A05.01 SkeeterSat Calibrations
LaACES Student Ballooning Course

Materials:

Student(s) should have the following materials, equipment, and supplies:

1. SAFETY GLASSES or GOOGLES
2. Assembled SkeeterSat
3. 9-volt alkaline battery
4. Beakers
5. Hot-Plate
6. Freezer or bag of ice
7. Thermometer
8. A computer equipped with a microphone.

Additionally, you will need access to software capable of plotting the frequency spectrum of an audio file. The software show in screenshots in this document is an opensource audio editing software available at https://www.audacityteam.org/ . However, any software with similar functionality will work

Using *SkeeterSat* as a Temperature Sensor

You can utilize the SkeeterSat as a temperature sensor. The pitch of the beep is dependent on the temperature of the thermistor. When the temperature rises, the resistance will decrease, and the pitch will go up. If the temperature decreases, the resistance will increase, and the pitch will go down.

Due to this relationship, it is possible to use the SkeeterSat as a temperature sensor by recording the audio frequencies emitted by the SkeeterSat and correlating the audio frequency to temperature. To make a reliable measurement, the pitch frequency should be recorded at multiple temperatures. This can be accomplished by submerging the thermistor into water that has been cooled or heated to a specific temperature.

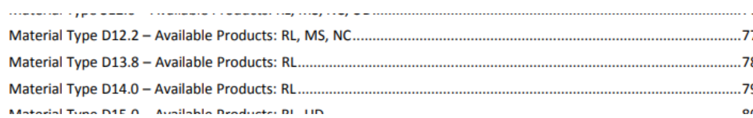
But before we do so we want to understand why this is causing a change in the pitch so we have some expectation of what the calibration should look like.

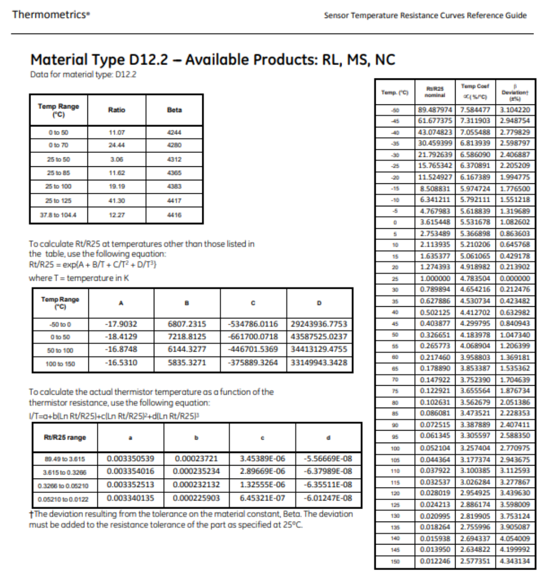
First, we want to consult the Thermistor Datasheet since we know that is the component that is being affected by temperature. The data sheet gives us the resistance at 25C and a material type but refers to a separate document to find the resistance with temperature.

Epoxy-coated thermistor

Type Number	Ro@ 77 °F (25 °C) (Ω)	Material System	A in	mm
RL0703-624-73-MS	1K	D7.3	0.120	3.05
RL0503-1248-73-MS	2K	D7.3	0.095	2.41
RL0703-1445-95-MS	2.5K	D9.5	0.120	3.05
RL0503-2890-95-MS	5K	D9.5	0.095	2.41
RL0703-2910-97-MS	5K	D9.7A	0.120	3.05
RL0703-3720-84-MS	6K	D8.4	0.120	3.05
RL0503-5820-97-MS	10K	D9.7A	0.095	2.41
RL0703-5744-103-MS	10K	D10.3	0.120	3.05
RL0503-7440-84-MS	12K	D8.4	0.095	2.41
RL0703-8780-96-MS	15K	F9.61	0.120	3.05
RL0503-11.49K-103-MS	20K	D10.3	0.095	2.41
RL0703-13.77K-120-MS	25K	D12.0	0.120	3.05
RL0503-17.56K-96-MS	30K	F9.61	0.095	2.41
RL0503-27.53K-120-MS	50K	D12.0	0.095	2.41
RL0703-27.68K-122-MS	50K	D12.2	0.120	3.05
RL0503-55.36K-122-MS	100K	D12.2	0.095	2.41

If we look at the Temperature Resistance curves for the Thermistor, we will see multiple tables for different material types including the one listed on the datasheet. If we look at the appropriate table, we can see the resistance as a function of temperature.




