated by its contact with the ground (which is heated by sunlight) and not directly by sunlight. The higher in the troposphere, the farther from the warm ground and therefore the colder the air.

The second atmospheric layer is the *stratosphere*, which grows warmer from energy absorbed by ozone molecules in the layer. As ozone blocks solar ultraviolet from reaching the ground, the energy of the ultraviolet photons warms the ozone molecules. The higher one climbs into the stratosphere, the more ultraviolet there is to block and therefore the warmer the air.

The *tropopause* is the boundary between the troposphere and stratosphere. Sensors often show the air temperature remaining constant within this transition layer. Figure 16.18 shows a typical temperature profile measured during a balloon experiment.

Temperature is a factor in how fast chemical processes operate. Low temperatures are a concern for the voltage and current output of batteries. Low temperature can also increase viscosity to the point that lubricated mechanical systems will seize. Another issue is that some items (such as plastic zip ties) become brittle in the cold and may not perform as expected in near space.

ALTITUDE AND TEMPERATURE RATING

Many GPS receiver modules will not work above 60,000 feet. When choosing a GPS receiver, make sure the datasheet specifies a maximum altitude above the expected maximum altitude of the balloon. Some popular modules known to work at stratospheric altitudes are those made by Trimble, Garmin, u-Blox, and Inventek, as well as high-altitude modules offered by Byonics and Argent Data.

Instrument modules designed for high altitude experiments should have a sufficient rating for conditions found at high altitude. Modules and other items made for general purpose use may not have an adequate altitude and temperature rating. That does not mean they will not work when those ratings are exceeded, but they may become unreliable or

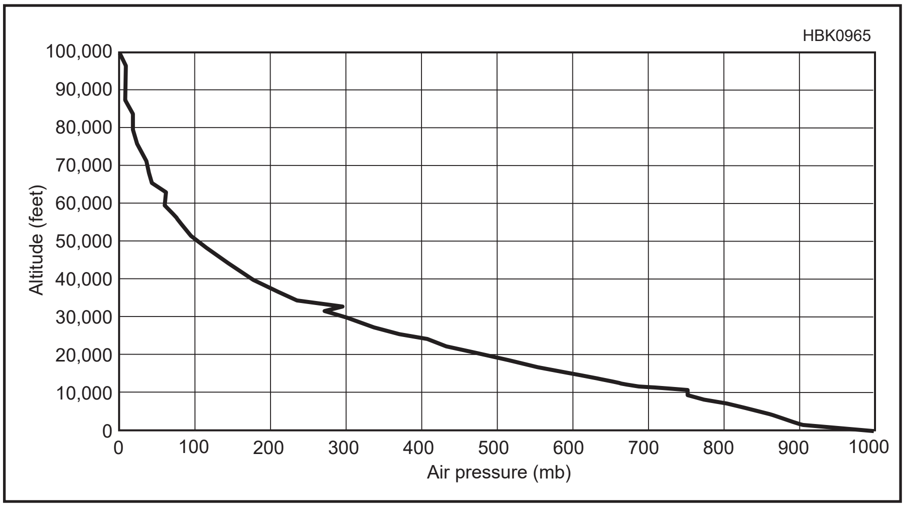

Figure 16.17 — A typical change of air pressure versus altitude.

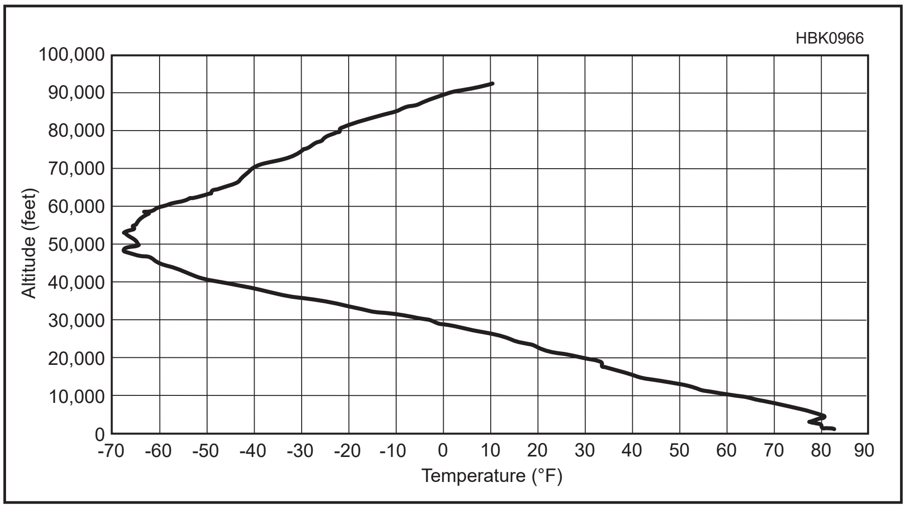

Figure 16.18 — Typical air temperature profile versus altitude, showing the troposphere (up to 50,000 feet) and the stratosphere (above 50,000 feet).

