Morse Code Telemetry for Small Rockets and Aircraft

Blast off for some rocketry fun with this transmitter and sensor package!

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There are many problems to overcome when designing telemetry systems for small amateur rockets and aircraft. The four big ones are size, weight, expense and versatility.

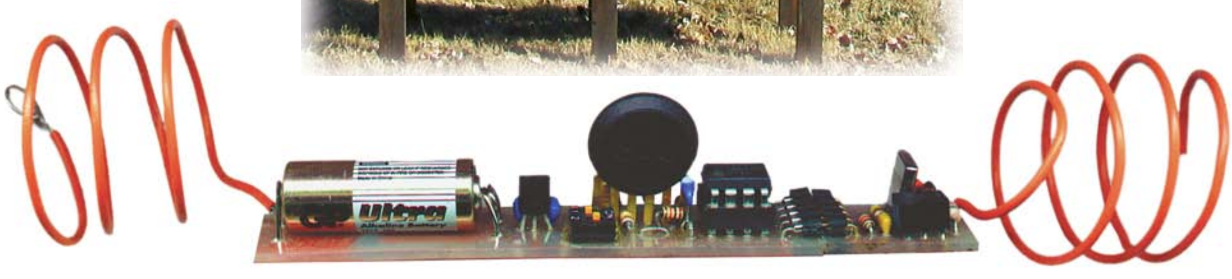
Size and weight are obvious problems when flying craft whose fuselage is less than an inch in diameter and whose payload capacity is measured in grams. Also important is the expense. Like it or not, flights don't always go as expected and some can even be explosive. Consequently, having a somewhat expendable avionics module increases the likelihood that it will actually be risked on a flight. Versatility in the field is another prime consideration, including consideration of multiple sensor configurations (both analog and digital), and compatibility with standard receivers, antennas and transmission modes.

The telemetry transmitter and sensor modules described in this article were designed primarily for small rockets, but are suitable for a variety of short-range remote data transmissions. Several principal design goals were accomplished in the final design. The goals and their results were:

- Operate in the 2 meter amateur band with an FM handheld transceiver. The transmitter operates between 144.1 and 148 MHz, depending on crystal selection. It can be both FM tone and On-Off-Carrier (OOC) modulated—in other words, continuous wave keying (CW). The firmware program in the microcontroller selects the transmission mode.
- A small light package that can be flown in small model rockets. The transmitter is ⅝ × 1 inch and weighs 0.2 ounces. The plug-detachable sensor and control module varies depending on the sensor configuration. The prototype had two different sensor and control modules. One, used for radiolocation without sensors, is ⅝ × 1½ inches and weighs 0.2 ounces, including the battery. The second prototype carries barometric pressure and temperature sensor circuits. That one is ⅝ × 3¼ inches and weighs 0.7 ounces, including the battery.
- To provide both analog and digital inputs. The prototype is configured for two analog and two digital inputs. The two digital inputs are used as switch inputs, but could be reconfigured through firmware as serial data inputs/outputs or additional analog inputs.
- A ground-to-air range of 1600 feet minimum and a ground-to-ground range of 1200 feet. Field tests with an ICOM IC-W32A handheld radio with 0.16 µV sensitivity and an 8 inch monopole antenna yielded a maximum ground-to-ground range of 1500 feet and air-to-ground range of at least 2000 feet (the maximum altitude tested to date).
- Constructed from standard size through-hole components. A single-sided printed circuit board ensures a solid and reproducible transmitter design that requires no adjustments or tweaking.
- Easily accommodate different sensor modules. The sensor and control modules were designed to be plug mountable, so they can be easily switched depending on the application. Two prototype designs are described in this article.
- Readable directly as well as by machine (computer, intelligent appliance, and so on). The transmission protocol selected was Morse code at 8 words per minute for human interpretation and 50 WPM for machine interpretation.
- Low-current battery operation.
- Transmitter and sensor circuits designed to operate from dime-sized lithium batteries or N size batteries. The current requirement at 5 V and full load is less than 17 mA.