Thermometrics® Sensor Temperature Resistance Curves Reference Guide

Material Type D12.2 – Available Products: RL, MS, NC

Data for material type: D12.2

Temp Range (°C)	Ratio	Beta
0 to 50	11.07	4244
0 to 70	24.44	4280
25 to 50	3.06	4312
25 to 85	11.62	4365
25 to 100	19.19	4383
25 to 125	41.30	4417
37.8 to 104.4	12.27	4416

To calculate Rt/R25 at temperatures other than those listed in the table, use the following equation:

$Rt/R25 = \exp(A + B/T + C/T^2 + D/T^3)$

where T = temperature in K

Temp Range (°C)	A	B	C	D
-50 to 0	-17.9032	6807.2315	-534786.0116	29243936.7753
0 to 50	-18.4129	7218.8125	-661700.0718	43587525.0237
50 to 100	-16.8748	6144.3277	-446701.5369	34413129.4755
100 to 150	-16.5310	5835.3271	-375889.3264	33149943.3428

To calculate the actual thermistor temperature as a function of the thermistor resistance, use the following equation:

$1/T = a + b(\ln Rt/R25) + c(\ln Rt/R25)^2 + d(\ln Rt/R25)^3$

Rt/R25 range	a	b	c	d
89.49 to 3.615	0.003350539	0.00023721	3.45389E-06	-5.56669E-08
3.615 to 0.3266	0.003354016	0.000235234	2.89669E-06	-6.37989E-08
0.3266 to 0.05210	0.003352513	0.000232132	1.32555E-06	-6.35511E-08
0.05210 to 0.0122	0.003340135	0.000225903	6.45321E-07	-6.01247E-08

†The deviation resulting from the tolerance on the material constant, Beta. The deviation must be added to the resistance tolerance of the part as specified at 25°C.

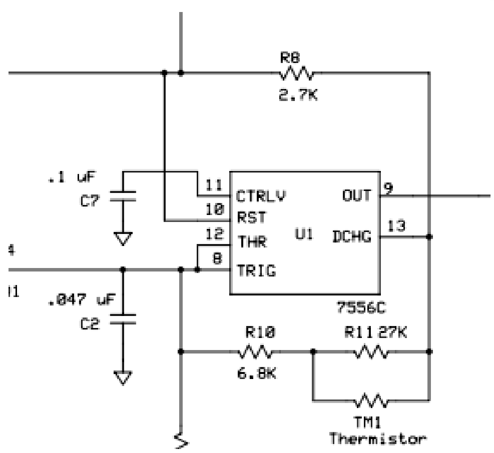
Temp. (°C)	Rt/R25 nominal	Temp Coef α(%/°C)	β Deviation† (±%)
-50	89.487974	7.584477	3.104220
-45	61.677375	7.311903	2.948754
-40	43.074823	7.055488	2.779829
-35	30.459399	6.813939	2.598797
-30	21.792639	6.586090	2.406887
-25	15.765342	6.370891	2.205209
-20	11.524927	6.167389	1.994775
-15	8.508831	5.974724	1.776500
-10	6.341211	5.792111	1.551218
-5	4.767983	5.618839	1.319689
0	3.615448	5.531678	1.082602
5	2.753489	5.366898	0.863603
10	2.113935	5.210206	0.645768
15	1.635377	5.061065	0.429178
20	1.274393	4.918982	0.213902
25	1.000000	4.783504	0.000000
30	0.789894	4.654216	0.212476
35	0.627886	4.530734	0.423482
40	0.502125	4.412702	0.632982
45	0.403877	4.299795	0.840943
50	0.326651	4.183978	1.047340
55	0.265773	4.068904	1.206399
60	0.217460	3.958803	1.369181
65	0.178890	3.853387	1.535362
70	0.147922	3.752390	1.704639
75	0.122921	3.655564	1.876734
80	0.102631	3.562679	2.051386
85	0.086081	3.473521	2.228353
90	0.072515	3.387889	2.407411
95	0.061345	3.305597	2.588350
100	0.052104	3.257404	2.770975
105	0.044364	3.177374	2.943675
110	0.037922	3.100385	3.112593
115	0.032537	3.026284	3.277867
120	0.028019	2.954925	3.439630
125	0.024213	2.886174	3.598009
130	0.020995	2.819905	3.753124
135	0.018264	2.755996	3.905087
140	0.015938	2.694337	4.054009
145	0.013950	2.634822	4.199992
150	0.012246	2.577351	4.343134

