Spring 4-1-2018

An investigation of low frequency noise in server rooms

Ahmed Al Naami
St. Mary's University, reflib@stmarytx.edu

AN INVESTIGATION OF LOW FREQUENCY NOISE IN SERVER ROOMS

A

THESIS

Presented to the Faculty of the Graduate School of

St. Mary's University in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

Engineering System Management

by

Ahmed Al Naami

San Antonio, Texas

April 2018

AN INVESTIGATION OF LOW FREQUENCY NOISE IN SERVER ROOMS

APPROVED:

____
Michael Johnson, Advisor

____
Rafael Moras, Ph.D., Committee Member

____
Ozgur Aktunc, Ph.D., Committee Member

APPROVED:

____
Winston F. Erevelles, Ph.D.
Dean of the School of Science, Engineering and Technology
Date:

ABSTRACT

Noise in a server room can have a major impact on the performance and well-being of the occupants. Sound level and low frequency noise are considered factors that influence the hearing ability of workers. This thesis is an investigation of low frequency noise in server rooms. We conducted the field study in a server room for a large financial institution. Some employees in this study indicated that they experienced headaches from the noise and requested an analysis of the sound to determine if there were any potential adverse health effects. Attributes of the noise were investigated by evaluating the sound pressure and frequency. Potential health effects were researched by examining relevent literature on the impact of noise that is generated in server rooms. The role of ergonomists to investigate these occurrences is crucial. Due to the occupational impact of this emerging technology, a growing concern has arisen to resolve this issue.

ACKNOWLEDGEMENTS

I thank my supervisor, Professor Michael Johnson, for his thoughtful encouragement and guidance. Your advice and assistance was invaluable to me. I also thank Professor Rafael Moras for his support and help.

I am grateful to my beloved family for all of their support, patience, and understanding throughout my study. I give my deepest gratitude and sincerest love to my parents for their love and support throughout my entire life.

I thank to all my colleagues, friends, staff, and lecturers in the School of Engineering at St. Mary's University in San Antonio, Texas, for the help and support they provided me at every step during this study. A special thanks to Dean Winston Erevelles for financing the poster I presented at the 2017 Human Factors Society annual meeting.

I wish to extend my grateful appreciation to all those who have contributed directly and indirectly to the preparation of this study. Thank you, Mr. Vernon Wier, for your assistance to accomplish my experimental study in the Engineering Department Laboratory, as well as the committee members for their helpful suggestions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Overview

The purpose of this pilot field and laboratory study was to investigate selected health and safety implications associated with low frequency noise in server rooms. Potential solutions for remediating the impact of this exposure to the occupants are provided. The field study was performed in a laboratory where over 30 racks of servers were housed. Each rack typically supported eight servers. We investigated noise exposure based upon the overall sound and potential sound mitigation strategies.

Large server rooms are relatively a new phenomenon in the workplace and merit investigation as an emerging technology. Excessive noise exposure may exist for employees working with servers in data storage locations (Sultan et al., 2016). Server rooms provide companies with a single location for housing computers to support business objectives, that is typically a small temperature controlled secured room with a minimum number of occupants. Keeping the room small allows for greater control of access (i.e., high degree of security), and also places the servers in a denser format.

The server is designed to process requests and deliver data to other (client) computers over a local network, or the Internet (Bryant & O'Hallaron, 2015). Server rooms house multiple devices that are responsible for transporting data to and from these locations. Server rooms have differing dimensions and densities contingent upon the geometry of the room, age of the servers, server brands, height of racks, as well as the proximity of the units to one another. The strategic placement of the units can amplify the sound in each respective server room as sound pressure is additive contingent upon the number of servers and how far they are placed from one another.

The density and proximity of servers has the potential for producing excessive unwanted noise. Some operators may find the volume and frequency of sound uncomfortable, and excessive noise can potentially be hazardous to their well-being.

Sound is measured in pressure (N/m^2 or Pa) and frequency (Hertz). Both variables have health implications on the users, but sound pressure is the only element that is regulated by OSHA (Occupational Safety and Health Administration) (OSHA, 2014). Sound in server rooms has a resonating frequency that may be offensive to some people and may or may not be a health issue, but it is not regulated by any governmental agency. Sound pressure levels are mandated by OSHA not to exceed a certain level so that they do not become an occupational health issue to workers in that respective area. We evaluated sound pressure in this study, and sound frequency was also investigated as it may adversely impact the users. For example, sound at gamma frequency (40 Hertz–100 Hertz) has been found to be distracting or uncomfortable for some individuals (Schlee et al., 2009). The average person maintains a hearing range from 20 to 20,000 Hertz. The frequency range investigated in this study can be reviewed in the Discussion section of this document. Our objective was to investigate if the sound created by the servers caused discomfort for the users that use and maintain the server rooms and also to investigate the characteristics of this sound.

The purpose of this analysis was to determine how much sound (power and frequency) the servers generated in a specific area, and then determine whether the sound levels need to be reduced to avoid health or productivity issues for the users. The preferred method of addressing occupational exposures is through engineering methods preferably in the design process. If the equipment or room can be configured in a manner that reduces or eliminates occupational exposures to the occupants in the workplace, then this should be the first approach by the human factors engineer assuming it is economically feasible. Engineering solutions (i.e., design of the workplace to avoid or reduce the exposure of workers to the risk condition) do not require administrative controls such as rotation of employees in a specific job position, reduction of the work hours of employees exposed to a certain contaminant (in this case, sound), or require annual hearing testing and compliance by wearing safety equipment. The preferred approach for sound reduction should always involve the engineering solution first, then administrative controls and as a last resort personal protective equipment. The usage of personal protective equipment requires the documentation of employees' hearing capabilities, and an investigation into the amount of sound reduction necessary to ensure compliance with OSHA's 29CFR1910.95 Hearing Conservation Program (OSHA 2014). The cost of performing annual tests to determine the hearing capabilities to choose the appropriate personal protective equipment can be expensive in the long term.

Sound reduction or minimization can be achieved in different ways contingent upon the configurations of the rooms, equipment placed in the rooms, building constraints of the walls/floors, and sound dampening materials. Noise encapsulation as an engineering solution potentially reduces the sound by isolating the sound emitting device from the user by completely enclosing it. Sound reduction methods may still allow the user to access the equipment easily but keep the sound at a level that is below harmful levels. Sound reduction may also involve the usage of appropriate personal protective equipment (ear plugs, ear muffs, etc.) if the sound pressure levels exceed the values outlined by OSHA. Another method of sound reduction from an engineering perspective is noise cancellation. Noise canceling devices use signal processing technology to reduce the noise by capturing the noise signal and then inverting the sound wave and emitting it, thereby canceling some of the sound waves. Other forms of sound reduction are accomplished by using acoustic materials on walls, floor, and ceilings that reduce the pressure emitted by the devices (Sharma & Vig, 2014). Personal protective equipment (PPE) is typically employed by organizations when administrative and engineering solutions do not eliminate or minimize sound to an acceptable level to comply with federal regulations (Sultan et al., 2016). Administrative solutions to protect the hearing of employees include reducing the time users are exposed to the equipment or rotating employees. These solutions create scheduling challenges for organizations and are therefore not as desirable as eliminating or reducing the sound exposure. Lastly, the use of earplugs, earmuffs or similar PPE may adversely impact the ability of workers to communicate while in a server room and cause errors due to poor communication (Sharma & Vig, 2014).