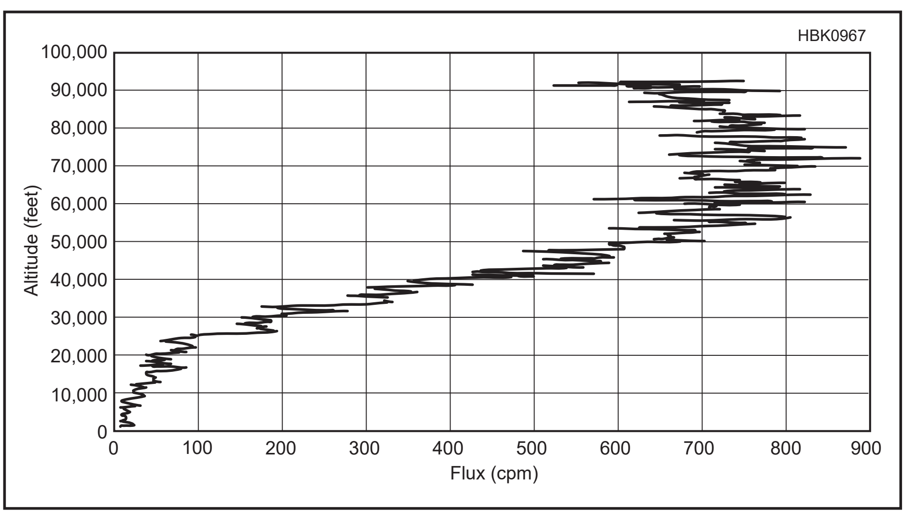

Figure 16.19 — Cosmic rays are encountered more frequently with increasing altitude in this typical balloon experiment.

fail to meet their performance specifications.

Since most consumer electronics and integrated circuits are rated for 0 to 70 ºC, you may want to find devices that are rated for the industrial temperature range (–40 to 100 ºC) or the automotive temperature range (–40 to 125 ºC) for near space payloads. Forums and user communities involved with high altitude ballooning will often have recommendations for specific models of equipment that perform well in these extreme conditions (see the preceding section on Temperature and Relative Humidity).

Cosmic rays are energetic subatomic particles. Most of this population of particles are protons, or the nuclei of hydrogen atoms. A smaller population of heavier nuclei can also be found in cosmic rays. When atomic particles enter the upper atmosphere, they are called *primary cosmic rays*.

When primary cosmic rays collide with molecules of oxygen and nitrogen, they break apart the atoms and create a shower of *secondary cosmic rays*. These secondary cosmic rays contain energetic X-rays and other subatomic particles such as neutrons, pions, and muons. Many of the secondary cosmic rays decay and lose energy though further collisions. The result of the multiple collisions is a peak in cosmic ray flux at around 62,000 feet (called the Pflotz Line). Depending on the type of radiation sensor used, at the Pflotz line the cosmic ray flux can be one hundred times greater than at sea level. (See **Figure 16.19**.)

Cosmic ray strikes can affect sensitive electronics. However, this should only be a concern in electronic devices with Very Large Scale Integration (VLSI) integrated circuits. This includes memories, processors, and advanced processing units. Smaller scale ICs have larger logic and circuit structures, making it more difficult for a cosmic ray to "flip a bit."

High-speed avionics may be at a slightly greater risk from cosmic-ray induced *single-event upsets* (SEU) during a near space flight. In fact, NASA research has found that avionics at 100,000 feet may experience an SEU once per 2.3 hours on average. Chances are the amateur will not have access to radiation-hardened electronics; in fact, it may raise suspicions if an amateur were to purchase such electronics! Advanced avionics uses software to detect and correct SEUs, but this may not be practical for amateurs either. The amateur's simplest solution is to design their avionics using electronics with large memory cells, and therefore not to use VLSI integrated circuits.

16.5.3 Balloon Platform Physical Design

Figure 16.20 shows a pair of typical balloon platforms. A weather balloon, once filled, is around seven feet tall. It is attached to the parachute and payloads with a *load line*. The load line is cut between 15 and 20 feet long so that the burst balloon's remains don't collapse on top of the parachute. Doing so may prevent the parachute from opening properly and slowing down the payload. Just after burst, the balloon's remains will fall slower than the parachute, which places the balloon above the parachute during the early descent.

There is however a risk of entanglement between the burst balloon and the parachute shroud lines or tracking antenna during late descent. This risk rarely is a problem as long as the load line is long enough to suspend the burst balloon below the tracking modules.

The parachute's diameter is chosen based on the payload's total weight. The goal is to provide a low-speed landing no greater than 5 meters/second, 1,000 feet/minute, or 10 miles per hour. A parachute six feet in diameter is usually large enough for a 12-pound payload.

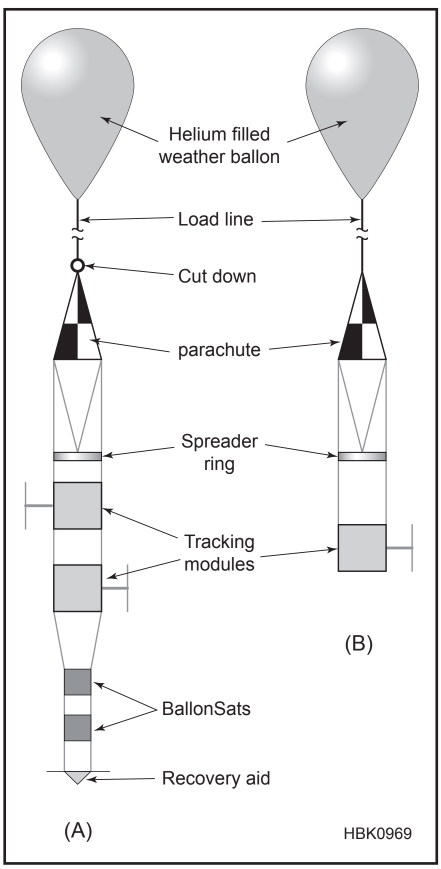

Figure 16.20 — (A) An idealized balloon platform showing the various components. (B) A simplified balloon platform with only the minimum necessary components.

