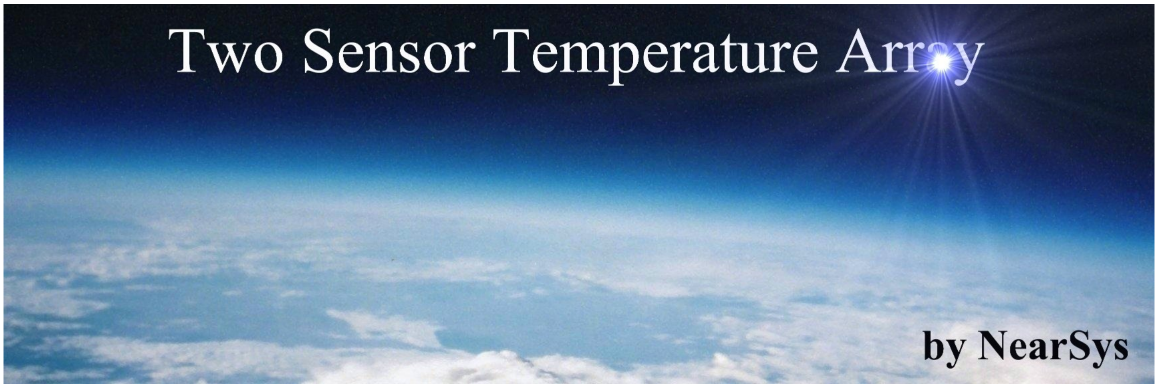

Two Sensor Temperature Array

by NearSys

The NearSys Two Sensor Temperature Array is a kit that permits a BalloonSat to measure two separate temperatures. When plugged into a flight computer like the BalloonSat Mini, the flight computer provides the power to operate the station and the memory to record the output from both temperature sensors. After recovery, BalloonSat teams can produce charts of temperature conditions of their experiments as a function of time or altitude by processing the temperature array's data with a spreadsheet.

Onwards and Upwards,
Your near space guide

Overview of the NearSys Two Sensor Temperature Array

There are five components and eight wires in the temperature array. At completion, the temperature array is capable of recording the temperature of two different locations during a near space mission. The heart of the NearSys Temperature Array is its two LM335 temperature sensors. Each sensor produces a voltage proportionally related to the temperature of the sensor. After plugging the array's cable into an analog port, a flight computer digitizes the voltages and records them for later analysis. The weight of the temperature array is only 12 grams, leaving a lot of weight free for other BalloonSat experiments.

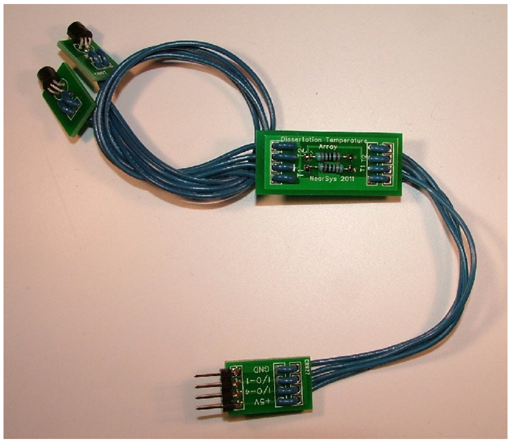

Figure 1. A complete Two Sensor Temperature Array

Parts List

Look at the top of the printed circuit board (PCB) and you'll see white lettering indicating the placement and orientation of individual electronic components. Each component has a unique and meaningful reference consisting of a letter followed by a digit. All resistors for example, have a reference beginning with the letter R. Below is a list of the components in the NearSys Temperature Array kit and their references you'll find on the PCB.

R1 1k ohm resistor (brown, black, red, gold)
R2 1k ohm resistor (brown, black, red, gold)
U1 LM 335 temperature sensor
The remaining items are required to complete the NearSys Temperature array, but they do not have a reference on the PCB.

Wire (#24 AWG)
Four-pin right angle header
Temperature Sensor Main printed circuit board
Two Temperature Sensor Head printed circuit boards
4-pin Easy-Plug printed circuit board

Component Pictorials

The following pictures illustrate the physical appearance of the components you'll find in the kit.