Theory of Operation

Figure 1 is the schematic of the telemetry system, which was designed as two modules consisting of a transmitter module and a plug-in sensor and control module. The sensor and control module contains the microcontroller, battery and sensors. Two different sensor and control modules were prototyped. The first was designed for altitude and temperature measurement and the second (lighter and smaller) was designed for radiolocation only. Tables 1 and 2 list the transmitter module components and control and sensor module components.



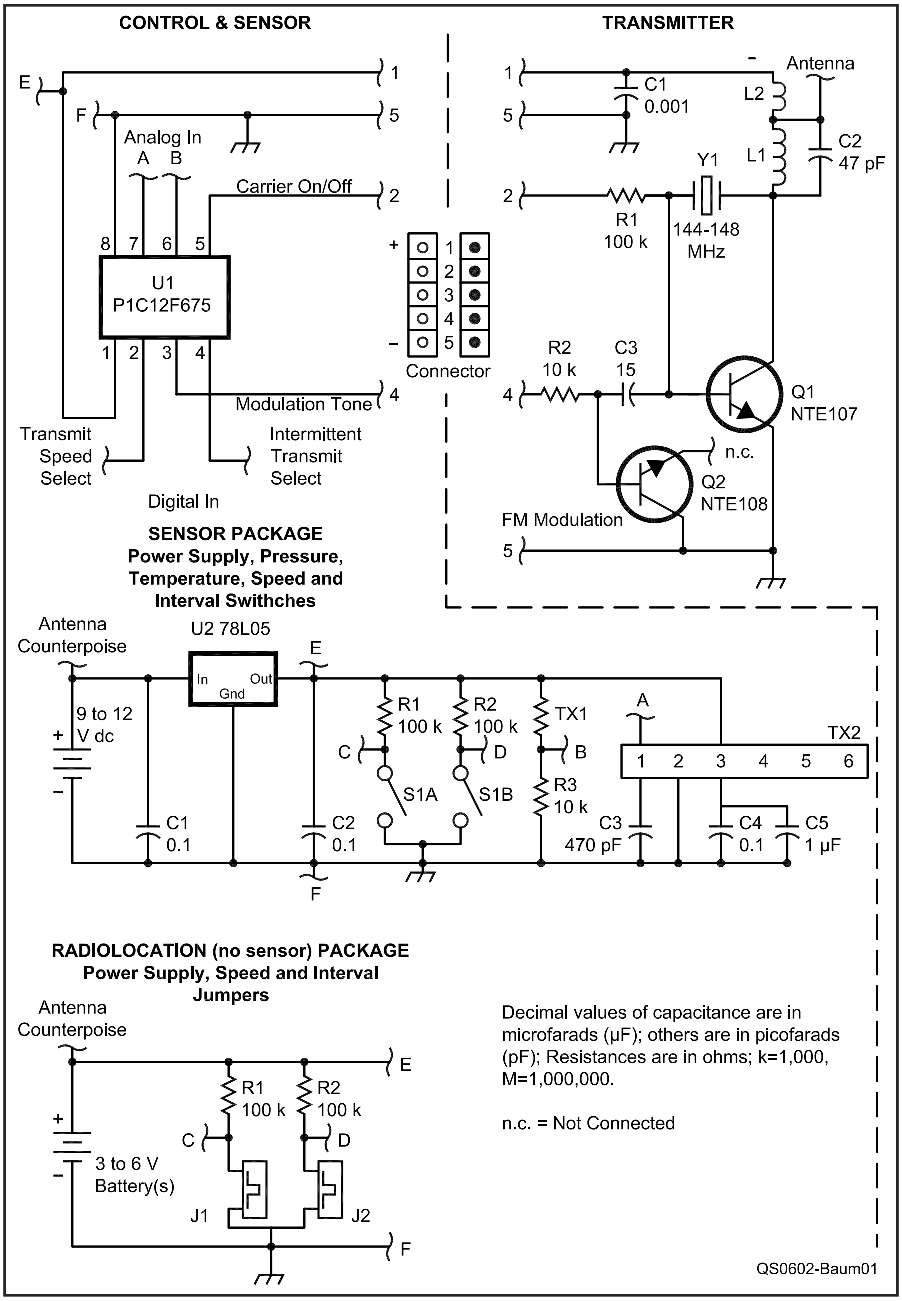


Figure 1—Schematic diagram of the transmitter module along with the control and sensor module. Either the sensor package or the radiolocation package are built along with the control module. Separate circuit boards are provided for the control and sensor module or the control and radiolocation module.

