Judah Wolf
SkeeterSat Calibration Report
LaACES Student Ballooning Course
October 14, 2019

Introduction

The SkeeterSat is a device intended to measure temperature and intensity of light through emitting variously pitched and timed emissions of sound. It is composed of a circuit board with a thermistor, photocell, piezoelectric buzzer (outlined by a square in **Figure 2**), and a TLC556CN dual CMOS timer (outlined by an oval in **Figure 2**).

The thermistor, as seen on the schematic of the SkeeterSat in **Figure 1**, is a negative temperature coefficient (NTC) thermistor, which means that its resistance to voltage exponentially decreases as temperature increases.

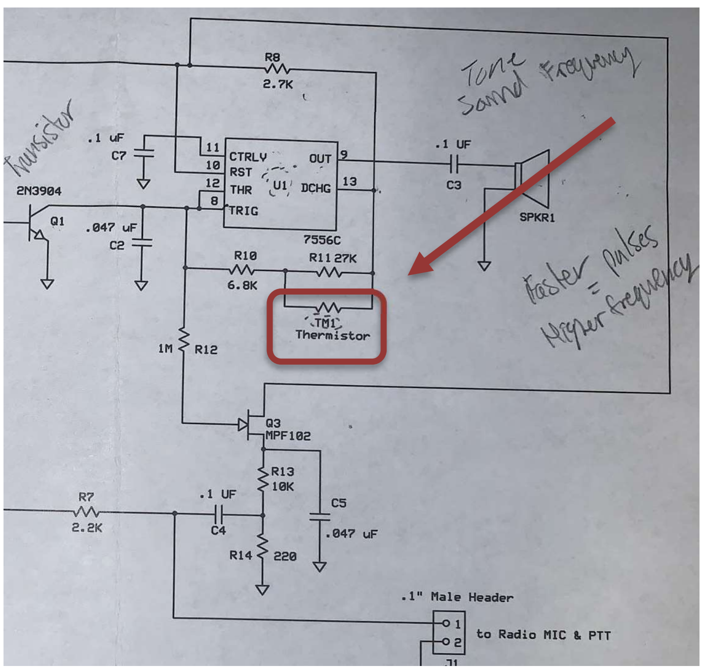

Figure 1: The SkeeterSat Schematic
This schematic helped with assembling the SkeeterSat. Every component is shown, as well as the relationships between these components. This is only half of the schematic, but take note of the placement of the thermistor: it goes directly into the trigger pin of its respective timer and leads to a capacitor, which helps explain how the Resistance-Capacitance circuit functions.

The thermistor varies the resistance to the timer based on the temperature measured by the sensor, which changes the frequency (pitch) of beeps emitted by the speaker.
The higher the temperature, the higher the frequency. The photocell varies resistance to the other timer based on the amount of light shining on it, which changes the interval between beeps.

The combination of resistors and capacitors creates an “RC Circuit,” helping the dual timer to act as a multivibrator. The capacitor receives voltage that passes through the variable resistor (thermistor or photocell), which causes the rate at which the capacitor charges and discharges to vary. The frequency of the timers’ oscillation depends on this rate of charge/discharge. The chain of events occurs in this order: the thermistor sensor detects temperature and adjusts the resistance. This affects the rate of charge/discharge of the capacitor, which directly affects the rate of oscillation of the timer. If the timer oscillates slowly, the piezoelectric buzzer is vibrated less frequently, which causes a lower pitched beep. If the detected temperature increases, resistance will decrease, and the capacitor will charge/discharge more quickly. As a result, the timer will oscillate more quickly to produce a higher pitched beep from the buzzer. Therefore, the oscillator works as a function of resistance. This explanation just describes the cause of the pitch of the beeps, but the same logic can be applied to understand the length of intervals between beeps.

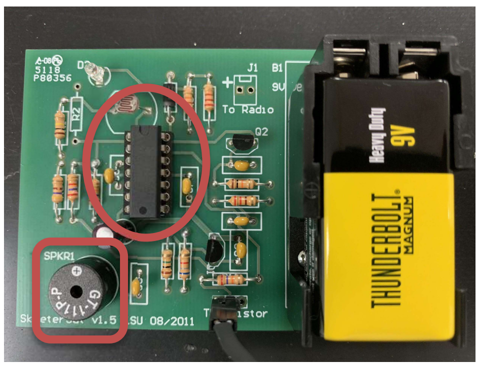

Figure 2: The Assembled SkeeterSat.
The SkeeterSat is composed of resistors, capacitors, diodes, a buzzer, and an IC chip soldered to a through-hole circuit board. It is powered by a 9 volt battery. The thermistor is hidden from view.

