River Level Monitoring via Packet Radio

By John Fletcher – KB7FND

BACKGROUND: During the 1996 Clark County area flooding, the County Department of Emergency Services requested the help of ARES/RACES in monitoring area rivers and streams, in real-time, for flooding conditions. Radio operators were positioned throughout the county and reported river levels at intervals of 15 minutes during the emergency. The reports were radioed to the Emergency Coordination Center (ECC) where they were put up on the status board. It was not an ideal mission for ARES/RACES members to be out in the rain and bad weather, waiting to report the next reading of the stick gauge or, if there was no stick gauge, an estimate. Although a number of these locations had recording type crest gauges, they did not provide real-time data or they depended on vulnerable telephone land-lines.

Since that time, a number of ARES/RACES members have been thinking about how to make this task easier, using current packet radio technology. In the fall of 1998, Zeph (N7WAP) and his wife, Jan (KB7OKG) worked with the county to identify all the locations that needed monitored and developed a handbook showing which locations had stick gauges, where to park for observation, what equipment to bring, and what to expect at each location. John (KB7FND) had been gaining considerable experience in using the newest version of the Kantronics Terminal Node Controller (TNC) called the KPC-3 Plus™. This TNC features two analog inputs, the values of which can be transmitted out as a beacon. Also featured are two control outputs. During the summer of 1999, these members along with Miles (AB7ZX), chairperson of the local Packet Interest Group, formed a committee to define a project using this technology to telemeter river and stream levels to the ECC during weather emergencies. The project was then presented to the Packet Interest Group, soliciting ideas and help in making it a realization. The project was on its way.

DESIGN PARAMETERS: One of the more difficult design tasks was how to measure the actual water level. Many designs were discussed, including floats, potentiometers, pulleys and even magnetic switches. Howard (KC7IZH) was familiar with the art of measuring liquid levels in storage tanks. He suggested using a pressure sensor suitable for liquid immersion. A differential sensor with one port open to the atmosphere would be required to cancel out the effects of atmospheric pressure.

After discussions with the County, a number of design parameters were defined. Two measurement ranges would be needed; 0-10 feet and 0-30 feet with a resolution of 0.1 feet. The sensors would be placed near the riverbank at a level which was just below the normal stream flow. All level measurements would be made relative to the sensor. All other levels (flood stage, warning level, bridge level, etc.) would be calculated in software. The sensor had to be packaged in a way to minimize the effect of debris, flow rate, and sediment. Sensor output had to be within range of the TNC analog input (0-5 vdc). All elements had to be temperature compensated or negligibly affected by temperature. The measurement site needed to operate unattended for a minimum period of up to five days. The total package needed to be as vandal-proof as possible.

It was decided that analog input AN0 to the TNC would switch between battery voltage and temperature measurements and analog input AN1 would be connected to the water level sensor. Control output, CTRL A, from the TNC would do the switching between battery voltage and a thermistor to measure temperature.

DIGITAL TELEMETRY: The Kantronics KPC-3 Plus™ Packet Terminal Node Controller (TNC) was the obvious choice for transmitting water level, battery voltage, and temperature via packet radio. The KPC-3 Plus™ has two analog input ports that are connected to its processor's Analog-to-Digital (A/D) converter. Each analog quantity (0 to +5 vdc) is digitized into an 8-bit binary number, which in turn is converted by the TNC's software to a decimal number in the range of 000 to 255. The decimal number for each of the two analog inputs is then inserted into a special telemetry beacon and transmitted at a user-defined interval (10 seconds to 42.5 minutes). This transmitted beacon can be digipeated by other packet stations in the region, allowing the use of a low power transmitter at the measurement site. A number of local ARES/RACES members have set up their home packet stations to perform this digipeating function to provide coverage throughout the county. The telemetry beacon is of the form:

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KB7FND-12>BEACON,RELAY,WIDE* [11/08/1999 22:05:32 PT]:
T#320,235,047,043,056,125,00011001
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In this example the first analog quantity is decimal 235 and the second is decimal 047 representing analog voltage inputs to the TNC of 4.0678 volts and 0.9216 volts respectively. Each decimal count represents 0.0196078 volts (5.0 volts divided by 255 count). The "T#320" is the telemetry beacon cycle number. Each time the telemetry beacon is transmitted, this count is incremented. The count starts out at 000 when the TNC is powered up. When the count reaches 999, it rolls over to 000. By keeping track of this number, the display software can determine if a beacon was missed. The display software also uses this number to eliminate multiple beacons received from more than one digipeating station.