Below the parachute and part of its shroud lines is a plastic ring called the *spreader ring*. The spreader ring is usually a plastic ring one foot in diameter loosely suspended between the parachute's shroud lines. It keeps the shroud lines from touching and wrapping around each other during the ascent. As long as the parachute shroud lines do not twist, the parachute will open properly soon after the balloon bursts (video records indicate this can take as little as one second). If the shroud lines are allowed to twist, the payload's descent is not properly braked. A descent from 70,000 feet can take as little as seven minutes in such cases. Furthermore, an improperly operating parachute can tangle up in payload antennas or even the payload itself.

A *cutdown device* is optional on a balloon flight meeting the strictest limits of FAR 101. The cutdown separates the parachute and payload from the balloon and load line on command or when conditions such as balloon burst or time of flight requirements are met. Most, if not all cutdown systems in use today use a series of DTMF tones sent over VHF or UHF FM channels. Typically, a DTMF decoder chip is connected to a VHF or UHF receiver on the payload, and the commands are sent as audio tones from a transmitter on the ground on the command frequency.

DTMF tone control permits the user to transmit a cutdown command followed by its password. Password protection for balloon cutdown ensures no false activation from DTMF tones intended for another purpose or payload. The cutdown is designed to either melt the load line with a coil of nichrome wire or slice the load line with a sharp blade.

Initiating cutdown starts the descent of the payload and allows the balloon to continue rising until it reaches its burst altitude. A cutdown that operates after the balloon bursts separates the balloon remains from the parachute. Separating the balloon fragments and load line from the parachute makes the descent less chaotic and protects the payload from the shock and acceleration of initial descent.

Following cutdown, the release of a near space balloon generates shaking and twisting for the attached platforms; however, the descent after balloon burst is significantly more traumatic. In fact, it's very evident when the balloon burst in the accelerometer chart shown in **Figure 16.21**.

Any object that places mass away from its center (has a lever arm) is subject to damage during balloon burst. Any object that is significantly denser than the rest of the platform can break free during balloon burst and become an impact hazard inside the platform or even escape the platform completely. Mounting methods that become brittle in the cold cannot be used to restrain dense or heavy objects on the platform.

ENCLOSURE AND INSTALLATION

The platform design must take into account the low temperature and low pressure of near space, the shock and vibration of the balloon burst, and to a much lesser extent, increased cosmic radiation.

A Styrofoam box is one of the most common enclosures. The foam is very light, provides insulation against the extreme temperatures encountered during flight for the payload electronics, and helps reduce the impact of landing. Even on the hottest summer day on the ground, it can be approximately –60 °F at 50,000 feet above the Earth. Most battery types do not work well at these temperature extremes, which are also outside the specification range of most electronic components. Fortunately, a Styrofoam box will help keep the internal temperatures well above those brutal outside conditions.

Covering the exterior of the Styrofoam housing with black tape (such as black packing tape) creates a passive heating system for the enclosed components. A second heat source is a chemical hand warmer. Hand warmers produce heat from the oxidation of iron and can produce heat for a two-hour flight. Start hand warmers an hour before launch to ensure the items they are heating get thoroughly warm. The ability of hand warmers to produce heat will degrade during the ascent (less oxygen availability), but the initial warmth and gradually decreasing heat output of the hand warmers will keep items about 10 degrees warmer throughout the flight.

Another technique is to mount the electronics and batteries on a foam-core board and wrap everything with three layers of small-cell bubble wrap. The insulation and trapped sunlight will keep the electronics warm.

Components inside the balloon platform can be protected from shock using foam rubber (foamed urethane). In all cases, every component must be mounted to the platform using fasteners that are strong enough to hold several times the weight of the component being immobilized. In addition, the fasteners cannot be constructed of materials that become brittle due to cold. Therefore, do not use plastic zip ties to restrain heavy or dense objects for high altitude balloon flights.

Any instrument requiring high voltage should receive additional electrical insulation, such as a coating of silicone glue. Items that may expand in volume when exposed to low air pressure should be evaluated on the ground (a vacuum chamber is ideal for this purpose) before being sent into near space. Devices requiring air cooling should be replaced with items not requiring air cooling, or perhaps given larger heat sinks.

BATTERIES

Lithium-based batteries are strongly recommended as a high-altitude power source as they

