Life Detection using Microwave Back scatter and prolate spheroids

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of a senior thesis submitted by

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This thesis has been reviewed by the research committee, senior thesis coordinator, and department chair and has been found to be satisfactory.

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ABSTRACT

Life Detection Using Microwave Back Scatter

and

Modelling Life as Prolate Spheroids

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The purpose was to see if it was possible to use a long-wavelength emitter to detect a living creature. An x-band microwave system was used to collect the back scatter from a living rat. The T-matrix code and how it was used to predict back scatter is presented with example values. The setup of equipment and the procedure to capture the back scatter from the rat is discussed and shown. The results for the rat scans are shown in both the time spectrum and power spectrum . It was possible to see the presence of the rat motion and it is highly likely that the breathing rate was captured. The procedure for obtaining the rat is discussed with the final approved procedure included.

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Acknowledgements

Thank you, Dr. Todd Lines thank you for being my mentor through this project and being an inspiring example. Thank you, Dr. Evan Hansen for being patient with me while I was writing. I would also like to thank the Physics department for the years of work you have put into me and getting me to this point. Further, I thank my parents and Lyndsey for their endless support.

Introduction

The ability to detect people in the aftermath of a natural disaster has always proven to be a labour intensive and difficult task. Large amounts of man hours are spent looking for people buried in rubble. Most of these volunteers have no way of knowing where in the area of a collapsed building to begin looking . The possible solutions that are being used right now are dogs and manual searching; these method have limited effectiveness . This has lead researchers to wonder if they could construct a system that could detect the movement or breathing of people buried in rubble. A proposed solution is the use of microwave beams to detect the scattering light off moving people. The use of microwaves would be ideal for this application due to it's ability to treat concrete block with little interference at these wavelengths. The light coming out of an emitter is able to pass through rubble and dirt and hit the moving object and bounce off in all directions. If a receiver was located at an angle ideal for detecting the difference in the shape caused by movement, then you could detect the movement of the living thing. The problem becomes: How to determine what angle to put the receiver at, relative to the object being detected. The purpose of the study was to test one of these methods using the equipment that is currently owned by Brigham Young University-Idaho. Rats were modelled using a prolate spheroid water balloon and a T-matrix scattering method.
A rat would be used as the scatter in the experiment. The actual experimental setup will make use of microwaves due the wavelength being appropriate for measuring rat sized objects. This system works similar to ground penetrating radar, but instead of using radio waves it will use microwaves. Another major departure is to make a system that does not need the detector or emitter to be touching the ground. Leading to the development of a system that could be put in a backpack or

used by a single person.

Section 1. Theory

The problem of scattering microwaves can be predicted using several methods. Most of these methods take an incoming planar wave and put them through a matrix which outputs the scattered wave in terms of intensity at angles. These methods give you a reading from 360^0 starting at the emitter, with 180^0 being directly across from the emitter. For the lab reference frame see the figure below.

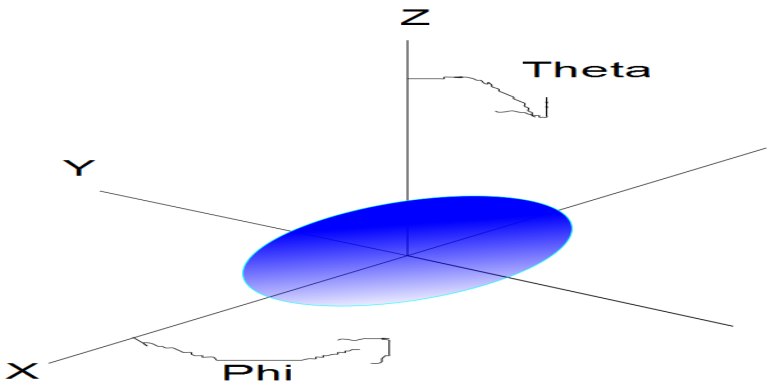


Figure 1 The lab reference frame

1.1 Mie Method

Mie scattering would be the most popular method by far[1]. Mie scattering is used on objects approximately the size of the wavelength of the beam. This method approximates the object to be spherical in shape. The parameters for this method are as follows: r representing the radius of the sphere, m being the index of refraction for the material, and x variable being the size parameter.

$$x = 2\pi r / \lambda$$

$$y = mx$$

$$k = 2\pi/\lambda$$

These parameters lead to two scattering functions:

$$S_1(\theta) = \sum_{n=1}^{\infty} \frac{(2n+1)}{(n(n+1))} [a_n \pi_n(\cos\theta) + b_n \pi_n(\sin\theta)]$$

$$S_s(\theta) = \sum_{n=1}^{\infty} \frac{(2n+1)}{(n(n+1))} [b_n \pi_n(\sin\theta) + a_n \pi_n(\cos\theta)]$$

Which are used in calculating intensity functions :

$$i_1(\theta) = \left|(S_1(\theta))^2\right|$$

$$i_2(\theta) = \left|(S_2(\theta))^2\right|$$

This is derived into a cross section of the intensity in terms of angles:

$$\sigma_s = \frac{\pi}{k^2} \int_0^{\pi} [i_1(\theta) + i_2(\theta)] \sin\theta \, d\theta$$

The derivation for this method is well known and can be referenced from several places. I would point the reader to Thomas G Kyle's '*Atmospheric Transmission Emission & Scattering'* [1] for a more detailed view of this derivation. Also, Liou's book has detailed descriptions [2]. A study conducted by by Kun-Mu , et al. called "*An X-band Microwave Life Detection* System"[3], Did a study on a human being who breathing rate was measured while recording the signal. The problem with this method was that most living organisms are not spherical in shape.

1.2 T-matrix Method

The use of T-matrix in this study was due to the shape of most living things is not being spherical, but being a prolate spheroid. As can be seen in the figure below a prolate spheroid is comparable to a crushed sphere. The T-matrix method uses the size parameters of the semi-major and semi-minor

axis, labelled on the figure below. The size parameter is $2\pi*a/\lambda$..

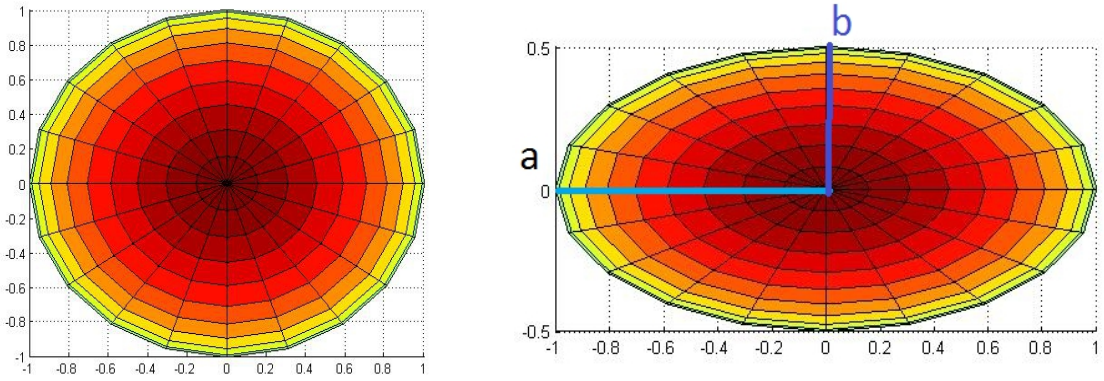


Figure 2 On the right a sphere, on the left prolate spheroid

The resonance regime, is the superposition of two waves represented by the T-matrix. This is due the resonance occurring inside the scatter which in this case is the rat. It clear that the wavelength being used is essential for accurate results. The sensor then picks up a combination of internal waves being scattered, and the outside wave that is not in resonance. This leads to a sensitive intensity reading, due to the shape of an object, which makes it ideal for detecting the breathing of living creatures.

The T-matrix method starts with an incident electric field of a plane wave being put through a transition matrix which generates the electric field of the returning wave. This can then be used to calculate the cross section of the return in terms of angles, which uses a method similar to the Mie method. This method takes an expansion of the field to come to a solution and expressing it in terms of angles.

The T matrix is actually composed of two other matrices refereed to as: A and B. The A matrix is used to calculate the internal field expansion coefficients and uses vector harmonic functions of the third kind. The B matrix is used to calculate the scattered field expansion coefficients using vector harmonic functions of the first kind. If further clarifications are needed please see Barber and Hill

[4]

$$T = B\,A^{-1}$$

$$A = \begin{pmatrix} K_{(\upsilon\mu)} + mJ_{(\upsilon\mu)} & L_{(\upsilon\mu)} + mI_{(\upsilon\mu)} \\ I_{(\upsilon\mu)} + mL_{(\upsilon\mu)} & J_{(\upsilon\mu)} + mK_{(\upsilon\mu)} \end{pmatrix}$$

$$B = \begin{pmatrix} K'_{(\upsilon\mu)} + mJ'_{(\upsilon\mu)} & L'_{(\upsilon\mu)} + mI'_{(\upsilon\mu)} \\ I'_{(\upsilon\mu)} + mL'_{(\upsilon\mu)} & J'_{(\upsilon\mu)} + mK'_{(\upsilon\mu)} \end{pmatrix}$$

The incident field expansion coefficients of an plane wave are as follows :

$$a_{(emn)} = 4\mathrm{i}^{n} e_0 \left[-i_\theta \sin m\phi \frac{m}{(\sin\theta)} P_n^m(\cos\theta) - i_\phi \cos m\phi \frac{d}{(d\theta)} P_n^m(\cos\theta) \right]_{(\theta=\theta_i,\,\phi=\phi_i)}$$

$$a_{(omn)} = 4\mathrm{i}^{n} e_0 \left[i_\theta \cos m\phi \frac{m}{(\sin\theta)} P_n^m(\cos\theta) - i_\phi \sin m\phi \frac{d}{(d\theta)} P_n^m(\cos\theta) \right]_{(\theta=\theta_i,\,\phi=\phi_i)}$$

$$b_{(emn)} = -4\mathrm{i}^{(n+1)} e_0 \left[i_\theta \cos m\phi \frac{m}{(\sin\theta)} P_n^m(\cos\theta) - i_\phi \sin m\phi \frac{d}{(d\theta)} P_n^m(\cos\theta) \right]_{(\theta=\theta_i,\,\phi=\phi_i)}$$

$$b_{(omn)} = -4\mathrm{i}^{(n+1)} e_0 \left[i_\theta \sin m\phi \frac{m}{(\sin\theta)} P_n^m(\cos\theta) + i_\phi \cos m\phi \frac{d}{(d\theta)} P_n^m(\cos\theta) \right]_{(\theta=\theta_i,\,\phi=\phi_i)}$$

These values for a and b are used similarly to the Scattering functions in Mie scattering to derive the f and g functions below.

$$\frac{\sigma_{(sca)}}{(\pi a^2)} = \frac{1}{(ka)^2} \sum_{\nu=1}^{\infty} D_\nu \left(|f_\nu|^2 + |g_\nu|^2 \right)$$

For a more complete discussion of the derivations of these formulas please refer to *Light Scattering by Particles:Computational Methods* by P W Barber and S C Hill [3]. Their code was used to make the scatter predictions for this study.

2. Experimental Setup

The purpose of this study was to determine whether by using a prolate spheroid model could detect the movement and breathing rate of a rat. To achieve this goal it was decided to place the rat in a 10 inch diameter PVC pipe, see figure for clarification. The rat was exposed to a microwave beam with a wavelength of 2.4 cm from an emitter, with the receiver being set off at an angle that would capture the returning of wave at a 25^0 angle from the emitter. This signal will be analyzed under two paradigms, that of a time spectrum and power spectrum. From the time spectrum it will be determined if it is possible to detect movement of the rat. The power spectrum will be used to look for the breathing rate.

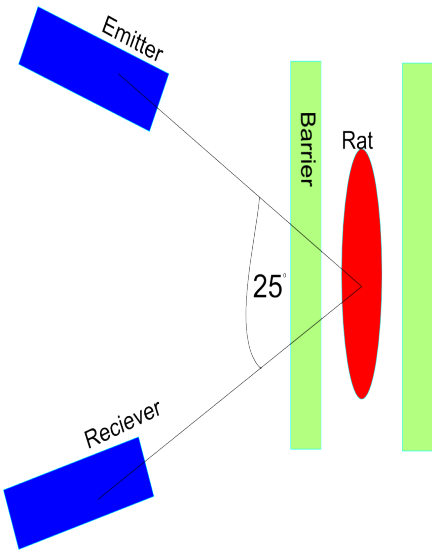


Figure 3 Graphical example of experiment with a rat

2.1 Running the T-matrix code

The T-matrix code was used to make the initial analysis. To see if there would be a change in the intensity of the scattered signal due to the changing of the rat's size. The T-matrix code takes into

account semi-major (a) and semi-minor (b) values. The 'a' value represents the the x-axis length of the spheroid, while 'b' represents the diameter of the spheroid. The T-matrix code also utilizes the index of refraction for water which was 7.5 for the real, while the imaginary part was 2.0 for x-band. The rat was modelled as water-filled prolate spheroid for a digital approximation. The rat's inhalation was a = 0.1651m and b = 0.04953m (figure 4). The rat exhaling was a = 0.1651m and b = 0.0445m (figure 5). The graphs were set up to look at the intensity of returning waves off the object. The horizontal axis was the angle in degrees around the object, the vertical axis was a measure of intensity.

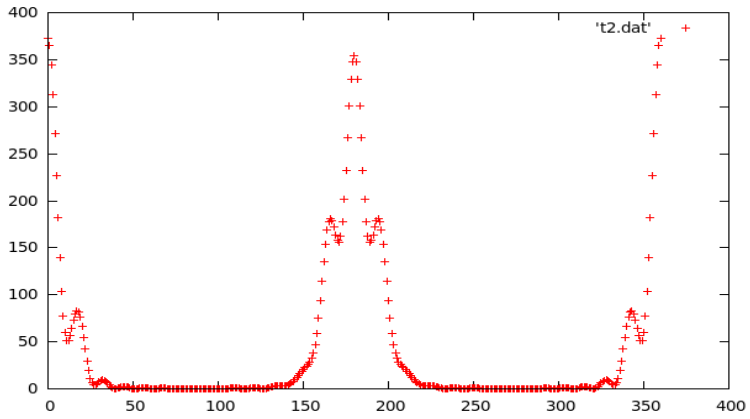


Figure 4 Graph of the rat inhaling

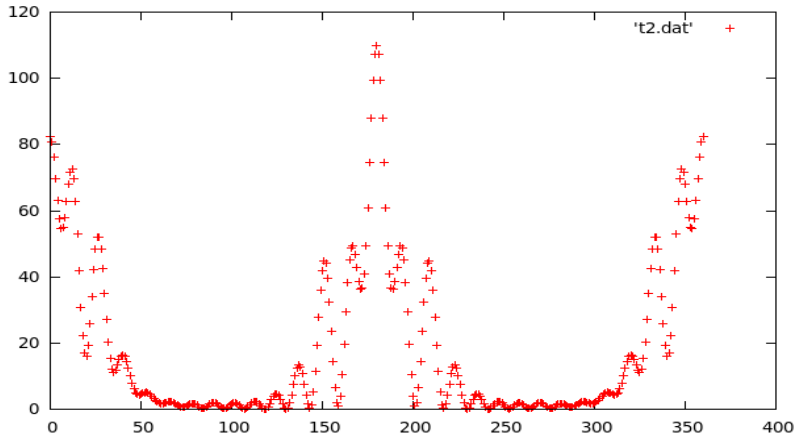


Figure 5 Graph of the rat exhaling

From these figures and looking at the underlying data file it can be seen that there is a difference in

the two shapes with regards to intensity. One of the most notable difference was in the 0 - 50 degree range, where the prolate spheroid grows as the levels of intensity dramatically decrease. For this experiment it was decided to set receiver a 25 degree angle from the back scatter mark because the theoretical modelling showed a significant change in intensity at this angle. When the size increases the signal intensity decreases. This is confirmed by Waterman see figure below [7]. Where we see in the range of the rat size increase in size parameter while the intensity decreases. Though the shape is not a prolate spheroid it is similar. The size parameter put the resonace right at the edge of being to large at 11-21

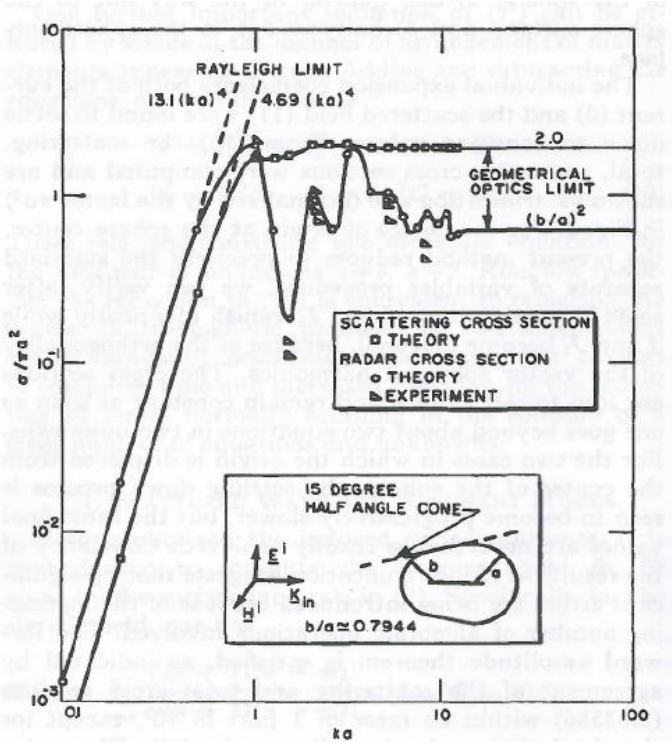


Figure 6 showing the cross section as the size parameter increases

2.2 Setup of Experiment

The materials used were a TX2 (emitter) & RX2AS (receiver) Microwave Apparatus by IEC , 10 inch diameter PVC pipe, signal generator, a DAQ, a coaxial cable, two alligator clip cables, laptop,

video camera, a compass sheet, water balloons of various sizes, and a living adult rat.

