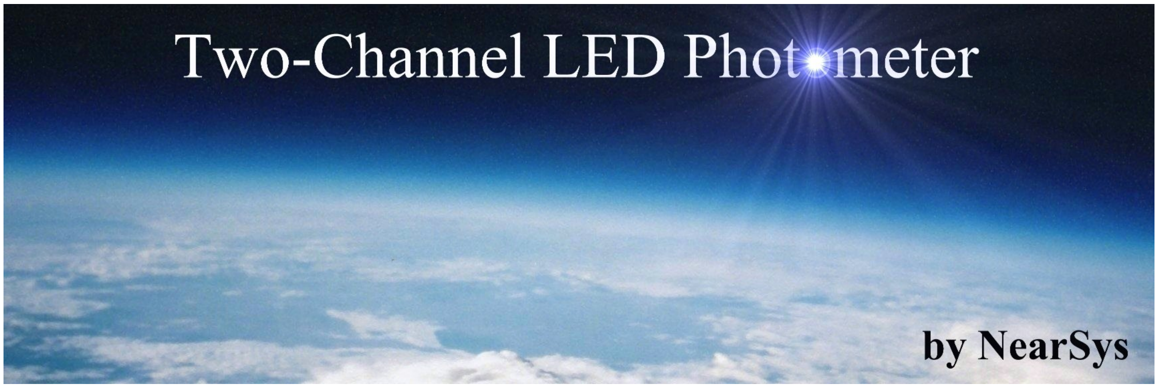

The NearSys Two-Channel LED Photometer is based on Forest Mims' 1992 article (Sun Photometer with Light-emitting Diodes as Spectrally selective Filters) about using LEDs as a narrow band photometer. The Two-Channel LED Photometer takes advantage of the behavior of LEDs to create a two channel photometer that while it is not as narrow banded as expensive professional photometers, is narrower than combination photocell or photodiode and theater gel. The result is an affordable way to measure the intensity of sunlight as a function of altitude.

Onwards and Upwards,
Your near space guide

Overview of the Two-Channel LED Photometer

A photometer measures the intensity of light over a narrow band of the electromagnetic spectrum. Typically, high quality photometers use interference filters to isolate very narrow bands of electromagnetic radiation (light). As a result, they can be very expensive. An LED normally operates as an emitter of light. The light emitted by an LED covers only a narrow band of the electromagnetic spectrum. What Mr. Mims found out is that the silicon chip inside an LED will create a measurable current when light shines upon it. This is the same thing a photodiode and solar cells do. However, unlike a photodiode or solar cell, an LED is only sensitive to light in a narrow band centered around the color of light it emits. The narrowband of sensitivity and inexpensive nature of LEDs makes them a great way to create photometers.

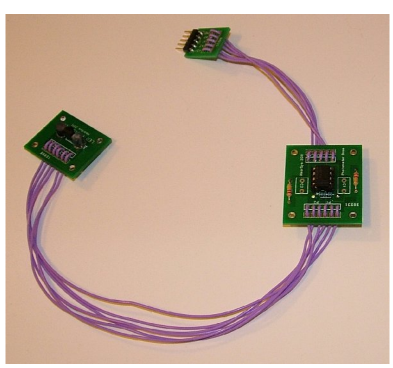

Figure 1. A completed two-channel LED Photometer

Parts List

Main Board

C1 220 pF capacitor
C2 220 pF capacitor
R1 1MΩ ¼ W resistor (brown, black, green, gold)
R2 1MΩ ¼ W resistor (brown, black, green, gold)

Note: If your photometer will use the infrared LEDs, then R1 and R2 are 100 kΩ ¼ W resistors (brown, black, yellow, gold) instead of 1 MΩ.

R3 1kΩ ¼ W resistor (brown, black, red, gold)
U1 TLC272 Op-Amp and 8-pin socket

Photometer Head

D1 LED T 1-3/4
D2 LED T 1-3/4
U1 LM335

The remaining items are required to complete the NearSys Two-Channel LED Photometer, but they do not have a reference on the PCB.

