2014

Modification and Optimization of a Gaussian Noise Generation System for the Study of Noise-Induced Hearing Loss

Kelly Wepsiec
Southern Illinois University Carbondale, woochles@gmail.com

Actual degree in Master if Engineering in Biomedical Engineering

Recommended Citation

Wepsiec, Kelly. "Modification and Optimization of a Gaussian Noise Generation System for the Study of Noise-Induced Hearing Loss." (Jan 2014).

MODIFICATION AND OPTIMIZATION OF A GAUSSIAN NOISE GENERATION SYSTEM FOR THE STUDY OF NOISE-INDUCED HEARING LOSS

by

Kelly Wepsiec

B.S., Southern Illinois University, 2005

A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
Master of Engineering.

Department of Biomedical Engineering
in the Graduate School
Southern Illinois University Carbondale
May 2015

RESEARCH PAPER APPROVAL

MODIFICATION AND OPTIMIZATION OF A GAUSSIAN NOISE GENERATION SYSTEM FOR THE STUDY OF NOISE-INDUCED HEARING LOSS

By

Kelly Wepsiec

A Research Paper Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Engineering

in the field of Biomedical Engineering

Approved by:

Dr. Jun Qin, PhD, Chair

Dr. Nazeih Botros, PhD

Graduate School
Southern Illinois University Carbondale
July 12, 2013

TABLE OF CONTENTS

LIST OF FIGURES

Introduction

Noise-induced hearing loss is a loss of hearing caused by exposure to noise. It is estimated that around 26 million Americans suffer from noise-induced hearing loss. The specific causes of NIHL can vary from individual to individual. A single highly impulsive noise can damage hearing, as can long term exposure to continuous noise. Highly impulsive noises can produce acoustic trauma, which is defined as permanent cochlear damage caused by a single impulsive noise event (Crocker, 1998). Acoustic trauma generally occurs when sound levels average about 130-140 decibels for most people (Rosen, 2001). Exposure to continuous noise can cause permanent hearing loss at sound levels as low as 80 decibels. In addition, Pierson (1996) suggests that maternal exposure to occupational noise may have damaging effects on fetal hearing.

Noise Exposure Safety Guidelines

Current occupational noise exposure limits require hearing protection for sound levels of 90 dB over an eight hour exposure time, but for sounds of less than fifteen minutes duration hearing protection is only required for sound levels over 115 dB (OSHA, 2012). The differences in sound levels requiring protection is based on the Equal Energy Hypothesis.

The Equal Energy Hypothesis, initially proposed in 1955, states that hearing loss is proportional to the total sound energy of a noise. This implies that different exposures with identical total energies will have the same effect on hearing and that amplitude fluctuations during a prolonged exposure do not affect hearing loss (Danielson, et. al. 1991). However Hammernik et.al. (2003) demonstrated that non-Gaussian noise causes more hearing damage than a Gaussian noise of equivalent energy. While this indicates that revision of current safety guidelines is needed, more research is necessary to determine how to classify complex noises and assess the damage potential before new guidelines can be introduced.

One of the emerging methods for predicting the level of hearing loss caused by a noise is the kurtosis metric (Qui, et. al. 2006; Hammernik et. al. 2003; Goley et. al 2010; Davis et. al. 2009; Zhao et. al 2010). The kurtosis statistic is used to determine the deviation of non-Gaussian noise from the Gaussian. Because non-Gaussian noise is more damaging than Gaussian noise, this can help determine how much more damaging a noise is to hearing compared to Gaussian noise of equal energy. By using *both* the total sound energy and the kurtosis value a more accurate assessment of potential hearing damage can be made. Hopefully applicable industrial guidelines can be drafted from research results.