The wave generator was connected to the emitter by way of the external channel connection. This was accomplished by connecting the two devices via signal cable. See figure below.

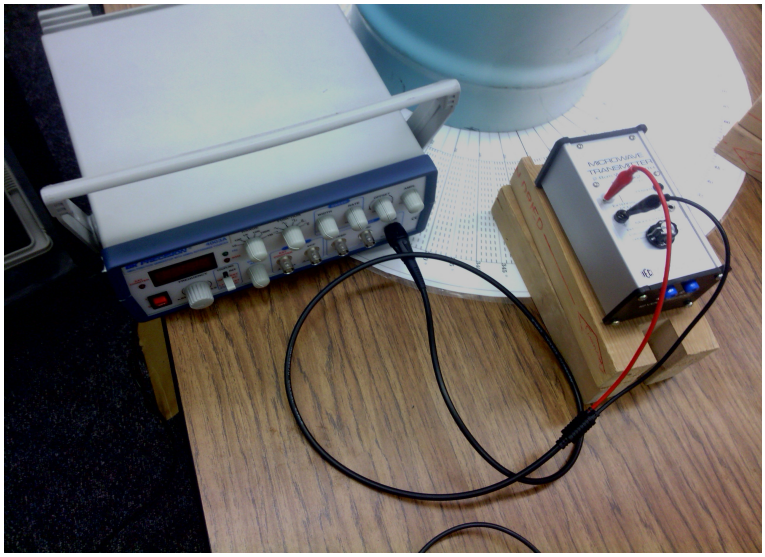


Figure 7 Set up for the wave generator and emitter

The wave generator was set to sine wave setting with a frequency of 101Hz. . The receiver was connected to a DAQ through the use of signal cables to the DAQ's data ports. The DAQ records the the change in received voltage which is proportional to the change in intensity. See figure below.

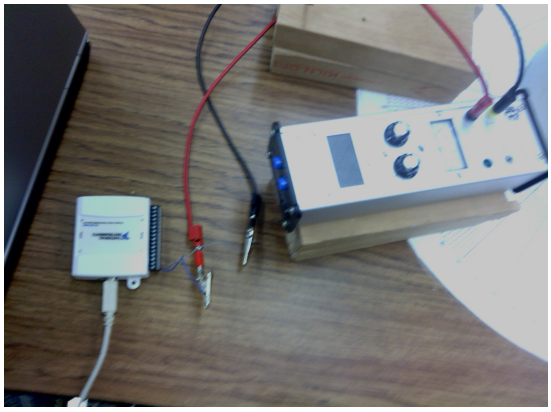


Figure 8 Set up for receiver and the DAQ

This voltage is recorded by a Labview program that acts as a voltmeter and outputs the data as an

excel spreadsheet. The emitter needs to be set to the 'external mode', while the receiver is set to 'gain 1'.

The gain setting acts as an amplifier for the receiver, with the Gain 1 applying no amplification . The safety equipment for this lab is somewhat specialized. We used a microwave blocking barrier that was constructed by Allen Andersen, a BYU-I graduate and former Microwave group leader [6]. The purpose of the barrier is to protect the user and bystanders from the microwaves emitted during the experiment. OSHA has rated the emitter for being safe for six minutes of exposure. See figure below for example set up. Though the safety barriers were deemed the safest option due to the scattering nature of the PVC pipe, the scattered wave created an 360 degree radius of emittance.

Figure 9 A Normal setup with protective foam wall.

The video camera was mounted on a tripod with the camera pointing into the PVC pipe. The purpose for this is to record the rat's movement during the experiment, with a view shown in the following figure.

Figure 10 Camera view of the experiment

2.3 The Water Balloon Trials

The two water balloons that were used were of different sizes, the second water balloon being 25% than the first one. This was done to simulate the rat breathing. These were placed into plastic cups such that the water balloons could be level with the emitter and receiver setup. To ensure that the plastic cups did not interfer with the experiment, the cups were measured before the water balloons and were seen not to affect the results. The time for recording the return wave information was on the range of thirty seconds.

2.4 The Blank Tube Trial

To understand the data from the rat trial. It was necessary to understand how light would be scattered by the PVC pipe. This setup was the same as all other trials. The time for recording was around forty-five seconds. The data gained in this run was used as a benchmark for the noise in the data for other trials. This noise had a minimum value of -1.42V. This value will be used in the analysis of the data.

2.5 The Rat Trials

The live rat trials were done on one rat that was fully grown. The rat had access to food pellets and a cardboard tube. The rat did not interact with the cardboard tube. Due to the rat's ability to move, the emitter and receiver were raised or lowered on wooden bricks to bring the rat into view. The trials were between thirty seconds and a minute and a half. The videos of the experiments are available on YouTube at http://www.youtube.com/playlist?list=PL08yssyqKoMNHhKvxTaEnQR3GDmNYhLK4. The data files and programs will be available from Ross Blaszczyk at ross.blaszczyk@gmail.com or Dr. Todd Lines PhD at linest@byui.edu .

2.6 The Data Analysis

The ability to make meaningful statements required analysis of the data. The following sections discuss this process.

2.6.1 Time spectrum

The voltage for each run was plotted as a function of time. The voltage is proportional to the intensity of return. The blank tube data was used to set a control of the data noise in this paradigm. The minimum value that was recorded by the blank tube was -1.42V for the back scatter. Everything above this level was zeroed out so that it could become easier to detect the movement of the rat on the time graph. The figure below is an example of the graphs that were produced by switching the

sign of the voltage for easier reading.

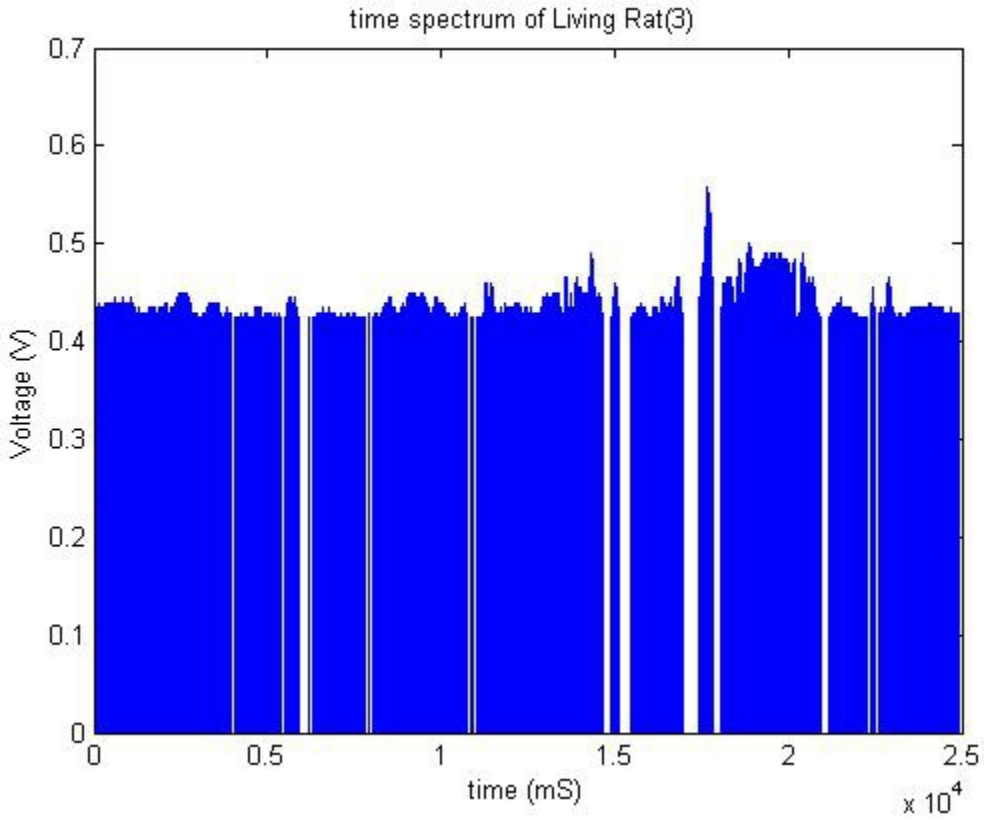


Figure 11 Rat presence and motion detected

2.6.2 Frequency Spectrum

The data was put through a Fast Fourier Transform which was completed through a Matlab function and went through an anti-aliasing process and also removed the negative portions of the power spectrum. This was then displayed on an Intensity (dB) vs Frequency (Hz) graph. The signals were overlaid with each other to see relationship between the rat data , blank tube data, and water balloon data. An example of the overlay can be seen in figure .

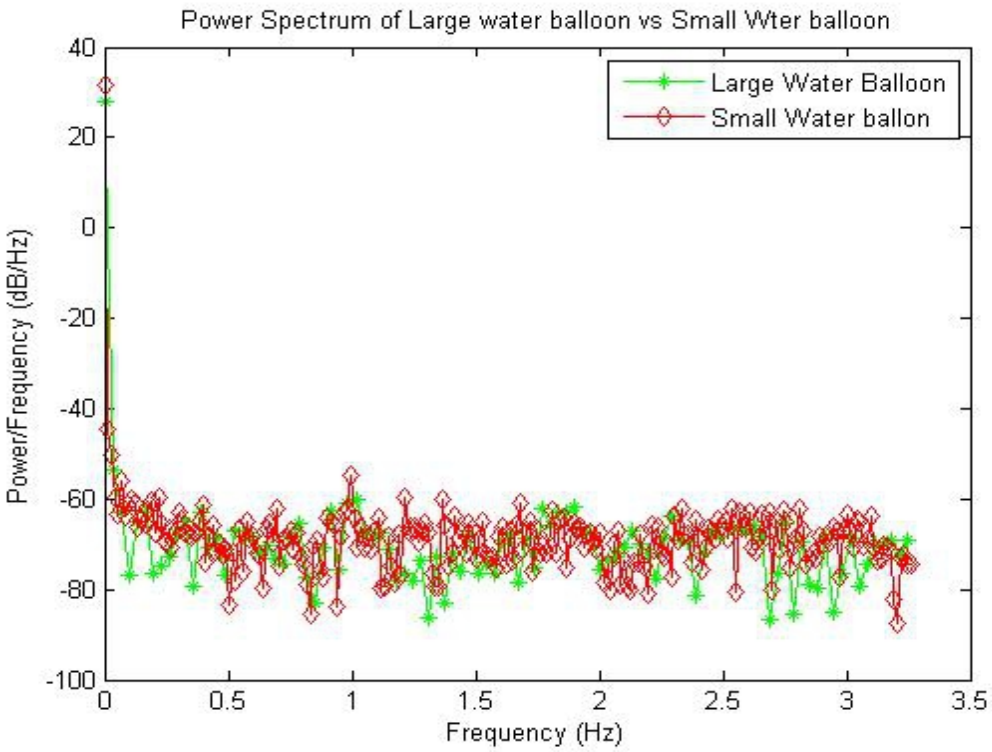


Figure 12 Overlay of the two sizes of water balloon

Noise in the signal was present thus a signal to noise ratio (SNR) is reported. This was calculated taking the data points over a given range and finding the mean and the standard deviation for these samples. See figure below of the graphical representation. You measure the distance from mean to the peak of the signal and divide by the standard deviation.

$$(x-\bar{x})/\sigma$$

The equation above was used to determined if the signal can be called significant or if it was part of the noise of the data. The range that was examined was from 0 Hz to 3Hz where the range of breathing was present.

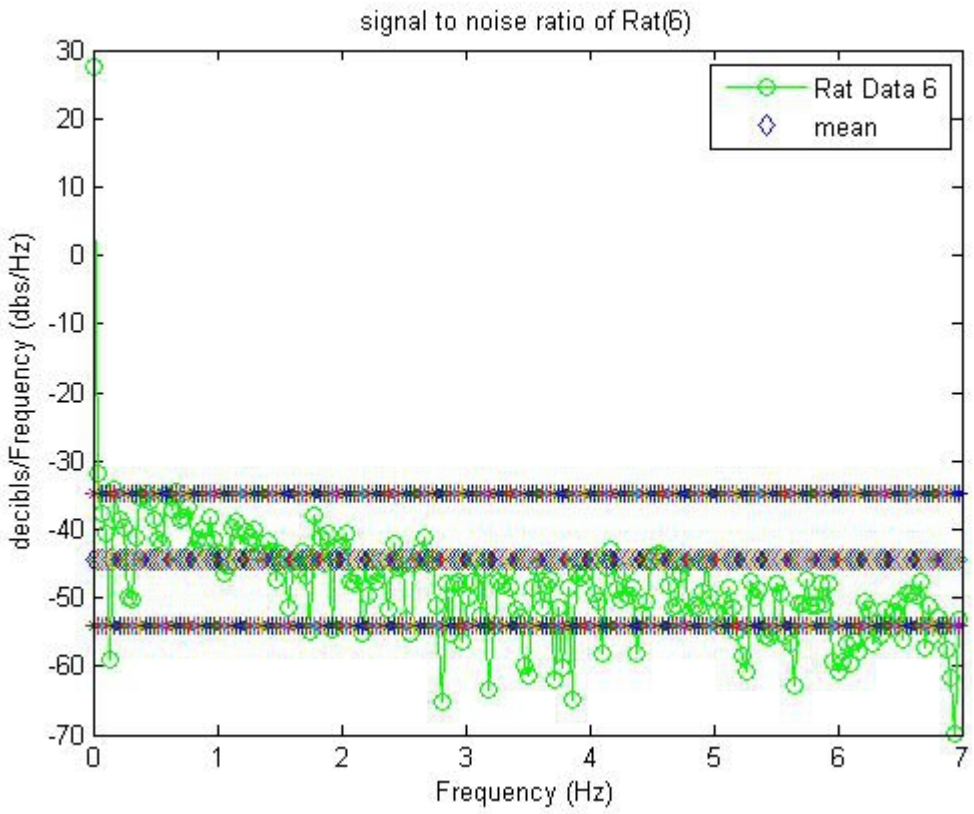


Figure 13 Signal to Noise for rat run number 6

3. Results

The Result will be discussed below.

3.1 The Detection of Movement

In order to show the detection of movement it was necessary to record the rat while voltage was being recorded from the receiver. The video footage would act as a control for detecting the movement of the rat in the beam. The rat's large range of movement meant it was not always directly in the beam or causing a scattering signal. The process by which the movement graphs were created was discussed in the previous section. The graph displayed below clearly indicates the rat's presence and movement as represented by the peaks.