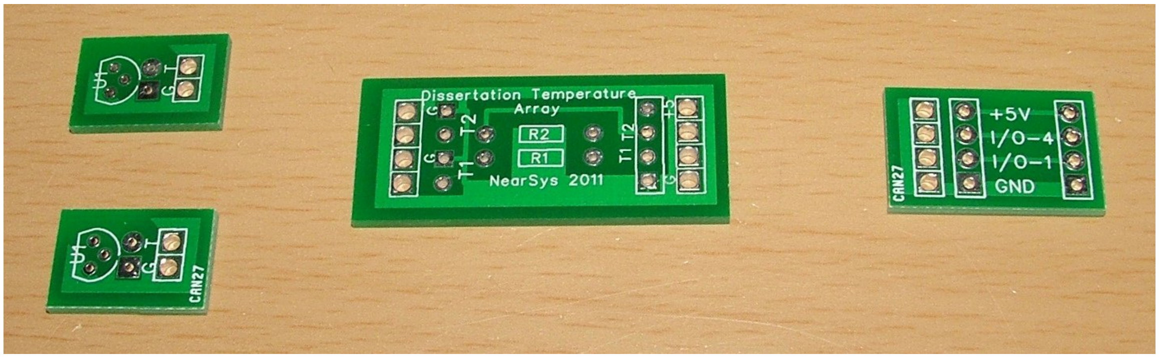

Figure 2. The four PCBs making up the Two Sensor Temperature Array. From left to right they are two temperature sensor heads, main board, and 4-pin Easy Connector.

Figure 3. Resistor

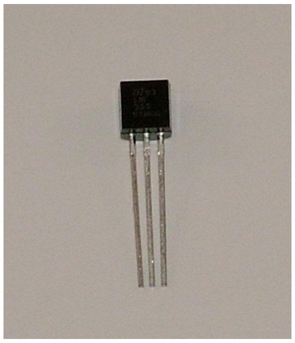

Figure 4. Temperature Sensor

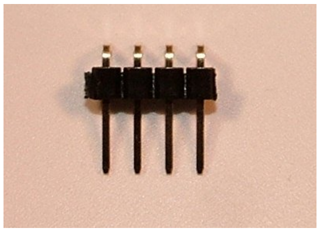

Figure 5. Five-pin right angle male header

Theory of Operation

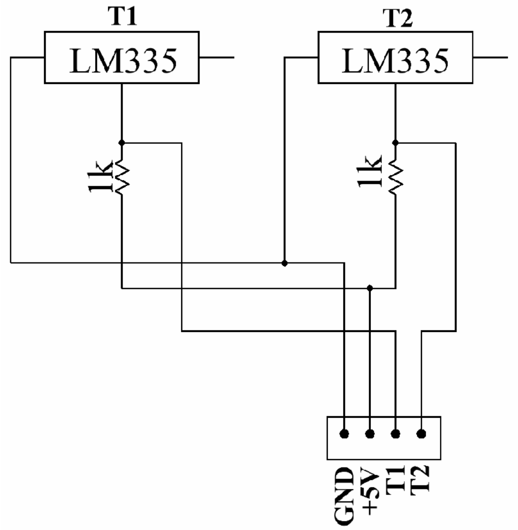

Figure 6. NearSys Two Sensor Temperature Array Schematic

The PCB of the NearSys Temperature array supports its two sensors in producing temperature sensitive output. Below is a brief description of each component and how it supports the mission of the temperature array.

The temperature sensors (LM335) produce a voltage that varies linearly with changes in the temperature. Ideally, it produces 0.01 (or 1/100th) volts for every kelvin and would theoretically produce zero volts at Absolute Zero. The Kelvin scale is an absolute temperature scales frequently used in physics. A single kelvin is equal to a degree Celsius, but the Kelvin scale begins at absolute zero, or -273° degrees Celsius. At room temperature, or around 293 kelvins, the LM335 produces a voltage of 2.93 volts. The temperature rating of the LM335 does not extend to temperatures as cold as they get in near space, but it still appears to produce a valid temperature regardless. A second way to understand the operation of the LM335 is to notice each one is in series with 1k-ohm resistors. Each LM335 therefore acts like a voltage divider with its resistor. As the temperature of the LM335 changes, so does its "resistance".

The temperature array terminates in a 4-pin Easy Plug connector. The first pin provides ground to each LM335. The second and third pins are the voltage outputs of each LM335 sensor. The last pin provides +5 volts to each sensor.

Assembling the NearSys Temperature Array

The diagram below illustrates the placement of the components you will solder to the temperature array PCB. Check off each step below as you complete it.