Anatomy and physiology of the ear

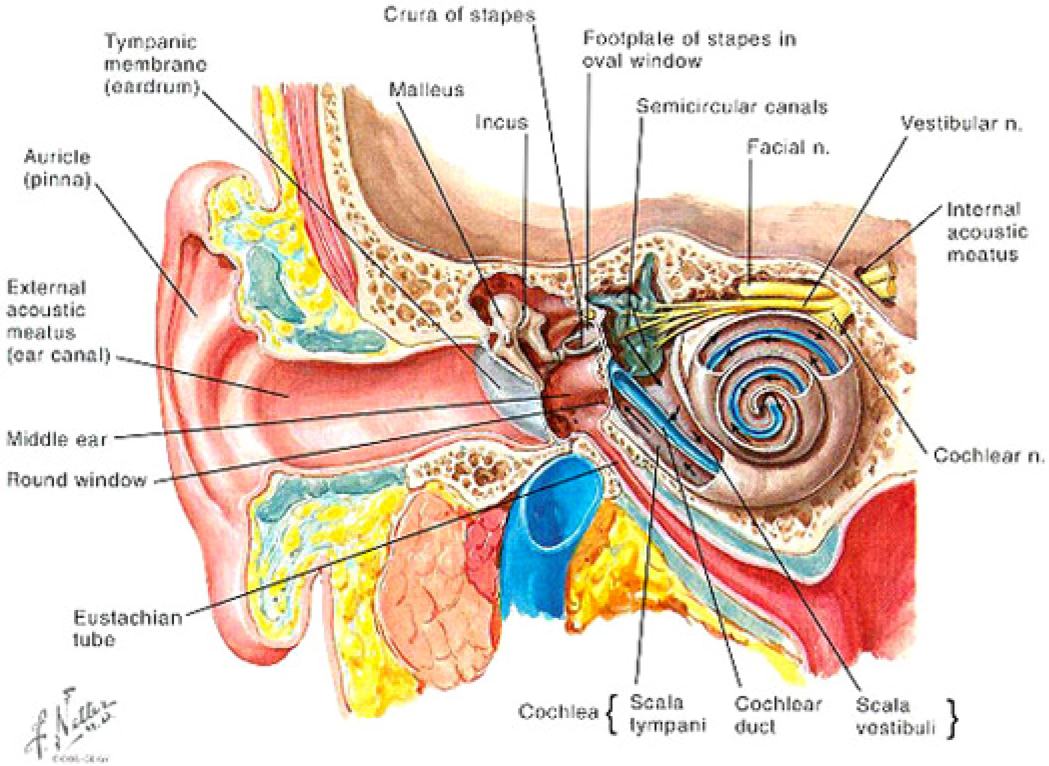


Figure 1: Detailed anatomy of the human ear

The ear has three main parts: the outer, middle and inner ear. The outer ear consists of the pinna and the ear canal. The tympanic membrane lies at the end of the ear canal, and serves as the boundary between the outer ear and the middle ear. The tympanic membrane is attached in turn to the three bones in the middle ear. These bones, the ossicles, are called the malleus, the incus, and the stapes. The inner ear consists of the cochlea, the cochlear vestibule, and the semicircular canals. The cochlea itself is divided into three tubes, the scala tympani, the scala media and the scala vestibuli, which all run the length of the cochlea. The stapes is connected to the scala vestibuli by way of the oval window. The scala tympani connected to the middle ear through the membrane of the round window.

The scala media is lined on one side by the basilar membrane, upon which lies the organ of corti. The organ of corti contains the inner and outer hair cells, which are the means by which sound pressure waves are converted into electrical signals and transmitted to the brain by the auditory nerve. There are three rows of outer hair cells and a single row of inner hair cells. Each hair cell has group of stereovilli projecting upward into the scala media. The stereovilli of each hair cell are graduated in length, and the longest stereovilli on the outer hair cells contact the tectorial membrane, which is a gelatinous membrane that lies just above the organ of corti (Boron & Boulpaep, 2009).

Sound pressure waves are directed down the ear canal by the shape of the pinna, where they cause the tympanic membrane to vibrate. The vibration is transmitted to the bones of the middle ear, and then to the inner ear through the oval and round windows. During the compression phase of the sound wave the tympanic membrane is pushed inward which causes the middle ear bones to push the oval window inward. This increases pressure within the scala vestibuli which places pressure on the scala tympani and causes the round window to bulge outward into the middle ear. In the rarefaction phase of a sound wave, the tympanic membrane is pulled outward. The bones of the middle ear then pull the oval window outward which pushes the round window inward.

The movement of the round and oval windows disturbs the perilymph fluid in the scala vestibuli and the scala tympani. Movement of the oval window outward causes the basilar membrane to lift. This creates a shear force between the outer hair cells and the tectorial membrane (Boron & Boulpaep, 2009). The stereovilli bundles tilt in the direction of the longer stereovilli. This opens transduction channels in the outer hair cells and depolarizes them. Depolarization of the outer hair cells causes contraction which amplifies the movement of the basilar membrane. When the basilar membrane lifts, it also pushes endolymph fluid from beneath the tectorial membrane. The movement of the fluid sweeps the inner hair cell bundles toward the lower stereovilli. This opens transduction channels in the inner hair cells and depolarizes them. Voltage gated Ca^{2+} channels then open and trigger release of glutamate which fires an action potential in the afferent neurons connected to the inner hair cells. These processes reverse when the oval window moves inward.

When discussing NIHL, the most common hearing loss occurs at higher frequency ranges, as well as frequencies around 4 kHz (Crocker, 1998). Different frequencies cause vibrations to concentrate at different places along the basilar membrane within the cochlea. Each area of the cochlea is sensitive to a different frequency, with low frequencies at one end and high frequencies at the other. This is the result of the shape and stiffness of the basilar membrane. When the cochlea is uncoiled, a triangular shape of the basilar membrane can be seen. The point of the triangular shape lies at the beginning of the coil and is 100 times stiffer than it is at the wide end (Boron & Boulpaep, 2009).

The human body also has ways to reduce hearing loss by damping loud sounds. The stapedius muscle moves the stapes and the tensor tympani moves the malleus. High intensity sounds trigger the acoustic reflex, which is a contraction of these two muscles. This stiffens the ossicular chain and muffles the sound. The strength of contraction depends not on intensity but on loudness of the sound (Raichel, 2006). For sounds with duration of greater than one half of a second, the contraction begins at 85-90 decibels of a pure tone and 70-75 decibels of complex noise. Full contraction strength is achieved when sounds are 30 decibels louder than the initial noise stimulus. The acoustic reflex occurs within 150 milliseconds (Crocker, 1998). It should be noted that the acoustic reflex is able to attenuate low frequency sounds best. When sounds have a frequency greater than 1000 Hz, the attenuating effect begins to wane.