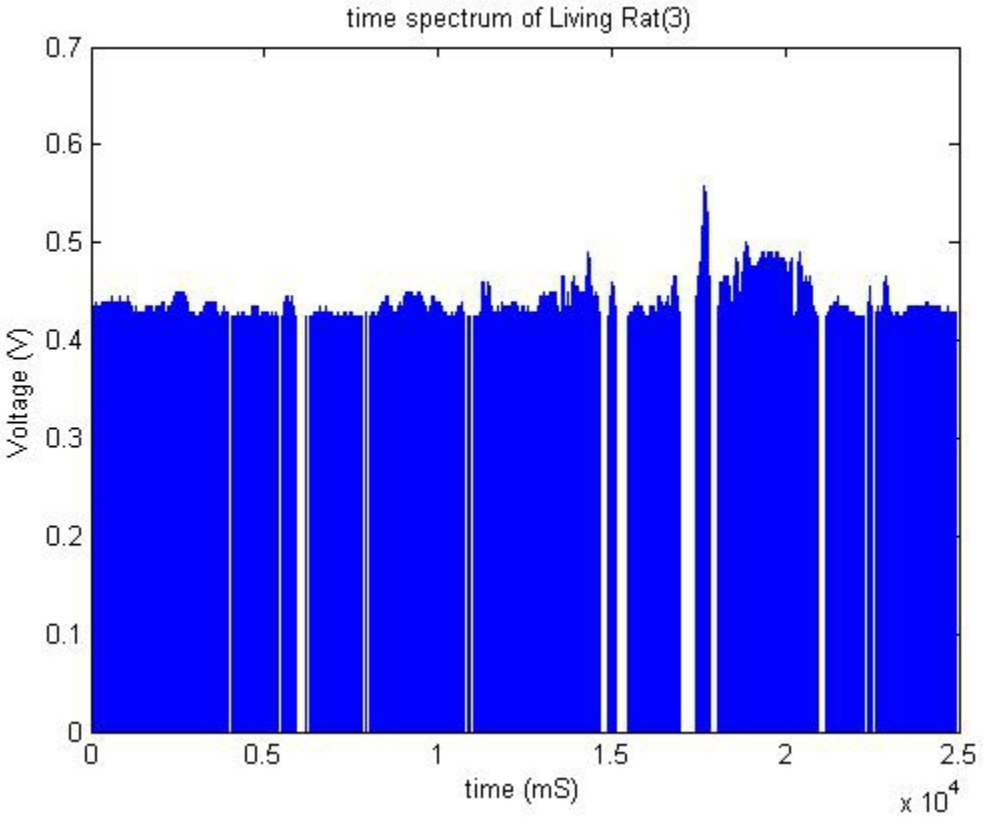


Figure 14 time spectrum of rat collection 3

The peaks were recorded and then compared to the rat's movements in the video. The peaks in the voltage correlate to the movements of the rat. This supports the hypothesis that it is possible with this setup to be able to detect the movement of the rat with a high degree of certainty.

3.2 The Detection of Breathing of the Rat

In order to detect the rat's breathing rate, it was necessary to convert the voltage read out to decibels in a frequency paradigm. From research it was determined that a rat's breathing rate is between 0.8 Hz -2Hz depending on the rat's activity level [4]. For the rat's breathing to be confirmed there needs to a be a signal in that range.

The first thing noticed about this power spectrum is a harmonic that occurs at the 10 Hz range and repeats itself at every 10 Hz, as seen in the figure below. Work was done to determine what was causing this harmonic to appear. One idea was that perhaps the harmonic might be caused by the diameter of the pipe being the correct size for the wavelength of light resulting in this harmonic. The diameter of the pipe was measured to make sure it was actually 10 inches which is 25.4 cm. The pipe was the correct diameter. Then calculation below was done to find the base harmonic that the pipe would generate generate. It is much to large for the 10 Hz harmonic that was seen in the data.

$$f = \frac{nV}{2\mathrm{L}}$$

$$v = 3\mathrm{e}8\, m/s$$

$$f = 5.9\mathrm{e}8\, Hz$$

It is clear from this analysis that the pipe was not the cause of the harmonic signal. So this lead to taking a look at the actual emitter and receiver. The setup of this check was pointing the emitter at a metal back and bounce the signal to receiver. The noted 10Hz harmonic was still present in the power spectrum of this test. So it was concluded that this harmonic is part of the transmitter noise. See the figure below for an example of the 10 Hz harmonic that is present in the data as seen in the figure below.

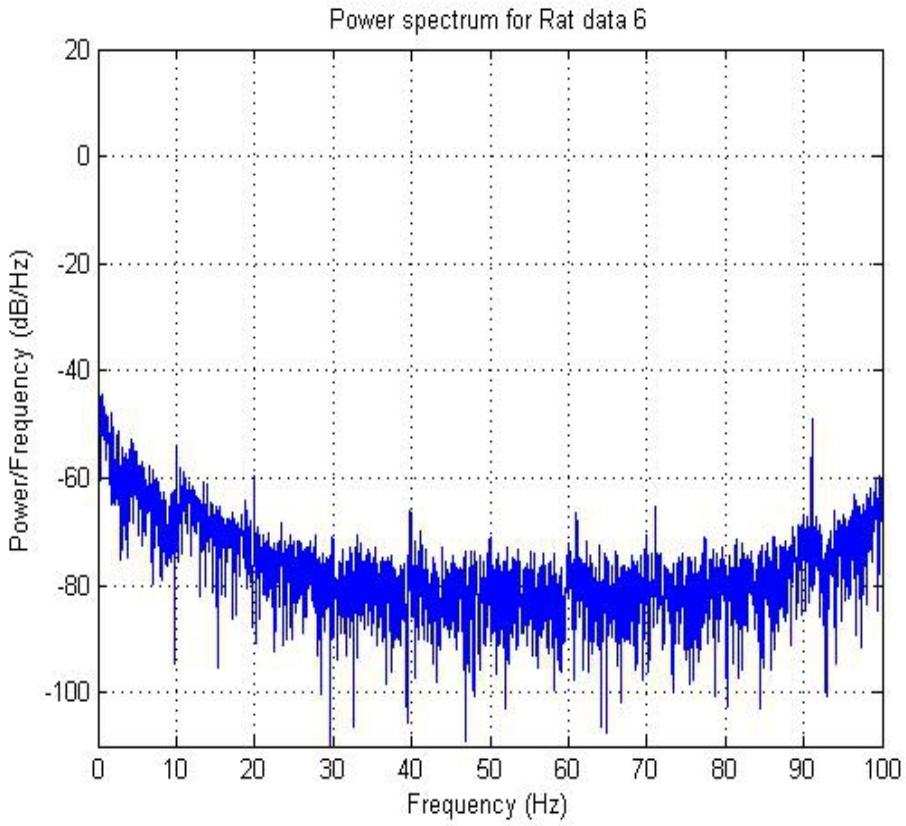


Figure 15 10 Hz harmonic in the data collection

3.2.1 Power Spectrum Overlay of Water Balloons

To determine whether a larger or smaller scattered signal would be expected, two water balloons of differing sizes were compared . When looking at the figure below it becomes clear that the expanded balloon had a decreased intensity, so these minimums were used as the points of reference for the breathing rate of the rat. This agrees with what the T-matrix code prediction of the intensity of the return signal at 25 degrees.

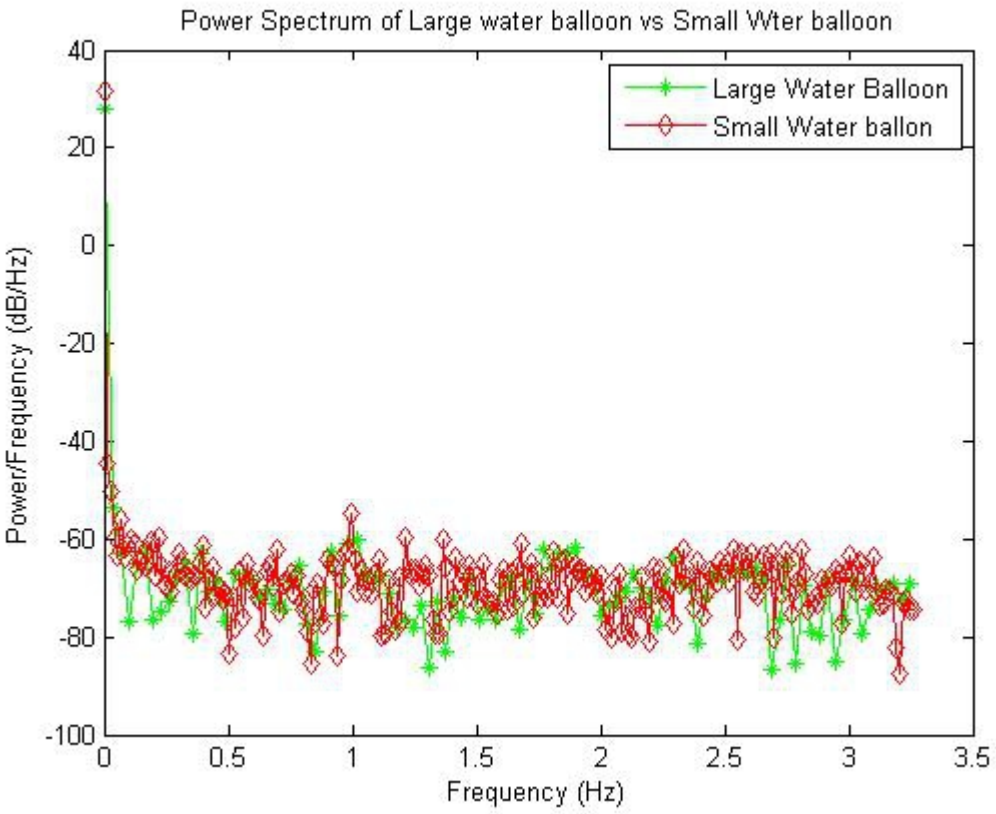


Figure 16 Water Balloon overlays

The next step was to look at the various power spectrums compared to each other. These overlay allow the difference in the spectrum shapes to be observed and allowed us to compare traits of the objects. Looking at the blank tube compared to the live rat data, we see the very drastic difference between an empty tube with no minimum spikes like those present in the living rat data in the frequencies that correspond to breathing. This range is from about 0.8 Hz to 1.8 Hz. There were usually several minimums in this range due to the rat's ability to have a free range of motion and activity which would lead to several breathing rates being present in one given trial.

When the living rat trials were compared to the the empty tube it became obvious that the rat produced more minimums in it's power spectrum than that of the empty tube. See figure 16 to see these structures. Most of this is believed to be related to the rat's personal grooming and movement in and out of the beam during it's trials because they had similar frequencies for these activities.

Though the minimums in the breathing rate range were present as long as the rat was in the beam for a sufficient amount of time.

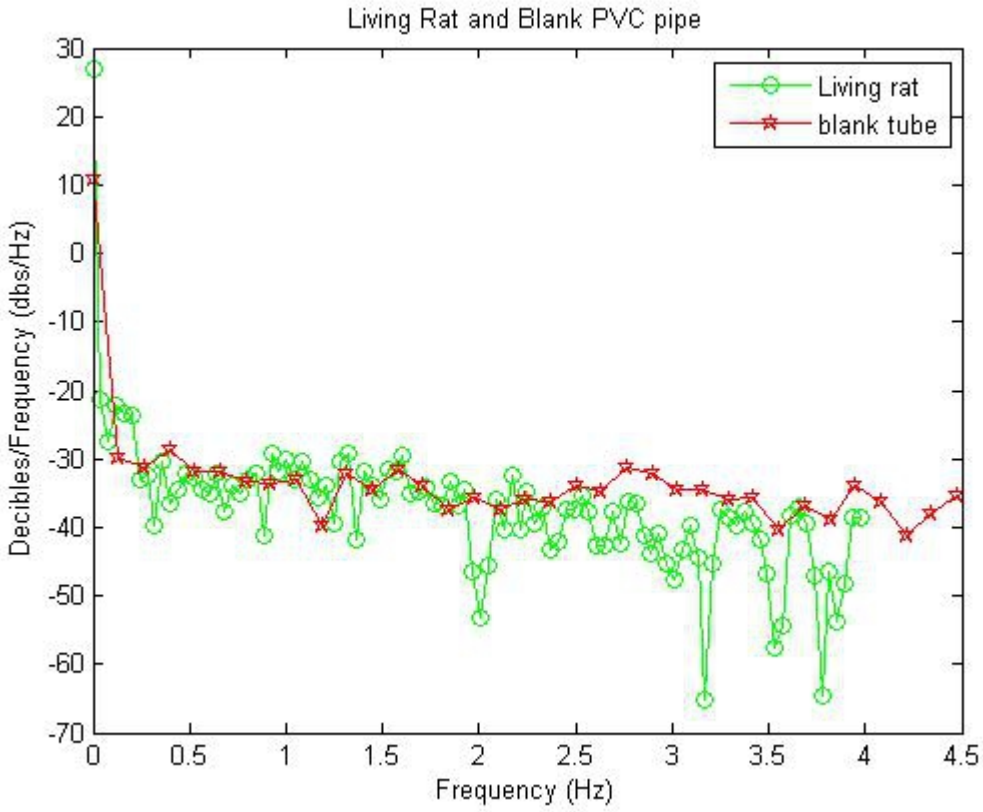


Figure 17 Rat compared to an empty PVC pipe in the frequency spectrum

Next we investigated was looking at the rat's returning signal versus the returning signal of a water balloon. The power spectrum of both objects was done because a rat and water balloon are of a similar shape and composed of similar materials ,both being a water based prolate spheroid . This comparison yielded an interesting result because the overall power spectrum is very similar with the only major difference being that the range of breathing of the rats minimums were present while the water balloon lacked such structure. This suggested that something was being detected. It was necessary to see if this was just noise or actually rat breathing, SNR was used to make this determination.