Wire (#24 AWG)
Two ¼" tall nylon spacers
Five-pin right angle header
Easy-Plug I/O printed circuit board
5mm thick CellFoam 88 sheet (2" by 2")

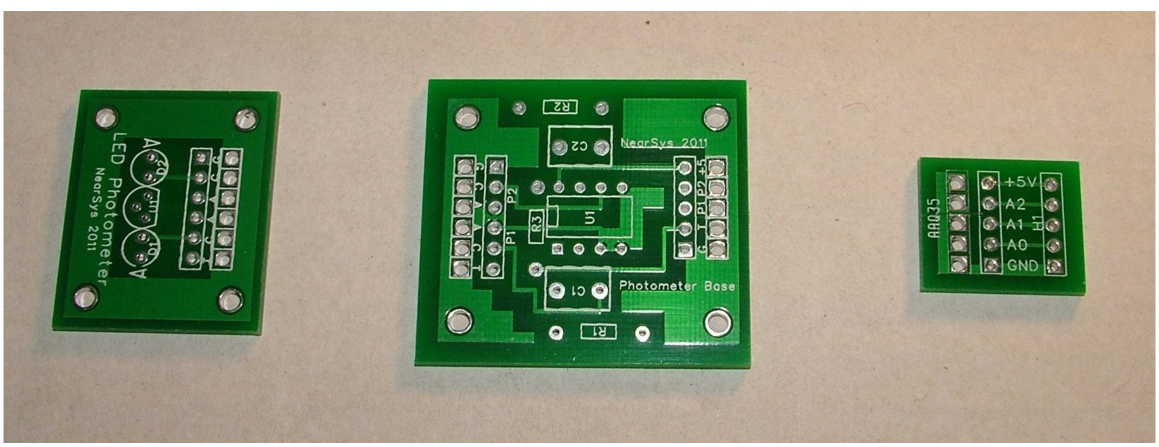

Figure 2. The PCBs from left to right are, The Photometer Head, Main Board, and 5-Channel Easy-Plug. They are connected together with #24 AWG wire.

Theory of Operation

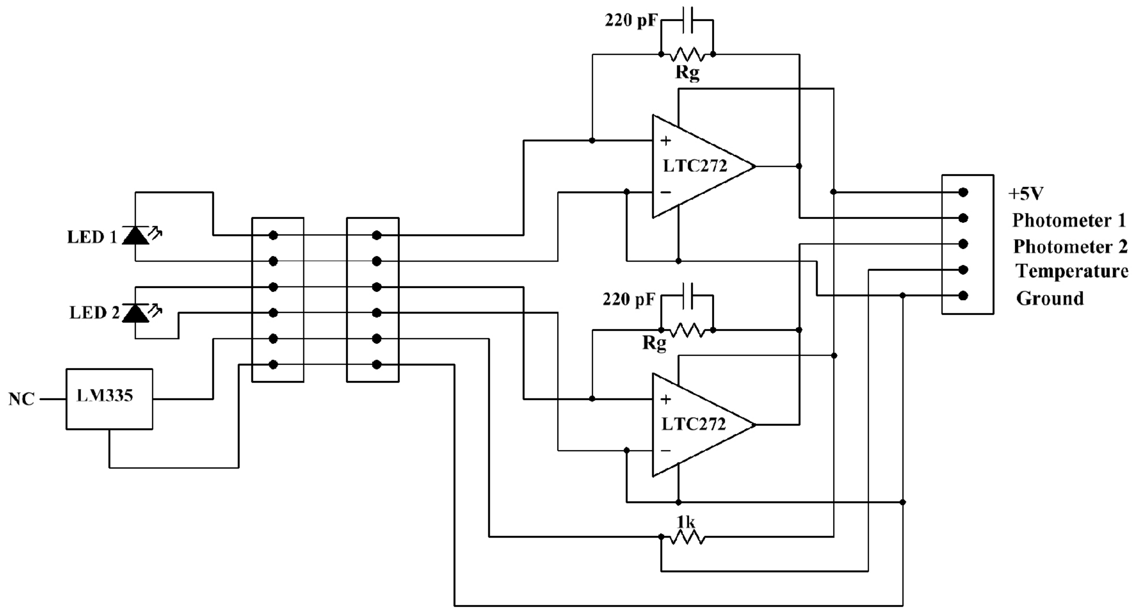

Figure 3. NearSys Two-Channel LED Photometer Schematic.