Hearing Loss

The acoustic reflex generates hearing loss in the form of Temporary Threshold Shift (TTS). Hearing threshold is the minimum sound level in decibels that the ear can hear. For most people the hearing threshold is taken to be 0 dB (Raichel, 2006). Temporary threshold shift is a temporary upward shift of the hearing threshold. Severity of TTS depends on the stimulus. For short bursts of intense noise, TTS can last several minutes. Repeated impulses or loud continuous noise can cause TTS that may take several days to recover.

If the body does not gets sufficient time to recover between sound exposures, permanent hearing loss may result. This can be in the form of Permanent Threshold Shift (PTS) or loss of sensitivity to a particular frequency range. Permanent threshold shift is a permanent loss of sensitivity to low sound levels. Damage to particular cochlear regions will result in loss of hearing in the frequency range detected by the damaged region. It is thought some hearing loss is from excessive vibration causing mechanical damage to the hair cells. Hearing protective devices can dampen the sound, lessening the vibration and preventing damage that leads to permanent hearing loss.

There are three main types of physical hearing protection devices: ear plugs, ear muffs, and helmets (Crocker, 1998). Ear plugs have been used for thousands of years. In Homer's Odyssey, Odysseus uses ear plugs to evade the song of the sirens. Ear plugs are small devices, usually made of foam or a similar material that fit into the ear canal. Unfortunately, while ear plugs are small and convenient to use, some people find the pressure in their ear canals uncomfortable. In that case ear muffs are another option. Ear muffs encompass the entire ear and are easier to fit than ear plugs. Helmets combine head protection with earmuffs for a streamlined fit.

Other studies have shown that there is a biochemical component to NIHL. Systemic effects of loud noises include pupil dilation in the eyes, vasoconstriction, and increased heart rate. Within the ear exposure to noise can increase mitochondrial activity and free radical formation, reduce cochlear blood flow, and cause necrotic and apoptotic cell death in the organ of corti (Le Prell et. al. 2007). Free radicals include reactive oxygen species (ROS) and reactive nitrogen species (RNS). Both are highly reactive substances that can damage lipid membranes, proteins and DNA within the cell. They also serve to upregulate apoptotic pathways which increases cellular death.

Ohlemiller et.al. (1999) probed hydroxyl radical levels in the cochlea and showed that hydroxyl levels increase four fold after noise exposure. Hydroxyl radicals initiate lipid peroxidation which damages cell membranes. Because of the damaging effects of free radicals, many studies have been done researching the use of antioxidants to protect hearing. Ohinata et. al. (2000) studied the effects of glutathione and found it reduced PTS. Other antioxidants shown to reduce noise-induced hearing loss are salicylate, *N*-L-acetylcysteine, pravastatin, and 1-{3-[2-(1-Benzothiophen-5-yl)ethoxy]propyl}azetidin-3-ol (T-817MA) (Kopke et. al. (2000); Park et.al. (2012); Yamashita et. al. (2008). Dr. Kathleen Campbell at the Southern Illinois University School of Medicine has studied the use of D-methionine as an otoprotective agent (Campbell et.al. 2007). The noise generation system described here has been developed specifically for her research needs. Other drugs, such as methylprednisolone, have been shown to reduce hair cell loss (Sendowski 2006). Finally, while not an antioxidant; inducing hypoxia can also potentiate PTS (Chen & Liu 2005).

Acoustic Review

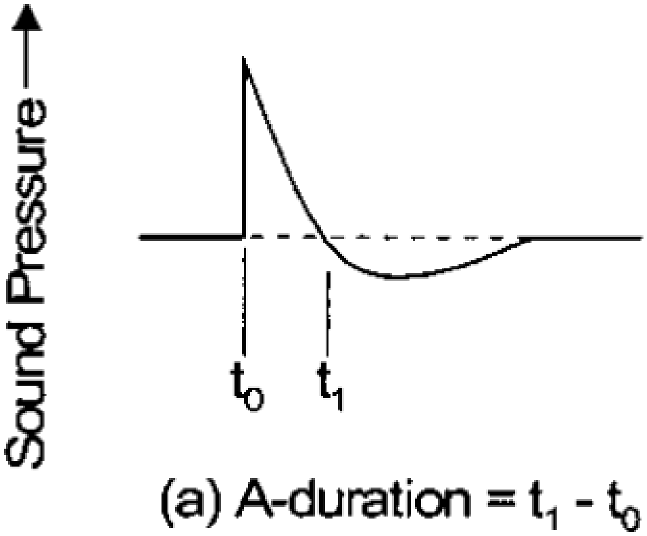


Figure 2: A-duration wave (Chan, Ho, Kan & Stuhmiller, 2001)

There are three types of noise that are typically studied in relation to noise induced hearing loss. They are impulse noise, Gaussian or white noise, and complex noise. Impulse noise consists of short duration, high energy noises. They are characterized by an A-duration waveform with a positive peak time of less than 200 ms (Johnston, 2012). The strength of impulse noise can quickly cause acoustic trauma and permanent hearing loss. In fact, Rabinowitz (2000) considered a single impulse of 140-179 dB to be equal in sound energy to forty hours of exposure to continuous noise at 90 dB A-duration waves are used to represent the sound of firearms when studying military hearing loss (Johnston, 2012). This wave can be represented by the Friedlander equation, where P_S is the peak pressure amplitude and t* is the time when the wave crosses the x-axis.

$$P(t) = P_S e^{t/t^*}(1 - t/t^*)$$

Gaussian noise is a type of continuous noise based on a normal distribution curve. In LabVIEW the set of random numbers is generated with $\mu=0$ and an adjustable standard deviation (Schlag, 2012). Gaussian noise can accurately be used to simulate continuous environmental noise. Complex noise is simple combination of continuous and impulse noise. It is difficult to simulate in a research environment without knowing the various individual components.