Table 1
Transmitter Module Parts List

C1—0.001 µF (Mouser 21RX510).
C2—47 pF (Mouser 21RD747).
C3—15 pF (Mouser 80-C315C150J1G).
L1—0.68 µH (Mouser 434-22-R68).
L2—4 turns 26 gauge wire tightly wound on an ⅛ inch diameter form.
Q1—NTE107 (Mouser 526-NTE107).
Q2—NTE108 (Mouser 526-NTE108).
R1—100 kΩ, ⅛ W (Mouser 299-100K).
R2—10 kΩ, ⅛ W (Mouser 299-10K).
Y1—144.1 to 148 MHz third overtone series crystal, EX45DL00, ICM HC-45/U series (FX=20.00-59.99MHZ), ICM (International Crystal Manufacturing).
Antenna—12 inch solid conductor wire.
PCB Header—64, 0.100 inch single row right angle header (Mouser 575-643909). Remove and use five of the headers.

Table 2
Control and Sensor Module(s) Parts List

C1—0.1 µF (Mouser 21RX310).
C2—0.1 µF (Mouser 21RX310).
C3—470 pF (Mouser 80-C315C471J2G).
C4—0.01 µF (Mouser 21RX410).
C5—1 µF (Mouser 80-T350A105K025).
J1, J2—Low-profile shunt jumper (Mouser 649-687886-202).
R1—100 kΩ ⅛ W (Mouser 299-100K).
R2—100 kΩ ⅛ W (Mouser 299-100K).
R3—10 kΩ ⅛ W (Mouser 299-10K).
S1A, S1B—2 position SPST dip switch (Mouser 653-A6T-2104).
TX1—Thermistor (Mouser 71-01C1002FP).
TX2—Absolute pressure sensor 0–15 PSI, Type MPX4115A (DigiKey MPX4115A-ND).
U1—PIC12F675 I/P, 8 pin FLASH-Based 8-bit CMOS Microcontroller (Mouser 579-PIC12F675 I/P).
U2—78L05 5-V regulator (Mouser 511-L78L05ABZ).
Socket—64 single row 0.100 inch right angle socket (Mouser 575-643903). Remove and use five of the headers.
Header—2 single row 0.100 inch straight headers (Mouser 649-69190-202).
Battery—12 V, type 573-23A.
Battery—3 V lithium (Mouser 658-BR1632).
PIC—12F675PICKIT I/P 8 pin Flash Starter Kit (Mouser 597-DV164101). Includes MPLAB-IDE microchip programming software.
Antenna counterpoise—12 inch solid conductor wire.

Transmitter

The transmitter is a crystal-controlled oscillator, which can accommodate either On-Off Carrier (OOC) modulation or FM tone modulation. The prototype firmware accompanying this article only supports the FM tone capability, however.

The transmitter is turned on by bringing pin 5 of the microcontroller high. This produces current through R1 and the base-emitter junction of Q1 (NTE 107 transistor), and Q1 conducts. With Q1 conducting, oscillation is determined by the third overtone series crystal between the base and collector of Q1 and the tank circuit consisting of L1 (0.68 µH inductor) and C2 (47 pF capacitor). The FM modulation tone is provided by a 700 Hz tone generated by the microcontroller and sourced through pin 3. This signal is acted on by R2, Q2 and C3 to frequency modulate the oscillator. Only the base and collector of Q2 are used in this configuration, which acts to produce a variable reactance in response to the tone.