LEDs, which emit specific colors of light, also generate tiny currents when exposed to the color of light that they emit. The output of the LED is proportional to the intensity of the light shining on it. An Op-Amp can convert this current into a voltage using a transconductance amplifier. The result is a voltage that is proportional to the intensity of light in a narrow spectral band.

The op-amp in the LED photometer is a TLC272, dual op-amp. Resistors Rg sets the gain of the amplifier. In this kit, these resistors are the 1 MΩ resistors. The 220 pF capacitors prevent the transconductance amplifier from oscillating.

The output of LEDs is strongly dependent on their temperature. Therefore, there is an LM335 temperature sensor positioned between the two LEDs on the Photometer Head PCB. The 1 kΩ resistor connects the LM335 to five volts. The voltage output of the LM335 is proportional to its temperature. Therefore, by measuring the voltage of the LM335, the temperature of the LEDs can be determined.

The Two-Channel LED Photometer has three outputs, two light sensors and one temperature. To connect the photometer to the Easy Port of a NearSys BalloonSat flight computer, the third PCB of the photometer is a five pin Easy-Plug board. When plugged into the flight computer, the Easy-Plug provides the +5V supply and ground needed to power the photometer. The remaining three I/O pins are the output voltages from the photometer.

Assembling the NearSys Two-Channel LED Photometer

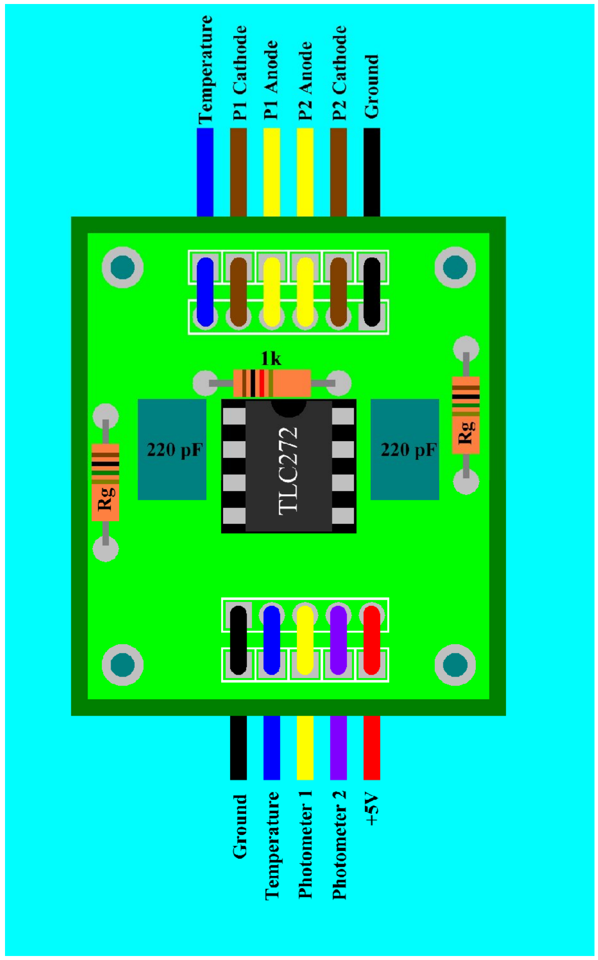

Figure 4. Parts layout for the photometer Main Board.

Solder the following parts

□ **R1 1 MΩ (brown, black, green, gold)**

□ **R2 1 MΩ (brown, black, green, gold)**

Note: If using the infrared LEDS, then use 100 kΩ (brown, black, yellow, gold) resistors for R1 and R2

□ **R3 1 kΩ (brown, black, red, gold)**

□ **C1 220 pF**

□ **C2 220 pF**

□ **IC Socket**

Note: Do not insert the TLC272 into the IC socket until after the socket is soldered into the PCB. The IC socket has a notch at the top. Align the notch with the notch in the top silk. The IC socket notch faces the 1kΩ resistor.

□ Cut the #24 AWG wire into 11 equal lengths (about six inches long)
□ Strip ¼ inch of insulation from one end of each wire.
□ Insert one wire into each strain relief hole and solder all the wires to the Main Board.
Note: The strain relief holes are the 11 large holes near the two opposite sides of the PCB. The wires pass through the holes from the bottom of the PCB and then bend over so the bare ends can be soldered into the smaller holes near the strain relief holes. Using strain relief prevents normal use from breaking the wires off the PCB.