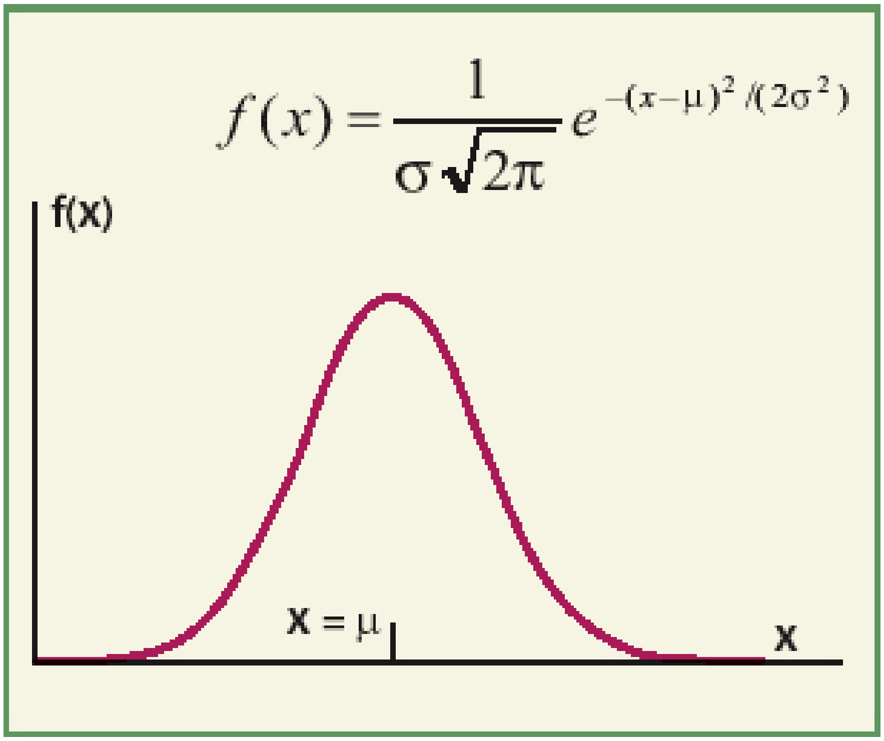


Figure 3: Gaussian Probability density

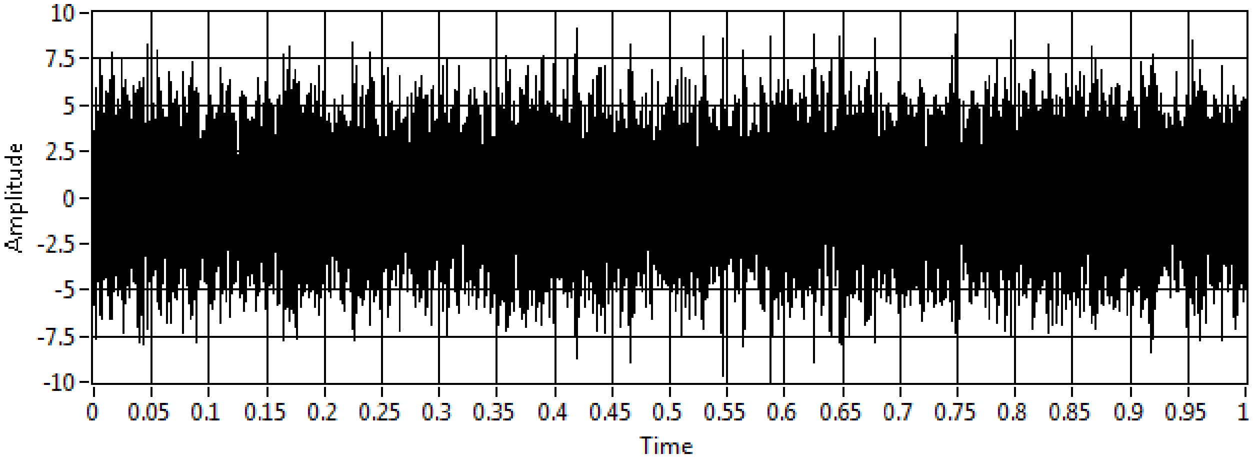


Figure 3: Continuous Gaussian Noise waveform

Noise Generation System

National Instruments' LabVIEW was used to create a virtual instrument (VI) that generates noise. The VI generates the signal, controls the signal's output and input, and monitors the signal during noise exposure experiments. The generated signal is sent by LabVIEW to an NI PCI-6251 multifunction data acquisition board. The data acquisition unit is equipped with two analog output channels with 2.86 MS/s update rate and 16 bit resolutions and sixteen analog input channels with sampling rate of 1.25 MS/s and 16 bit resolution. The digital signal generated by LabVIEW is converted to analog by the data acquisition unit and sent via output channel to a 750 Watt Yamaha 8Ω/Bridge P 2500 S power amplifier. This is a commercially available amplifier which allows for easy duplication of the system without needing to build all components in the lab. The amplifier's power bandwidth of 10 Hz - 40 KHz is more than sufficient for various noise generation needs.