Occupational Noise

The exposure to sound involves occupational and environmental noise. Occupational noise is considered a risk factor for injury in the workplace as a chronic health issue if it accelerates hearing degradation. Excessive noise can cause occupational hearing loss in the work environment if the power of the sound is excessive as outlined OSHA (Concha-Barrientos et al., 2004).

Hearing impairment and loss is a major health outcome of excessive occupational noise in the workplace. Exposing humans to excessive sound levels can adversely impact the ability of workers to hear certain wavelengths, as well as decreasing their ability to hear overall. This impact can be quantified by hearing tests performed by audiometrists, and these tests are required by OSHA for areas with excessive noise. A hearing threshold shift of 10 dBA at 2, 3, and 4 kHz in each ear defines an occupational deterioration in hearing and is compensable under law through Workers' Compensation and can impose a large financial hardship on companies and their respective employees (Concha-Barrientos et al., 2004).

Hearing loss can also cause degradation in the ability to monitor the work environment (i.e., equipment sound and warning signals). Hearing loss impacts the workforce where there is already a shortage of qualified information technology employees who can support the data center.

Goal

The main goal of this research was to find and measure the sound level of server room noise in an IT facility, and then determine if it was necessary and possible to reduce the sound in the room to a manageable level by engineering or administrative controls or through PPE. This was accomplished by comparing the sound level pressure measured in the server room to that of OSHA's eight-hour time weighted average (TWA) for comparative purposes. The TWA is the regulatory amount of sound to which a worker can be exposed over an eight-hour work period for a lifetime without suffering adverse hearing loss. The eight-hour TWA provides workers with an acceptable noise exposure that a company cannot exceed without violating federal regulations and exposing the company to fines due to excessive noise in the workplace. The investigation of regulatory requirements is necessary in order to determine if noise exceeds the statutory requirements, and then develop a compliance goal and strategy plan if the sound is excessive. We were tasked with determining the characteristics of the sound (power and frequency) in the server room and providing guidance on what measures should be taken to minimize the impact of sound in those confined locations. That was performed regardless of whether the sound pressure was excessive as outlined in the OSHA standard on Hearing Conservation published in 1970. The frequency of sound is not regulated by OSHA.

Problem Statement

The emergence of cloud computing has led to an increase in the number of server rooms in the United States (Sultan et al., 2016). Server rooms host data servers that allow people worldwide to store and backup data in massive storage systems. A typical server room is shown in Figure 1.

Figure 1. Server room (Fehrenbacher, 2012).

Servers are generally housed in server rooms with an uninterrupted electrical power source to keep them running continuously. Other devices in the server room include routers, switches, and repeaters.

These devices produce unwanted noise that can impact productivity and the well-being of people working in these rooms (Sharma & Vig, 2014). At the time of this thesis, the impact of the low and high frequency noise had not been investigated extensively in the literature as it pertained to sound in the workplace that is represented by the data center.

Aims

Sound can be measured in the workplace with sound level meters or noise dosimeters (Miljković, 2016). Sound level meters measure the sound level intensity instantaneously, while noise dosimeters are affixed to the subject's collar (or a similar area) to measure sound over the entire workday.

Sound level dosimeters more accurately reflect the sound levels as they are placed close to the subject's ear and capture sound levels over an eight-hour time interval. Sound level meters are generally used in environments where the impact of sound has been investigated with preliminary assessments performed by a sound level meter. If the instantaneous sound pressure levels already exceeds the federal standards during the initial assessment with the sound level meter, then the Human Factors engineer can follow-up further with an eight-hour analysis performed by a noise dosimeter for documentation of the given exposure over an eight-hour workday.

Sound level meters are not typically utilized over an entire eight-hour workday to measure sound fluctuations as per regulatory requirements. A sound level meter, shown in

Figure 2, generally serves this purpose, and allows data to be gathered and subsequently transferred to a computer for analysis.

Figure 2. Quest Technology Model 2900/Type 2 (All Safe Industries, 1996).

Sound level measurement equipment is usually calibrated prior to each use with a calibration tunnel unit before data are gathered on each analysis and at least one time per year by the manufacturer or respective representative laboratory. Sound level meters require that the human factors engineer be present during the entire time the analysis data is captured. Information from the sound level meter is captured every ten seconds and saved on a memory card and analyzed on a computer. The sound level meters used in this study allowed us to record the sound level and frequency of the noise and to analyze the audio files on the computer. The features of the sound were extracted and compared to the noise signal to determine the characteristics of the sound for possible sound cancelation by placement of the servers in a strategic position (e.g. spacing or direction).

Objective

The aim of this research was accomplished by reviewing the applicable literature, recording and measuring the sound levels in the respective area, and analyzing the data for specific characteristics. The initial field study was an analysis of the sound in a server room in a large financial institution, and then that activity was followed up by a laboratory study at St. Mary's University. This allowed for differing configurations of sound emitting devices to be constructed and variables controlled outside the initial field study. Both studies encompassed measuring of the sound levels using sound level meters at different locations while exploring the geometry of the room and the implications of moving the sound emitting devices closer and further from one another while maintaining the sound level meter in the middle of the sound emitting devices. In the laboratory, that was performed by changing the distances between the speakers. The same speakers were configured to simulate the field environment by reconstructing the same sound levels that were observed in the field. This involved the calibration of the speakers in the laboratory to more closely represent what was initially observed in the field analysis.

Recording and investigating the impact of placing sound-emitting devices with sound level meters allowed us to determine whether sound waves at a specific frequency would be able to cancel one another in lieu of amplification. In addition, the specific distances between the sound-emitting devices were measured and compared to one another to ascertain whether the sound frequency was impacted by the configurations in the room and the relative placement of the speakers. The sound level was measured during each change in a concerted effort to standardize all sound devices so that they would emit the same sound power and frequency. We performed a statistical analysis of the data to review the impact of moving the "sound generators" at various distances. Upon completion, a characterization of the sound data was performed to propose a solution that would reduce noise levels (power and frequency).

Proposed Solution

Field and laboratory studies were conducted on noise, and the potential reduction of sound in the workplace was not limited to server racks. These results may be significant and provide design guidance for the development of criteria on any type of equipment that creates low-frequency vibration and hence low-frequency sound and may have potential implications on sound generating equipment on submarines, planes, and equipment in industrial facilities.

Sound waves produced from servers in a server rack may partially cancel one another through the similarity, time-delay and the correlation between the produced signals from all the devices (McDonough, 2007). Solutions may not require significant noise reduction equipment or materials if this approach can be demonstrated to be viable.

CHAPTER II

DISCUSSION

Occupational Noise

The assessment of hearing loss should be performed by audiologists and is a function of the shifting of the hearing threshold as defined by audiometry. The degradation of hearing associated with excessive noise is irreversible (NIOSH, 1998). Many other relative risks that can be developed from noise-induced hearing loss are impaired communication with family and coworkers, social isolation, irritability, anxiety, decreasing of self-esteem, and loss of productivity.

Noise in Server Rooms

Network engineering technicians and other workers access server rooms to install, fix, and configure devices on a regular basis. Noisy environments at data centers represent occupational safety threats to those staff members who spend a considerable amount of time in the rooms to perform daily tasks.