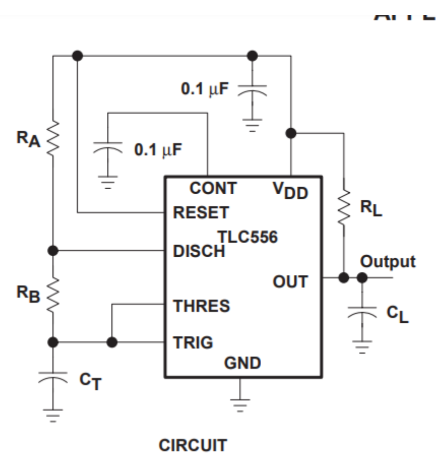
NOTE: If we look at the table, we see that Resistance is not linearly related to temperature but actually a complicated function so we should not really expect a linear behavior when we calibrate.

We now want to understand how the resistance of the thermistor affects the frequency. If we look at the datasheet for the timer chip, we can see a sample application on page 10. This is "astable operation" is how we are generating the signal that goes to the buzzer creating the tones.

If we compare the circuit from the datasheet, we see that R_A is equivalent to R_8, C_T is equivalent to C_2, and the combination of R_{10}, R_{11}, and TM_1 are R_B. Thus, we can use the equation for Period from the datasheet to determine how quickly the circuit is oscillating on and off. This oscillation is what is generating the beep. In fact, the frequency 1/Period.

The sound emitted by the SkeeterSat is a combination of multiple frequencies being emitted simultaneously. These frequencies are harmonics – repeating signals that are multiples of a base or fundamental frequency. You can calculate the fundamental frequency by measuring the difference between adjacent harmonics. To get an accurate measurement of the temperature, a measurement of the resonant frequency is required.



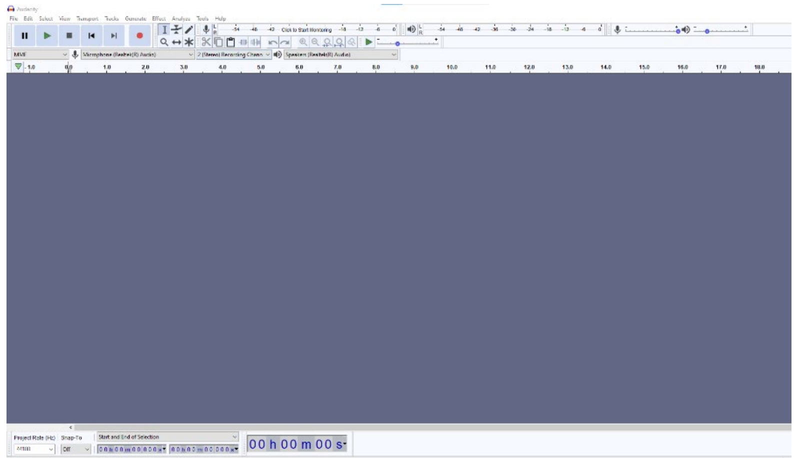


Measuring the frequency

While you can just listen to *SkeeterSat* beeping happily, some means of reducing the beeps to numerical data is needed if this simple telemetry system is to have meaning. We need to use some software that can record and analyze the beeps.

For this we will be using Audacity software.

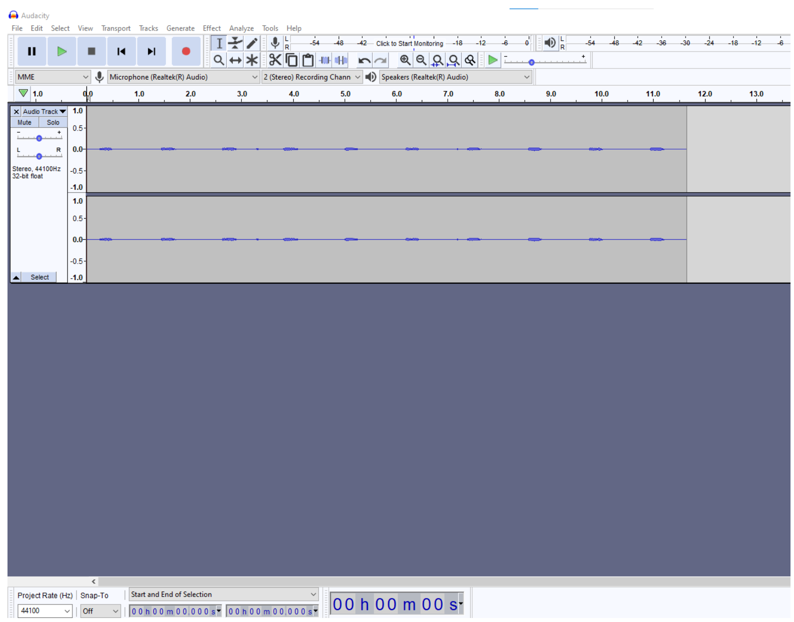
When we first open the software, we will see a screen like the right. The key thing is we want to make sure the correct microphone is selected. Usually this should just be your embedded microphone unless you are using an external device, also be careful if you are using a headset/headphones as they may have a microphone that might be selected.