The compression driver chosen when initially building this system is the JBL 2446 H/J compression driver. It has a 150 Watt power capacity on a continuous program and a frequency range of 500 Hz-20 kHz. Because it is a commercial compression driver, it has exceptional durability qualities which allow for transport and disassembling/reassembling the system as needed. The compression driver is connected to a 2" diameter shock tub with 1/2" thick acrylic walls. The system allows for varying lengths of shock tube to be used. At the end of the shock tube was placed a JBL 2380A flat front horn to distribute the sound evenly without distortion.

The final component of the system is the monitoring microphone. For calibration purposes a PCB 426B03 pressure field microphone was chosen because it can detect high pressure short duration noises accurately. It is also sufficient to detect differences in highly random continuous noise. This creates for a very precise and accurate picture of the signal at the subject level of the system. For simple monitoring of long duration signals, an Audio-Technica ATR-3350 omnidirectional lavaliere microphone was chosen. Because this microphone is omnidirectional, it can be clipped to a subject cage in any orientation and still pick up the signal. It is also inexpensive, which allows for easy replacement in case of animal related damage. It is also not necessary to have a highly precise microphone for monitoring because the purpose is to verify the continuity of the signal rather than any particular characteristic of the signal.

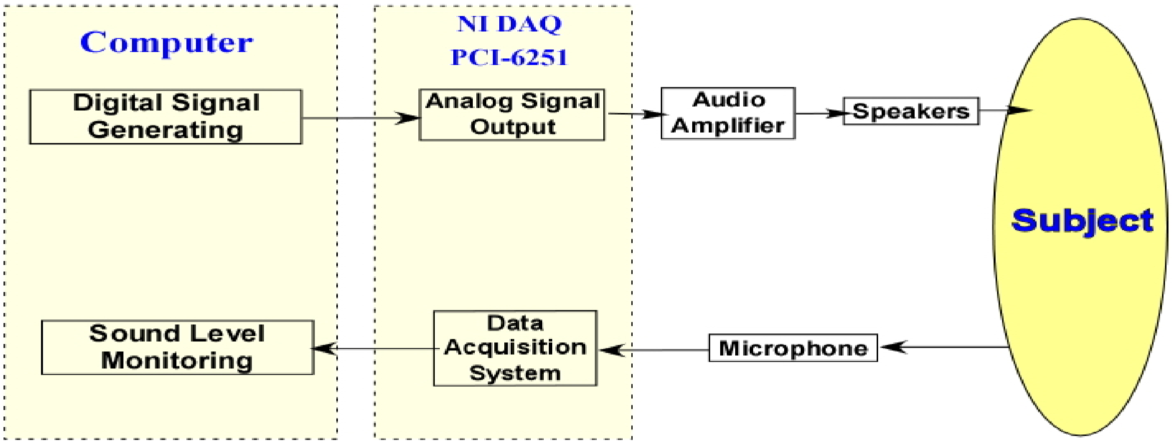


Figure 5: System Schematic

Figure 4: Noise generation system assembled at the SIU School of Medicine

The compression driver and horn are both mounted on acrylic plates measuring 12"x12"x1". These shock tube connects these two plates. Framing made of T-slotted aluminum supports the acrylic plates as well as the subject cage. The corner posts are cut from 2"x2" aluminum while the cross supports, upon which rest the acrylic plates and subject cage are made of 1"x2" or 1"x1" aluminum. The entire frame is situated within a portable sound booth. The monitoring microphone cord and the stereo wire connecting the compression driver to the amplifier run through an access hole in the side of the booth. All other components are set up on a wheeled cart, allowing the entire system to be moved without disassembling the components.

Modification of a Gaussian Noise System

Schlag (2012) designed a Gaussian noise generation system compatible with physical apparatus designed by Johnston (2012). Unfortunately, there were several issues that needed to be corrected before the system could be installed at the SIU School of Medicine in Dr. Kathleen Campbell's lab. Schlag's program was ideal for calibration but was cumbersome for research use. The LabVIEW front panel interface was busy and confusing with eleven graphic displays and numerous input options. While the system was intended for extended exposures of six hours, the program ran into memory use issues and froze after two hours of continuous operation. The input time was also faulty. The "run time" input did not refer to time but rather to loop iterations in the programming. Because it takes the computer longer than one second to run the loop once, entering a time of six hours did not result in a noise generation duration of six hours. The final problem that needed to be resolved was the lack of a simple monitoring system. The microphone used for calibration of the system is expensive and needs a signal conditioner to properly relay the signal.