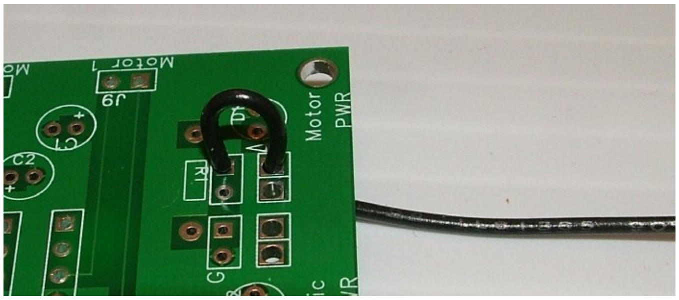

Figure 5. An example of a wire and the strain relief hole. Notice that the wire remains insulated as it passes through the strain relief hole. The only place the wire is bare of insulation is where it is soldered to the inside soldering pad.

□ Insert the TLC272 op-amp into the IC socket (watch the orientation).

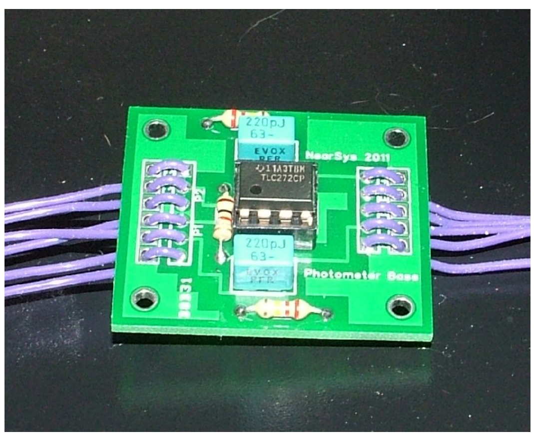

Figure 6. The finished Main Board.

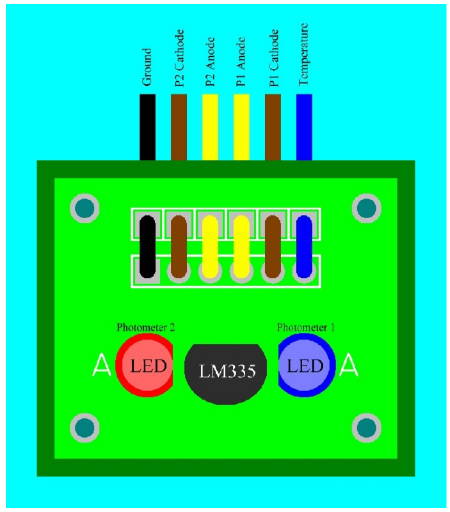

Figure 7. The parts layout for the Photometer Head.

□ Select two LEDs for the photometer

Note: If an 880 nm and 940 nm IR LEDs are selected, then the relative changes in their signal can be used to measure water vapor in the air. That's because water vapor absorbs 940 nm radiation, but not 830 nm radiation.

□ File the top of both LEDs with sandpaper to flatten them
□ Smooth the flattened tops with finer sandpaper

Note: This removes the lens form the top of each LED, making them less sensitive to pointing direction.

□ Slide a nylon spacer over one lead (wire) of an LED (it doesn't matter which one)
□ Insert the LED into D1 and solder

Note: The spacer keeps the LED above the surface of the PCB.
Note: The LED is a polarized device. The short lead is normally the cathode of the device. This is also the side of the LED body with the flattened edge. The other lead is the anode and this is the lead that is inserted into the pad closet to the "A" printed on the PCB.

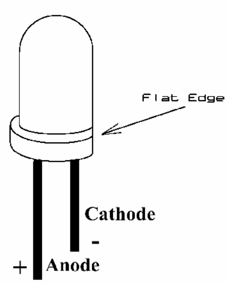

Figure 8. The anode and cathode of an LED.