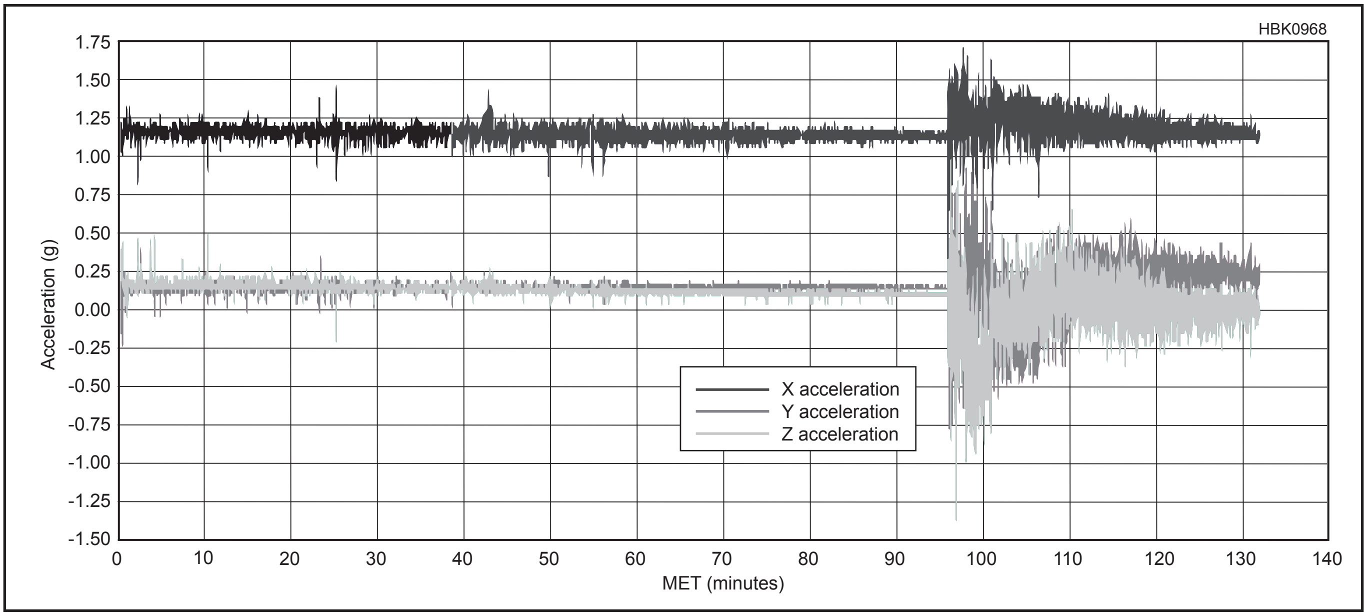

Figure 16.21 — The acceleration profile of a typical balloon experiment clearly shows the balloon bursting very clearly at about 95 minutes.

tend to handle the cold temperatures without excessive voltage drop. Batteries may be incorporated into the main enclosure, or they can be included in a separate container. The weight of a separate battery box below the main enclosure helps to stabilize the entire platform.

A practical source of lithium batteries is an RC hobby shop. Racing car batteries come in several voltages and capacities. Since many APRS trackers are designed to operate on 5 V, select a two- or three-cell battery pack (7.2 V or 11.1 V). If your tracker electronics has a low dropout voltage regulator, then your tracker can operate with a two-cell battery pack. The Eveready L91 AA lithium battery is popular for use with amateur radio high-altitude balloon platforms.

Not only do you have a choice of battery voltages with RC racing car batteries, you also have a choice of capacities. Measure the current draw of your APRS tracker and avionics and multiply that value by 24 hours. That will give a rough idea of the minimum battery capacity for your tracker.

Batteries must have sufficient capacity to operate the tracking system for its typical three-hour near-space flight plus additional time spent on the ground prior to launch and awaiting recovery. For example, it's nice to have extra reserve to make sure the tracker produces position reports overnight should it get lost during descent.

PREDICTING FLIGHT PATHS AND TRACKING

When flying a high-altitude balloon, it is a good idea to run a flight prediction a few days before launch. Repeat the prediction the night before a flight. The goal is to be sure the balloon doesn't land in a densely populated area or where making a successful recovery will be difficult. There are two popular downloadable prediction programs that can be accessed at the **www.arhab.org** website.

Amateur radio is a popular way to monitor the progress of a balloon's flight. The minimum system required to track a weather balloon flight consists of a GPS receiver that is certified to operate above 60,000 feet, an APRS TNC (terminal node controller), and a 2 meter FM transmitter. (A radar reflector is often included to increase the platform's visibility to air traffic control systems.)

The usual APRS configuration is to transmit a position report once a minute with the recommended path set to WIDE2-1. A power level below 1 W is quite sufficient, and many systems work quite well with just 200 mW.

Note that time and altitude data can be used to calculate the ascent rate of the weather balloon as a function of altitude. In addition, the same information can be used to calculate the descent rate of the parachute. Since a parachute's descent rate is a function of air drag, which is controlled by air density, the parachute's descent speed during descent can be used to estimate air density as a function of altitude. Note also that since a weather balloon is captive to the wind, measurements of altitude, speed, and heading are measurements of wind speed and direction at specific altitudes.

Including a second tracker may be an attractive form of insurance for mobile automated platforms such as weather balloons. If an APRS tracker were to fail at an altitude of 100,000 feet, the weather balloon can still be tracked and recovered using the second tracker. Redundant APRS trackers will need to use different SSIDs. In addition, they need to be time slotted so that their transmissions do not occur at the same time and jam each other. Preferably, redundant trackers will transmit on the same frequency as the primary tracker, which simplifies tracking for the people in search of the automated platform.

Finally, a *recovery aid* is a backup recovery method that's most useful after the parachute and its payload have landed. A recovery aid can include systems such as a loud audio beeper, strobe lights, or a fox-hunting (direction finding) transmitter. These help a chase crew recover a balloon platform after it has landed in trees or brush or tall crops where a GPS position is not enough to locate the platform.

APRS TELEMETRY

APRS is most popular and often used on short duration balloon flights (lasting for only a few hours), and where line of sight communication is possible between the chase crew and digipeaters. The use of IGates permits unlicensed individuals to participate in balloon chases by using a smartphone or tablet.

The simplest APRS telemetry string useful for balloon flights includes an identification, time of message, and the balloon's three-dimensional position, the balloon's course and speed. Such a string looks like the examples in the APRS message format specification at **www.eoss.org/aprs/aprs_formats_eoss** and in the APRS-IS.net specification at **www.aprs-is.net/q.aspx**. (See the preceding section on APRS for a sample string.)