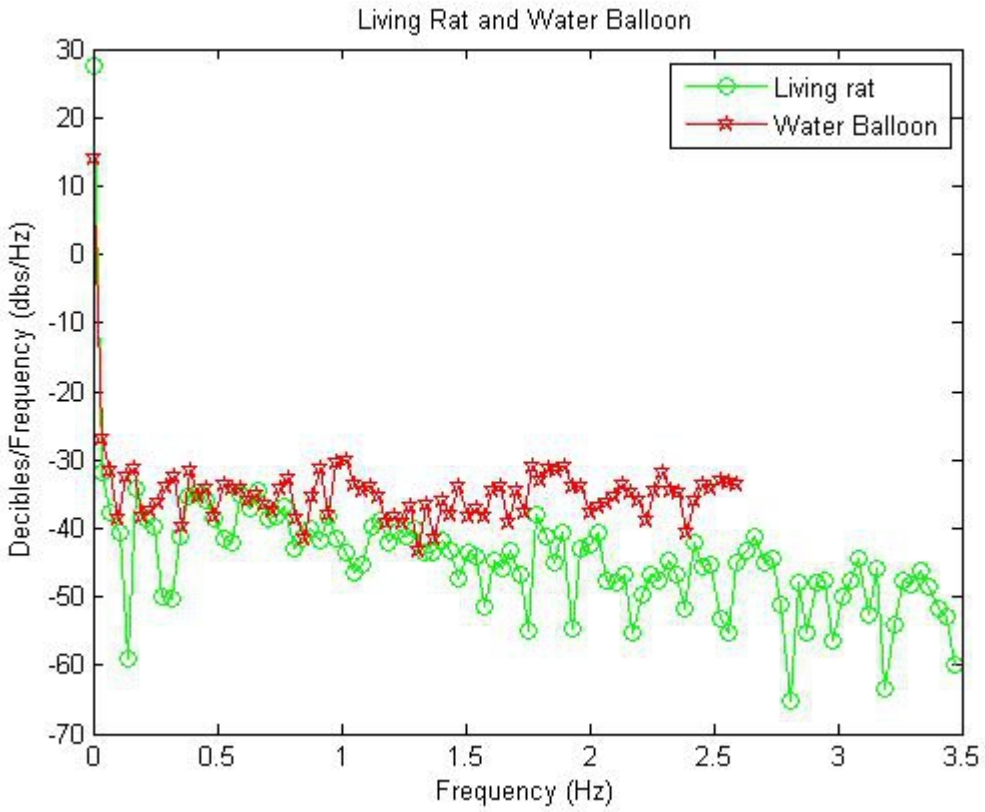


Figure 18 Rat and water balloon overlay

3. 3 Error Analysis – Signal to Noise Ratio (SNR)

As with all measurement it is necessary to make a statement of accuracy in signal processing this is done by taking a signal to noise ratio. The signal to noise ratio is looking at the signal and how far from the mean by standard deviations is it. If it is greater than one it can be assumed that there is a signal present. The higher this ratio the more certain it is that you are detecting a significant signal. For new methods getting about 2 is an acceptable value but with refinement of equipment and technique a higher value would be more appropriate and expected. For this study since it was unclear if it would be possible to get a breathing signal at all it was decided that a ratio of 2 would be sufficient to say something is there and warrants future study. The mean was drawn from the zero point until 3 Hz because the signal above 3Hz was produced by rat movement and grooming

activity.

$$x - \mu / \sigma$$

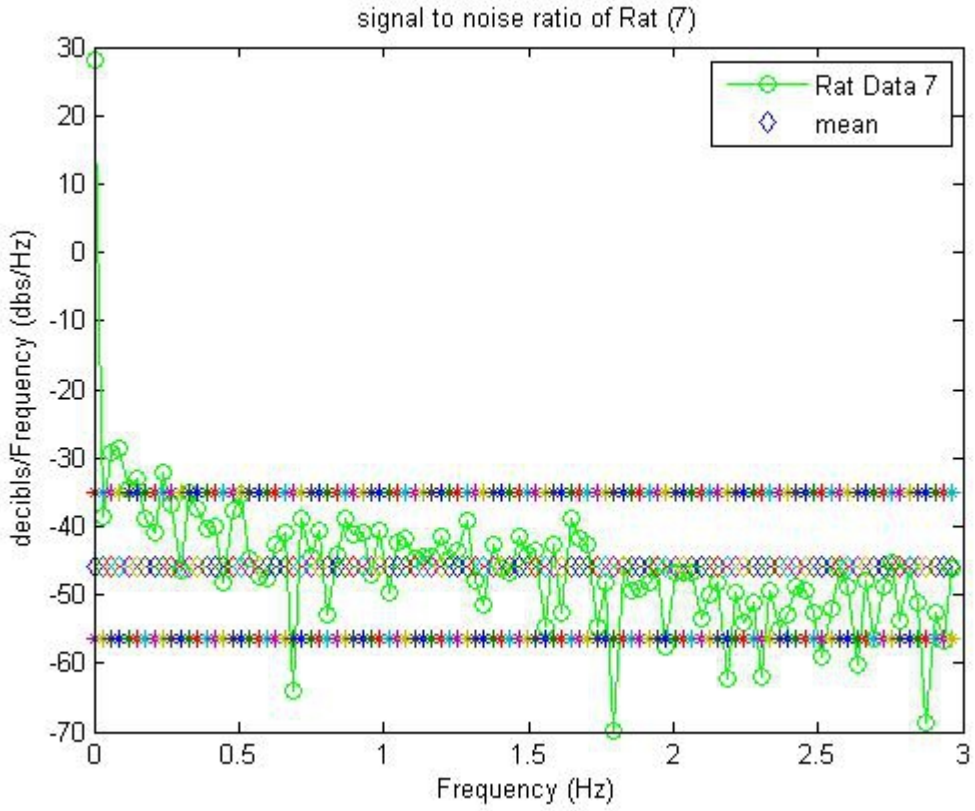


Figure 18 signal to noise ratio for collection 7 of the Living Rat

The visual examination is only marginally helpful to judge if the signal is significant. The SNR was calculated by finding the mean, standard deviation, and the larger dips. This was done for all the living rat trials and compiled into the table below.

Table 1- Break down of Living Rat runs

Data Set	Mean value(db)	Standard Deviations(db)	The Frequencies in range of breathing	Signal to noise ratio
2	-36.58	8.62	1.5/1.719/	1.72/1.19/
3	-37.31	9.94	2.008	1.6/
4	-37.86	9.98	1.189/1.958	1.71/1.701
5	-34.59	9.29	1.518/1.545/1.843 /1.951	1.29/1.119/1.706/1. 645
6	-44.37	9.63	1.754/1.93	1.09/1.068
7	-45.82	10.63	1.796/	2.27
8	-43.62	10.07	1.531/	1.22
9	-48.37	10.21	1.289/	1.19
10	-43.26	10.85	1.795/	1.49
11	-54.55	10.89	1.83	1.68
12	-58.29	12.35	1.201/1.257/1.564 /1.76	1.37/1.23/1.81/1.34
13	-50.36	10.25	1.684/1.891	1.34/1.69
C1	-54.1	12.15	1.4	1.04

It is clear from the analysis that the breathing rate signals are near the noise cut off. This would suggest for the need to do further research and changes to the experimental design to achieve more conclusive results.

Conclusion

In conclusion the object of this study was to be able to detect the movement of a living creature and to detect it's breathing rate. The ability to detect movement is possible and is an easy task with the current equipment that BYU- Idaho is in possession of. The ability to detect the breathing rate of the rat is not absolutely certain, but the presence of weak signals suggests that further investigation is justified.

In Continuing Work

Further research could be done to refine the experiment and reduce the rats movement so less noise is present in the power spectrum . This could be done by anaesthetizing the rat. This method is ideal because the rats breathing rate would be monitored during the procedure which would give a more accurate basis for analysis. Also the detection of the breathing and movement through walls of snow or dirt would an interesting and important comparison to the data using a PVC pipe. Another direction that the research could be taken is to check to see if a larger wavelength could give better resonance.

Appendix A- Animal use proposal

The use of the rat required a live experiment protocol that need approval from Brigham Young University-Idaho Institutional Animal Care and Use Committee. These restrictions included also the use of the 10 inch diameter PVC pipe to contain the rat came from getting approval from the committee. On the following page is the procedure that was approved.

Animal Study Protocol Application Form

Brigham Young University-Idaho Institutional Animal Care and Use Committee

Section 1: General Information

1. Project Title: : Microwave Life Detection System Using Prolate Spheroids

2. Principal Investigator: Todd Lines

Department: Physics **Telephone: 208-496-7740** **Email:** linest@byui.edu

4. Protocol Type: ☐ Instruction ☐ Training ☒ Research

5. Protocol Category: ☒ new ☐ revision ~ original protocol #:

6. Will this protocol require funding? Yes ☐ (please respond to the question below) **No** ☒

7. Please specify the source of funding for this protocol: N/A

8. **Project Period:** 03/ 01 / 2014 **to** 12 / 31 / 2017

9. Other Personnel (including students) Working with Animals on this Project:

Name	Department	Phone	Email	Role
Christopher Ross Blaszczyk	Physics	208-313-8392	bla10021@byui.edu	Researcher

Section 2: Study Overview and Assessment of Unnecessary Duplication

1. Provide a brief abstract describing the nature and purpose of this study. Include an answer to the following question: Why is this study important?

The purpose of this study is to look at a unique model for life detection systems. The basis of this study is the idea that long-wavelength light will scatter from higher living organisms differently as the organism's volume changes with breathing. Previous studies have modeled all animals as spheres. This study will make use of a different modeling shape, a prolate spheroid (think egg shaped over ball shaped). We believe this will give a closer match to most mammals, since this shape more closely resembles the actual animal. The results will

let us build better detectors. This study could lead to the development of systems for the detecting of people trapped in collapsed buildings or buried in avalanches.

2. Briefly explain the experimental design and specify all animal procedures. This description should allow the IACUC to understand the experimental course of an animal from its entry into the experiment to the endpoint of the study. Specifically address the following:

The animal will be removed from its housing and transported to the lab and placed in a 10in PVC pipe. The experimental setup will include a light emitter and receiver. The emitter and receiver will be placed on the same side of the apparatus with the PVC pipe being placed between two microwave absorbing barriers. The emitter releases a wavelength of 2.8 cm wavelength light. The frequency of these waves is 10.7 GHz. The Rat will be placed into a 10-inch diameter PVC pipe enclosure. This pipe will be stood up on its end so it acts more like a corral to keep the rat in a relatively consistent location. Please see section 7 on how we will reduce the animal's stress to this environment. The rat will be exposed to 30-second burst of light. 10.7 GHz light is not detectable by rat eyes; the rat will be unaware of the light. The receiver will measure the light that bounces back off the rat. The major difference from previously conducted studies is the analysis of the data collected. We are going to use a prolate spheroid, which more closely resembles a rat's (or human's) true shape, where the previous studies only used a sphere. The pervious experiments were done as a proof of concept. We wish to improve the relation between the model and the actual data. This experiment will be repeated ten times over the experimentation period to ensure good results leading to a total exposure of 10 minutes. As shown in Adang's paper, results of similar waves, at much longer exposures than those this experiment is purposing, had minimal negative effects to the animal. Adang, who exposed the rats to similar wavelengths for two hours every day, seven days a week, at three and eight months, only noted that the exposed group hand a 20% difference of monocytes

Upon entry, the animal will be given time to be acclimatized being in the 10 inch diameter PVC pipe enclosure. After making sure the animal is acclimatized with being the pipe, we will use positive stimulus, in the form of food, to get the rat into the tube and then proceed to measure the rat using the lab setup described above. The rat will be transported from Ricks 113A to 113B and back in its enclosure. The rat will be returned to its enclosure before looking at data so total time in the tube will be less than five minutes. After data is collected, the animal will be released to the endpoint transfer to Protocol number #1302001: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats and veterinarian technicians' restraint techniques and minor procedures.

- **Experimental injections or inoculations** (substances, e.g., infectious agents, adjuvants, etc.; dose, sites, volume, route, and schedules). N/A
- **Blood withdrawals** (volume, frequency, withdrawal sites, and methodology). N/A
- **Surgical procedures** (provide details of survival and non-survival surgical procedures on Appendix II). N/A
- **Radiation** (dosage and schedule). N/A
- **Methods of restraint** (e.g., restraint chairs, collars, vests, harnesses, slings, etc.). Include how animals are restrained for routine procedures like blood withdrawals. Prolonged restraint must be justified with appropriate oversight to ensure it is minimally distressing. Describe any sedation, acclimation or training to be utilized. The rat will be placed in a 10" pvc tube with air holes and can move around the tube.
- **Animal identification methods** (e.g., ear tags, tattoos, collar, cage card, implant, etc.). cage card
- **Resultant effects,** if any, that the animals are expected to experience (e.g., pain or distress, ascites

production, etc.). May experince distress due to being in the pvc pipe.
• **Other potential stressors** (e.g., food or water deprivation, noxious stimuli, environmental stress) **and procedures to monitor and minimize distress.** If a study is USDA Classification E, indicate any non-pharmaceutical methods to minimize pain and distress. N/A
• **Experimental endpoint criteria** (e.g., tumor size, percentage body weight gain or loss, inability to eat or drink, behavioral abnormalities, clinical symptomatology, or signs of toxicity) must be specified when the administration of tumor cells, biologics, infectious agents, radiation or toxic chemicals are expected to cause significant symptomatology or are potentially lethal. List the criteria to be used to determine when euthanasia is to be performed. Death as an endpoint must always be scientifically justified. N/A
• **Veterinary care** (indicate desired plan of action in case of animal illness, e.g., initiate treatment, call investigator prior to initiating treatment, euthanize). N/A

Section 3: Assessment of Unnecessary Duplication

1. **USDA regulations require that the principal investigator assure that the proposed research does not unnecessarily duplicate previous work. Provide a narrative describing the methods or sources used to determine that this project does not duplicate previous work, or, if it does, why duplication is necessary. If a computer-assisted literature search was conducted, provide the name(s) of the database(s) used, and the date(s) of the search(es). Please keep copies of the search results.**

   The initial search started with looking for papers written by the members of the initial paper. We realized that they had continued to work under the same model, just using it under different circumstances.

   K. M. Chen, D. Misra, H. Wang, H. R. Chuang, and E. Postow, "An X-band microwave life-detection system", IEEE Trans. Biomed. Eng., vol. BME-33, pp.697 -702 1986

   this was the original article that started our desire to try a different shape. This article is the basis for all future articles that i found on the subject.

   K. M. Chen, J. Kallis, Y. Huang, J. T. Sheu, A. Norman, C. S. Lai, and A. Halac, "EM wave life-detection system for post-earthquake rescue operation", 1994 URSI Radio Science Meeting, 1994 :University of Washington

   Adang, Dirk, Remacle, Claude, Vorst, Andre "Results of a Long-Term Low-Level Microwave Exposure of Rats" IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 57, NO. 10, OCTOBER 2009

Section 4: Justification of Species Selection and Number of Animals

1. **Complete following table:**

Species or Strain	Common Name	Number to be used in Yr. 1	Number to be used in Yr. 2	Number to be used in Yr. 3
rattus rattus/ norvegicus	Lab rat	1	0	0

2. Justify the selection of species (check all applicable boxes).

☐ This is a new model.
☐ A large database exists for this species, which will allow comparisons with previous data.
☐ The anatomy, genetics, physiology, or behavior of the species is uniquely suited to the study.
☐ The species selected is the lowest possible on the phyologentic scale.
☐ The results of this study will be directly applicable to the health and care of this species.
☐ Other (please describe): The rat is similar enough to a human in biology that it makes a good human analog for data collection.

3. Justify the number of animals to be used. The number of animals should be the minimum number required to fulfill the purpose/objective of the study and/or to obtain valid and meaningful results.
We need one animal so we can test our model on a living organism. We have done the scanning with a water balloons and were able to detect a difference due to varying sizes. A rat is similar in biology to a person, in the fact that it has moving organs and has the freedom to move which more closely resembles a person. The lab rat is the right size so it won't be hurt by long wavelength light. We need the rat so that we can collect raw data and then analyze that data under a new geometrical model.

Section 5: Pain or Distress Classification and Consideration of Alternatives

1. Pain or Distress Classification: C (see USDA Classifications and examples below)

B. Animals being bred, conditioned or held for use in teaching, testing, experiments, research or surgery, but not yet used for such purposes.

Examples:

- Breeding colonies of any animal species (USDA does not require listing of rats, mice, birds) that are held in legal sized caging and handled in accordance with the *Guide* and other applicable regulations. Breeding colony includes parents and offspring.
- Newly acquired animals that are held in proper caging and handled in accordance with applicable regulations.
- Animals held under proper captive conditions or wild animals that are being observed.

C. Animals upon which testing, research, experiments, or tests will be conducted involving no pain, distress, or use of pain-relieving drugs.

Examples:

- Procedures performed correctly by trained personnel such as the administration of electrolytes/fluids, administration of oral medication, blood collection from a common peripheral vein per standard veterinary practice (dog cephalic, cat jugular) or catheterization of same, standard radiography, parenteral injections of non-irritating substances.
- Euthanasia performed in accordance with the recommendations of the most recent AVMA Panel on Euthanasia, utilizing procedures that produce rapid unconsciousness and subsequent humane death.
- Manual restraint that is no longer than would be required for a simple exam; short period of chair restraint for an adapted nonhuman primate.

D. Animals upon which experiments, teaching, research, surgery, or tests will be conducted involving accompanying pain or distress to the animals and for which appropriate

anesthetic, analgesic, or tranquilizing drugs will be used.

Examples:

- Surgical procedures conducted by trained personnel in accordance with standard veterinary practice such as biopsies, gonadectomy, exposure of blood vessels, chronic catheter implantation, laparotomy or laparoscopy.
- Blood collection by more invasive routes such as intracardiac or periorbital collection from species without a true orbital sinus such as rats and guinea pigs.
- Administration of drugs, chemicals, toxins, or organisms that would be expected to produce pain or distress but which will be alleviated by analgesics.

E. Animals upon which teaching, experiments, research, surgery, or tests will be conducted involving accompanying pain or distress to the animals and for which the use of appropriate anesthetic, analgesic, or tranquilizing drugs will adversely affect the procedures, results, or interpretation of the teaching, research, experiments, surgery, or tests.