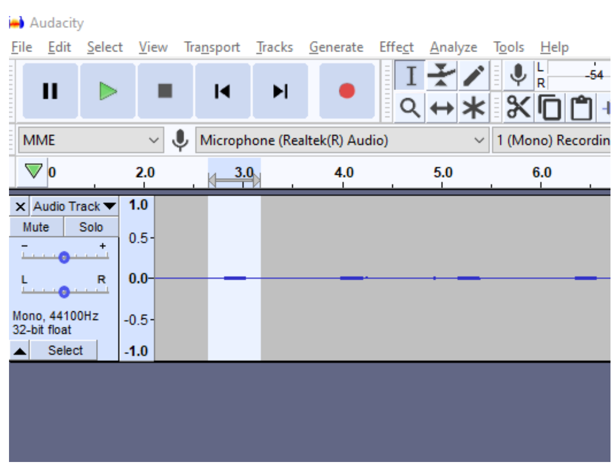
The other important control to notice is the play, stop, and record buttons in the upper right.

Next, we want to power our SkeeterSat on so that it is beeping. Next hit record and you will see a waveform begin to be drawn. If we let recording proceed for several seconds, we can see the loud portions where the beep was occurring and the quite portions where there was no beep. You may need to adjust the position of your SkeeterSat and microphone to get a good recording. To delete a recording simply click the X on the left side of the waveform.

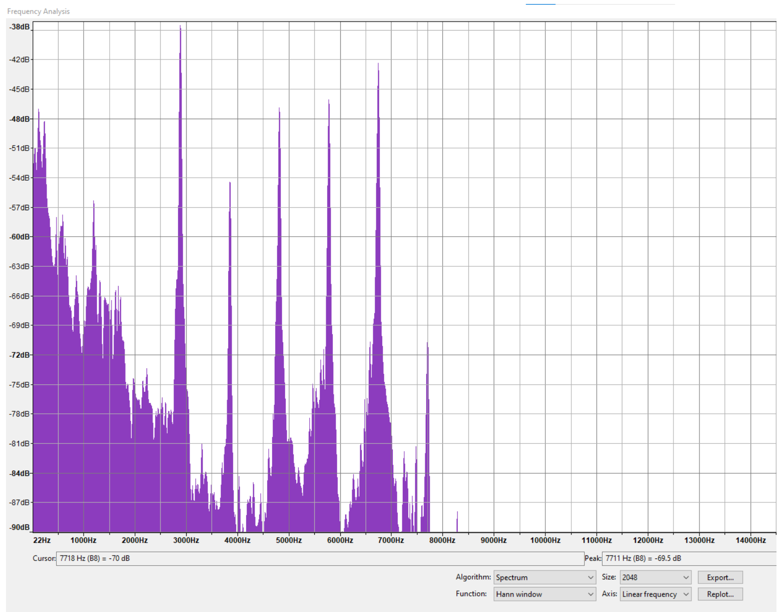
Once have a good recording of several beeps we can use the software to analyze one of them.



Using the select tool (the one that looks like an I) we can highlight a single beep in the timeline. We want to then select “Plot Frequency” from the Analyze menu. After doing so we should see histogram of various frequencies on the X axis with decibels (dB) on the Y axis.



It should look something like this.



We can see a series of regularly spaced peaks. These are our harmonics. The spacing between any adjacent pair of peaks is our harmonic frequency.

We should note a few features of this window. First there is the box that indicates the position of the cursor, ie the Frequency and dB value where the mouse is. If we get the mouse near a particular peak, we will notice a grey vertical line snap to to the peak and we can see the value of that peak in the box labeled peak.