16.6 Unmanned Aerial Vehicles (UAVs)

16.6.1 General UAV Platform Requirements

Drones or UAVs and their control systems are grouped in the category of *Unmanned Aerial Systems* (UAS). The regulating agency for UAS is the Federal Aviation Administration (FAA). For the purposes of Part 107, the FAA does not consider UAVs to be the same as model airplanes. One reason is that model airplanes are considered to be simple systems incapable of flying autonomously. Therefore, a model airplane must remain within sight of the pilot to be controlled. The applicable regulation for UAS is Federal Aviation Regulation Part 107 (FAR 107) or Title 14: Small Unmanned Aircraft Systems (14 CFR 107). Part 107 applies to pilots flying UAVs for a business; hobbyists have different requirements. By becoming a licensed remote pilot, however, additional privileges become available to the pilot.

This chapter will focus on the requirement for people flying UAVs as a hobby or for education. For these people, the following stipulations apply:

1) You do not need to be certified as a remote pilot to fly your UAV if you are flying for a hobby or pleasure.

2) You must register your UAV if it weighs between 0.55 and 55 pounds (this requirement has changed several times since it was first implemented).

3) You cannot fly your UAV within five miles of an airport without first contacting the airport and/or *air traffic control* (ATC). Note that some small airports do not have an ATC. In those cases, you'll need to contact the airport manager.

4) Your UAV must always yield right of way to manned aircraft.

5) You must keep your UAV within sight, or in visual line-of-sight.

6) Your UAV must weigh less than 55 pounds.

7) You must follow any community-based safety guidelines.

8) You cannot fly a UAV higher than 400 feet above the ground.

9) You cannot fly a UAV over people or stadiums.

10) You cannot fly a UAV over people who are not a part of the drone operation.

11) You cannot fly a UAV over moving vehicles.

12) You cannot fly a UAV while under the influence of drugs or alcohol.

13) You cannot fly a UAV over or around sensitive property or infrastructure.

14) You cannot use a UAV to spy on or monitor people when they have a reasonable expectation of privacy.

UAV pilots can find additional information at **www.faa.gov/uas** and from the Academy of Model Aeronautics (AMA) at **www.modelaircraft.org**.

UAV pilots are strongly encouraged to download the app *B4UFly* to their mobile phones prior to flying a UAV. The app shows airports and other restricted sites close to your location, or in other words, locations near which you are not allowed to fly a UAV.

16.6.2 UAV Data and Navigation Subsystems

Commercial UAVs require the same digital radio controllers used for traditional radio-controlled airplanes. These controllers can come with the UAV or may be purchased separately. A separate purchase is more common for advanced UAV pilots who are assembling their UAV from parts. Since the radio controller is operating a multirotor aircraft rather than a fixed wing aircraft, the aircraft pilot must configure the radio controller for UAV operation. Otherwise, the operation of the radio controller for a UAV is nearly identical to that of a fixed-wing aircraft.

An outdoor multirotor UAV is so complex that a human pilot cannot directly operate one by controlling each of the UAV's rotors. Instead, many UAVs carry an onboard flight controller that incorporates a GPS receiver and inertial navigation components such as accelerometers, gyroscopes, and a compass (magnetometer). The flight controller makes adjustments to the UAV's rotors based on joystick input and internal conditions. Combining all these elements into a single flight controller makes it so much easier to fly a UAV — the pilot only needs to push joysticks to control the thrust, pitch, roll, and yaw of the UAV.

Many onboard UAV flight controllers permit the pilot to set the UAV's flight characteristics and behaviors by changing the flight computer's settings through RC switch settings or even software. For example, a UAV can be configured to hold altitude (remain at the same altitude when the thrust joystick is left centered), fly in the direction the joysticks are pushed (regardless of the UAV's heading), and even programmed to fly a predefined course without further joystick input.

The most popular data transmitted from a UAV is video imagery (called *first person view* or FPV). Some UAVs transmit helpful navigational data such as altitude, heading, and speed. In addition, battery condition is transmitted in some UAVs to help the pilot manage the UAV's flight. Battery condition is frequently indicated by onboard LED colors.

To be a successful platform, UAVs are not usually required to transmit other types of data as a telemetry stream, because of the immediacy of the data collected. In other words, a drone can rapidly reach operational altitude, record data, then return to the launch site in a few minutes or less. Therefore, unlike weather balloons, data from UAVs is rapidly accessible and remains timely when it's downloaded.

However, if a UAV is going to transmit data, the pilot must test for the compatibility between the data transmitter and the radio controller and the onboard GPS. A pilot cannot safely operate a UAV if an onboard data transmitter interferes with the reception of RC commands, or if it interferes with the UAV's GPS receiver.

Testing for interference between the data transmitter and the UAV must be performed outdoors and with the UAV propellers removed. The pilot can then safely monitor the UAV's status LEDs or other status transmissions while the data transmitter operates onboard the UAV.

One additional safety test the pilot should perform is a measure of the UAV's center of gravity. UAV flight controllers have expectations about the UAV's center of gravity. Adding a payload to a UAV that changes that center of gravity substantially will make the UAV difficult or even impossible to control. If a payload will be added to a UAV, the pilot must determine the center of gravity before and after the modification.

16.6.3 UAV Platform Configuration

Most pilots purchase their UAV *ready to fly* (RTF) or *almost ready to fly* (ATF). Therefore, in the vast majority of the cases there is no need to worry about mounting or protecting the UAV's flight subsystems.

If a pilot is purchasing a UAV in parts and assembling it, then follow the assembly directions to construct the UAV. Directions will show the proper way to mount the UAV's flight subsystems. The proper placement is important in order to maintain the UAV's correct *center of gravity* (CG). When the CG is not located as the UAV's flight controller expects, unpredictable flights and even crashes can result.