Antenna

The antenna consists of a 12 inch length of 22 gauge or smaller solid wire. It can be coiled on a ½ inch to 1 inch diameter form to shorten its length and reduce space requirements. Maximum transmission range is achieved with the antenna fully extended. An additional wire, equal in length to the primary antenna wire and extending from the positive battery terminal in a direction opposite to that of the antenna more than doubles the transmission range. The antenna should be external to a metal fuselage, and the counterpoise (the wire connected to the positive battery) can be internal and connected to

Table 3
Temperature Conversion Chart—A/D units to Degrees Celsius

A/D Units	*Degrees Celsius*	*A/D Units*	*Degrees Celsius*	*A/D Units*	*Degrees Celsius*
240	0	523	26	768	52
250	1	534	27	775	53
259	2	545	28	782	54
269	3	556	29	789	55
279	4	567	30	795	56
289	5	578	31	802	57
300	6	588	32	808	58
310	7	599	33	814	59
321	8	609	34	820	60
332	9	619	35	826	61
342	10	629	36	831	62
353	11	639	37	837	63
364	12	649	38	842	64
376	13	659	39	847	65
387	14	668	40	852	66
398	15	677	41	857	67
410	16	686	42	862	68
421	17	695	43	867	69
432	18	704	44	871	70
444	19	713	45	888	75
455	20	721	46	892	76
467	21	729	47	896	77
478	22	737	48	899	78
489	23	745	49	903	79
501	24	753	50	906	80
512	25	760	51	910	81

the rocket, aircraft fuselage or nose cone.

Sensor and Control

The sensor and control module consists of a PIC 12F675 flash microcontroller IC and a selectable set of sensors that can be either analog or digital. This module also includes the power supply. Two different sensor and control modules were prototyped and described in this article. Although many combinations are possible without modifying the firmware, even more flexibility can be achieved with only slight program modifications.

The first sensor and control module measures altitude by using an absolute barometric pressure sensor and measures temperature with a thermistor. The barometric pressure circuit consists of the pressure transducer and capacitors C3, C4 and C5. The pressure transducer has a high level output (0 to 5 V). Pin 1 of the transducer is attached to pin 7 of the controller, which is configured as an analog input. The transducer voltage output relates to atmospheric pressure.

$V_{out} = [V_s(0.009\ P - 0.095)] \pm$ error, where P = pressure in 1000s of pascals (kPa).

The result of the processor's analog to digital (A/D) converter can range from 0 to 1023 (10 bit). A 5 V input will produce a 1023 output from the A/D converter and a 0 V input will produce a 0 result from the A/D converter. Intermediate voltages translate to A/D output values distributed proportionally between those extremes. The altitude calculations can be made by using the following equations:

p = sea level pressure obtained from your local weather station or NOAA broadcast in inches of mercury (in Hg)

p1h = ground level reading

p2h = post flight reading

For either p1h or p2h:

pnh = [(A/D reading × 0.032047) + 3.11754] ± error. (This converts the A/D reading to in Hg.)

"Error" usually ranges between 0 and 0.1 inch of mercury.

Preflight altitude at launch site or postflight maximum altitude =

$$\frac{10^{\frac{\log\left(\frac{pnh}{p}\right)}{5.2558797}} - 1}{-6.8755856 \times 10^{-6}}$$

A Microsoft *Excel* spreadsheet constructed from this equation can be downloaded from the ARRL Web site.[1]

The temperature sensing circuit consists of R3 and thermistor TX1. The thermistor resistance changes in response to the temperature. Table 3 is a chart to convert the A/D units to degrees Celsius.

The second sensor and control module actually contains no sensors. It is the smaller of the two and is used for radiolocation only. It retains the ability to select transmission speed and wait interval by removable jumpers.

[1]Notes appear on page 31.

Power Supply

The telemetry transmitter is powered from the control and sensor module. With the altimeter/temperature sensor design, one small 12 V "lighter" battery (23A) is used. Voltage regulation is provided to the sensor module and the controller by U2, a 78L05 linear voltage regulator.

The smaller radiolocation control and sensor module is powered directly from one or two 3 V lithium batteries and does not require voltage regulation. The current requirements for the transmitter and altitude sensor and control module are less than 17 mA while the current requirements for the transmitter and smaller (radiolocation) sensor module is less than 6 mA.