The Algorithm and Function boxes have to do with the software that analyzes the sound, and we should just leave them on the default values of "Spectrum" and "Rectangular Window". The axis box lets us switch between a linear and log scale for the frequency axis, we want linear. The size drop down lets us select the number of frequency bins the data is broken into. So, I higher size number means we will have better resolution but if we set it too high we might not be able to see the peaks,

From this plot we can find each of the harmonics by finding the values of the peaks. If we subtract two adjacent peak values, we can find the harmonic frequency.

One thing to be careful of is that we want to be careful to make multiple **independent** measurements of the frequency. If we make two calculations of the fundamental frequency that depend on the same peak, they are not independent. However, if we make measurements on separate beeps at the same temperature the frequency plot for each beep will be independent. So, we can close the frequency plot, select a different beep in the timeline, and repeat the analysis to get multiple measurements.

SkeeterSat Calibration

Now that you know how to record the audio frequencies, you can begin to calibrate the SkeeterSat. You will need at least one beaker of water, a thermometer, a hot plate, and ice or a freezer.

Ensure that your thermistor has been water-proofed by either coating it in liquid electrical tape or protecting it in a plastic bag.

Submerge the thermistor into the water. Measure the temperature of the water in the beaker at room temperature and record the audio frequencies emitted.

Repeat this process with multiple temperatures maximizing the range of temperatures at which we measured, heating and cooling the water as needed. More accurate calibrations can be made by including a larger data set with appropriate analysis.

Next, plot the fundamental frequency as a function of temperature. Include each data point recorded and analyze the trend. Using the values from the circuit and the datasheets, we should be able to calculate expected frequencies for several temperatures and compare our measured values to these. Are there any irregularities in the data? What can you determine about the characteristics of the thermistor from this data? What are some limitations of using the SkeeterSat as a temperature sensor?

We also want to be aware of any sources of uncertainty while making our measurements. How wide are our frequency peaks? How accurate was our thermometer? Was the water heating and cooling as we took sound measurements?

Be sure to document the details of your procedure and measurements in your lab notebook to make that available when writing your calibration report.

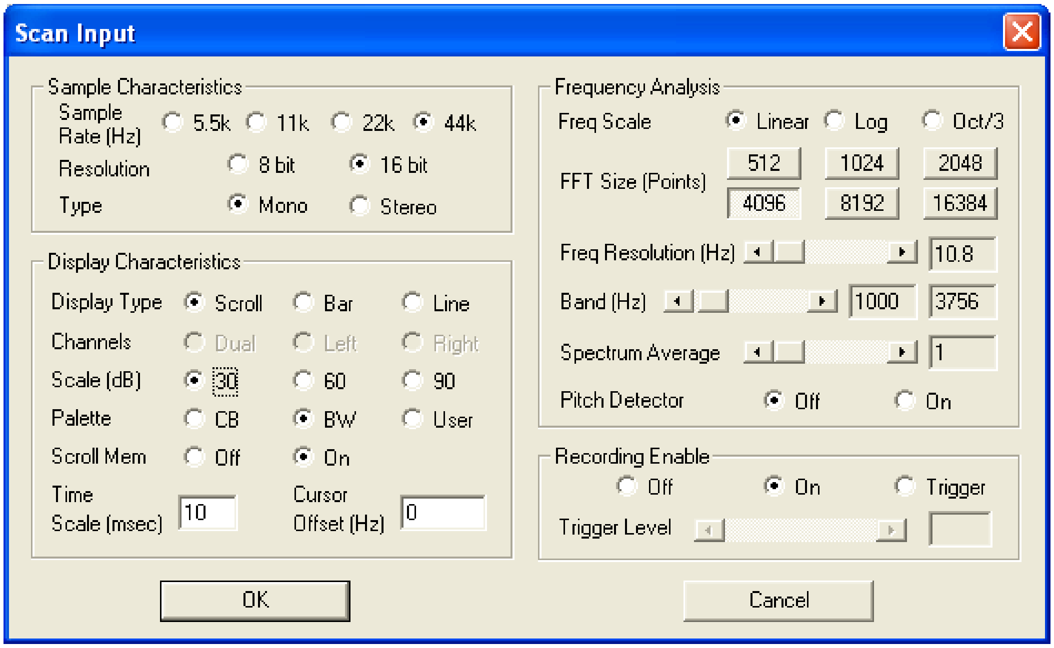
The following section describes the previous software used to do frequency analysis if it is preferred for students to use SpectroGram.