Examples:

- Procedures producing pain or distress unrelieved by analgesics such as toxicity studies, microbial virulence testing, radiation sickness, and research on stress, shock, or pain.
- Surgical and post-surgical sequella from invasion of body cavities, orthopedic procedures, dentistry or other hard or soft tissue damage that produces unrelieved pain or distress.
- Negative conditioning via electric shocks that would cause pain in humans.
- Chairing of nonhuman primates not conditioned to the procedure for the time period used.

2. Consideration of Alternatives: If any procedures fall into USDA's Classification D or E, causing more than momentary or slight pain or distress to the animals, describe your consideration of alternatives and your determination that alternatives are not available. Delineate the methods and sources used in the search. Database references must include databases searched, the date of the search, period covered, and the keywords used. Alternatives include methods that (1) refine existing tests by minimizing animal distress, (2) reduce the number of animals necessary for an experiment, or (3) replace whole-animal use with in vitro or other tests. When ascites production is used to produce antibodies, justification needs to be given as to why in vitro systems cannot be used.

3. Anesthesia, Analgesia, Tranquilization, Other Agents: For 'Classification D' animals, specify the anesthetics, analgesics, sedatives, or tranquilizers that are to be used. Include the name of the agent(s), the dosage, route, and schedule of administration.

4. 'Classification E' Animals: An explanation of the procedures producing pain or distress in these animals and the justification for not using appropriate anesthetic, analgesic, or tranquilizing drugs must be provided on **Appendix I**. This information is required to be reported to the USDA, will be available under the Freedom of Information Act, and may be publicly available on the internet via USDA's website.

Section 6: Animal Housing and Husbandry

1. From where will you obtain the animals involved in this study (e.g., specific commerical vendor, transfer from another protocol)?:
Charles River Company

2. Indicate if the animals involved in this study have been or will be used in other experiments or

INSTRUCTIONAL LABS.

☐ THE ANIMALS INVOLVED IN THIS STUDY HAVE NOT BEEN AND WILL NOT BE USED IN OTHER STUDIES OR INSTRUCTION. (*Go to question 4.)*

☐ THE ANIMALS INVOLVED IN THIS STUDY HAVE BEEN USED IN PRIOR STUDIES OR INSTRUCTION. (*Respond to question 3, and then go to question 4.)*

☒ THE ANIMALS INVOLVED IN THIS STUDY WILL BE USED IN CONCURRENT STUDIES OR INSTRUCTION. (*Respond to question 3, and then go to question 4.)*

3. PLEASE DESCRIBE PRIOR OR CONCURRENT USE OF THESE ANIMALS, AND WHAT MEASURES WILL BE TAKEN TO PREVENT OVER-USE. #1302001: Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats and veterinarian technicians restraint techniques and minor procedures. The animal will be placed in marked cage and we will be the ones to remove the animal and put them back into the enclosure.

4. PLEASE INDICATE WHERE THE ANIMALS INVOLVED IN THIS STUDY WILL BE HOUSED (INCLUDE FACILITY NAME, BUILDING, AND ROOM NUMBER AS APPLICABLE). THE CONCURRENT STUDY WILL BE IN CHARGE OF THE FEEDING, HOUSING OF THE ANIMAL AND ALL VETERINARY CONCERNS.

Brigham Young University - Idaho
Ricks building Lab 113

5. PROVIDE THE LOCATION(S) WHERE EXPERIMENTAL PROCEDURES WITH ANIMALS WILL BE PERFORMED (INCLUDE FACILITY NAME, BUILDING, AND ROOM NUMBER, AS APPLICABLE).

Brigham Young University - Idaho
Ricks building Lab 113

6. ARE SPECIAL OR UNUSUAL HOUSING OR HUSBANDRY CONDITIONS REQUIRED FOR THE ANIMALS INVOLVED IN THIS STUDY?

☐ SPECIAL OR UNUSUAL HOUSING OR HUSBANDRY CONDITIONS ARE REQUIRED. (*Respond to questions 7 and 8, and then go to section 7.)*

☒ THERE ARE NO SPECIAL OR UNUSUAL HOUSING OR HUSBANDRY REQUIREMENTS. *(Go to section 7.)*

7. PLEASE INDICATE WHAT TYPE OF SPECIAL OR UNUSUAL HOUSING OR HUSBANDRY CONDITIONS ARE REQUIRED.

☐ FOOD RESTRICTION.
☐ WATER RESTRICTION.
☐ SINGLE HOUSING OF SOCIAL ANIMALS.
☐ BRIEF RESTRAINT.
☐ ENVIRONMENTAL TEMPERATURES OUTSIDE OF ESTABLISHED RANGES.
☐ CAPTIVE HOUSING OF WILD-CAUGHT SPECIES.
☐ OTHER. DESCRIBE:

8. PLEASE DESCRIBE THE NECESSITY FOR SPECIAL OR UNUSUAL HOUSING OR HUSBANDRY REQUIREMENTS, AND HOW ANIMAL COMFORT WILL BE ASSURED UNDER THE CONDITIONS.

N/A

Section 7: Animal Well-Being

1. Will animals be physically restrained longer than one hour in a conscious state?

☐ **YES** ~ COMPLETE TABLE BELOW
☒ **NO**

SPECIES	PURPOSE	TYPE OF RESTRAINT	FREQUENCY	DURATION

Justify the duration of restraint:

How will animals be monitored?

2. Have any of these animals been previously used in an experimental procedure or another protocol?

☐ **YES** ~ LIST SPECIES AND EXPLAIN IN FIELD BELOW
☒ **NO**

Explanation:

3. Is it likely animals in this protocol will experience pain/discomfort?

☒ **YES** ~ DESCRIBE IN FIELD BELOW
☐ **NO**

Description: The rat may experince discomfort from being in the pvc pipe.

4. Will biological fluid(s) be collected? (BLOOD, LYMPH, BILE, CEREBROSPINAL FLUID, URINE, ETC.)

☐ **YES** ~ COMPLETE TABLE BELOW
☒ **NO**

SPECIES	FLUID	VOLUME	COLLECTION FREQUENCY	COLLECTION SITE	ANESTHETIC	DOSE

5. Explain how you will minimize expected animal pain and distress and enhance animal well-being (e.g., use of sedatives, tranquilizers, or anesthetics; familiarization/conditioning of the animal; enrichment opportunities).

Before conducting the experiment we will train the rat to go into and become acclimatized with the pvc pipe. We are confident this can be done in such a way to reduce stress to the animal when we do the actual experiment. Food would be used as a positive reinforcement as well as a positive stimulus. We will know when the rat is acclimatized when it displays normal rat behavior (aka eating, walking around)

Section 8: Euthanasia and Animal Disposal

1. Will animals be euthanized during or at the conclusion of this study?

☒ **Animals <u>will not</u> be euthanized.** *(Respond to question 2, and then go to section 9.)*
☐ **Animals will be euthanized.** *(Go to question 3.)*

2. Describe the intended state of the animal(s) at the conclusion of the study (e.g., transferred to another approved study, maintained in a research, teaching, or training herd, donated to an animal shelter, etc.).

The animal will be transferred to Protocol number #1002003 : Investigating Principles of Learning Through Maze Running, bar pressing, and navigation through other obstacles, by rats

3. Indicate the proposed method of euthanasia. If a chemical agent is used, specify the dosage and route of administration. If the method(s) of euthanasia include those not recommended by the **AVMA Panel Report on Euthanasia** (e.g., decapitation or cervical dislocation without anesthesia), provide justification why such miethods must be used. N/A
4. How will you dispose of animal carcasses? N/A

Section 9: Principal Investigator Assurance

☒	The information provided in this protocol form accurately reflects the intended use of animals for this research activity.
☒	I certify that I have completed the institution's base training module ("the humane care and use of laboratory animals") <u>and</u> the species module(s) relavent to this study.
☐	I certify that I have completed the institution's safety module ("occupational health and safety").
☐	I certify that all personnel involved in this study have completed the institution's base training module ("the humane care and use of laboratory animals"), the species module(s) relevant to this study, and the safety module ("occupational health and safety").
☐	I certify that I have discussed the design and implementation of this protocol with the **Attending Veterinarian.**
☐	I certify that this protocol is not unnecessarily duplicative of previous work.
☐	<u>For **USDA Classification D and E** protocols only</u>. I certify that I have reviewed the pertinent scientific literature and the sources and/or datatbases as noted in **Section 5.2**, and have found no valid alternative to any procedures described herein which may cause more than momentary pain or distress.
☐	I certify that I will obtain formal approval from the **IACUC** <u>prior</u> to implementing any significant changes in this study.
☐	I certify that I will notify the **IACUC** regarding any unexpected study results that impact the animals, and that any unanticipated pain or distress, morbidity, or mortality will be reported to the **Attending Veterinarian** and the **IACUC.**
☐	If the **IACUC** approves my application, I agree to execute this work as described and assume responsibility for the supervision and work of all associated personnel.
☐	I agree to comply with the provisions of the **Animal Welfare Act**, the **Public Health Service** policy, and the guidelines established by **BYU-Idaho** regarding the care and use of laboratory animals.
☐	Training of researchers in proper positive reinforcement techniques of rats by the lab rat techninans
State the reason/s if you cannot certify or agree to any of these statements:	

Principal Investigator	
Signature:	**Date:**

Section 10: Protocol Approval

Certification of review and approval by the Institutional Animal Care and Use Committee:	
Name:	**Title:**
Signature:	**Date:**

OFFICE USE ONLY
DATE RECEIVED:
PROTOCOL #:

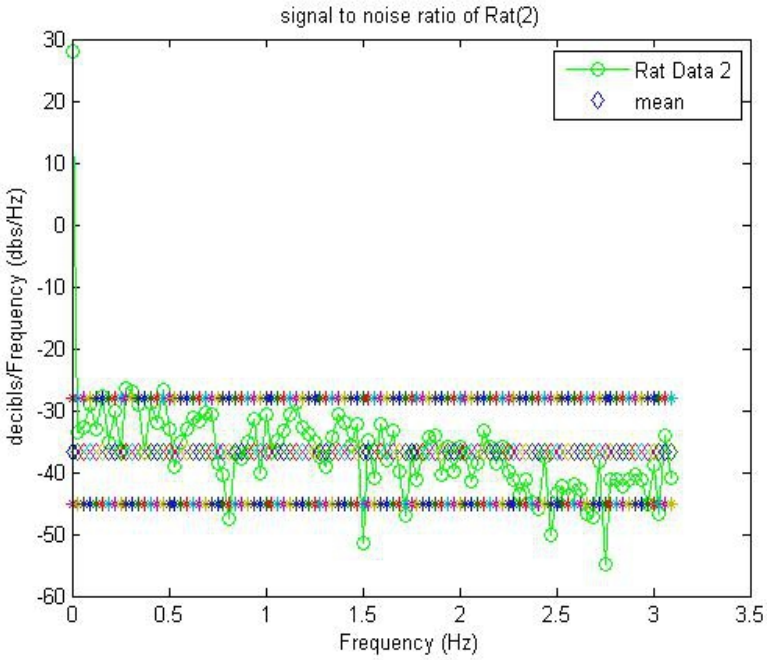
Appendix B - code

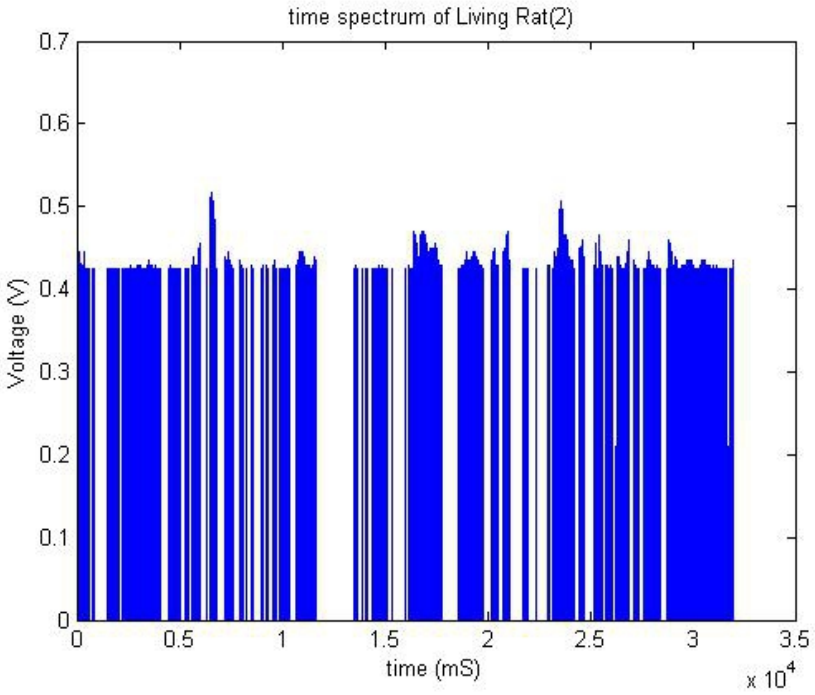
```
% The Time graph deriving program
% Will in take data then make a time axis in seconds then graph data
% on that graph

clear
%import the data from text files
x=importdata('databt.txt');
%measure the length of the file
n=length(x);
%remove the blank tube noise
for i=1:n
    if x(i)> -1.42
        x(i)=0;
    else
        x(i)=x(i)+1;
    end
end
% make that the new axis
y=1:1:n;
figure
plot(y,x)
title('time graph of Data blank tube ')
xlabel('time')


%Signal to noise ratio code
%by Ross Blaszczyk
clear
close all
x=importdata('datac1.txt');

% I want to take the mean and standard deviation of the data.

fs=101; % Hz twice my higest frequency, this is the minumum sampling frquency
% the collect time should be many periods of my frequency i want to measure
% so

N = length(x);  % Number of points
T=N/1000; %seconds this is the time to collect based on my highest frequenc


% the sampling frequency?
FS=101;
%Fs=N;            %  ?????
xdft = fft(x);  %  Take the fft of the data

xdft = xdft(1:N/2+1); % take the positive size of the fft

psdx = (1/(FS*N)).*abs(xdft).^2; % normalize and square the fft (not sure about
this normalization)

psdx(2:end-1) = 2*psdx(2:end-1); % leave out the DC value and multiply the rest
by 2?
```

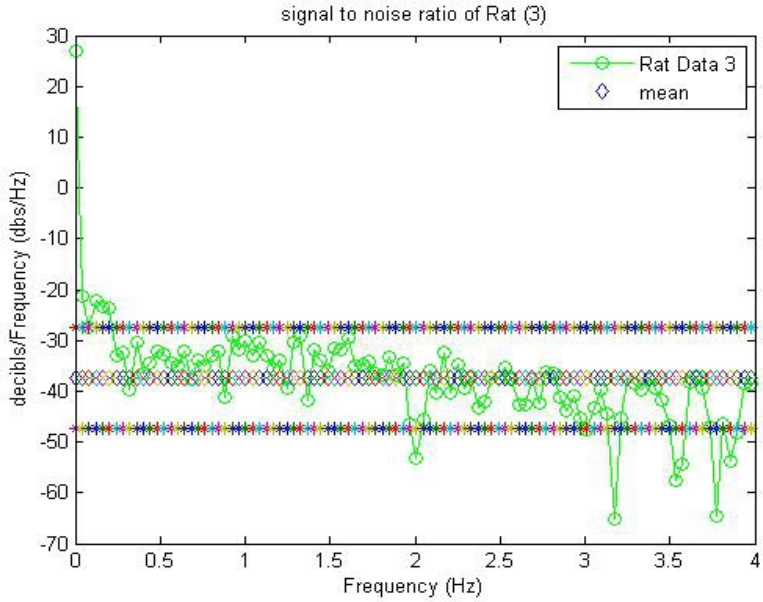
```
freq = [0:N/2]/T; %Hz build an array of frequencies for the axis. Remember
mean=sum(10*log10(psdx(1:100)))/100;
standarddeviation=sqrt(sum((10*log10(psdx(1:100))-mean).^2)/100);
xu=mean+standarddeviation;
xl=mean-standarddeviation;
% that  n=T/Ts so fs = 1/Ts = n/T. This is our sampling frequency. We plot
% in terms of our sampling frequency
% We should get out a plot with a peak at ft Hz

figure
plot(freq(1:200),10*log10(psdx(1:200)),'g-
o',freq(1:100),mean,'d',freq(1:100),xu,'-*',freq(1:200),xl,'-*'); grid on;  %
plot the power spectrum

title('signal to noise ration of Rat data 6');
legend('Rat Data 6','mean');
xlabel('Frequency (Hz)'); ylabel(' decibls/Frequency (dbs/Hz)');



%power spectrum and overlay code
%by Dr. Todd Lines PHD, Ross Blaszczyk
clear
close all
x=importdata('wbs1.txt');
y=importdata('wbl2.txt');
% I want to take enough data to make sure I get a good feel for the
% frequency. Nyquest says the sameple reate should be twice the highest
% frequency so
ft=.6; % Hz my target frequency to measure
fh=20; %Hz my highest freuqncy that I want to measure
fl=0.1; %Hz lowest frequency of interest
fs=101; % Hz twice my higest frequency, this is the minumum sampling frquency
% the collect time should be many periods of my frequency i want to measure
% so
N2=length(y);
N = length(x);  % Number of points
T=N/1000; %seconds this is the time to collect based on my highest frequenc
T2=N2/1000;              % I think this is bad, should be the lowest frequency

% the sampling frequency?
FS=101;
%Fs=N;           %  ?????
xdft = fft(x);  %  Take the fft of the data
ydft = fft(y);
xdft = xdft(1:N/2+1); % take the positive size of the fft
ydft = ydft(1:N2/2+1);
psdx = (1/(FS*N)).*abs(xdft).^2; % normalize and square the fft (not sure about
this normalization)
psdy = (1/(FS*N2)).*abs(ydft).^2;
psdx(2:end-1) = 2*psdx(2:end-1); % leave out the DC value and multiply the rest
by 2?
psdy(2:end-1) = 2*psdy(2:end-1);
freq = [0:N/2]/T; %Hz build an array of frequencies for the axis. Remember
freq2 = [0:N2/2]/T2;
% that  n=T/Ts so fs = 1/Ts = n/T. This is our sampling frequency. We plot
```