The battery used with the altimeter module is well suited for model rocket use because it is small and inexpensive—under $1. When operated in the continuous transmit mode, however, a new battery will only last about 1 hour and 20 minutes before the voltage drops below the level required by the voltage regulator. The transmitter will continue to operate after it reaches this point but the sensor data will not be correct. If longer operation time is required, a heavier battery (9 V to 12 V) will be needed.

Firmware

The firmware for the telemetry transmitter was written using MicroChip MPLAB-IDE and programmed on their Flash Starter Kit. A copy of the source file can be downloaded from the ARRL Web site. See Note 1. The program primarily consists of an organized series of calls to subroutines, which make the functionality of the program easy to modify should a different configuration be required. The prototype firmware:

- Turns the transmitter on and off by bringing pin 5 high or low.
- Modulates the oscillator by placing a tone on pin 3 in Morse code format.
- Uses pins 6 and 7 as A/D inputs from analog sensors.
- Uses pin 2 as a speed-of-transmission selection switch (either 8 WPM or 50 WPM).
- Uses pin 4 as an intermittent transmission selection switch. If high then the transmitter will wait 60 seconds between transmissions.

Transmission Protocol and Mode

I wanted to use the telemetry transmitter with a 2 meter FM handheld radio because of its general availability. Because of this, I decided to use FM modulation and Morse code as the preferred protocol and transmission mode. Although many other digital protocols could be used, Morse code was selected because it could be interpreted directly using only a standard handheld radio, an advantage in remote field applications. It also can be machine readable with computer software

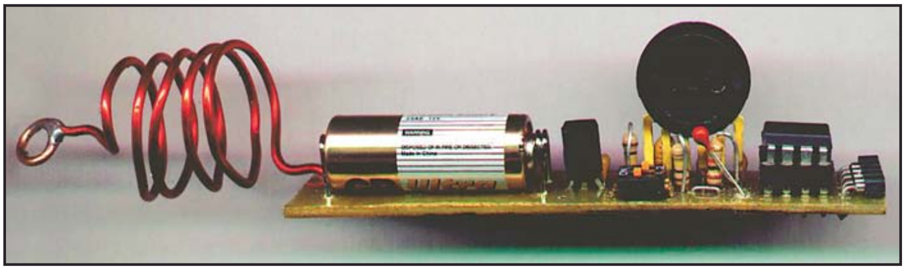


Figure 2—Altimeter and temperature sensor and control module and the edge connector for the transmitter module.

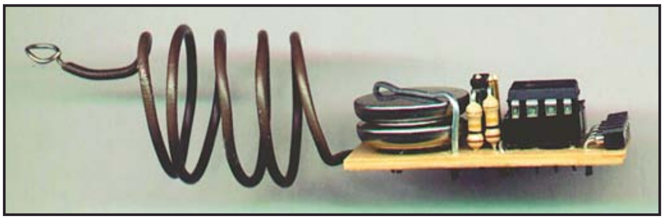


Figure 3—Radiolocation and control module with the edge connector for the transmitter module.

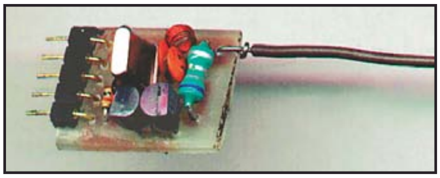


Figure 4—Transmitter module ready to plug into a control and sensor module.

and several commercially available handheld devices. The code speed is switch selectable to either 8 WPM for human interpretation or 50 WPM for use with machine decoding.

The sequence of the Morse code transmission for the prototype firmware is:

1. Current reading from A/D converter on pin 7 (preceded by the letter A)
2. Minimum reading since power on of the A/D converter on pin 7 (preceded by AT)
3. Current A/D converter reading on pin 6 (preceded by B), and
4. The control station call sign.

A copy of a transmission might be:

a0789 at0560 b523 kd5zug
a0790 at0560 b522 kd5zug etc.

The first line would be read in A/D units as current pressure = 789, minimum recorded pressure = 560, temperature = 523 and station call sign = KD5ZUG.

The controller records the minimum reading from the sensor on pin 7 to accommodate a pressure mode altimeter circuit. The minimum pressure recorded represents the maximum altitude obtained.