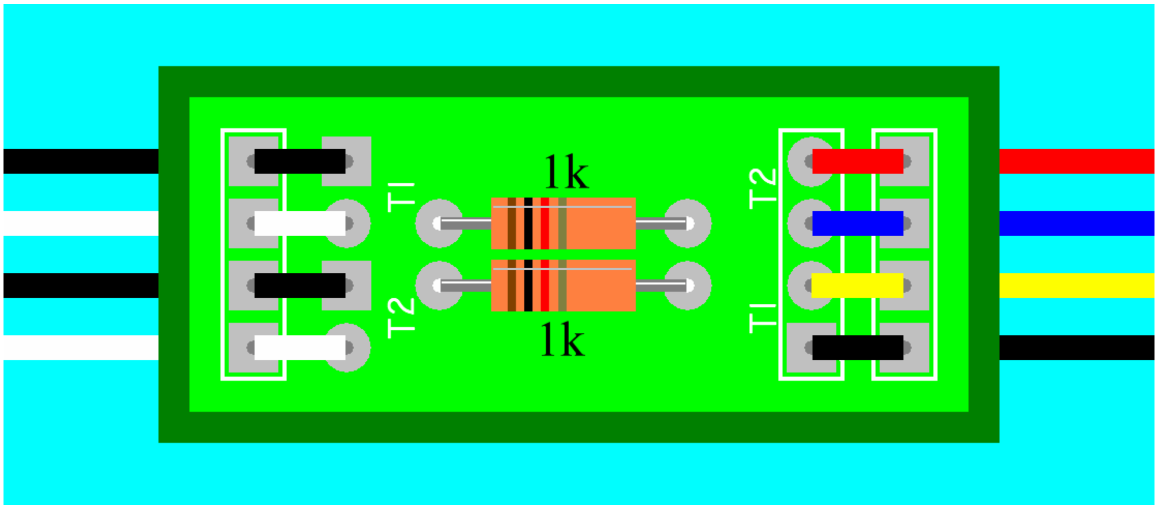

Figure 7. Parts Layout for the NearSys Two Sensor Temperature array. The right side is the I/O side of the PCB and the left side is the sensor side of the PCB.

□ R1 1 k-ohms (brown, black, red, gold)
□ R2 1 k-ohms (brown, black, red, gold)

Cable

□ Cut eight wires equal lengths (about six inches)
□ Strip ¼” of insulation from both ends of each wire
□ Thread the wire through a large strain relief hole and back into the PCB pad as shown below

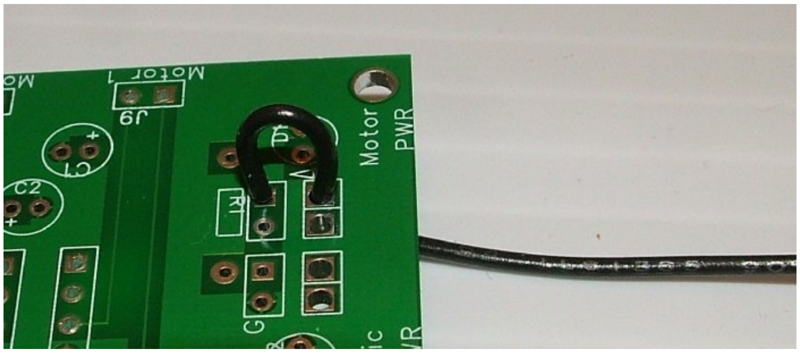

Figure 8. A strain relieved wire. This wire is threaded from the underside of the PCB and through a large near the edge of the board. It is then bent and soldered into a pad inside the strain relief hole. Note that the insulation is intact where it passes through the strain relief hole.

□ Solder wire and trim
□ Repeat for the other seven wires

Making the Easy Connector

□ Insert the 1 by 4 right angle header into the 4-pin Easy Connector printed circuit board and solder

Note: The short pins must be soldered to the printed circuit board. Leave the long pins free so they will plug into the flight computer’s I/O port.

□ Strip ¼ inch of insulation from the ends of the four wires at the I/O side of the Main Board. These wires are in pads marked +5, T1, T2, and G.
□ Insert the wires into the Easy connector printed circuit board using the strain relief holes.

Note: Wire G is soldered to GND, T1 is soldered to I/O-1, T2 is soldered to I/O-4, and +5 is soldered to +5V

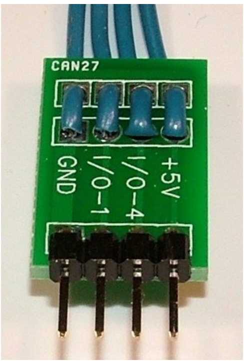

Figure 9. The completed 4-pin Easy Connector.

Temperature Sensor Cables

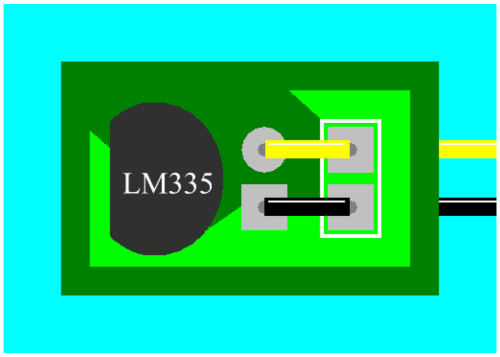

Figure 10. Temperature sensor head.