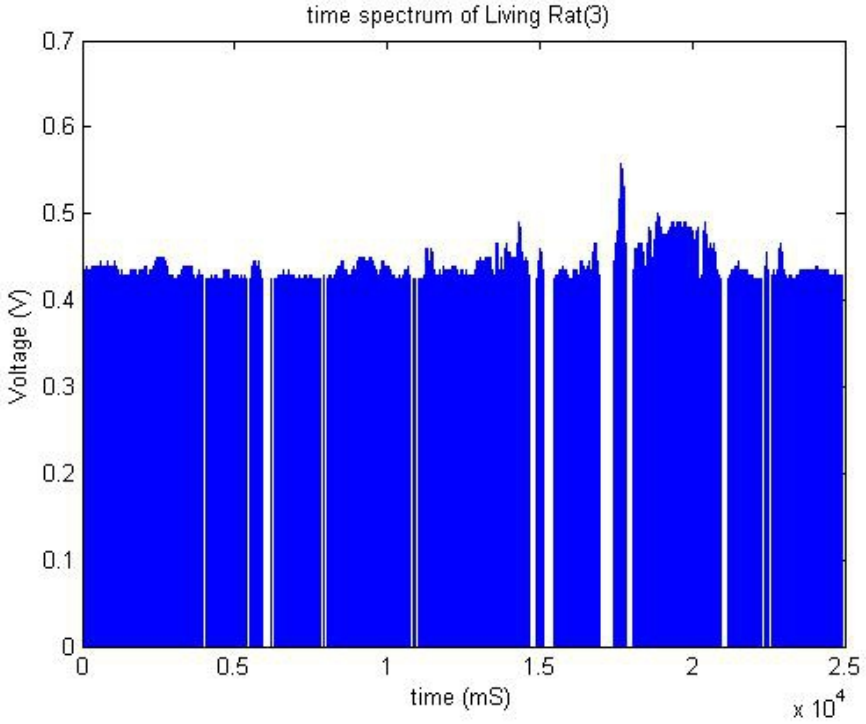
```
% in terms of our sampling frequency
% We should get out a plot with a peak at ft Hz

figure
plot(freq(1:200),10*log10(psdx(1:200)),'g-
o',freq2(1:100),10*log10(psdy(1:100)),'r-p'); grid on;  % plot the power
spectrum

%plot(freq,10*log10(psdx)); grid on;
%axis([0 110 -110 20]);
title('water balloon small vs water balloon big');
legend('Water balloon small','Water Balloon large');
xlabel('Frequency (Hz)'); ylabel(' Decibles/Frequency (dbs/Hz)');
```

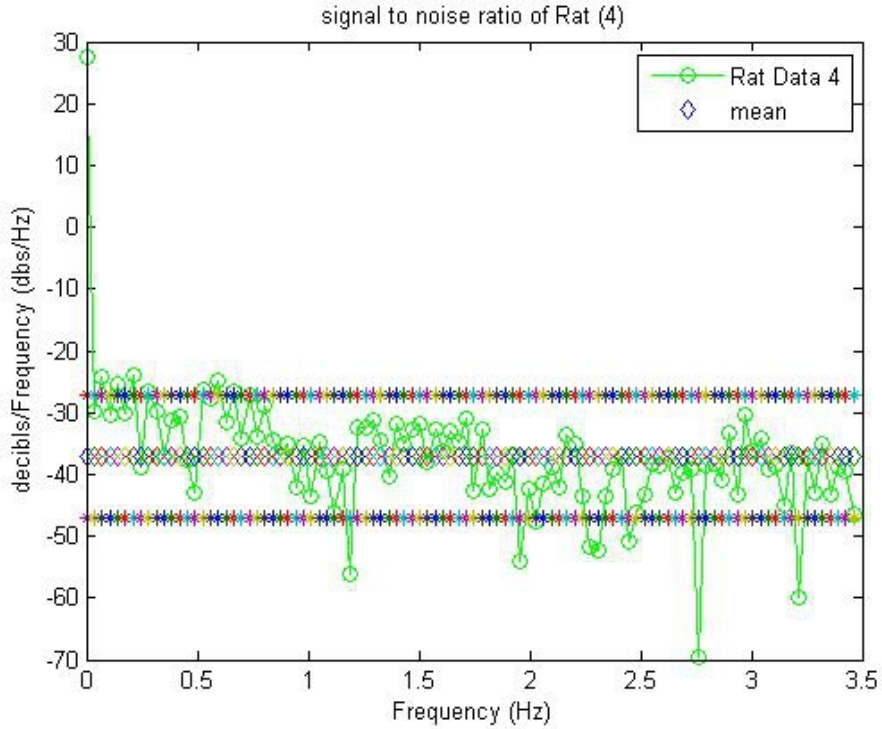
Appendix C- Graphs of Data sets

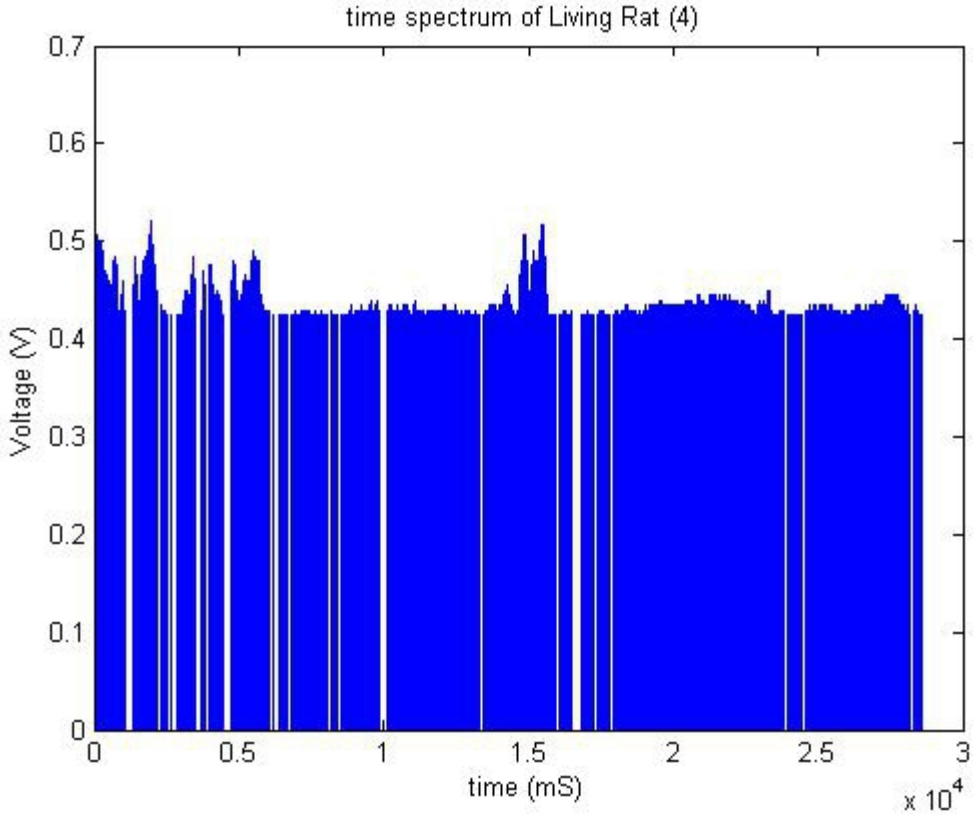


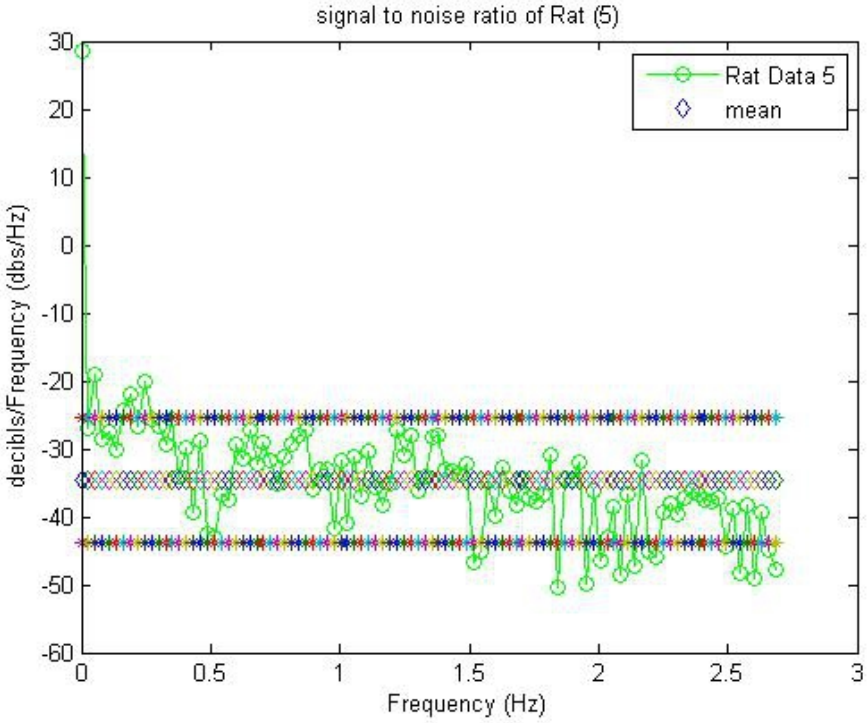


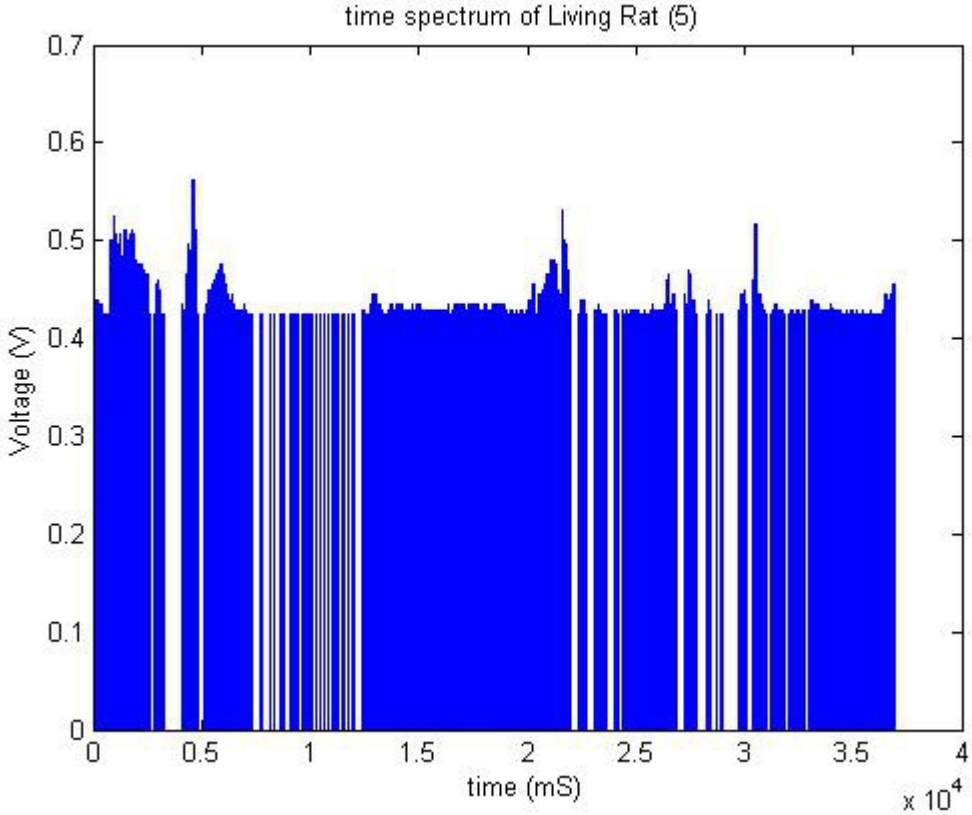

signal to noise ratio of Rat (3)
Rat Data 3
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
0.5
1
1.5
2
2.5
3
3.5
4

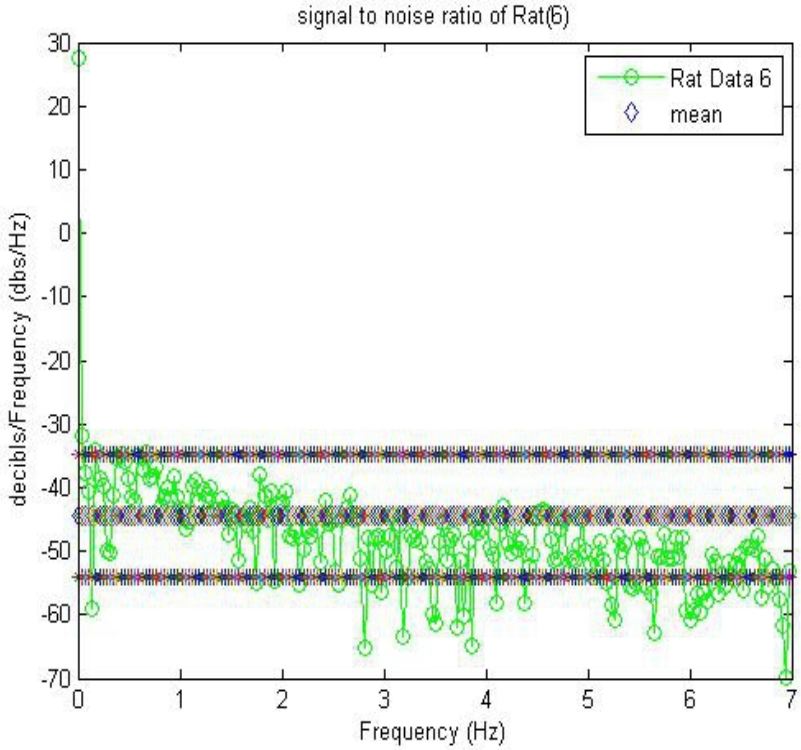

time spectrum of Living Rat(3)
Voltage (V)
time (mS)
x 10^4
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5