16.6.4 UAV Electronic Subsystems

Prior to installing a new electronic system on a UAV, the pilot must ensure RFI from the payload cannot interfere with the UAV's GPS receiver. This can be an issue with some digital cameras, for example, where the crystal-controlled clock inside the camera can emit enough RF to prevent a GPS from gaining a proper lock or even worse, losing satellite lock during flight. Therefore, the UAV should be left on the ground while its new electronics payload is tested in place on the UAV and then tested around the UAV. Since many commercial UAVs are capable of reporting their GPS status through LEDs and the radio controller, the remote pilot should monitor them for a while to ensure GPS lock remains steady as the new payload electronics is tested.

One useful electronic subsystem for a UAV is a voice or digital repeater. (See the preceding section on VHF/UHF Payloads.) The UAV's ability to climb to an altitude of several hundred feet with a payload makes it a rapid-to-deploy antenna tower. The limitations of a UAV-based antenna tower include the following:

• Limited weight — usually no more than one pound

• Limited time aloft — upwards of 30 minutes with new batteries and less as the payload becomes heavier

• Limited authority — poor authority means a UAV cannot prevent it from drifting with the wind, if the wind blows too strongly

• Limited to flying during daylight hours

• Limited antenna orientations — antennas must be placed where they do not interfere with the UAV's propellers

• Limited to only flying above people who are not involved with operation of the UAV

A second useful electronic subsystem is FPV or first person view video. (See the preceding section on Image and Video payloads.) A UAV flown with FPV adds a synergy to search and rescue (SAR). Hams can use the UAV to rapidly scan long distances, fly over steep terrain, and even peer over fences and into steep canyons. These abilities can reduce search times and the risk hams experience climbing into and out of potentially hazardous terrain. A thermal imaging camera is another powerful tool to add to a UAV-enhanced SAR.

Complete FPV systems containing the video camera and the transmitter are readily available at minimal cost. They use the unlicensed 5.8 GHz radio frequencies and transmit with a power of hundreds of milliwatts. In addition, the systems are designed to be lightweight and not to interfere with the operation of the UAV. However, the remote pilot will need an observer to provide assistance to the pilot who is flying the UAV.

A non-electronic application of UAVs is carrying one end of a lightweight string over a tree or structure so that an antenna can be pulled up afterward. This permits an operator to place an antenna with more precision than is usually possible with a sling shot or "antenna launcher."

16.6.5 Powering the UAV

The motors of a UAV have a very high current demand. Twenty or more amps per motor isn't uncommon. The heavy current demands of motors (four of them on a quadcopter and six on a hexacopter) and the requirement for a lightweight quadcopter means a high capacity, high current draw, and a lightweight battery is required. These requirements and the ability to recharge the flight battery are best met with lithium polymer (LiPo) batteries. Read the recommendations for your UAV before purchasing new batteries.

16.7 Rockets

16.7.1 General Rocket Platform Requirements

Like amateur radio, amateur rocketry is a self-regulated activity. Since model rockets use the national air space, the ultimate regulating agency for model rockets is the Federal Aviation Administration (FAA). The applicable FAA regulation for model rockets is the Federal Aviation Regulation Part 101 (FAR 101) or Title 14: Aeronautics and Space, 14 CFR 101. In addition, the National Fire Protection Association (NFPA) creates safety codes that keep rocket motors safe to transport and use. NFPA 1127 - Code for High Power Rocketry Scope covers the construction, propellant mass, and reliability of rocket motors for amateur use. Rocket motor manufacturers follow these codes and as long as amateurs purchase their motors from reputable dealers, this will not be a concern when flying model rockets. The National Association of Rocketry (NAR) and Tripoli Rocketry Association (TRA) are the self-regulating organizations for model rocketry. Therefore, it's strongly encouraged that you join either one of these organizations prior to launching model or amateur rockets.

16.7.2 Suitable Rocket Data and Navigation Subsystems

Amateur radio is seldom used with low-power model rocket flights. This is mostly because of the extreme weight limits placed on payloads by small model rockets and their limited range. Amateur radio does however appear in some high power amateur rockets as an aid to recovering rockets after flight. There are several commercial products available for this purpose.

Radio tracking products for rockets are available in licensed and unlicensed frequencies. They also appear as either APRS (onboard rocket GPS receivers) or radio direction finding (fox hunting) products. The only other tracking system is an audio beacon and therefore does not rely on amateur radio.

Amateur radio is also making an appearance in model rocketry for purposes of telemetry. Data typically includes acceleration, velocity, and altitude. UHF frequencies are preferable for rocket telemetry in order to keep the antenna short and lightweight. The antenna's orientation is necessarily vertical due to the construction of the rocket.

16.7.3 Rocket Platform Configuration

All electronics mounted inside an amateur rocket will experience very high accelerations at lift off, over 10 g of acceleration in some cases. (1 g is equivalent to the force of gravity at the Earth's surface.) Therefore, all electronics must be securely mounted to the rocket's airframe in a way that will prevent them from coming loose. This is especially true for batteries, which can be denser than electronics. In additional to acceleration, rocket payloads can experience mechanical shock and rapid shaking in multiple directions.

Most model rockets can't climb high enough to experience significant changes in temperature and pressure. Therefore, their electronics payloads do not have to be protected from these conditions. However, there are some high power amateur rockets that do climb to over 10,000 feet and can therefore experience rapid changes in air pressure and air temperature. Unlike high altitude weather balloons, the electronics reach high altitudes so fast (compared to a balloon) that the payload does not cold soak long enough to become completely chilled.

Sensors onboard rockets experience rapid changes in the physical conditions they are measuring. This can result in noisy reading from the sensors that must be accounted for. Sensors used to control the operation of the rocket, such as for determining peak altitude for parachute deployment, must have their outputs filtered in real-time to be useful. Other data can be filtered after the rocket is recovered and its data downloaded.