Display stations (using a PC and appropriate software) can be set up anywhere in the county to monitor the water level and battery voltage/temperature of each measuring site. The demonstration software program has been written to demonstrate the capability of the system. The program can display up to eight sites in "gauge" form, or the operator can select a graph form which plots the previous 24 hours of collected data for a selected site. Alarm points can be set for each site to sound an audible alarm when the water level or rate of rise reaches a critical value. Another alarm sounds when the battery voltage drops below 11.0 volts. Each display station needs only a receiver on the packet frequency (a scanner will do) and any TAPR-2 style TNC to receive and display the transmitted beacons. The following parameters need to be set in the receiving TNC in order to output the above format to the software:

```
DAYTIME (date/time in the format of YYMMDDHHMM[SS];seconds optional)
HEADERLN ON
MON ON
MSTAMP ON
MBEACON ON
```

An additional feature of the KPC-3™ series of TNC's is the ability of the packet SYSOP to change the TNC's parameters remotely. The telemetry beacon interval is one of the parameters that can be changed. This allows the SYSOP to remotely change the interval at a particular site as stream conditions change. The longer the interval, of course, the longer the battery life at the measurement site. Tests have shown that a 7-Ampere Hour (AH) battery can power a site (5-watt transmitter) for six days at a beacon interval of 30 minutes before reaching a battery voltage of 10.5 volts. This is well above the deep discharge point. The battery should be disconnected before reaching the 9.6 volt level to avoid possible damage.

The remote control feature can be used to activate a second control output function, CTRL B.