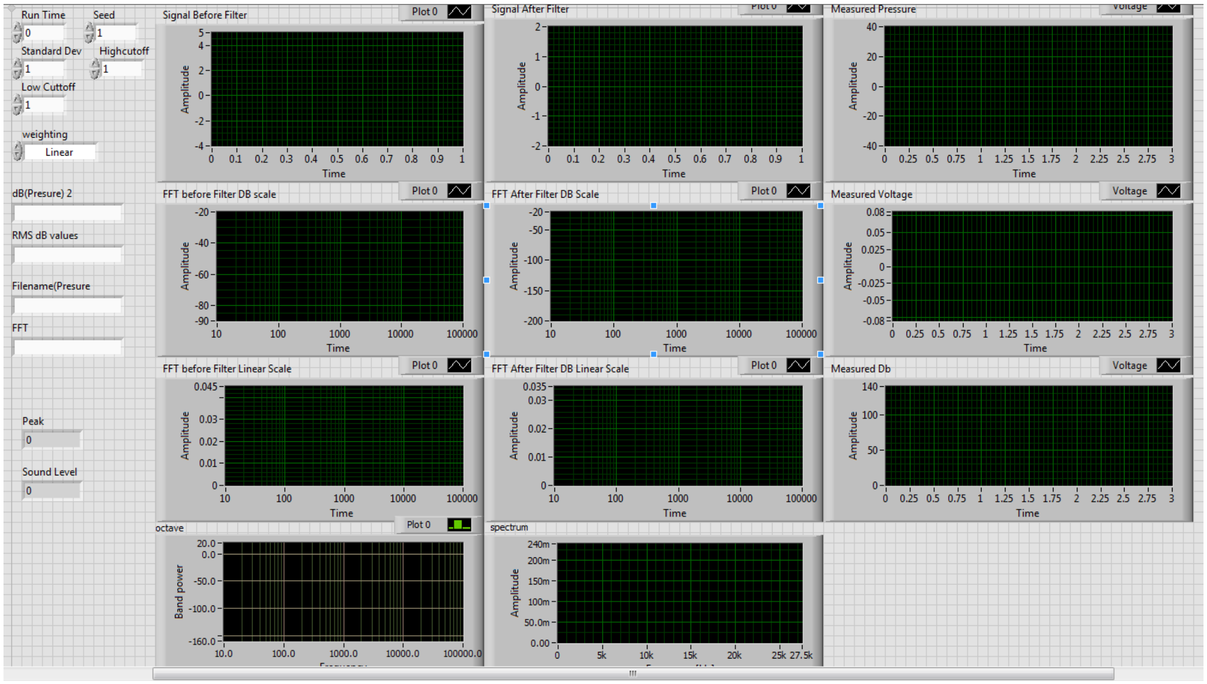
Resolving the busy user interface was as simple as removing unnecessary aspects of the program. While these features were needed to determine proper programming regarding frequency spectrum and octave band of the noise generated, once this information was known the programming became superfluous. Researchers at the SIU School of Medicine needed only a graph of the original signal, a graph of the fast Fourier transform of that signal, a graph displaying the monitoring microphone’s signal, and a chart displaying the running root-mean-square calculation of the signal averaged over one second intervals.

The original signal and the FFT were displayed for signal verification purposes. This way researchers can see that the signal generated is indeed the desired signal. The running RMS value is the square root of the arithmetic mean of the squares of the individual values. This produced a non-zero average for a set of data that includes both positive and negative values. It is valuable for rapidly fluctuating signals and allows researchers to verify the constancy of the signal and determine how long, if at all, the signal was lost. The monitoring signal displays the monitoring microphone’s waveform and demonstrates that the signal research subjects are exposed to matches the profile of the original signal. As it turns out, the data acquisition unit was unnecessary for the monitoring signal. Instead the microphone was plugged into the computer and LabVIEW accessed the signal from the computer’s sound card. This removed the need for a signal conditioner.

Memory problems were solved both by simplifying the program and by adjusting sampling rates. While the program can continuously sample the signal it generates, this uses up memory and causes errors in the program. Instead, a sampling rate of 52,600 samples per second was chosen for the output signal. The computer’s sound card is restricted to 48,000 samples per second so that is the rate used for the monitoring signal. These sampling rates do not overload the memory and still give researchers a complete picture of the noise generated by the system.