Sound is measured in A-weighted decibels (dBA) that closely represents the sonic volume as heard by the human ear (Carstenpxi, 2010). OSHA mandates that the sound level over an eight-hour time period should not exceed 90 dBA. The environment of a server room may produce sound that, at times, exceeds 90 dBA. The time weighted average (TWA) analysis in a server room is therefore appropriately performed by equipment that can tabulate the data in a format where the mean exposure over the entire day is evaluated accordingly.

The evaluation of the noise exposure and the method of analysis are standardized over the United States, and they are representative of the exposure over a employee's lifetime. This standard was developed in 1970 and is therefore dated based upon what we understand today.

Engineering professionals review the applicable health standards for workers' safety and typically adopt the most stringent standard. One such standard for noise levels is defined by the National Institute for Occupational Safety and Health (NIOSH) which serves as the research arm for OSHA. NIOSH defines the TWA permissible limit for the occupational noise exposure for different levels of noise over different shift periods (Table 1). The limit for noise exposure for an eight-hour time shift is 85 and 90 dBA for NIOSH and OSHA, respectively. However, prolonged exposure to noise at specific hearing frequencies might also cause hearing degradation even when the sound level does not exceed the regulatory (OSHA) and recommended standards (NIOSH) (Pinosova et al., 2015). For example, it is theorized that working in a data center can cause an unpleasant ringing or Tinnitus in a person's ears. Tinnitus might develop over time and lead to adverse health conditions (Sharma & Vig, 2014) given the appropriate sound frequency and duration of exposure.

Duration (hr)	OSHA Noise Level (dBA)	NIOSH Noise Level (dBA)
8	90	85
4	95	88
2	100	91
1	105	94
0.5	110	97
0.25	115	100

Table 1. OSHA and NIOSH Noise Limit (Johnson, 2014)

Alternative Solutions for Server Room Noise

There are several approaches for mitigating the impact of server room noise on the employees evaluated. In this study, the sound pressure values did not exceed federal mandates.

They were, however, periodically over the NIOSH recommended values in some locations in the server room. It is important to note that the frequencies need to be investigated as well even if they are not regulated by federal health and safety mandates.

A common approach to reduce occupational noise exposure is by reducing the sound volume by administrative procedures (i.e., reducing time of the operators in the server room) or through personal protective equipment like earplugs. The construction of the earplug allows the users to insert this device into the ear canal to reduce the sound pressure on the inner part of the ear. The use of these plugs is effective in reducing noise if employees use them correctly, but it impacts their ability to communicate with one another in the server room.

Earmuffs are another solution for noise in server rooms. They cover the pinna (the external part of the ear) to reduce the energy of sound that reaches the inner ear (HSE, 2014). Earmuffs are more effective in this manner due to encapsulation of the entire ear compared to earplugs. This solution has some drawbacks as it still impedes the conversation between employees. They are more expensive than the earplugs and also cause the employees' head to feel compressed as well as warming of the ears and are a challenge with interference for employees that have glasses due to the glass frames. Some research also indicates that covering the pinna in this manner for extended periods of time can cause ear infections due to poor air movement that takes place when the ear muffs are secured in place (IOSH, 2006). New technology that allows employees to communicate is evolving with ear muffs, but this type of solution may be expensive to some companies (Sensear, 2016). Therefore, the standard earmuff is not the ideal approach for this kind of work environment as PPE (Sultan et al., 2016).

OSHA requires the use of hearing protection such as earplugs and earmuffs only when there are not a feasible cost-effective engineering or administrative solutions for noise mitigation. OSHA also recommends engineering over administrative controls, since administrative controls require changes in the work schedule to reduce or eliminate exposure of workers to sources of noise and monitoring of compliance by employees (OSHA, 2014).

The efficacy of active noise control that may serve for noise reduction in a data center is the subject of numerous research efforts. Active noise control methods have received some attention as they do not require any noise absorbing material (Sharma & Vig, 2014). These methods are based on distractive interference and are applied in industrial applications such as aircrafts, air conditioning systems, and exhaust fans. The active noise control concept is based on the interference of two signals with opposite phase and equal amplitude. As a result, the subtractive interaction of the two signals can decrease the overall amplitude. The amount of noise reduction depends upon the accuracy of the phase and amplitude anti-noise signal (Kuo & Morgan, 1999). Active noise controls are generally performed with an adaptive filter that uses differing algorithms for modifying the parameters of the controller.

There are several algorithms that can be applied for the controller such as the least mean square (LMS) filter, the recursive least square (RLS) algorithm, and the filtered reference least mean square (FxLMS). Active noise control methods are complicated and expensive to deploy in large server rooms and therefore may not be cost effective.

Potential Health Effects of Low-Level Frequency Sound

Hearing loss is a significant health hazard that occurs naturally with aging. Tinnitus is a hearing disorder and may cause a ringing in the ear without the presence of a physical sound (Leaver et al., 2010). This disorder affects more than 40 million people in the United States. Fourteen percent of adults suffer from chronic Tinnitus, and 50 percent of normal adults with no clinically confirmed hearing disorders experience subtle Tinnitus in a silent environment (Sedley et al., 2016). Increases in noise exposure and the natural aging process of people can increase the incidence of Tinnitus (Rauschecker et al., 2010). Several causes of Tinnitus have been proposed, but since there is no effective way of curing this unpleasant hearing disorder, the preferred method is eliminating the exposure (Rauschecker et al., 2010).

Tinnitus is typically associated with damage that occurs to chronic noise exposure or noise trauma (Schlee et al., 2009). Such damage may lead to changes in the central auditory system, specifically the neural synchrony within the central auditory system. These changes have been reported in human and animal studies and can be caused by various pathologies (Schlee et al., 2009). It has been reported that these exposures are tied specifically to sound in the gamma range frequency (Schlee et al., 2009). Further information on the potential health effects of gamma frequency noise is available in Appendix A.

CHAPTER III

METHODOLOGY

Research Methodology

We collected data in a server room (data center) using various sound measuring tools to determine the noise level and then compared the results with regulated values mandated by OSHA and recommended by NIOSH. A qualitative evaluation was performed by meeting with technicians and the network engineers who were working in the server room and asking them about the impact of the noise on their performance. That meeting helped to define the effect of that kind of noise on the performance of the workers and symptoms of the physiological harm on the people as some of the employees complained of distractions associated with the unwanted sound in the data center.

We analyzed the data using tools such as MATLAB, Minitab, and Microsoft Excel to help customize and exhibit the data in a manner that could be easily understood. Some of the operators indicated that noise in the room caused them anxiety. They were worried about the long-term impact of noise on their hearing ability and their health as well. That provided the motivation and genesis of evaluating the sound power and frequency.

Server Room Noise

Sound in a server room has been modeled and measured by other researchers. For example, Jerome (2010) performed 15 minutes of recorded sound measurement inside a data center without defining the size of the room or the number of the devices inside that room. In this study, we utilized the sound analysis tools available on MATLAB to demonstrate a preliminary evaluation of the noise amplitude from Jerome's recording, as shown in Figure 3. The time domain signals indicated that the signal fluctuated between ± 0.25 V (Volt) on average, with some spikes at specific times that resulted from additional sounds emanating from other devices located on the racks.