□ Solder a LM335 to a Temperature Sensor Head
□ Locate the two wires for T1 on the Main Board (on the sensor side of the Main Board)
One solder pad is marked with a G and the other is blank
□ Solder the T1 G wire to the G pad of the temperature sensor header
□ Solder the remaining T1 to the remaining open pad of the temperature sensor header

Note: The T1 wires are NOT on the I/O side of the Main Board, which also includes the +5 wire.

□ Repeat for the second Temperature Sensor Head

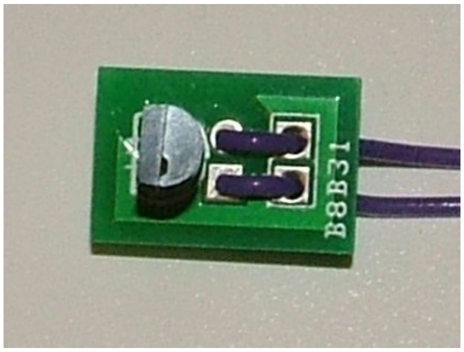

Figure 11. Completed temperature sensor head.

Checking Your Work

That completes the assembly of the NearSys Temperature Array. However, don't plug the temperature array into a working flight computer just yet. That's because if there is an error in the assembly, the temperature array could be damaged, or it could damage a flight computer when powered up. Now perform these five checks.

1. Check the Soldering

Check the underside of the PCB looking for blobs of solder that may bridge across two pads. If there appears to be such a bridge, briefly apply some heat to the pads with your soldering iron and "pull" the molten solder into two separate cones. Or you could lay solder wick across the solder and try to wick up the excess solder. Do these actions quickly as too much heat can damage copper traces on the PCB.

2. Check for a Short Circuit

Set the digital multimeter (DMM) to the continuity setting and tap the test leads together. The DMM will ring or beep to indicate there is a short between the test leads. If your DMM does not include a piezo speaker, then you will observe the DMM's displayed resistance approach very close to zero ohms. Now perform the test for real by tapping one test lead to the +5V pin and the other test lead to the GND pins of the header. There should be no ringing or indication of zero ohms of resistance. If there is, then there's a short in the PCB that you need to locate and repair. Pretty much the only way a short can exist in the PCB is through a solder bridge. So look over the underside of the PCB again for a solder connection that has overflowed its pad.

3. Check signal voltages

Connect the temperature array into a flight computer with its 4-pin Easy Connector and then power up the flight computer. Write the following program in the BalloonSat Mini and download

```
Temperature:
  readadc 1,b0
  readadc 4,b1
  debug
  goto Temperature
```

The debug window will open after the program downloads into the flight computer. Look at variables B0 and B1 and for a value around 149 for each one. The exact value depends on the temperature of each sensor. Be concerned when the values are close to 0 or 255. A bad value is possible for broken connections, shorts, or reversed sensors.

Using the NearSys Temperature Array

The cable on each temperature sensor allows you to route the sensors to widely spaced experiments. The PCBs can be hot glued into place. The LM335 temperature sensor should be shielded form direct sunlight as its black surface will absorb light and warm up. The result will be a false higher temperature reading. At the same time, the covering for a temperature sensor should permit air to flow around it. A temperature sensor located outside the BalloonSat airframe could be covered with a white plastic lid with holes drilled in its rim.

Post Mission Data Processing

After BalloonSat recovery and data download, you should have a file similar to this one for processing (this example was generated with a 10-bit ADC).

```
602,601
601,599
593,598
584,597
571,597
565,595
```

Data collected with the **READADC** (8-bit) command has smaller numbers than data collected with the **READADC10** (10-bit) command. Regardless, the first step is to convert the numbers from ADC counts to volts. This is done by dividing the number by the maximum value of the READADC command and multiplying by five.

For READADC10
voltage = (count/1024) * 5

For READADC
voltage = (count/256) * 5

Temperature Conversion

The voltage of the temperature sensor is in units of 100 kelvins. So multiplying the voltage by 100 converts it to a temperature reading of kelvins. Since kelvins is common unit for most people, convert the units of kelvins into units of Celsius by subtracting 273.

$$\mathbf{^{O}C = (voltage * 100) - 273}$$

Celsius can be converted to Fahrenheit two ways. The neatest way takes advantage of the fact that there is 1.8 Fahrenheit degrees for every 1.0 Celsius degrees and that they intersect at -40 degrees.

$$\mathbf{^{O}F = ((^{O}C + 40) * 1.8)-40}$$

A sample Excel spreadsheet is available at the NearSys website at the Temperature array webpage.

PICAXE Links

You’ll find PICAXE resources like the program editor and datasheets at the PICAXE website: http://www.rev-ed.co.uk/picaxe/. The Program Editor’s Help menu contains the BASIC command references for the PICAXE.

8 December 2012