□ Slide a nylon spacer over one lead (wire) of the second LED
□ Insert the LED into D2 and solder
□ Insert and solder the LM335

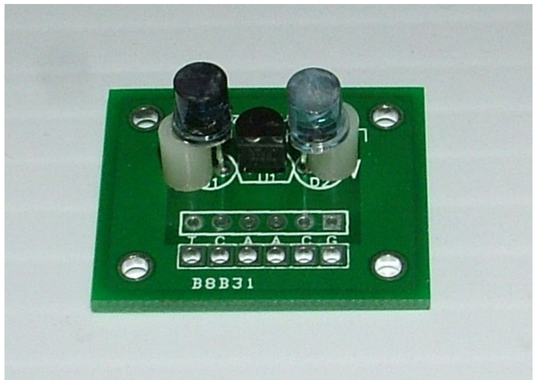

Figure 9. LEDs and LM335 temperature sensor soldered to the Photometer Head.

□ Strip ¼ inch of insulation off the ends of the six wires on the Main Board
□ Insert the six wires From the Main Board into the Photometer Head PCB, using the strain relief holes

Note: Carefully line up the wires between the Photometer Head and the Main Board. The holes are marked G, C, A, A, C, and T. G is ground and T is for the temperature sensor. The C and A next to the G are for the first photometer channel. Note that there is P1 above this C and A on the Main Board. The D1 LED soldered to the Photometer Head is the channel 1 photometer.

□ Drill two ¼ inch diameter holes in the sheet of two inch by two inch Styrofoam. The holes are 1 cm apart (center to center).
□ Use hot glue to attach the Styrofoam sunshield to the Photometer Head. The holes permit the LEDs to look out while shielding the LM335 from direct exposure to the sun.

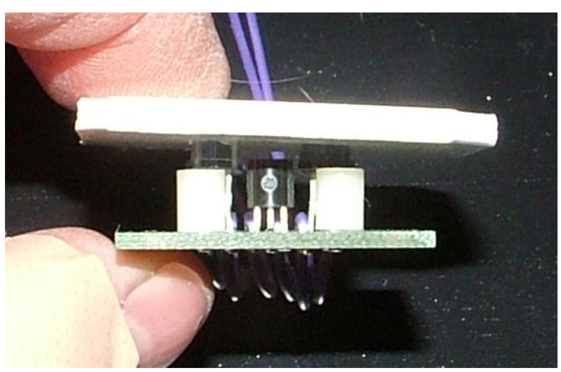

Figure 10. Side view of the Photometer Head with the sunshield in place.

□ Solder the five-pin right-angle header to the Easy-Plug board

Note: The five-pin header is soldered to the Easy-Plug in the holes marked H1.

□ Insert the five wires from the Main Board PCB into the Easy-Plug board using the strain relief holes (see the table below)

Main Board	Easy-Plug
G	GND
T	A0
P1	A1
P2	A2
+5	+5V

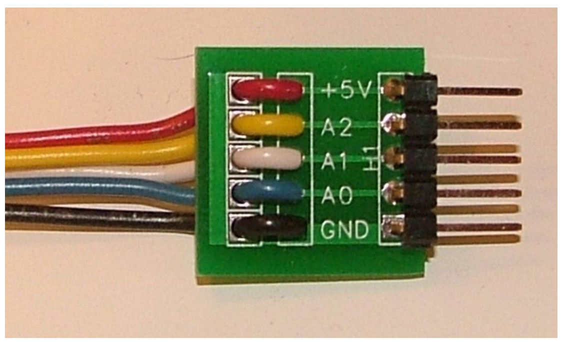

Figure 11. Easy-Plug.

Using the Two-Channel LED Photometer

The Easy-Plug fits into the Easy-Port of the BalloonSat Easy flight computer. The pins are oriented properly, so verify the Easy-Plug's +5 pin is plugged into the +5V socket on the BalloonSat Easy.

The Flight Computer needs code to digitize the three voltages produced by the photometer. There are two BASIC commands that can do this, which is referred to as analog to digital conversion (ADC). The first converts a 0 to 5 volt signal to an 8-bit value between 0 and 255.

READADC 0,B0

The second example converts a 0 to 5 volt signal to a 10-bit value between 0 and 1023.

READADC10 0,B0

Which command you use is up to you. Just remember that the 10-bit conversion requires one word (two bytes) of memory to store (as opposed to only one byte of memory to store the 8-bit value). However, the greater resolution afforded by the 10-bit conversion is four times greater than the 8-bit version.

With the configuration recommended in these directions, I/O channel A0 will report the temperature of the LEDs. This is important because LEDs are sensitive to their temperature. Their output voltage decreases as their temperature increases, even while the light intensity remains constant. This means the LEDs will need a temperature adjustment in order for the photometer to give meaningful results for the entire flight.