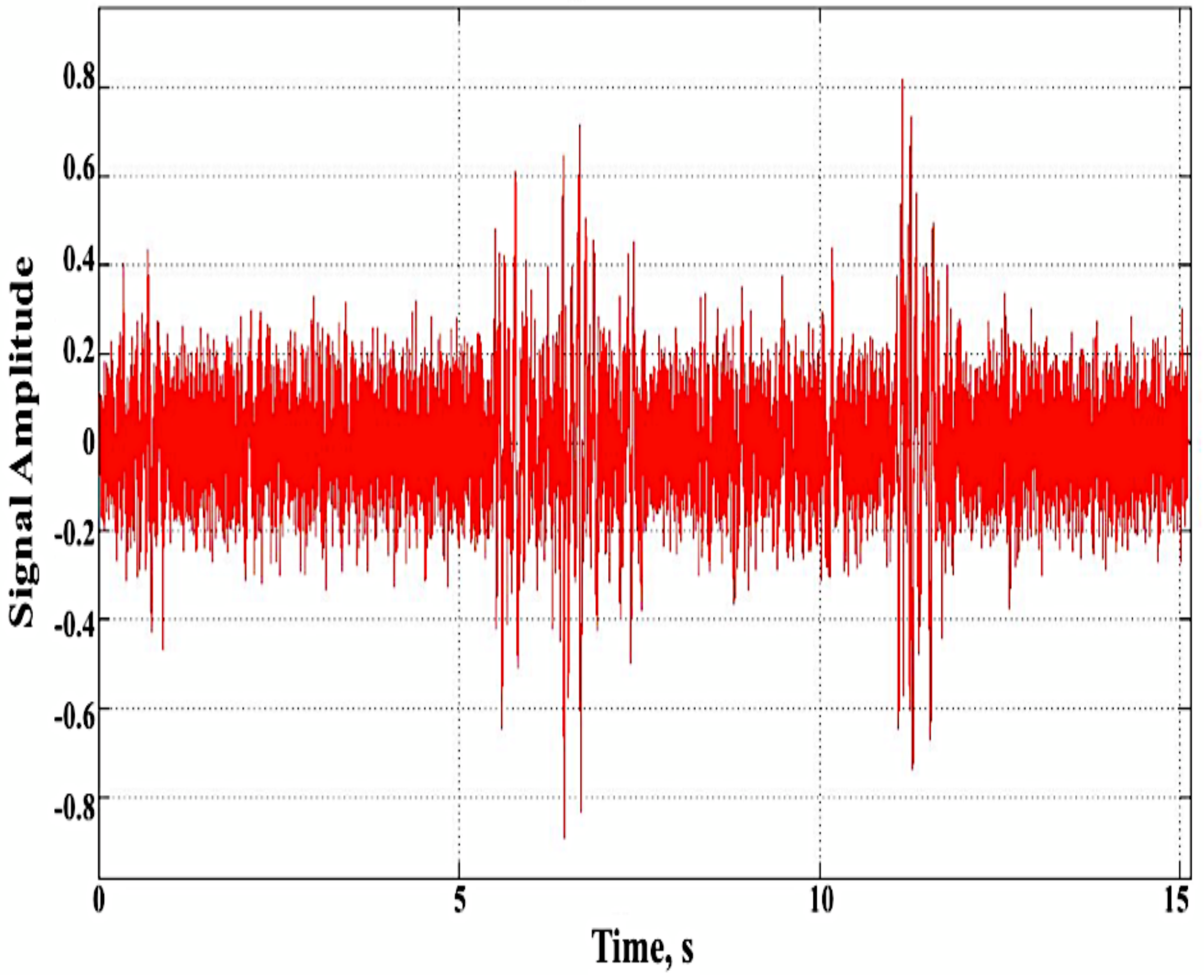


Figure 3. Server room noise signal.

We performed additional statistical analysis of the noise signal on Jerome's website recording to highlight the probability distribution for the signal (Figure 4). The data appeared to resemble the standard normal distribution. No filter was added to that signal to exclude the crackling noise of the rack because the record was for real-time server room noise values. We concluded from the time domain figure and the probability distribution for the signal that the noise was continuous and its amplitude was fixed over time. Sounds at that frequency can potentially induce a whistling sound in a person's ear even after leaving the data center, depending upon the duration and the proximity to the source of the sound. Noise or unwanted sound between 40 Hertz–100 Hertz (sound at gamma frequency) has been found to be distracting or uncomfortable, as previously mentioned (Schlee et al., 2009).

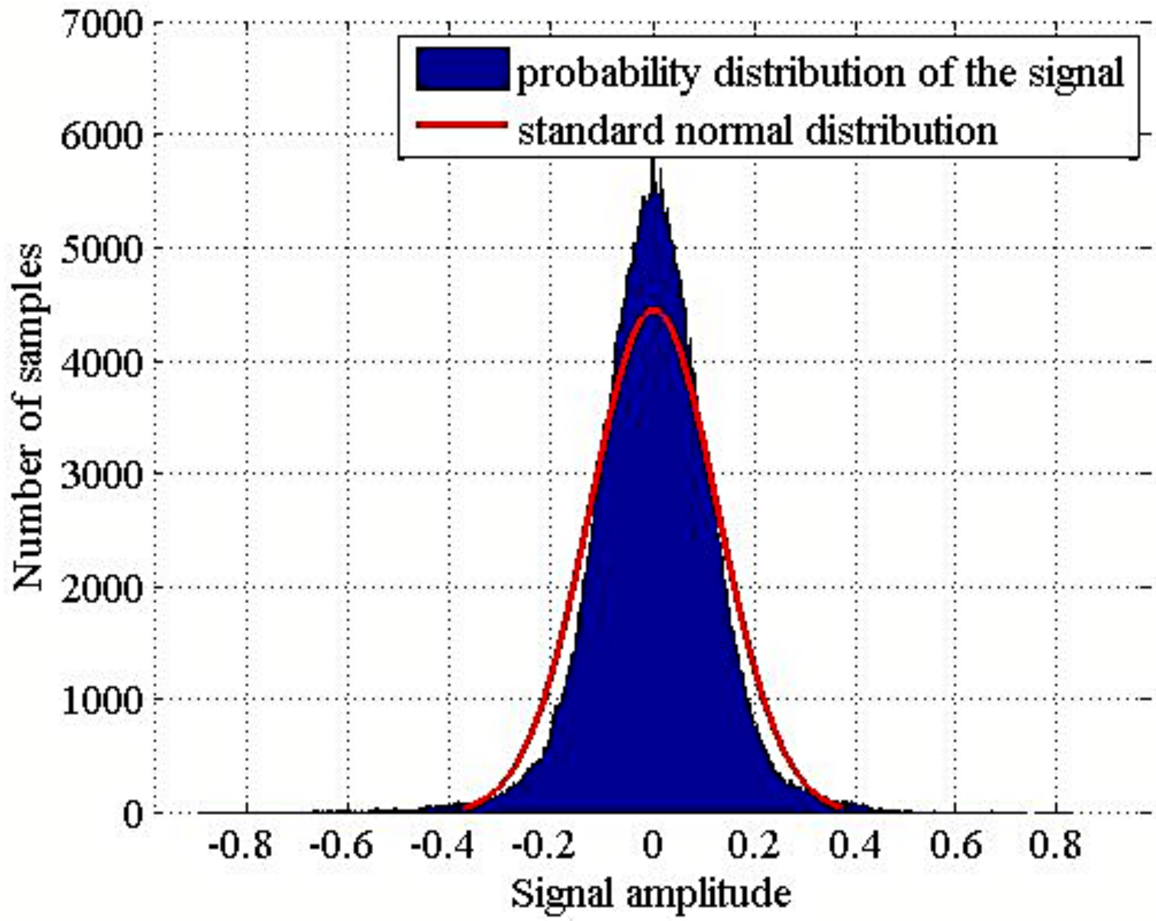


Figure 4. Probability distribution of the noise signal.