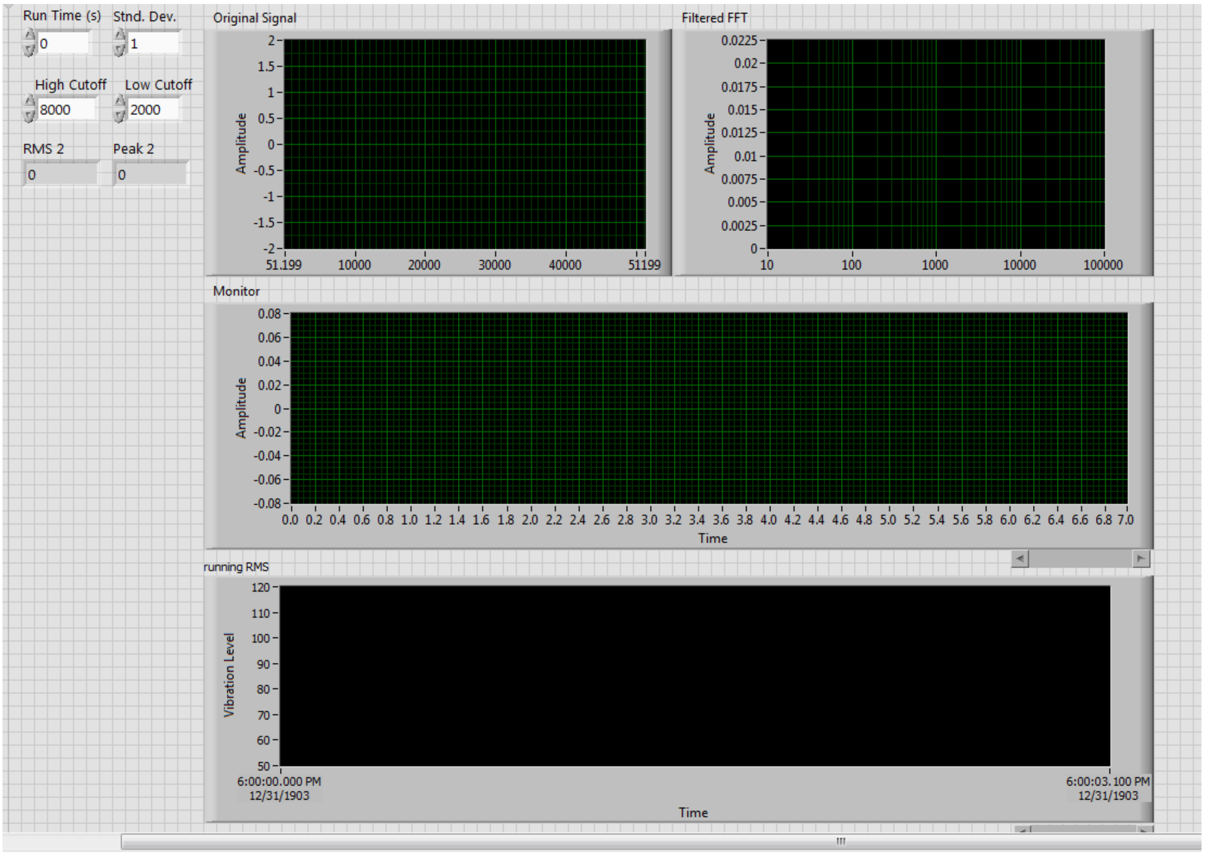
The timing problems were actually simple to solve. A series of test runs were timed and the information used to determine a divisor for the “run time” input. By timing the system duration when values of 30, 60, 90, 120, 1800, 3600, and 21600 were entered into the “run time” input a calibration curve could be generated. The slope of the linear regression was used as the divisor. This way the value entered in seconds actually determines the number of seconds the system will run. Unfortunately, the three computers tested all had slightly different processing times, so the timing calibration must be carried out for each computer the program is run on.

By solving these problems the Gaussian noise generation system was completed and transported to Springfield, IL for use in live animal studies. Problems that initially seemed to be complicated required only ingenuity and patience to solve. The result is an optimized streamlined noise generation system.



Run Time: 0
Seed: 1
Standard Dev: 1
Highcutoff: 1
Low Cuttoff: 1
weighting: Linear
Peak: 0
Sound Level: 0

Figure 5: user interface designed by Schlag (2012)



Run Time (s) 0

Stnd. Dev. 1

High Cutoff 8000

Low Cutoff 2000

RMS 2 0

Peak 2 0

Figure 6: Simplified User Interface

Future Work

Since complex noise is thought to be more damaging than other types of noise, a way to study its effects in the laboratory is needed. The noise generation system described here can easily be adapted to generate complex noises combining Gaussian noise, various impulse noises and pure tones. The difficulty is not in generating complex noise, but it determining the individual components of the specific complex noise to be studied. Analytic wavelet transforms (AWT) offer more temporal and spectral detail than traditional Fourier transforms (Zhu & Kim, 2006). AWT can be used to analyze occupational noises so that accurate replication in a laboratory setting is possible. Accurate representation of noise in animal studies provides far more meaningful results and can better predict the damage potential of such noises.

Conclusion

Current hearing protective guidelines are based on the Equal Energy Hypothesis. Unfortunately different types of noise produce different amounts of hearing loss even when the total sound energy is the same. The Kurtosis statistic used in conjunction with sound energy level could provide a much better system with which to evaluate the damaging potential of a noise. Using analytic wavelet transforms to break complex noises into their various components could help researchers replicate complex noises to determine the extent of hearing damaged caused by those noises.

Once the damage capability of a noise has been determined, various physical and chemical methods to reduce permanent threshold shift can be developed. The optimized Gaussian noise generation system described can be easily modified to produce complex noises of varying composition.

REFERENCES

Boron, W.F. & Boulpaep, E.L. (2009). *Medical physiology, a cellular and molecular approach.* (2nd ed., pp. 389-399). Philadelphia: W B Saunders Co.

Campbell, C.K., Meech, R.P., Klemens, J.J, M, G.T., Dyrstad, S.S., Larsen, D.L., Hughes, L.F. (2007) Prevention of noise- and drug-induced hearing loss with d-methionine. *Hearing Research.* 226 (1-2). 92-103.

Chan. P.C., Ho, K.H., Kan, K.K., & Stuhmiller, J.H. (2001). Evaluation of impulse noise criteria using human volunteer data. *Acoustical Society of America.* 110(4), 1967-1997.

Crocker, M. J. (1998). *Handbook of acoustics.* Hoboken, NJ: Wiley-Interscience.