At the gauge transmitting station the following TNC parameters must be set:

```
MYCALL (station call)
MYREMOTE (remote call for remote control functions)
RTEXT (remote password text - see TNC manual)
TELEMTRY 180 (1800 sec) (beacon interval of 30 min., for example)
CD SOFTWARE (the MFJ-8621 radio does not have carrier squelch)
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Also, the following jumpers must be set in the gauge station TNC:

J8 (analog input AN0) – Center pin & Pin 2
J9 (NOR/HT) – Check to make sure jumper is in NOR position.
J10 (analog input AN1) – Center pin & Pin 2

RADIO: Although a low power 2-meter FM data transmitter could have been used for this project, a transceiver was desirable to allow for remote control of the TNC. The MFJ-8621 VHF "Packet Only Data Radio™" was found to be ideal for this application. It is a 5-watt, crystal controlled VHF data radio especially designed for packet use. The receiver does not have carrier squelch, so the TNC must be set to operate with its carrier detect (CD) parameter set to "SOFTWARE".

ANTENNA: Another design challenge was the antenna. In order to make a package that was as vandal-proof as possible, it was necessary that the radio feed a low profile antenna. A "Directional Discontinuity Ring Radiator (DDRR) design, described in *Electronics*, January 1963, was used (see "*The ARRL Antenna Book*"). A 2-meter version of this low profile antenna was constructed by AB7ZX. The antenna was mounted on top of the metal enclosure that houses the electronics and was covered with a plastic radome.

- *Although this measurement package is low powered with a somewhat inefficient antenna, the transmitted data can be distributed around the county by digipeating through a nearby packet station in a manner similar to that used in APRS™.*

BATTERY: The gauge site radio, TNC and interface are powered by a 12 volt DC gel-cell type battery (these batteries are typically the type used in alarm systems). A 7-AH battery will power the station for six days. Additional batteries can be paralleled (through diodes) to provide longer operation between battery changes.

INTERFACE BOARD: An interface board makes up the final part of the station package. As shown in Figure 1, the fused 12 volt battery output is dropped and regulated to +5 volts for input to the pressure sensor. Output from the sensor is connected to the TNC analog input AN1.

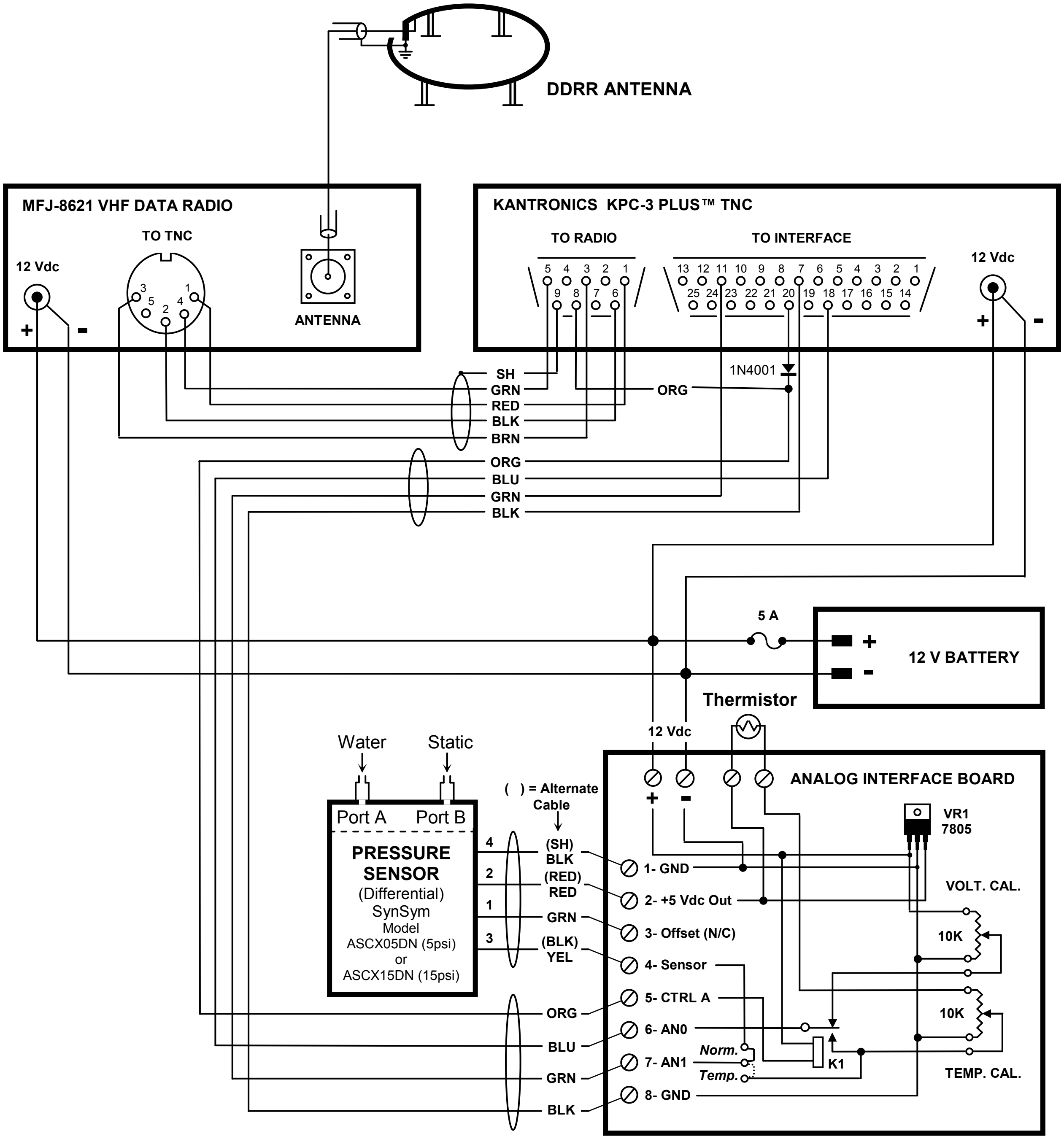
A 10 k-ohm trimmer resistor scales the battery voltage measurement by one third making it suitable for the TNC analog input, AN0.

A control relay allows analog input AN0 to be switched to a thermistor to measure temperature instead of battery voltage. The control relay is operated remotely by the "CTRL A" feature of the TNC. The first bit of the eight bits transmitted as the last field in the beacon (00011001 in the example above) is used to tell the display software that temperature is being measured instead of battery voltage. When measuring temperature, the first bit will become a "1" (10011001).

The interface board may also be used at a temperature monitoring site by switching a jumper for analog input AN1 to the thermistor (TEMP) position instead of the pressure sensor (NORM) position. Again, a 10 k-ohm trimmer resistor is used to calibrate the temperature measurement.

- **Figure 1 is a wiring diagram of the river gauge station.**

Figure 1 – Wiring Diagram of River Gauge Station



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SENSOR PACKAGE: The basic element of the sensor package is the pressure sensor itself. The sensor chosen is manufactured by **SenSym**. Depending on the measurement range, a 5 psi (pounds per square inch) or a 15 psi element is selected for a particular site. The 5 psi allows measurement of water depths up to 10 feet and the 15 psi up to 30 feet. Part numbers are: 5 psi – ASCX05DN, and 15 psi – ASCX15DN. Both are differential, having one port measuring water pressure and the other port connected to a static tube open to the atmosphere to balance out the effect of atmospheric pressure changes. The sensor element is housed in a 2-inch PCV pipe with the ends capped. The static tube and a power/signal cable are fed through a conduit from one end of the package up to the radio and TNC package. The measuring port of the sensor is connected to a short length of tubing which projects through the side of the PVC pipe. This opening is protected from sediment and debris using an aquarium porous stone. The whole package is protected by a storm drain housing and anchored to the river bank. Figure 2 is a drawing of the sensor package.

DISPLAY SOFTWARE: Display software can be written to meet the needs of the user. Since the data from each monitored site is received in "raw" form, the display software must interpret the data and display it in the desired manner. It can be as complicated as a "windows" application with an interconnection to an internet web-site to provide real-time data to multiple users.

A demonstration software package has been written in BASIC language and then compiled into an ".exe" file for execution on any older surplus PC that may be available. It will also run as an "MS-DOS" application in "Windows". This simple program is used to demonstrate the capabilities of the system. See Figure 3.

The following formulas are used to calculate the water level in feet, given a particular pressure measured by the sensor:

1. The weight of one foot of fresh water, in pounds per square inch (psi), is given by:

   Pressure of water in psi = 62.4 lbs/ft.^{3} / 144 in.^{2} = 0.433333 psi/ft. in height

2. For a 0 to 5 psi sensor, output voltage as a function of pressure is given by:

   Output in volts = pressure in psi * 0.9 + 0.25 volts Where 0.9 is the slope of the sensor calibration line and 0.25 is the offset voltage (as specified by the manufacturer)

3. The output voltage of the sensor is converted to a decimal count by the TNC using the following:

   Count = sensor voltage * 255 / 5 (the count is rounded to the nearest integer)

4. At the display end, working backwards from the TNC count given in the telemetry beacon:

   Water height in feet = (Count * 5 / 255 - 0.25) / 0.39 Where 0.39 is a factor derived as a result of combining equations 1, 2 and 3 above (62.4 / 144 * 0.9)

5. For a 0 to 15 psi sensor, the water height calculated above would be multiplied by a factor of 3.

For those stations measuring temperature instead of water level or battery voltage, the software uses a look-up table as follows, taken directly from the data statements in the software:

```
4500 :
5000 REM *** ANALOG TERMPERATURE LOOKUP TABLE
5005
5006 REM  FIRST LINE = ANALOG A1 COUNT
5007 REM SECOND LINE = TEMPERATURE
5010 :
5011 REM  30   31   32   33   34   35   36   37   38   39
5012 DATA  1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.1, 2.4, 3.6
5013 :
5020 REM  40   41   42   43   44   45   46   47   48   49
5021 DATA  5.0, 6.0, 7.0, 8.0, 9.0,10.0,11.0,12.0,13.0,14.0
5022 :
5023 REM  50   51   52   53   54   55   56   57   58   59
5024 DATA 15.0,16.0,17.0,18.0,19.0,20.0,21.0,22.0,23.0,23.8
5025 :
5026 REM  60   61   62   63   64   65   66   67   68   69
5027 DATA 24.7,25.6,26.5,27.6,28.3,29.3,30.1,31.0,32.0,32.7
5028 :
5029 REM  70   71   72   73   74   75   76   77   78   79
5030 DATA 33.5,34.2,35.0,35.7,36.4,37.2,37.8,38.7,39.5,40.2
5031 :
5032 REM  80   81   82   83   84   85   86   87   88   89
5033 DATA 41.0,41.7,42.6,43.4,44.2,45.0,45.8,46.6,47.5,48.3
5034 :
5035 REM  90   91   92   93   94   95   96   97   98   99
5036 DATA 49.2,50.0,50.7,51.5,52.3,53.0,53.7,54.5,55.2,56.0
5037 :
5038 REM  100  101  102  103  104  105  106  107  108  109
5039 DATA 56.7,57.5,58.2,59.0,59.7,60.5,61.3,62.0,62.7,63.5
5040 :
5041 REM  110  111  112  113  114  115  116  117  118  119
5042 DATA 64.3,65.0,65.7,66.5,67.3,68.0,68.7,69.5,70.3,71.0
5043 :
5044 REM  120  121  122  123  124  125  126  127  128  129
5045 DATA 71.8,72.5,73.3,74.0,74.8,75.5,76.3,77.0,77.8,78.5
5046 :
5047 REM  130  131  132  133  134  135  136  137  138  139
5048 DATA 79.3,80.0,80.8,81.5,82.3,83.0,83.8,84.5,85.3,86.0
5049 :
5050 REM  140  141  142  143  144  145  146  147  148  149
5051 DATA 86.8,87.5,88.3,89.0,89.8,90.5,91.3,92.0,92.8,93.5
5052 :
5053 REM  150  151  152  153  154  155  156  157   158   159
5054 DATA 94.3,95.0,95.9,95.8,97.7,98.6,99.5,100.4,101.3,102.2
5055 :
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CONCLUSION: The Clark County ARES/RACES River Monitor system is a demonstration project to determine the feasibility of using Packet Radio to monitor water level at streams and rivers. It's purpose is to provide, as a public service to the County Department of Emergency Services and other agencies in Clark County, information about potential flooding conditions during emergencies and disasters. It is not meant to replace any commercial system. This is a service provided by volunteer Amateur Radio Operators and no warranties of service availability are expressed or implied. Hopefully it can be expanded in the future.