Construction

Construction of the telemetry transmitter and sensor modules is straightforward. First etch and drill a circuit board using the foil patterns.[2] Then, using the part-placement diagrams, identify the parts and place them on the printed circuit board at the locations shown.[3] The only special detail to perform is to remove the emitter from Q2 before installation on the transmitter module.

The battery clips for the altimeter sensor and control module are made from the spring end of a number 1 size safety pin. Remove the spring end by cutting the latch portion off. Insert the ends of the pin through the circuit board and bend ¼ inch over so it lays flat on the foil. Solder the pin in place, being sure to cover the entire length where the pin and the foil are touching. This process works well and produces a very small battery holder; however, it can be a bit cumbersome to install. If you would rather use a commercial battery holder any size N holder will work. See Figure 2.

The battery holder for the radiolocation module consists of two jumpers made from trimmed off resistor leads soldered flat against the component side of the circuit board. These two jumpers form the negative battery terminal. The positive battery terminal is made from a small metal paper clip and arches over the top of the batteries. The depth of the arch should just be high enough to allow two 3 V lithium coin batteries to fit under it as shown in Figure 3. A commercial holder designed for the 16xx series lithium coin batteries will also work.

Solder each component in place, trim the excess leads and inspect for a good connection. Be especially careful not to create any solder bridges between foil tracings. The tracings are very close together and great care is required. Figure 4 shows the completed transmitter module.

Operation

A field test using an ICOM IC-W32A handheld radio with the original 8 inch antenna resulted in ground-to-ground (6 foot elevation) range of 1500 feet with both the transmitter antenna and sensor antenna counterpoise fully extended in a vertical plane. A ground-to-ground range of 600 feet resulted when used with only the transmitter antenna. Intermediate ranges were obtained when both antenna and counterpoise were air wound on ¾ inch diameter forms of varying lengths.

Several successful test flights were conducted as well as some not so successful ones. Apparently the G force at liftoff is sufficient to snap the connector that connects the transmitter to the sensor and control module if it gets in a bind. Also, the battery and microprocessor can be ripped out of their mountings during acceleration or when the parachute charge is ignited. I used a wooden Popsicle stick as a “splint” to reinforce the connector joint and help strengthen the circuit board. Cut the stick to the combined length of the transmitter and sensor and control modules. Tape the stick to the bottom of the circuit by tightly wrapping electrician’s tape around the connector, circuit board and stick. Also wrap the microprocessor and battery in the same way. With these corrections made, the circuit performed excellently with solid communications to 2000 feet and a minimum signal strength of S4 as recorded by the IC-W23A radio.

Mounting the circuit in the payload compartment proved to be tricky. The method that gave the best performance was to coil the antenna counterpoise on a ¾ inch diameter form to a length of 1 inch and then connect the free end of the counterpoise to the base of the nose cone so that the circuit hung vertically in the payload compartment. The transmitter antenna was extended out the base of the payload compartment and along the fuselage toward the tail fins. The coiled counterpoise helped absorb the shock of acceleration and the external antenna provided maximum signal radiation.

Conclusion

Watching the data spill across the computer screen as your rocket disappears into the sky can be a real rush. It can be even more gratifying when you can turn on your 2 meter handheld radio and find your wayward rocket simply by following the signal.

Notes

[1] A Microsoft *Excel* spreadsheet based on the pressure calculations given in the article, as well as the microprocessor source code can be downloaded from the ARRL Web at **www.arrl.org/files/qst-binaries/Baumeister0206.zip**.

[2] Foil patterns and part-placement diagrams are part of the zip file listed in Note 1.

[3] See Note 2.

Jerry Baumeister, KD5ZUG, has been licensed since November 2003, but has been a lifelong electronics hobbyist. He holds an Associate’s degree in Electronics, Bachelor’s degrees in Biology and Medical Technology, and a Master’s in Business Administration. He is currently employed as the Director of Ambulatory Support at Mercy Health Center in Oklahoma City, Oklahoma. You can contact Jerry at 8525 NE 129th St, Jones, OK 73049 or at **jerry_baumeister@msn.com**.