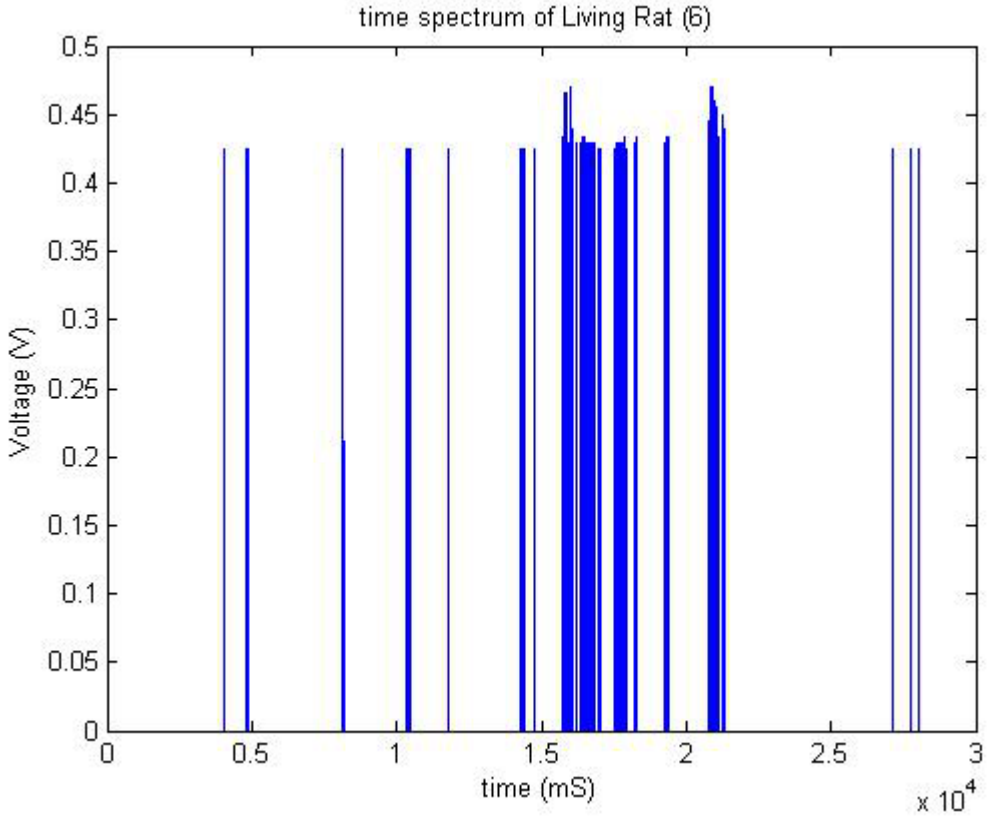

signal to noise ratio of Rat (4)
Rat Data 4
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
0.5
1
1.5
2
2.5
3
3.5

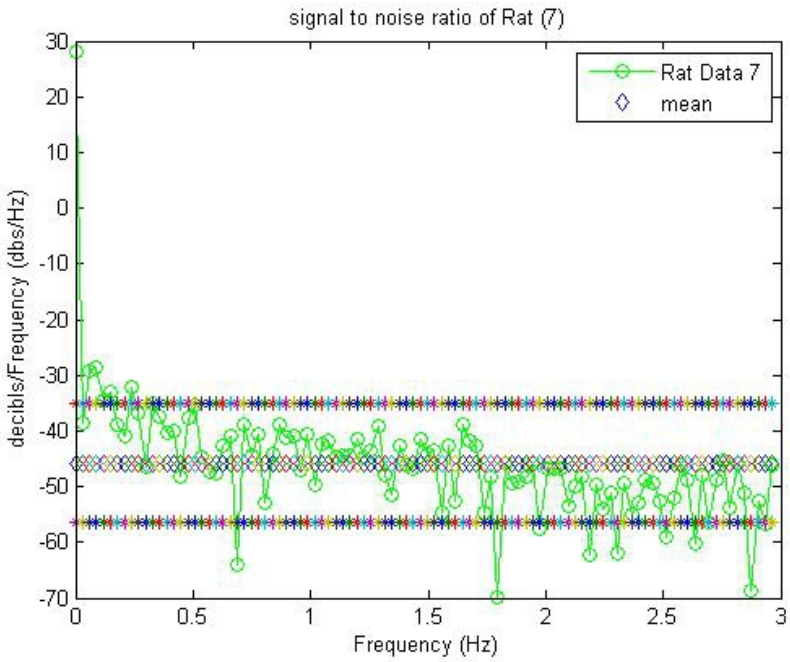

time spectrum of Living Rat (4)
Voltage (V)
time (mS)
x 10^4
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3

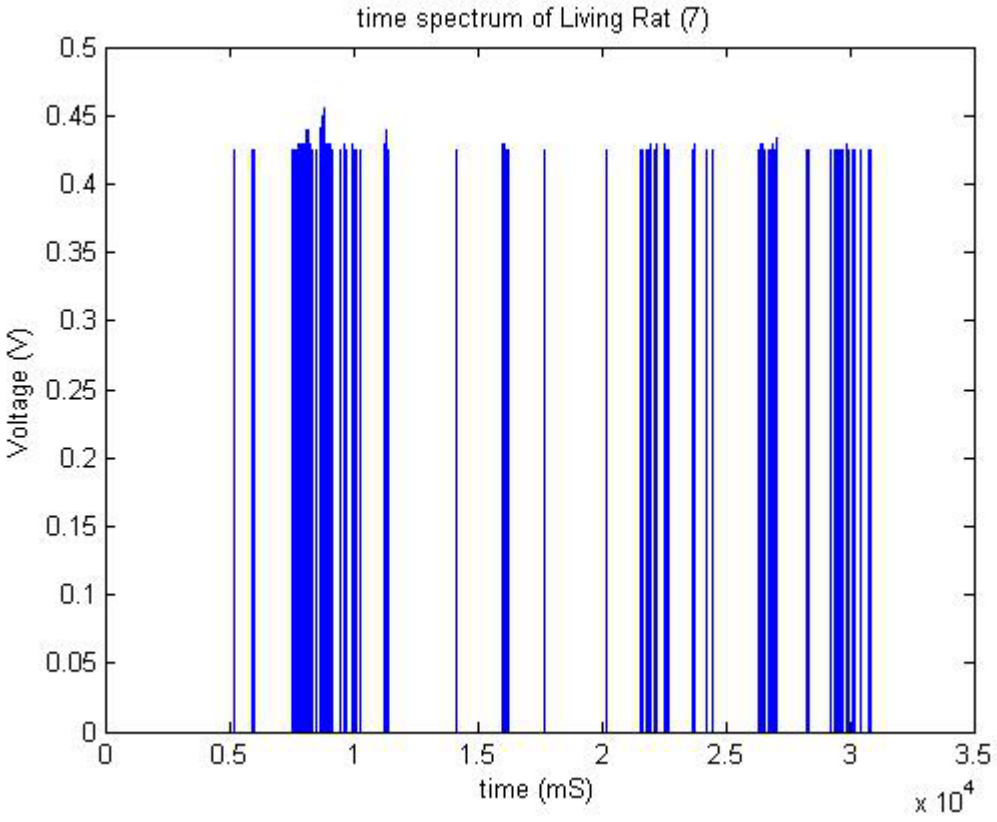

signal to noise ratio of Rat (5)
Rat Data 5
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
-50
-60
0
0.5
1
1.5
2
2.5
3

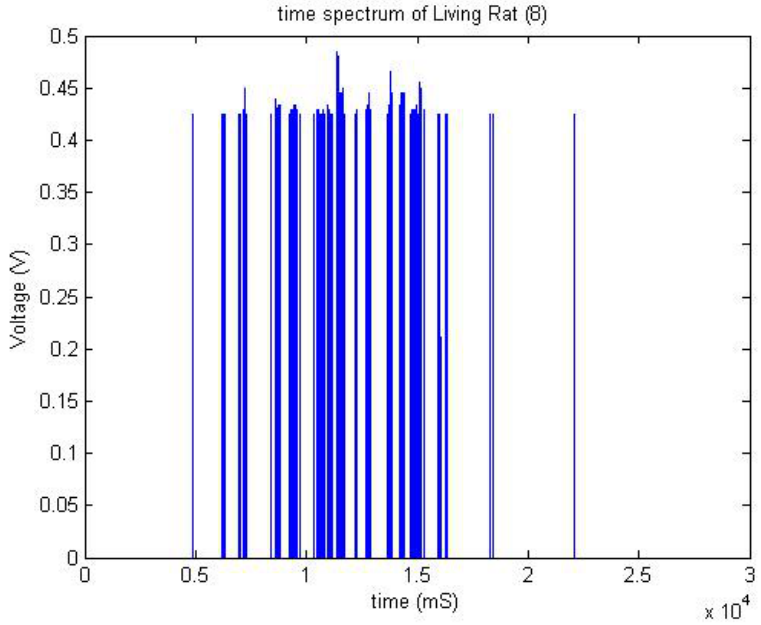

time spectrum of Living Rat (5)
Voltage (V)
time (mS)
x 10^4
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4

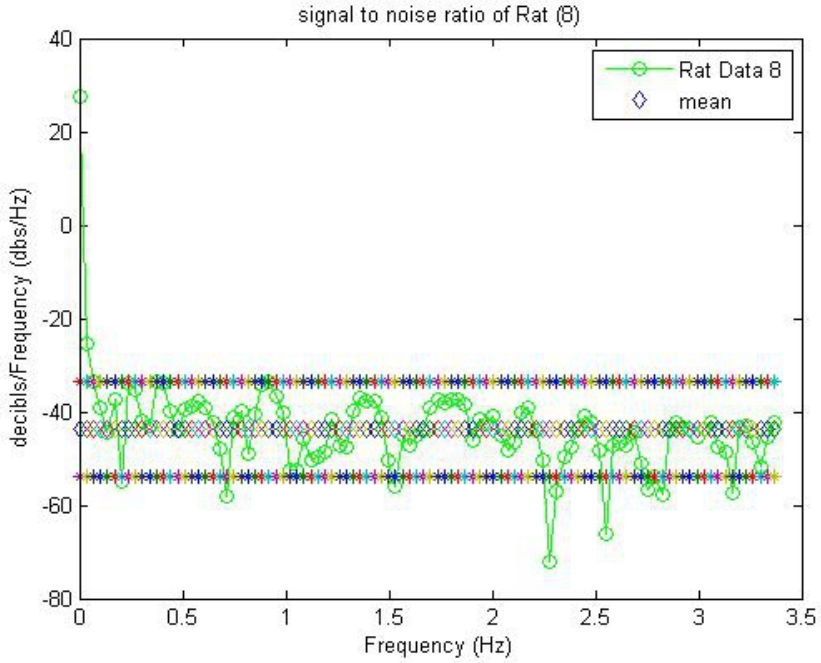

signal to noise ratio of Rat(6)
Rat Data 6
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
1
2
3
4
5
6
7

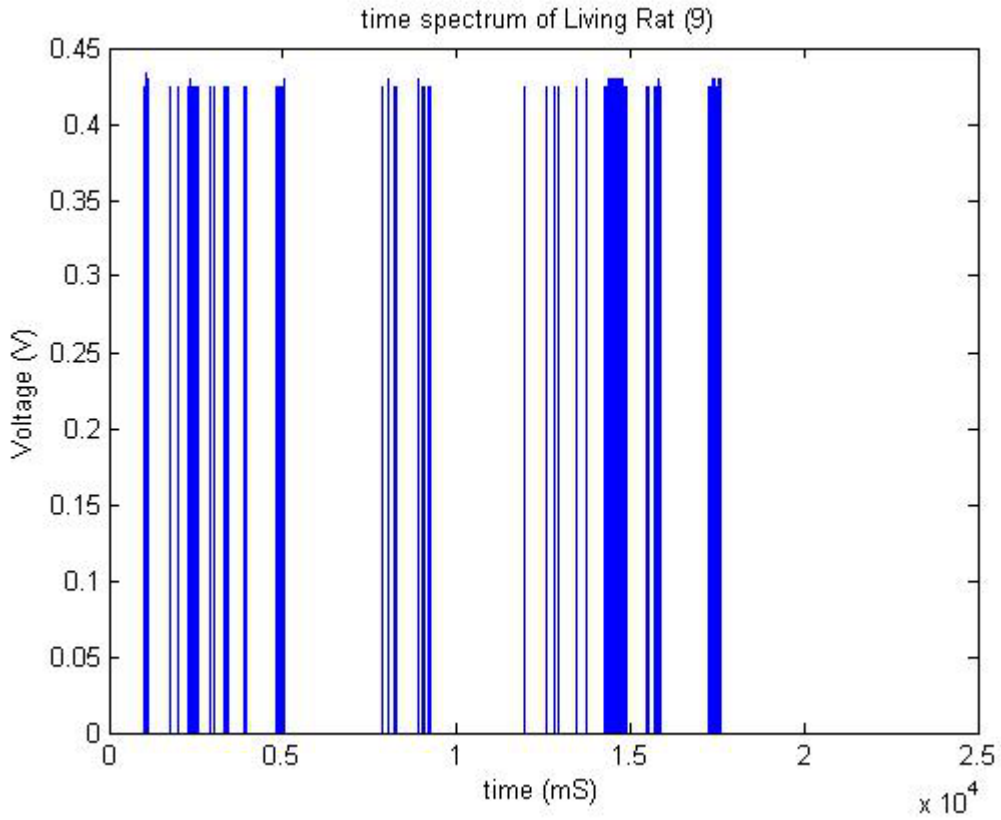

time spectrum of Living Rat (6)
Voltage (V)
time (mS)
x 10^4
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3

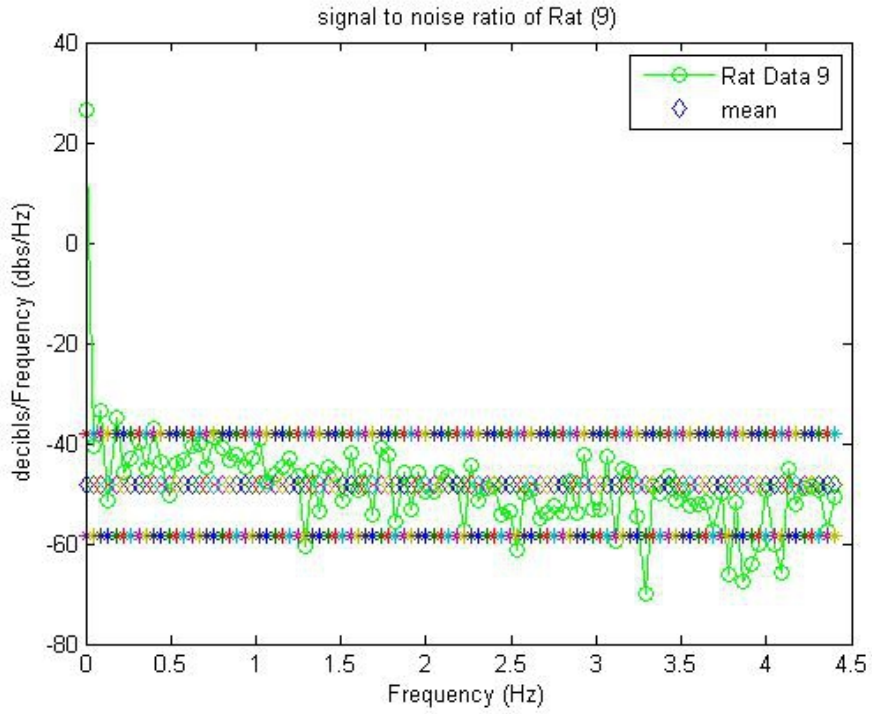

signal to noise ratio of Rat (7)
Rat Data 7
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
0.5
1
1.5
2
2.5
3