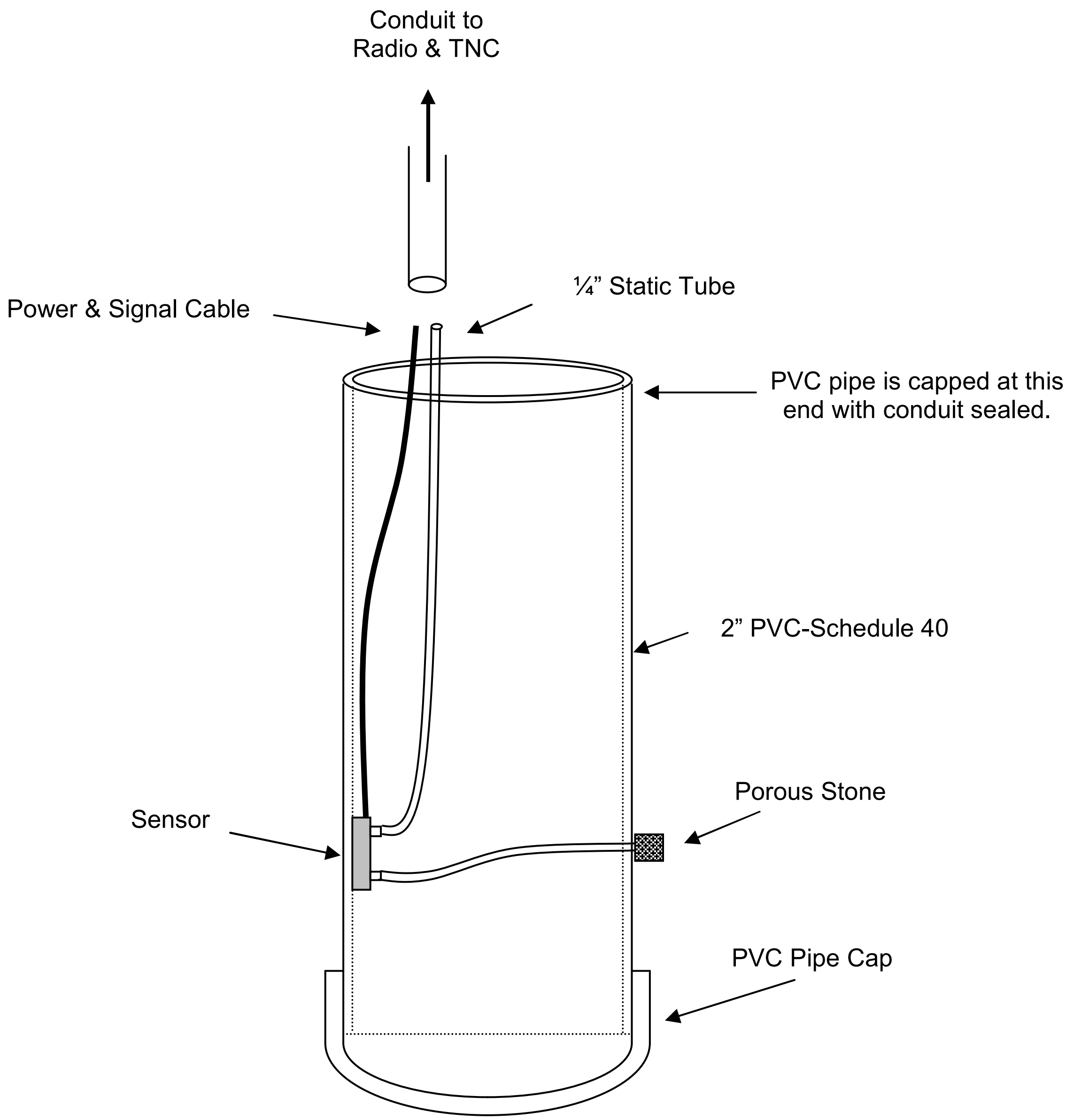

Figure 2 - Sensor Package