The amplitude spectrum of the recorded signal is measured on a semi-log graph in decibels(dB) on Figure 5. Clearly, most of the noise power is at the frequency most harmful to the auditory parts of the human ear (20 Hz to 20 kHz). The sound power was concentrated between the frequency of 100 Hz to 20 kHz, with the highest power of the signal located at lower frequencies.

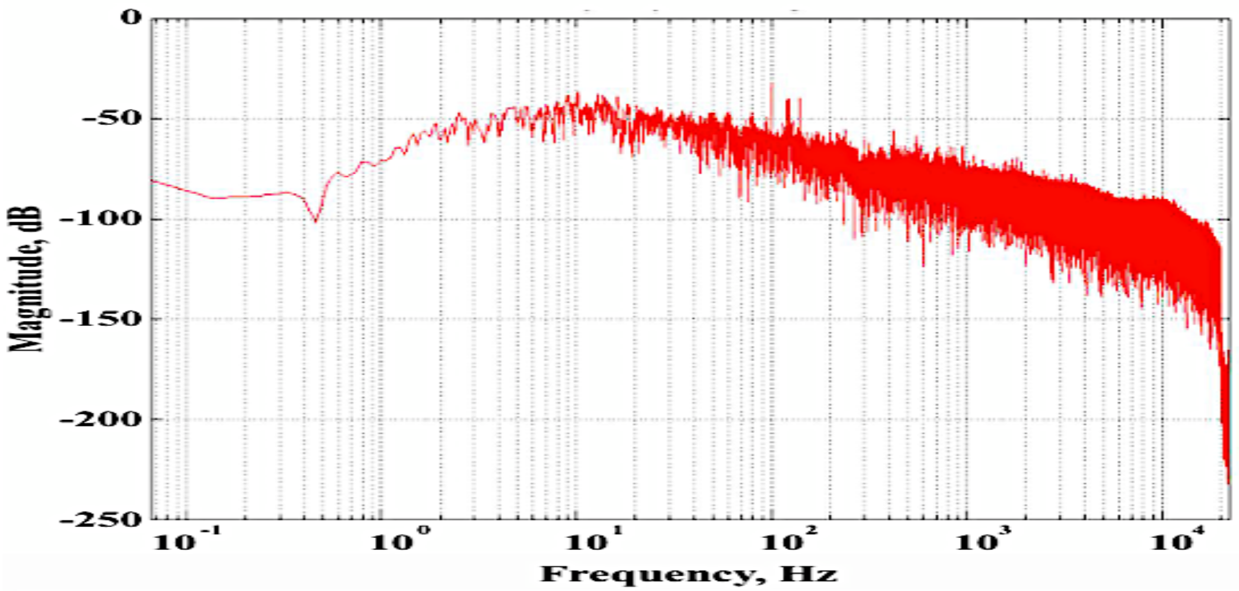


Figure 5. Amplitude spectrum of the signal.

A spectrogram of the noise signal provides the power distribution in time and frequency domain (Figure 6). The X-axis provides the time in seconds, the Y-axis gives the frequency characteristics of the signal, while the color reflects the power of the noise signal. The power of the noise signal is high at a low frequency all the time. It is interesting to note that while the signal is losing its power, the frequency of the signal increases inversely.

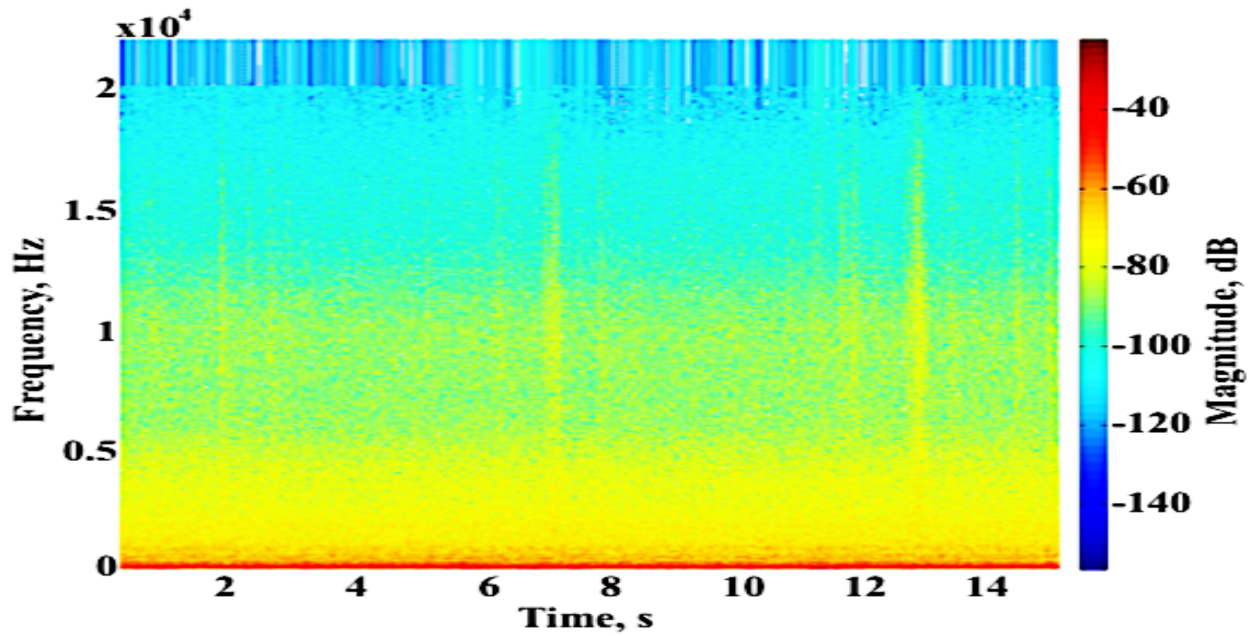


Figure 6. Spectrogram of the noise signal.

The signal pressure level for the recorded noise signal indicates that the sound pressure remains consistent over the time intervals that it was evaluated, according to the plot in Figure 7. The overall noise pressure level is 76 dBA as the pressure level range for the noise signal is between 60–90 dBA. This means that the signal did not exceed the 90 dBA threshold defined by OSHA. Our primary concern was on frequency, as OSHA standards only apply to sound pressure levels. Some individuals may experience hearing loss, discomfort, or impact productivity for the ranges indicated in Figure 7, but this is not a violation of federal safety standards.