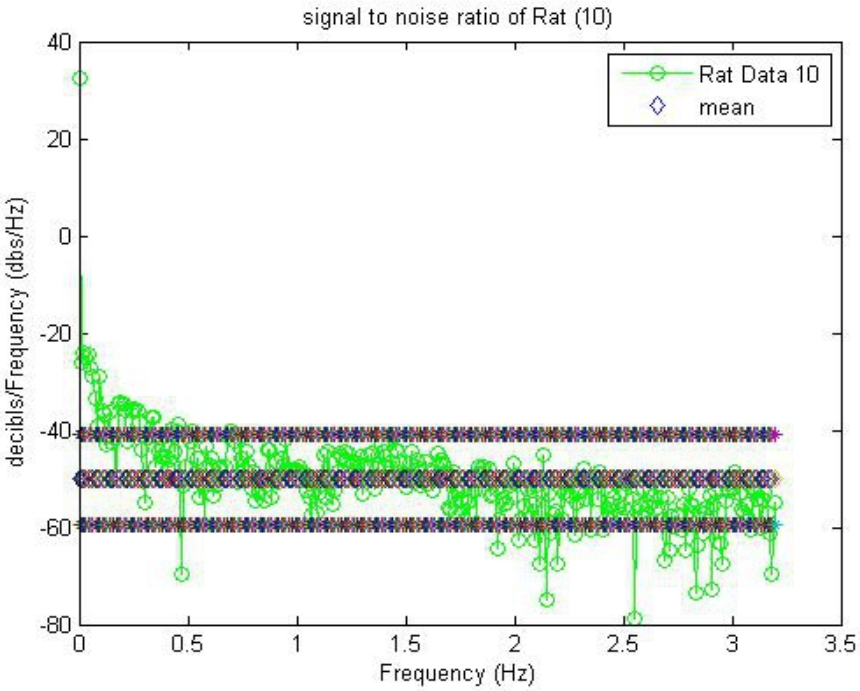

time spectrum of Living Rat (7)
Voltage (V)
time (mS)
x 10^4
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5

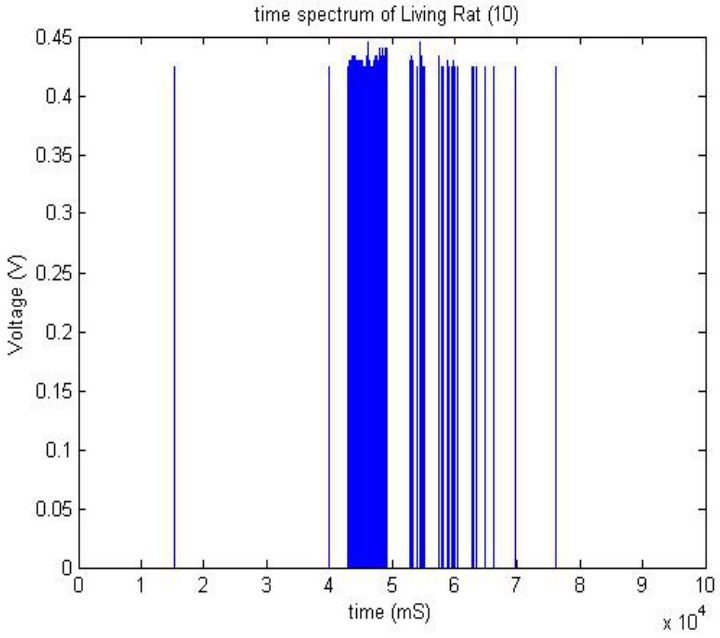

time spectrum of Living Rat (8)
Voltage (V)
time (mS)
x 10^4

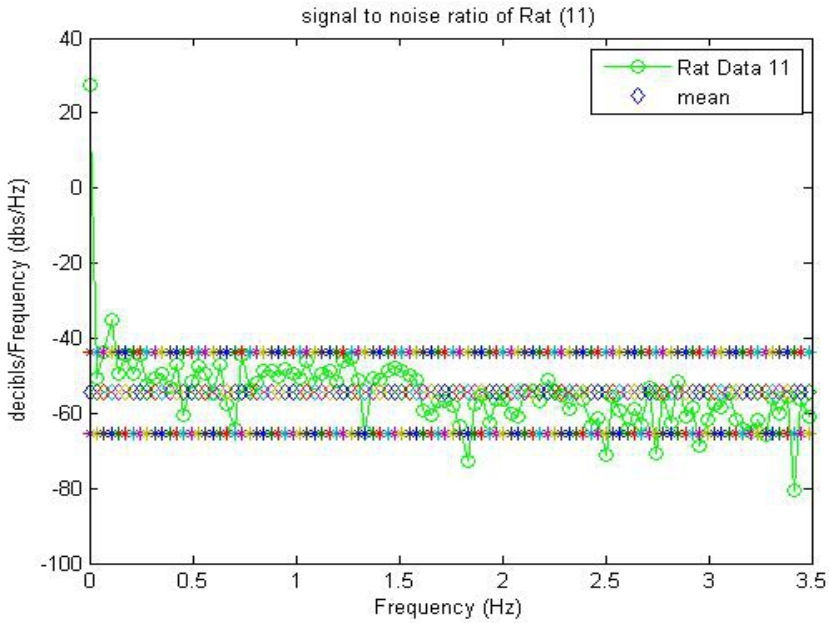

signal to noise ratio of Rat (8)
Rat Data 8
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)

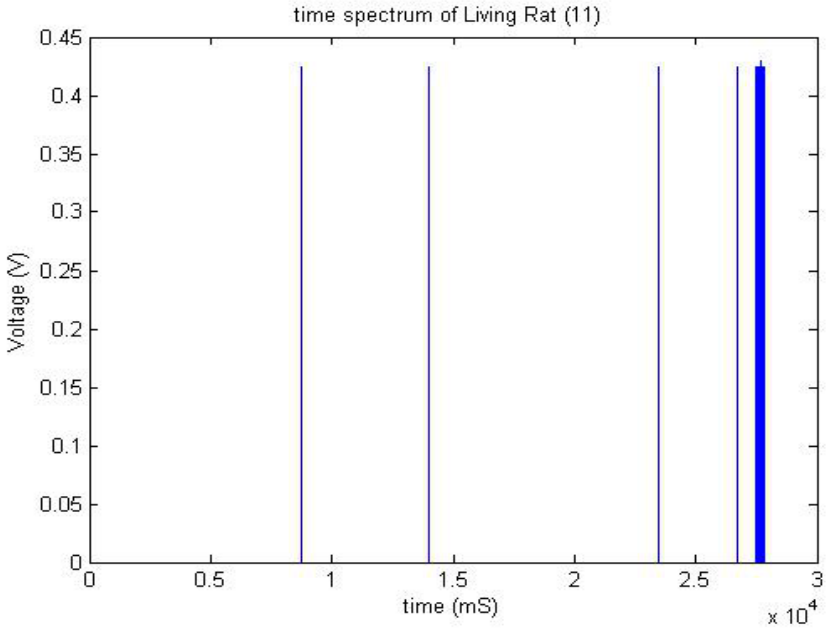

time spectrum of Living Rat (9)
Voltage (V)
time (mS)
x 10^4
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5

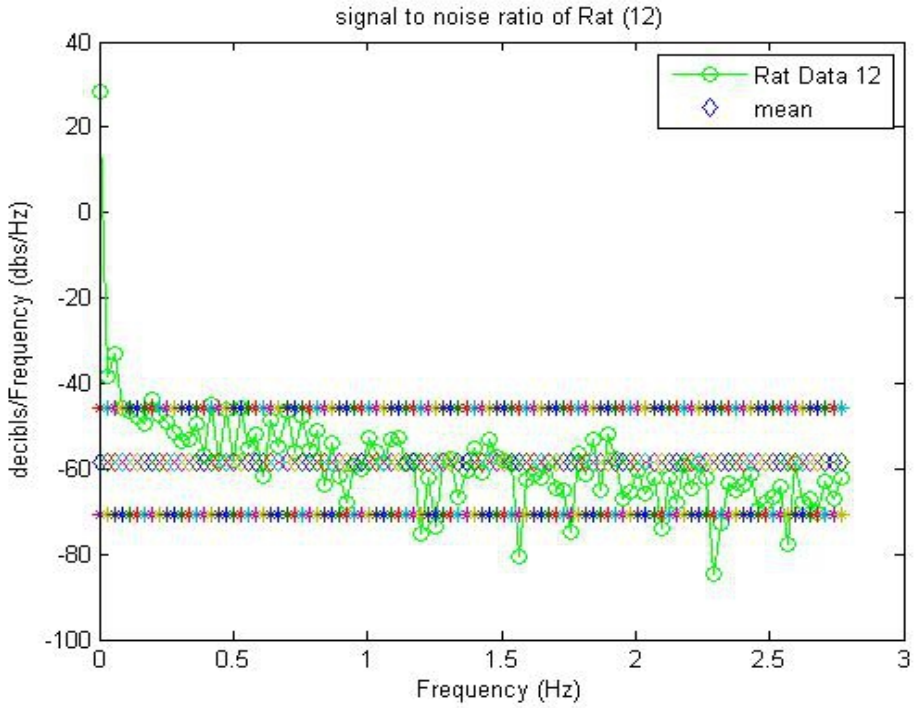

signal to noise ratio of Rat (9)
Rat Data 9
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
40
20
0
-20
-40
-60
-80
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

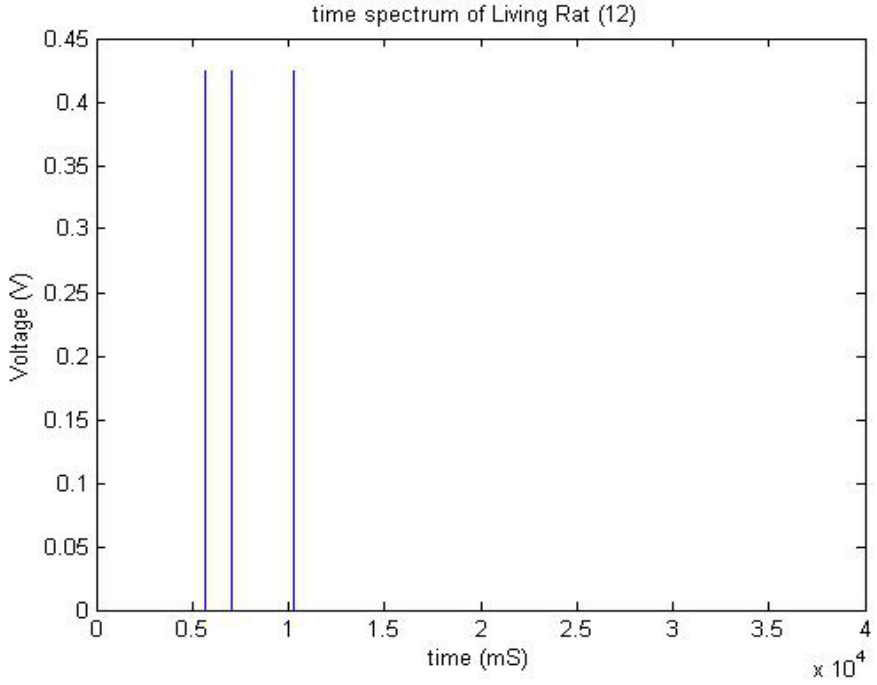

signal to noise ratio of Rat (10)
Rat Data 10
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
40
20
0
-20
-40
-60
-80
0
0.5
1
1.5
2
2.5
3
3.5

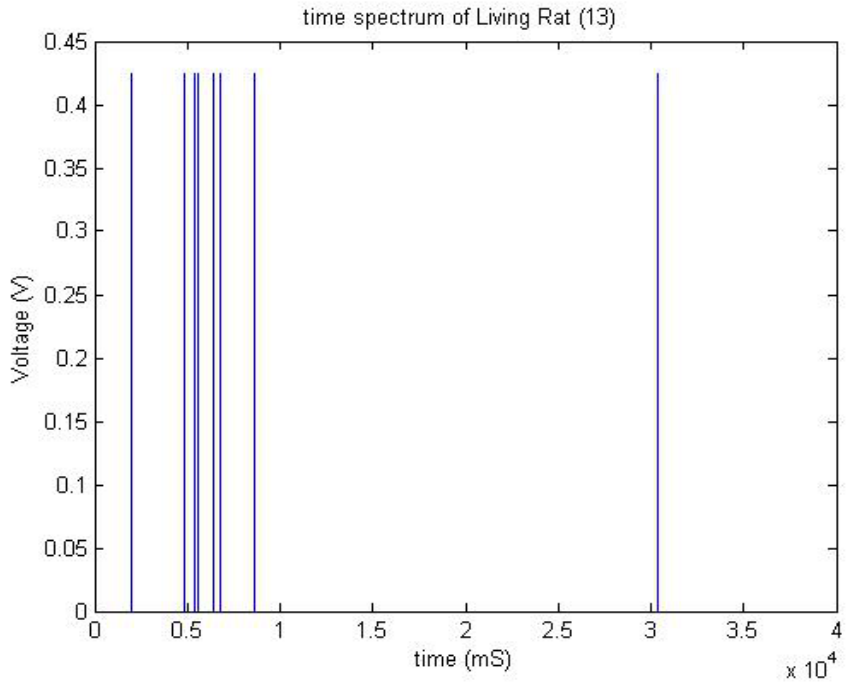

time spectrum of Living Rat (10)
Voltage (V)
time (mS)
x 10^4
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10

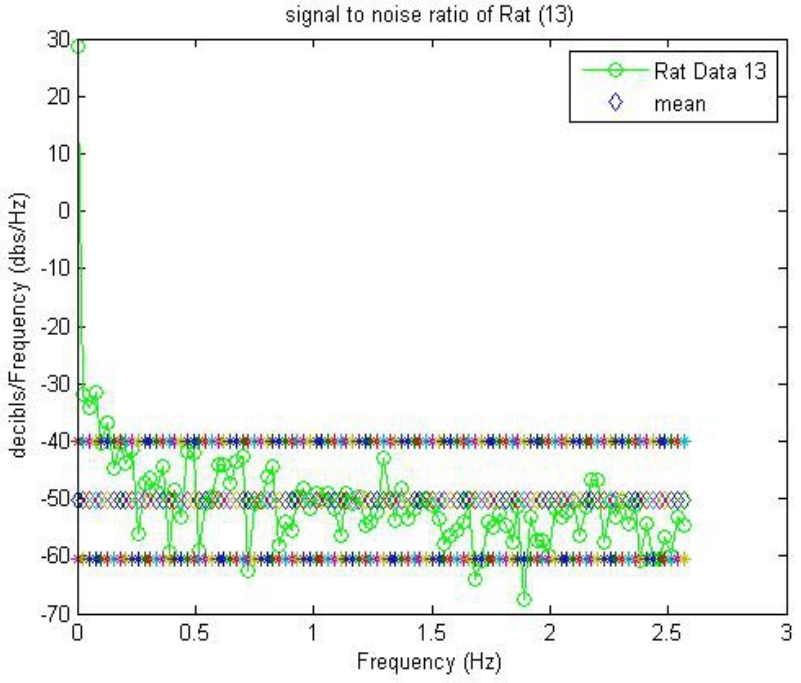

signal to noise ratio of Rat (11)
Rat Data 11
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
40
20
0
-20
-40
-60
-80
-100
0
0.5
1
1.5
2
2.5
3
3.5


time spectrum of Living Rat (11)
Voltage (V)
time (mS)
x 10^4
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3


signal to noise ratio of Rat (12)
Rat Data 12
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)
40
20
0
-20
-40
-60
-80
-100
0
0.5
1
1.5
2
2.5
3


time spectrum of Living Rat (12)
Voltage (V)
time (mS)
x 10^4
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4


time spectrum of Living Rat (13)
Voltage (V)
time (mS)
x 10^4


signal to noise ratio of Rat (13)
Rat Data 13
mean
decibls/Frequency (dbs/Hz)
Frequency (Hz)

Resources

[1] Thomas G. Kyle;Scattering; Atmospheric Transmission, Emission and Scattering, Pergamon Press Inc., 1991, 124-135

[2] Liou,K.N.;Lorenz- Mie Theory of Light Scattering by Spherical Particles; An Introduction to Atmospheric Radiation;Academic Press; 2002;188-189

[3] Chen, Y.F. Department of Electrical Engineering and Systems Science, Michigan State University ,Misra, Devendra;Wang, Huei;Huey-Ru Chuang;Postow, E.,Am X-band Micorwave life-detection System Biomedical Engineering, IEEE Transactions on (Volume:BME-33 ,Issue: 7), 697-701,1986

[4] P W Barber; S C Hill;Scattering By Axisymmetric Particles: T-Matrix Method; Light Scattering by Particles: Computational Methods, World Scientific Publishing Co. Pte. Ltd., 1990,79-185

[5]Waterman, P.C.;Matrix Formulation of Electromagnetic Scattering;Proceedings of IEEE, 1965 August; 805-812

[6] Allen Andersen, Microwave Optic Research, Brigham Young University – Idaho, 2012

[7] http://ratguide.com/health/basics/advanced_health_check.php