Objectives

A calibrated SkeeterSat will ensure accurate temperature measurements, and will allow users to interpret the responses of the indicators to stimuli. For example, users should be able to interpret certain frequencies as indicators of certain temperatures.

Materials

1. Hot plate
2. Beaker
3. Heat resistant gloves
4. Laptop with Spectrogram application downloaded
5. Model SF-9616 Demonstration Multimeter (or other thermometer)
6. Safety glasses
7. External microphone
8. Lab notebook
9. Writing utensils
10. Calculator
11. 9 volt battery
12. SkeeterSat Assembly

a. Resistors
b. Thermistor
c. Photocell
d. TLC556CN dual CMOS timer
e. Piezoelectric buzzer
f. LED
g. Transistors

Various electronic components were used to construct the SkeeterSat, which are shown on the materials list. For more specific information about the components, view “SkeeterSat Assembly and Operation Manual.” A 9 volt battery powers the device. A spectrogram software program called Spectrogram was used to record and interpret the frequencies emitted by the speaker.

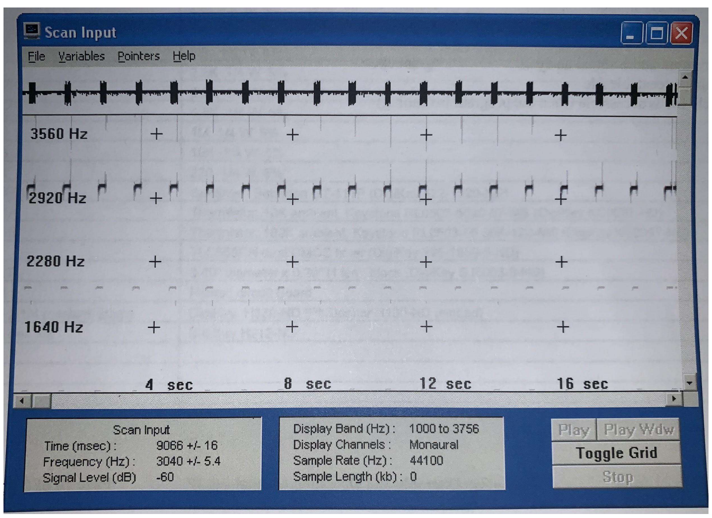

Figure 3: Spectrogram in Action
Shown is an example of Spectrogram being used to measure sound frequencies. Spectrogram splits pulses into different frequencies, which allows users to identify the fundamental frequency. Vertically aligned marks indicate harmonic frequencies of the same base frequency.

Calibration Procedure

1. All materials were gathered and prepared for use. The hot plate, laptop, and digital multimeter were plugged into power. The external microphone was plugged into the laptop and tested to ensure it recorded sound. I opened the spectrogram program and configured the settings as suggested in “SkeeterSat Assembly and Operation Manual.”
2. I heated a beaker containing about 250 mL of water to a boil using a hot plate. On subsequent measurements, I heated it again with the hot plate or cooled it with ice.
3. Using protective gloves, I carried the beaker to my work station.
4. I installed the 9 volt battery into the SkeeterSat.
5. I measured the temperature of the water using the multimeter by placing the tip of the thermometer in the approximate center of the mass of water. I recorded this in my notebook.

6. After removing the thermometer, I placed the tip of the thermistor in the approximate center of the mass of water.
7. Once the SkeeterSat's beep reached a consistent pitch, I enabled recording on the laptop and recorded about ten seconds of sound.
8. I stopped the program, then recorded the temperature of the water again to help determine uncertainty.
9. Following the removal of the battery, I used Spectrogram to determine harmonic frequencies of the beep. For most measurements, I recorded 3 sets of 3 adjacent harmonic frequencies.
10. To find approximations of the base/fundamental frequency, I found the difference between adjacent harmonic frequencies at a certain instance in time. Because I was able to record a total of 9 harmonics per temperature, except for instances where the window size of the program limited me, I generally found 6 approximations of the base frequency per temperature. Then, I found the average of these measurements to determine the formal measurement of base frequency.
11. Steps 3-10 were repeated for a total of 15 temperatures.