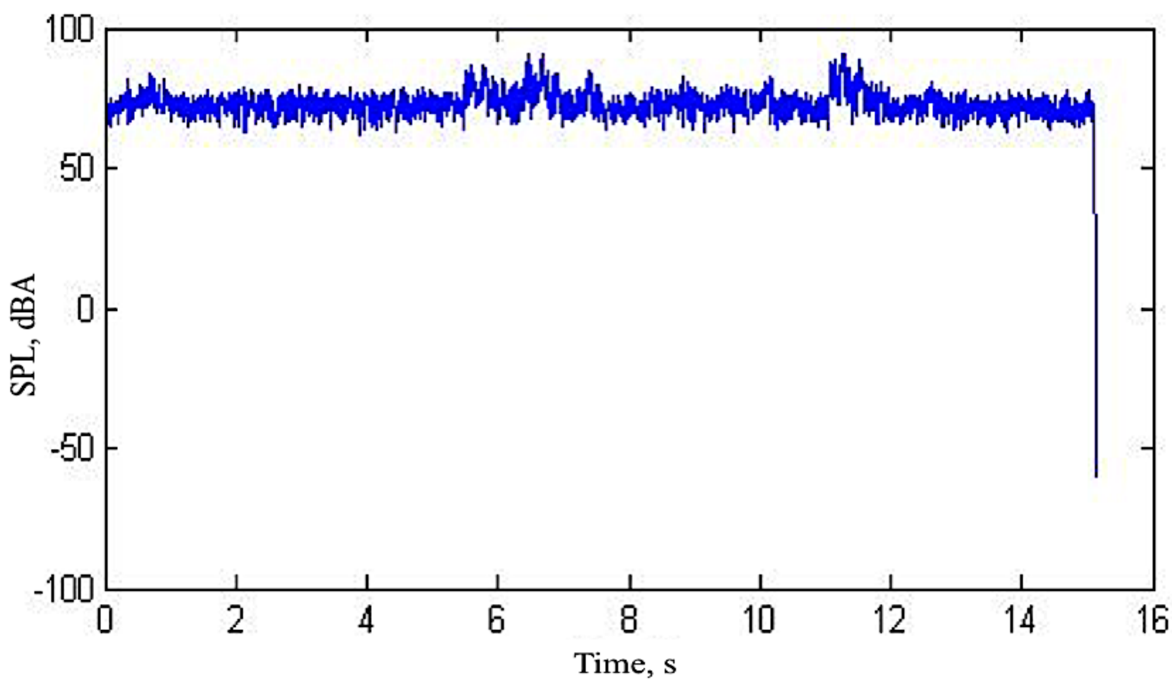


Figure 7. Noise power level.

The characteristics for the signal autocorrelation in the server room noise for the sound recordings are summarized in Figure 8. At any delay, the correlation coefficients decreased with no significant correlation between the noise signal and any delayed versions of the noise.

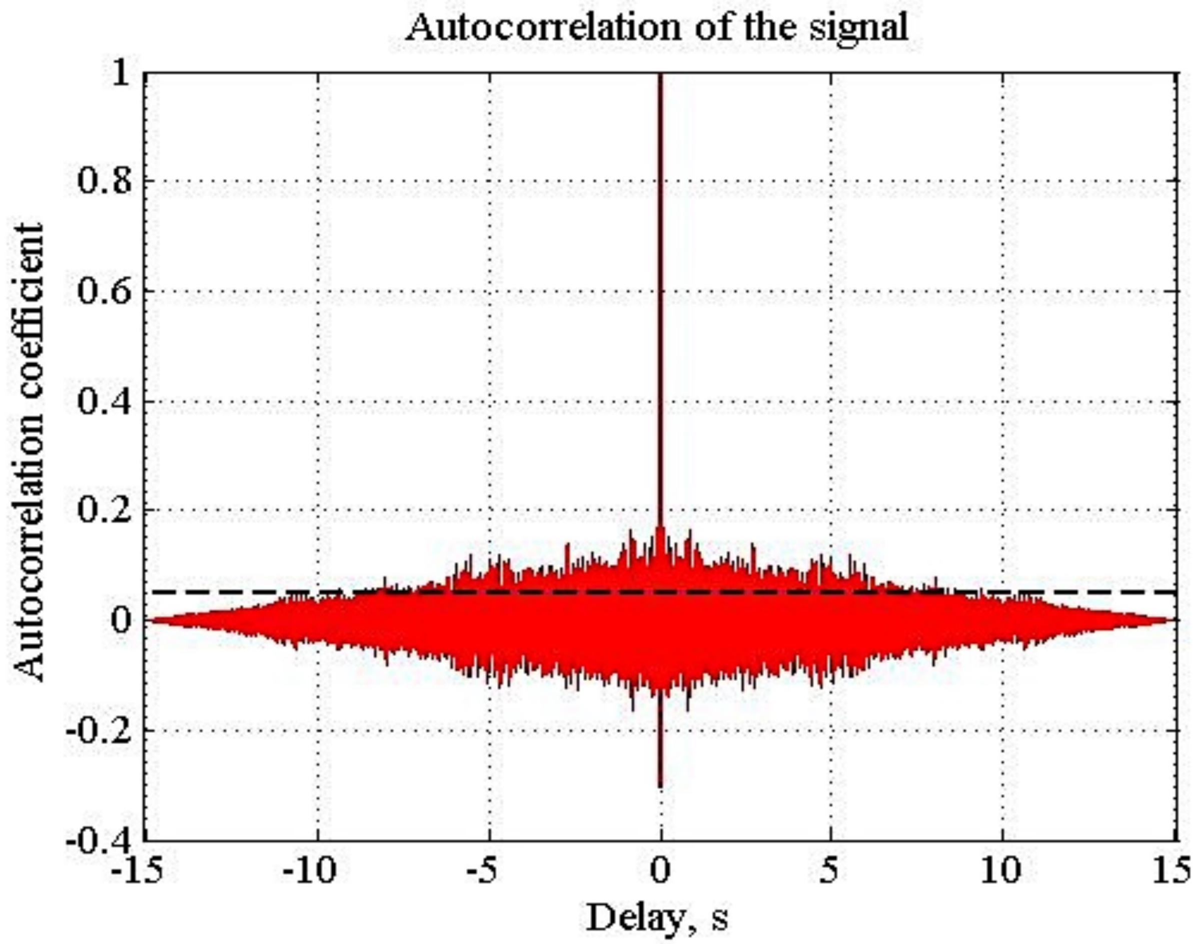


Figure 8. Autocorrelation for noise signal.

Data Collection Tools

We collected noise volumes in the server room twice following different methods. Firstly, the data were captured utilizing a Sound Pro sound level meter. The sound level meter is manufactured by Quest Company (Model 2900/Type 2). We collected sound level data at 12 locations in the server room (Figure 9). The layout of the room and servers are depicted in Figure 9 along with the 12 respective locations (A-13, M-15, W-13, I-19, M-18, R-19, A28, M-21, W-28, D6-2, D6-1, D6-4) where data were collected and annotated to distinguish sampling locations in the server room. The locations were selected based on the requirements of this research to make an initial measurement of the sound levels in the facility to address employee's discomfort concerns.