Converting Temperature Signals into Temperatures
One volt of the temperature sensor represents 100 kelvins. Use the following calculations to convert the result of the ADC of the temperature signal into the temperature.

From the READADC Command

Temperature (K) = (ADC Value / 256) X 500

From the READADC10 Command

Temperature (K) = (ADC Value / 1024) X 500

Since the kelvin temperature scale is not a common unit for most people, convert the units of kelvins into units of Celsius by subtracting 273.

$$^{O}C = K - 273$$

The Celsius scale can be converted to the Fahrenheit scale 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 the Celsius and Fahrenheit scales intersect at -40 degrees. With this in mind, the conversion is as follows.

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

The LED Outputs
It’s not important to convert the Channel 1 (I/O pin A1) and Channel 2 (I/O pin A2) readings back into voltage. This is because the conversion doesn’t add any new information to the LED readings and may in fact reduce the accuracy of the signals for comparison purposes. It is only necessary to compare the two outputs by dividing one by the other. If the photometer uses 830 nm and 940 nm LEDs, then the comparison should divide the output of the 940 nm LED by the 830 nm LED.

Changes in the ratio of the two LED’s outputs indicates a relative change in the intensity of the two colors. However, the results will be more accurate if the temperature of the LEDs is taken into consideration.

Temperature Calibration of the Two-Channel LED Photometer
The easiest way to determine the temperature behavior of the photometer is measure the output of the LEDs as their temperature changes and the light intensity is kept constant. Since the photometer will be used to measure the intensity of sunlight, this test should be performed outside.

Begin by programming a flight computer to record the photometer's temperature and light intensity for both LEDs. Data should be recorded once per second and don't forget that the program for the BalloonSat Mini must also download the data. Next, find a sunny location that can quickly be reached from the kitchen freezer. At the sunny location, the photometer and flight computer must be held absolutely still as any movement may throw off the calibration. In addition, the location must be dry so that condensation does not form over the photometer's LEDs. Now chill the photometer in the freezer, making sure frost does not form over the LED. Quickly carry the photometer to the sunny location and begin recording voltages. After recording for a few minutes, stop recording data and download it using the Terminal program in the PICAXE Editor. Then import the data into a spreadsheet. The data will look like the sample below.

Temperature	Red	Orange
109	117	38
139	136	50
152	141	55
158	141	57
160	140	59

Table 1. Sample output from a red and orange photometer.

After importing into a spreadsheet, create a graph of the data. Temperature is the independent variable (along the x-axis) and the LED outputs are the dependent variable (y-axis).

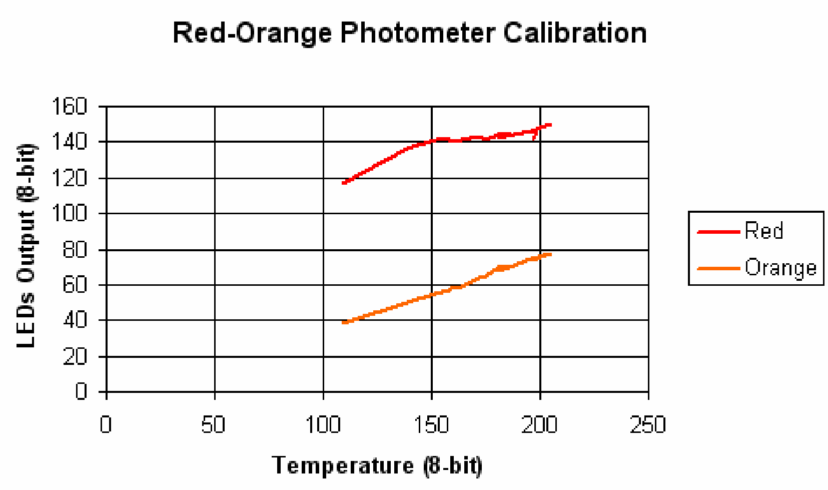

Figure 12. Graph of the red and orange sample calibration data.

Now add a Trendline (linear) and ask that the equation for the Trendline be included into the graph.