Calibration Results

Freq. (Hz	Temp. (°C
486 ± 21	5.5 ± 1.2
491 ± 21	9 ± .5
506 ± 22	12.3 ± .1
525 ± 11	21 ± .021
550 ± 1	27.5 ± .1
576 ± 10	32.9 ± .2
621 ± 11	39.2 ± .1
689 ± 0	47.4 ± .9
754 ± 21	55.2 ± 1.5
856 ± 23	64.2 ± 2.8
916 ± 21	68.9 ± 1.6
1041 ±22	78.7 ± 2.9
1052 ±22	81 ± 2.1
1210 ± 11	91.9 ± 4.5
1254 ± 21	95.8 ± 3.1

Table 1: Table of Calibration Results
This table indicates the uncertainty in the measurements, as well as the increasing behavior of the temperature as a function of the frequency.

During calibration, there were no issues with the SkeeterSat's emission of sound. The circuit appeared to be working properly. I used Spectrogram, which visually divides pulses into harmonic frequencies, to determine the fundamental frequencies of the pulses. ***Table 1*** shows the temperature compared to the respective average base frequencies.

Uncertainties of Measurement

In the right column, the degree of uncertainty was determined by the difference between the two temperatures measured before and after the sound was recorded. The only exception to this is the cell with a temperature of 21°C, which has an uncertainty determined by the data sheet of the multimeter (1%). The listed temperatures are the averages of the temperatures measured before and after recording sound. The uncertainty in the left column is determined by subtracting the lowest number used to find the respective average base frequency and subtracting it from the highest. I initially attempted to find the standard deviation of each average and divide it by the square root of the number of measurements (algebraically written as $\frac{\sigma}{\sqrt{n}}$), but the numbers were negligible compared to the much larger uncertainty of the range of the numbers. The uncertainty of the Spectrogram crosshair is 11 Hz, although I still find difficulty in combining this uncertainty with others.

Expected vs. Actual Results

Figure 4 shows data points for expected and actual temperatures and frequencies. The best fit equation for the actual results on the graph is:

Equation 1

$$y = 89.221 \ln(x) - 539.26$$

This was generated by Excel after I chose a logarithmic best fit curve. **Equation 1** is logarithmic, which seems to fit the data best because it increases with a gradually decreasing slope -- the function is graphically concave downward. The expected results were derived using formulas from the TLC556CN dual CMOS timer data sheet. It gives this equation:

Equation 2

$$Period \approx C_t(R_A + 2R_B) \ln 2 \ \ s$$

Using the schematic shown in **Figure 1**, actual values can be substituted for the **Variables** shown in **Equation 2**.

Variables

$$C_t = 0.047\ \mu F = 4.7 * 10^{-8}\ F$$
$$R_A = 2700\ \Omega$$
$$R_B = 6800 + (27000^{-1} + TM1^{-1})^{-1}\ \Omega$$

Substituting the values for **Variables** in **Equation 2** yields **Equation 3**, shown below.

Equation 3

$$Period \approx 4.7 * 10^{-8}(2700 + 2(6800 + (27000^{-1} + TM1^{-1})^{-1}))\ln 2 \ s$$

TM1, which represents the resistance of the thermistor at a certain temperature, is the only variable left in **Equation 3**. To find this resistance, refer to the thermistor data sheet. The thermistor's resistance at 25 °C is 100K Ω. The data sheet has a table of Rt/R25 values, which, when multiplied by 100K, gives the resistance of the thermistor for the temperature associated with that Rt/R25 value. This can be shown by **Equation 4**.

Equation 4

$$TM1 = \frac{R_t}{R_{25}} * 100{,}000$$

Substituting the resistance of TM1 for a given temperature found from **Equation 4** into **Equation 3** yields the period of the charge and discharge cycle of the timer. After calculating the period, I simply found the reciprocal of the period to identify the expected frequency of the beep, which is used to measure temperature. The graphed results are shown in **Figure 4**.