Danielson, R., Henderson, D., Gratton, M.A., Bianchi, L., Salvi, R. (1991). *The importance of "temporal pattern" in traumatic impulse noise exposures.* Buffalo, NY: SUNY Buffalo.

Davis, R.I., Qiu, W., Hammernik, R.P. (2009). Role of the kurtosis statistic in evaluating complex noise exposures for the protection of hearing. *Ear and Hearing.* 30 (5). 628-634.

Goley, G.S., Song, W.J., Kim, J.H. (2010). Kurtosis corrected sound pressure level as a noise metric for risk assessment of occupational noises. *Journal of the Acoustical Society of America*, 129 (3), 1475-1481.

Hammernik, R.P., Qiu, W., Davis, B. (2003). The effects of the amplitude distribution of equal energy exposures on noise-induced hearing loss: the kurtosis metric. *Journal of the Acoustical Society of America*, 114 (1), 386-395.

Johnston, A.M. (2012). *Noise exposure system for noise induced hearing loss.* (Master's Thesis). Available from ProQuest Dissertations and Theses database. (UMI No. 1514224)

Kopke, R.D., Weisskopf, P.A., Boone, J.L., Jackson, R.L., Wester, D.C., Hoffer, M.E., Lambert, D.C., Charon, C.C., Ding, D.L., McBride, D. (2000). Reduction of noise-induced hearing loss using L-NAC and salicylate in the chinchilla. *Hearing Research.* 149 (2000) 128-146.

Le Prell, C.G., Yamashita, D., Minami, S.B., Yamasoba, T., Miller, J.M., (2007). Mechanisms of noise-induced hearing loss indicate multiple methods of prevention. *Hearing Research*. 226, 22-43.

Netter, F.H. (Artist). Pathway of Sound Reception [illustration], Retrieved June 21, 2013, from: http://www.netterimages.com/image/4635.htm

Ohinata, Y., Yamasoba, T., Schacht, J., Miller, J.M. (2000). Glutathione limits noise-induced hearing loss. *Hearing Research.* 146 (2000). 28-34.

Ohlemiller, K.K., Wright, J.S., Dugan, L.L., (1999). Early elevation of cochlear reactive oxygen species following noise exposure. *Audiol. Neurootol.* 4, 229–236.

Park, J.S., Kim, S.W., Park, K., Choung, Y.H., Jou, I., Park, S.M. (2012). Pravastatin attenuates noise-induced cochlear injury in mice. *Neuroscience.* 208 (2012) 123-132.

Pierson, L.L. (1996). Hazards of noise exposure on fetal hearing. *Seminars in Perinatology.* 20:1, 21-29.

Qiu. W, Hammernik, R.P., Davis, B. (2006). The kurtosis metric as an adjunct to energy in the prediction of trauma from continuous, nonGuassian noise exposures. *Journal of the Acoustical Society of America*, 120 (6), 3901-3906.

Rabinowitz, P. (2000). Noise-Induced Hearing Loss. *Am Fam Physician*, 61(9), 2749-2756.

Raichel, D. R. (2006). *The science and applications of acoustics.* New York, NY: Springer Science+Business Media

Rosen, E.J. (2001). *Noise induced hearing loss.* Retrieved from University of Texas Medical Branch website: http://www.utmb.edu/otoref/Grnds/Hear-Loss-Noise-000110/Hear-Loss-Noise.htm

Schlag, A.W. (2012). *Development and modification of a gaussian and non-gaussian noise exposure system.* (Master’s Thesis). Available from ProQuest Dissertations and Theses database. (UMI No. 1533617)

Sendowski, I., Abaamrane, L., Raffin, F., Cros, A., Clarencon, D. (2006). Therapeutic eficacy of intra-cochlear administration of methylprednisolone after acoustic trauma caused by gunshot noise in guinea pigs. *Hearing Research.* 221 (2006). 119-127.

United States. Department of Labor. Occupational Safety and Health Administration. (2012). *Occupational Safety and Health Standards; Occupational Health and Environmental Control; Occupational Noise Exposure. Standard 1910.95.* Retrieved 21 June 2013 from

United States Department of Labor website: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9735

Yamashita, D., Shiotani, A., Kanzaki, S., Nakagawa, M., Ogawa, K. (2008). Neuroprotective effects of T-817MA against noise-induced hearing loss. *Neuroscience Research*. 61 (2008). 38-42.

Zhao, Y., Qiu, W., Zeng., Chen, S., Cheng, X., Davis, R.I., Hammernik, R.P. (2010) Application of the kurtosis statistic to the evaluation of the risk of hearing loss in workers exposed to high-level complex noise. *Ear and Hearing.* 31 (4). 527-532.

Zhu, X., & Kim, J. (2006). Application of analytic wavelet transform to analysis of highly impulsive noises. *Journal of Sound and Vibration.* 294(2006). 841-855

VITA

Graduate School

Southern Illinois University

Kelly Wepsiec

woochles@gmail.com (permanent email address after graduation)

Southern Illinois University Carbondale

Bachelor of Science, Physics, August 2005

Research Paper Title:

Modification and Optimization of a Gaussian Noise Generation System for the study of Nosie-Induced Hearing Loss

Major Professor: Jun Qin