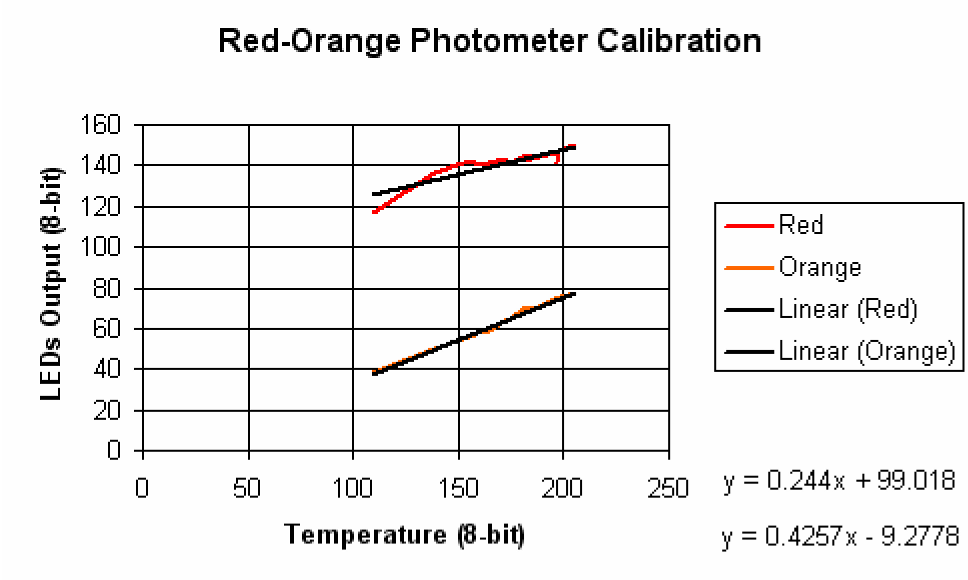

Figure 13. Trendline added to the sample calibration data.

In the sample data displayed above, the (8-bit) output of the photometer's red LED changes according to the equation, y = 0.244x + 99.018. In this equation, y is the output of the LED and x is the photometer's temperature. For the orange LED, the equation is y = 0.4257x – 9.2778. These two equations will later be used to correct the photometer's output due to its temperature.

Follow the same procedure is using 10-bit data. However, you can only use the 8-bit calibration equation for 8-bit data and the 10-bit calibration equation for 10-bit data.

Using the Two-Channel LED Photometer
After collecting data during a near space mission, download it through the PICAXE Terminal and then import the results into a spreadsheet.

Step 1
Use the temperature readings and the calibration equations to calculate the photometer's expected output (for both LEDs) at the time the calibration data was collected.

Step 2
Divide each LED's actual output to the expected output. This is the ratio of the actual photometer output to the output expected at this temperature. This ratio will be the true output of the photometer.

Step 3
Now compare the true outputs of the photometer during the flight to the initial output on the ground. Do this by dividing the initial output of the photometer into each reading at altitude. The result is a calibrated comparison of how the light intensity changed during the mission. This data should be graphed in relationship to the altitude at which the data was collected.

In most cases, the independent variable (altitude in this case) is plotted along the x-axis. However, the graph is more informative if the altitude is plotted along the y-axis.

Options
The LEDs in the Two-Channel Photometer will never be insensitive to their pointing direction. Therefore, you will find the intensity data varies as the BalloonSat rotates in relationship to the sun. So what can we do?

First, a sun sensor can be combined with the photometer to determine the position of the sun. The flight computer might only collect data at particular orientations of the sun.

Second, a diffuser like a ping pong ball could be placed over the sun shield. A diffuser like this will help make the sky look more uniform from the LEDs' perspective.

Third, data could be collected very rapidly. The data should show a cycle of the photometer rotating to face the sun and then rotating away. The highest value of each cycle could be saved and the rest of the data discarded. Then a comparison of the data will show less variation due to the BalloonSat rotating.

Forth, a camera could be incorporated into the BalloonSat. The camera could photograph the pointing direction (relative to the sun) of the BalloonSat. Alternately, the camera could record the angle of a shadow cast by a dowel at each photometer reading. In either case, only data collected while the sun was in the proper location would be kept and the rest discarded. Then a comparison of the data will show less variation due to the BalloonSat rotating.

Fifth, commercially available UV-B photodiodes can be purchased for around $100. A photodiode like this could be substituted for an LED to create a photometer capable of detecting changes in the amount of ozone between the photometer and the sun.

23 September 2012