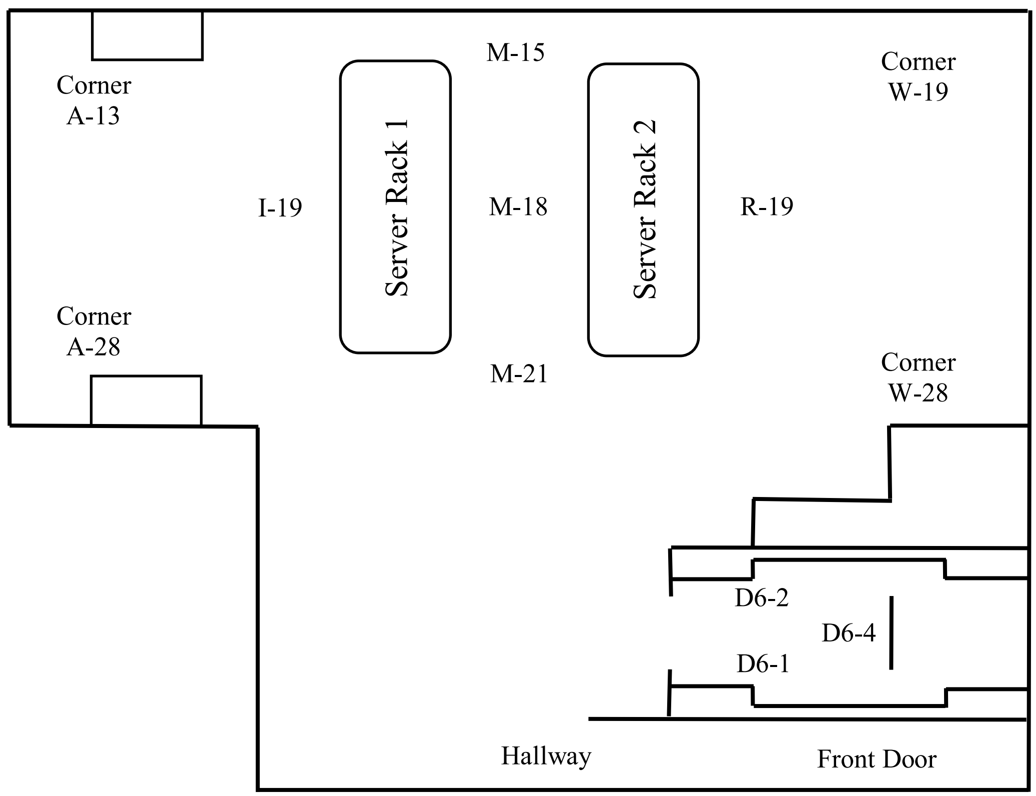


Figure 9. Server room layout.

The Quest Sound Pro Sound Level meter was used to measure the sound pressure level (SPL) for the room associated with servers through algorithms of dBA, dBB, dBC, and linear slow scales, respectively. We were primarily interested in measuring sound on the dBA scale, as sound for humans is usually evaluated using this scale, and OSHA's requirements apply to the dBA scale explicitly.

We collected data using the sound level meter and laptop sound recorder applications under Windows 7. Data were collected by the sound level meter and the laptop simultaneously at I-19, M-18, and D6-4 (Figure 9). The distance from the source of noise is a significant parameter in data collection to test due to the potential fading of the noise signal with increased distances. Data were collected for a period of 15 minutes at each defined location listed in Figure 9.

Software Analysis Tools

We performed several tests on the collected data. Microsoft Excel/Visual Basic (MS Excel/VBA) was the primary software utilized to process and analyze the data collected from the sound level meter through the Detection Management Software for Quest Company (Air-Met Scientific, 2017). The Detection Management Software system is proprietary software from Quest for characterizing sound. MS Excel/VBA helped to organize the data and build a Pareto chart for interpretation of the data. This software has facilitated mathematical calculations for the data to find a summary statistical description.

Minitab software possesses features that analyze data for quality improvement (Minitab, 2017). Minitab measured specific details for the probability distribution and construction of control charts that define different characteristics of the data collected in this study. These characteristics help correlate different relationships between the parameters of that same data. Minitab can also build other charts that assist in understanding the data (i.e., sound level pressure of noise in different locations in the room).

The recorded sound in the data center was read and subsequently processed by using MATLAB 2013. This software reads the recorded data and samples the noise signal, then saves the results in a matrix as numbers (MathWorks, 2017). We created code in MATLAB to build different graphs to show features and characteristics of the signal under evaluation. In addition, this software can compute the auto-correlation coefficient of the noise signal to measure echo signal effect on the original source and the noise source.

Experimental Study

Upon conclusion of the data compilation phase in an actual server room, we performed an experimental study to evaluate and compare results. In the laboratory study, the recorded sound of the noise signal was generated on a personal computer with multiple speakers to simulate in a laboratory the ambiance of the data center and to measure the sound levels with a sound level meter (Quest/Model 2900).

The laboratory study provided more control and yet a flexible environment that assisted in further defining and measuring sound as parameters of the noise sources were changed (i.e., the density of the noise sources and the distance between those sources). As a result, the servers in the physical locations of the data center with different configurations could be simulated for analysis.

The experimental portion of this study was performed at the St. Mary's University Electrical Engineering Laboratory (Figure 10). No effort was initiated to control reverberation of sound off the floor, ceiling, or furniture/equipment in the room. Pieces of software and hardware were configured to create a small laboratory where sound levels could be captured, configurations modified, and lastly analyzed for the purpose of this experiment.

A MacBook Pro computer was utilized to capture and subsequently analyze the recorded noise files. The computer was connected to a Peavey XR8600D mixer amplifier (Figure 11) to control the audio signal of six Peavey PR15 sound speakers (Figure 12) that were connected to the mixer through 30 ft (feet) of speaker cable. Not all of the speakers were the same configuration or model, but all sound was created from the Peavey Mixer amplifier (Figure 11). We were not able to acquire all speakers with the same model and same dimensions and acknowledge that this could introduce some error and variability if this study is replicated.

Figure 10. St. Mary's University in Electrical Laboratory

Figure 11. Peavey XR8600D Mixer Amplifier

Figure 12. Peavey PR15 Sound Speakers.

CHAPTER IV

RESULTS

We collected the results following differing methodologies as the sound pressure levels in the field evaluation study could not be manipulated as the racks in the data center were fixed and not flexible to alternative configurations.

Site Results

We captured the data over 60-minute intervals and collected them in 12 server room locations. An analysis of the data (Table 2 and Figure 13) revealed that location I-19 had the highest sound level pressure at 82.7 dBA, and M-18 (the location in the middle of the two server racks) was the second highest sound level of 80 dBA.

Location	dBA	dBC
Front door (entrance)	65.3	71.6
Hallway	69.4	74.7
Corner A-28	77.5	83.4
Corner A-13	77.1	84.1
Corner W-28	74.0	79.2
Corner W-19	73.3	77.0
R-19	75.1	78.7
M-15	76.1	80.1
M-18	80.0	82.9
M-21	75.5	80.2
I-19	82.7	86.1
D6-4 office	65.5	71.5
D6-2 office	65.0	72.0
D6-1 office	66.4	71.5

Table 2. Sound Level Results (dBA and dBC)

All other locations within the server room were 80 dBA or lower. From a regulatory perspective, the base measurement (average level 82.7 dBA) did not exceed the OSHA requirement (90dBA) that represents the threshold limit to the human ear for an eight-hour shift. This did not necessarily mean that the sound was not annoying or causing harm to the employees in some manner. Rather, it was taken as an indication that the sound level pressure was in compliance with occupational health standards in the United States.