Antennas on rockets must be small and lightweight and they must not interfere with rocket staging or parachute deployment (which involves ejecting the rocket nose cone). These requirements make a UHF dipole a useful antenna. The ends of the antenna must be secured to the rocket body so they don't vibrate in the air flowing over the rocket body. Or the antenna must be secured inside the rocket body. Some radio trackers use flexible antennas and whips. Bird trackers make popular radio trackers for rockets since they have similar requirements.

As with UAVs, any electronic devices included in a rocket's payload should be tested for interference — especially when a GPS receiver is used for the rocket's maximum altitude determination.

Since rocket flights tend to be short, a high capacity battery is not typically required. Form factor (shape and dimensions) and weight are often the important considerations. This means alkaline batteries are often acceptable for rocket electronics.

16.8 Robotics

16.8.1 General Robotics Platform Requirements

Robots are defined as systems capable of acquiring sensory input, making decisions based on that input and the robot's current state, then acting based on the results of that decision. A robot's need to combine sensory data and current status means most robots include some type of programmable microcontroller.

Being able to act doesn't mean a robot must be very mobile. Industrial robots, for example, are typically stationary and only able to operate within defined boundaries. A robot's method of acting can be electrical (such as motors and servos), pneumatic (air pressure), or hydraulic (liquid pressure). Each has its own abilities, requirements, and interfacing requirements with a robot controller.

Robots span a range of autonomies. A robot can be completely autonomous and capable of operating without any human intervention for long periods of time, or a robot can require regular, predictable human intervention (such as a planetary rover). When a robot requires human input, that communication can be wireless or via a tether containing wire or fiber optics.

The many types of sensors, the many internal states, the many types of control systems, the many levels of limitation of mobility, many mechanical systems, and many ways to communicate between humans and robots make it impossible to define a general platform for robotics. Each robot is typically as unique as the person or people who created it.

Unless robots interact with the public, there is no regulation controlling their amateur use. This is changing with the advent of self-driving cars and trucks.

16.8.2 Suitable Robotics Data and Navigation Subsystems

Robots confined to traveling in small areas typically use inertia navigation methods or position measurement systems to navigate. Typical sensors include:

- Accelerometers
- Magnetometers
- Encoders
- Range Finders
- Light Detectors
- Line Detectors
- Laser Range Finders
- Limit Switches

Robots traveling over large distances or regions can combine GPS-based navigation systems into onboard inertia and local position measurement systems.

APRS is a good method for robots (such as the Mars Rover) that send navigation or sensory data wirelessly to a human operator/monitor. In addition, a human operator can send instructions back to the robot via APRS messages.

Robots that transmit imagery can rely on either slow scan (SSTV) or amateur television (ATV). SSTV is a suitable method when conditions are slow to change or when only low power levels are available to send imagery. ATV is important where the robot is traveling at speeds high enough that human intervention is needed constantly. (See the preceding sections on Image and Video payloads.)

Although robotics projects using amateur radio are currently few, one of the more successful as of early 2018 is the HF Voyager project (**www.jrfarc.org/hf-voyager**). An autonomous "wave glider," HF Voyager operates under automatic control, making contacts with the call sign KH6JF/mm on 20 meters using FT8 and PSK-31 as the primary operating modes. It can also use WSPR in times of poor propagation.

A possible solution to long-range communication between humans and a robot might be through satellites. An iridium modem would permit the onboard robot controller to send and receive data from virtually anywhere in the world.

Finally, there are unlicensed radio bands, such as ISM, that amateur robotics engineers are using for their short-range robotics projects. These bands permit human-robot communications in both imagery and data.

16.8.3 Robotics Platform Configuration

Small, indoor robots typically have few limitations (other than those imposed for competitions). The roboticist can replace their batteries frequently, the robots don't experience extreme high or low temperatures, no rain falls on them, and small and lightweight motors suffice for making them mobile.

A roboticist designing a large, outdoor robot will need to balance the robot design with many of the limitations mentioned above. This starts with a strong but lightweight robot body (often made from aluminum). Weatherproof enclosures are required to protect the onboard electronics. Motors need to be sealed where dust and rain are issues. The motors must be powerful enough to make the robot mobile at reasonable speeds. The robot's battery design must have the capacity to operate the robot's electronics and motors without excessively weighing down the robot. Finally, depending on the speed of the robot, the design might call for physical shock protection.

Most robots use flexible antennas to communicate with human operators. The antenna is typically mounted at a high location on the robot where it can't interfere with cameras and robotic arms.

Robots that operate without direct human contact for long periods of time will need to use solar charging in order to keep their batteries topped off. Solar charging systems need to monitor the battery level and then act to recharge batteries at the appropriate voltage and current. The high power demands of robots means they can never operate solely on solar power and without batteries. This also means robots will need down time at some point in order to recharge their batteries.

Lithium polymer (LiPo) batteries are good batteries for robots since they are light weight, can operate across a large range of temperatures, and are capable of meeting high current demands.

16.9 Fixed Stations

16.9.1 General Fixed Station Platform Requirements

Fixed stations such as weather stations are found in locations where environmental conditions are hostile to humans, or where it's not practical or safe to record data. Moored or drifting buoys are included in this classification. Therefore, fixed stations must be constructed to handle extreme weather conditions. And their data subsystems are critically important if they can't be tended on a regular basis.