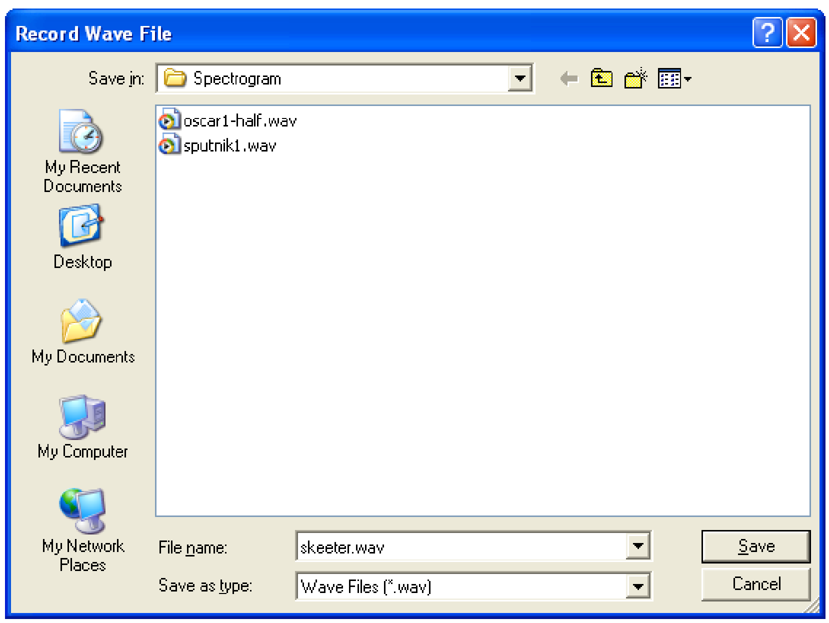
SpectroGram Operation

While you can just listen to *SkeeterSat* beeping happily, some means of reducing the beeps to numerical data is needed if this simple telemetry system is to have meaning. The *Sperctrogram* program provides that tool.

On a flash drive or other storage device provided by LaACES you will find a folder called *Spectrogram*. Copy the files from the *Spectrogram* folder to your computer's hard drive. No installation process is needed, you can just launch the application <*gram.exe*> Be sure you have a microphone connected to your computer's soundcard input, and that the microphone recording input is enabled, with its volume slider set about halfway to maximum. Place the microphone close to *SkeeterSat's* speaker.

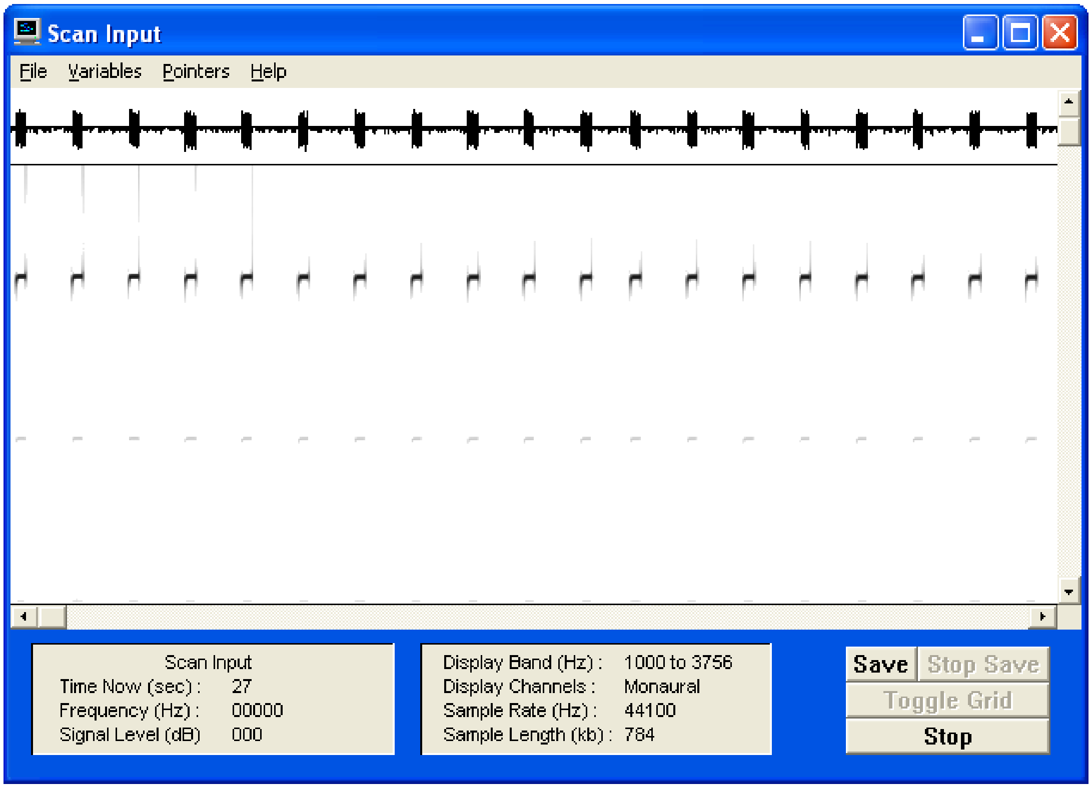
The first thing you will encounter is a setup screen like the one pictured. For now, just click the appropriate button to make your setup the same as the one shown.