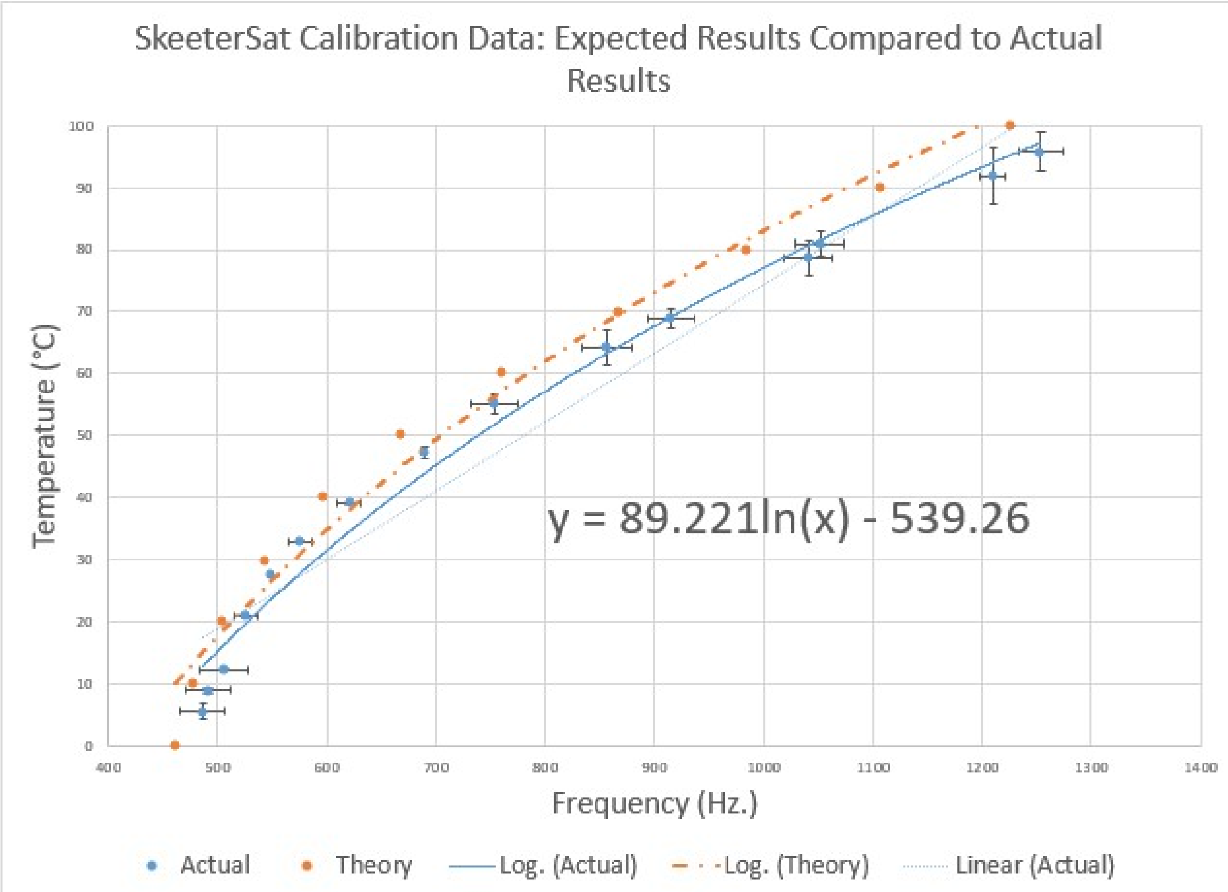

Figure 4: Differences between Expected and Actual Results
This graph shows the actual frequencies of the buzzer to be lower than the expected frequencies. However, the general trend is the same, and the difference in results can likely be attributed to uncertainty of measurement.

Conclusion

Overall, the calibration was successful. Despite not matching exactly with the expected results, there are no apparent signs of a lack of functionality. Using the SkeeterSat and Spectrogram, I am now able to determine a temperature based on an emitted frequency. The certainty of this temperature is limited by the accuracy of the best fit curve, which itself relies on frequencies measured with a degree of uncertainty. Unfortunately, I still feel I lack the knowledge to properly define the uncertainty of a temperature found using the **Equation 1**. Regardless, a frequency can be inserted into **Equation 1** as the x-value to measure a temperature as the y-value.

Sources

TLC556CN dual CMOS timer Data Sheet: http://www.ti.com/lit/ds/symlink/tlc556.pdf

Rt/R25 Table Data Sheet:
http://www.patarnott.com/atms360/pdf_atms360/class2016/Themometrics_ThermistorResistanceCurve%20D12_2.pdf

Thermistor Data Sheet:
http://www.farnell.com/datasheets/1855954.pdf?_ga=2.224241694.400641136.1571116348-113390964.1570240187