The FCC is the agency responsible for the telemetry requirements of fixed stations that use radios to communicate. The data transmission requirements for fixed site data collectors and dataloggers (such as moored buoys) are simpler than they are for drifting buoys. This is because a drifting buoy can be carried by ocean currents into international waters or the coastal waters of other countries. Since each country has its own rules governing the use of amateur radio, drifting buoy designers and builders must become acquainted with the communication rules of other countries to insure their drifting buoy's don't violate amateur radio laws.

When the need is to monitor weather conditions continuously on land, a weather station is the preferred solution. An amateur must mount a weather station above the level of obstacles (such as buildings and trees) that will interfere with the flow of wind. This means many weather stations can be found mounted above roofs and on tall masts or radio towers.

When it comes to monitoring conditions in bodies of water, a buoy is used. Buoys can be of two types — those remaining stationary by mooring them to the seabed or those free to drift with the ocean and wind currents. Moored buoys have been used by the National Oceanographic and Atmospheric Administration (NOAA) since 1951, and drifting buoys have been in use since 1979 (Wikipedia). At this time, the editors are unaware of any communication requirements from NOAA.

Anchored or fixed datalogging stations should not be anchored or fixed in locations where people have a reasonable expectation of privacy or their presence will interfere with navigation or right of way.

16.9.2 Suitable Fixed Station Data and Navigation Subsystems

The needs of data and navigation systems for weather stations and buoys are similar to those mentioned in previous sections. The data needs are addressed based on the distance between the station and the amateur recording the data.

For short distances, such as from the roof to the interior of a house, a wire connection between the station and a PC or display often suffices. Where it's not practical to route a communication cable into the house, then an unlicensed radio system will often work and is usually available with the fixed station. Otherwise, where long distance, line-of-sight communication is needed, APRS is one of the best methods available. In fact, there are many weather stations with integrated APRS capability available for purchase.

For fixed stations located long distances from the data user, HF modes are often the best solution. This includes the WSPR, Hellschreiber, RTTY, CW, and JT9 modes.

Satellite communication methods such as Spot (**findmespot.com**) and iridium modems are a possible solution for long distance fixed and mobile stations. A Spot tracker only reports its position; therefore it is best used for reporting the position of mobile stations such as buoys. An iridium satellite modem will telemeter data, unlike the Spot. Both of these satellite systems require a subscription. Therefore the amateur must determine whether or not the value of the data justifies the cost of a subscription prior to placing the fixed station into operation.

16.9.3 Fixed Station Platform Configuration

WEATHER STATIONS

Commercial weather stations use components capable of handling hot and cold temperatures and house most of them inside of an enclosure. Weather sensors, on the other hand, must be exposed to the elements in order to collect their data.

Pressure sensors can be left inside the house (if it's close to the weather station) or inside the enclosure since the enclosure is not air tight. Relative humidity sensors must be exposed to the air, while at the same time, protected from rain and condensation. One solution is to house the relative humidity (RH) sensor inside of a housing with vents cut in its sides. Temperature sensors (such as the LM335) must be exposed to the air, but not to sunlight because solar absorption will warm the sensor above ambient air temperature. A sun shield placed over the temperature sensor usually suffices. Alternatively, a temperature sensor can be mounted to the underside of the weather station enclosure.

Two of the more difficult weather sensors are the anemometer and wind vane. They are often made from position sensors that can rotate 360 degrees without needing to unwind (for the wind vane) or with generators (for the anemometer). These are mechanical systems that need protection from moisture while still remaining free to rotate continuously without impediment. Other systems that are less difficult to protect include the hot wire anemometer and the ultrasonic anemometer and wind vane.

BUOYS

Drifting buoys are used to track ocean currents, water, and weather conditions (temperature, pressure, RH, water temperature, salinity). A moored buoy can report on wind speed and direction, while a drifting buoy can't report with the same level of accuracy due to its movement.

Buoys must have an overall density less than the density of water (1.0 grams/cc) if they are to float. A lower density will raise the top of the buoy higher above the water than for a higher density buoy. Be careful — density that is too low can result in an unstable buoy that tips over. Therefore, buoys need ballast so they can maintain an upright configuration in rolling waters and waves. The ballast placed in a buoy must be located below the buoy's desired center of gravity. Any ballast must be securely attached to the buoy so that it can't shift its position when the buoy is tilted by waves. Finally, the ballast attachment cannot compromise the watertightness of the buoy.

All buoy components must be protected from fresh or salt water. Therefore, buoys must be constructed with water-tight seals.

This can be a challenge for buoy antennas, which are often located on top of the buoy. These antennas will be exposed to fresh or salt water on a regular basis. Therefore, buoy antennas require insulation to keep salt water off of their metal components, including connectors. Be careful in the selection of insulating materials — cold water can make some materials stiff or brittle. Select insulating materials that maintain their strength and flexibility when they get cold.

Insulation slows changes in temperature but can't stop those changes. Since buoys can operate for days or weeks in cold conditions, insulation such as Styrofoam is less effective in protecting electronics. Two options are to add heaters to the buoy or to use electronics that are designed to operate in cold conditions.

16.9.4 Powering the Fixed Station Platform

Indoor and some outdoor fixed stations may have access to household or commercial electrical power. If so, there will be no power concerns for these stations. Other outdoor fixed stations require batteries that must function in extreme conditions unless heating and cooling is provided for the batteries. In addition, batteries may be exposed to damp conditions if they can't be hermetically sealed in protective containers. The requirement to seal batteries is critical for buoys since they are exposed to salt water.

If a fixed station must operate for a good part of a year without maintenance, then the amateur should give consideration to using solar power to recharge the station's batteries. The solar cells must be encapsulated to protect them from moisture.

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Verhage continues to write the "Near Space" column as of early 2018.