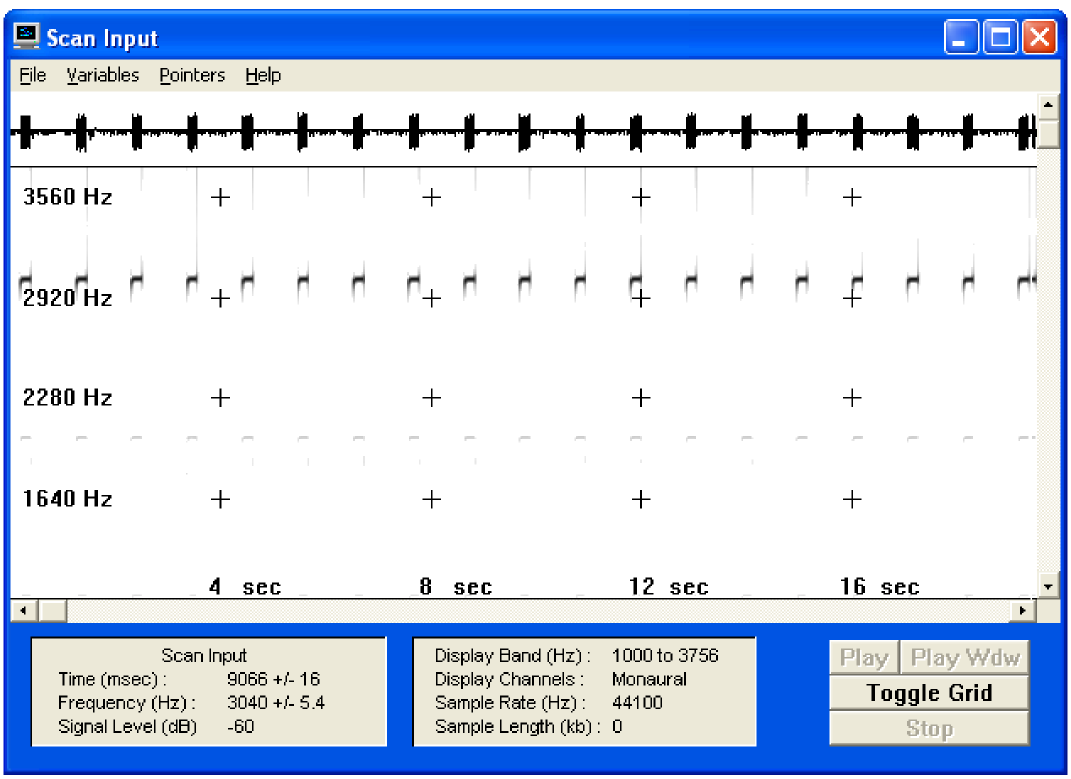


When you click <*OK*> you will be prompted for a filename to be used to save a wav file. Enter a name of your choosing and click <*SAVE*>

A pattern similar to the one pictured next should begin scrolling across your screen.



Click <*STOP*> then wait a few seconds for the program to respond.
Now click <*TOGGLE GRID*> and you should see the following display.



As you move the cursor around the screen notice how the box in the lower left shows you the time, frequency, and amplitude of the recorded signal. This is the tool you need to make meaningful measurements with *SkeeterSat*. *Spectrogram* has many other features and capabilities. Spend some time reading through the HELP file within the program.