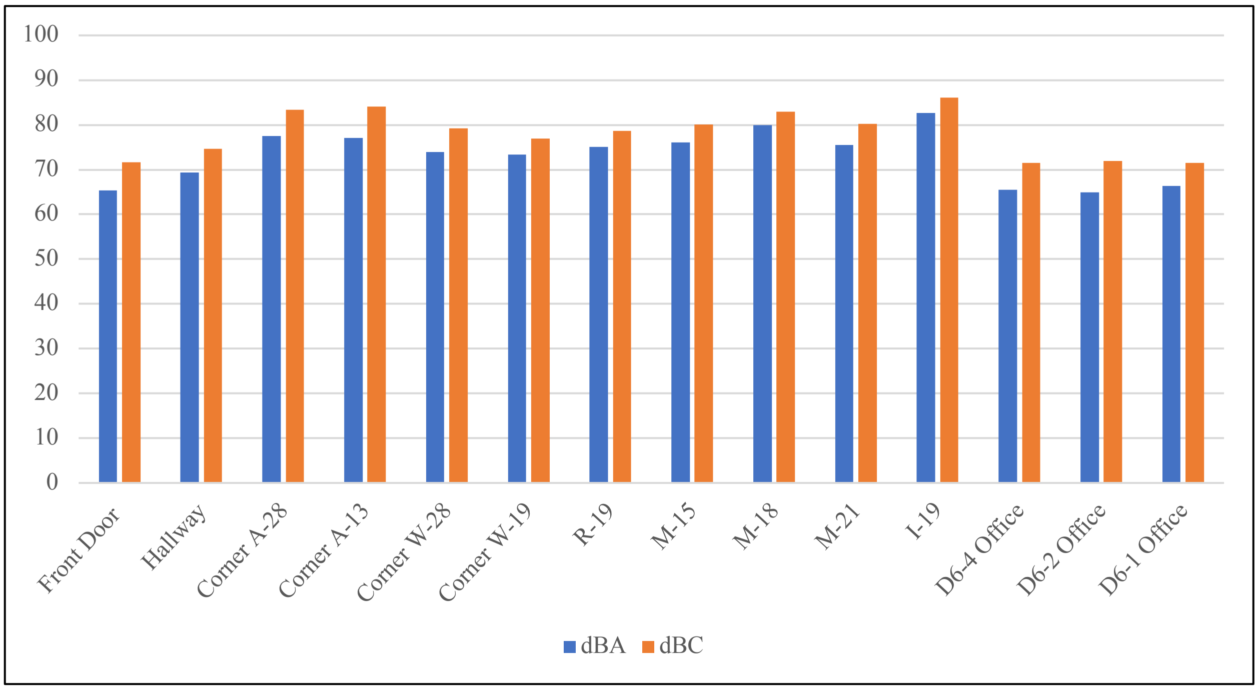
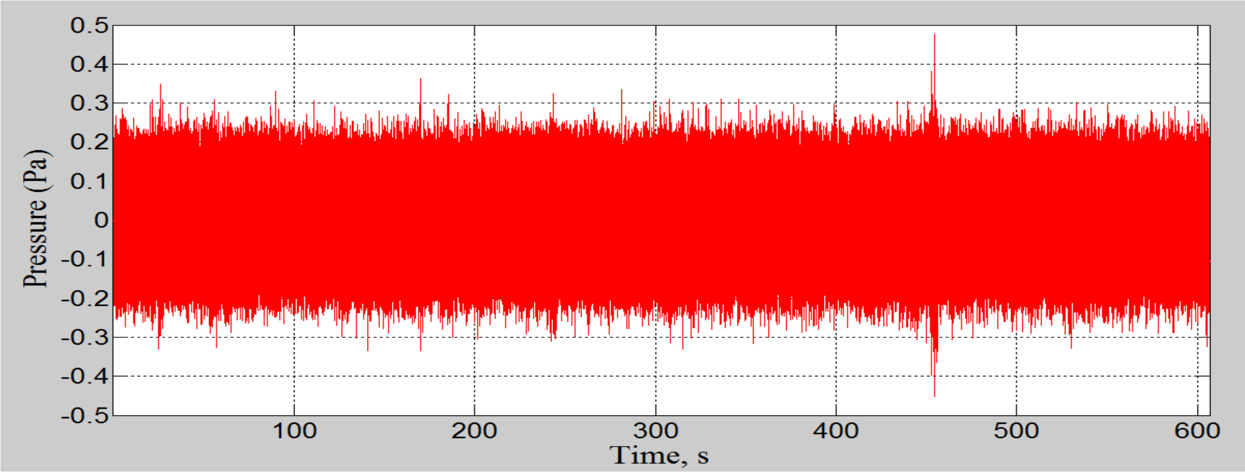


Figure 13. Sound level in dBA and dBC.

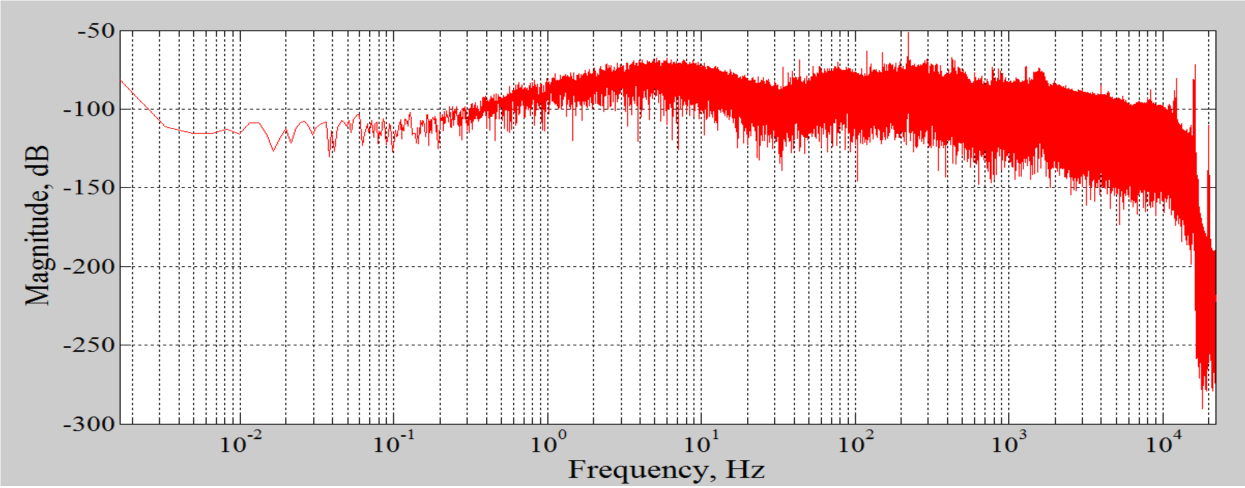
The room size was 20 feet wide, 15 feet long, and 10 feet to the ceiling and it was configured with only two server racks. This room housed servers for the Research and Development division of the company. This would constitute a small server room for large organizations with limited number of servers in comparison to larger data centers for companies that support cloud service or hosting of data for a large number of users.

We recorded sound in three different locations where servers were parallel to one another, as well as other locations in the room where employees primarily work supporting the servers (M-18, I-19, and D6-4). Sound was recorded using Windows Sound Recorder software without any filtering. We read and analyzed noise data with MATLAB that tabulated the noise signal and spectrum. The analysis of the sound signal in the server room at I-19 is presented in Figure 14 (a, b, c), respectively. This location maintains the largest exposure to the operators in the server room, due to the fact that I-19 had the highest noise level. The power of the signal increased significantly when the signal was collected in between the two server racks. The pressure of the sound shown in Figure 14(a) was relatively high because of the convoluted noise signals that were produced from the two racks which led to an increased level of noise. The level of the noise signal referenced in Figure 14(a) is between ±0.3 Pascal (Pa), while a few spikes fell in the range of ±0.5 Pa. Generally, any other source of noise can increase the level of the signal and exceed the limit of ±0.3 Pa and make the noise more distractive to the employees. This sound level made communication difficult as its magnitude was over 80 dBA (Table 3). We noted that some employees at the data center were compensating for that by increasing the volume in their voice to convey information between one another.

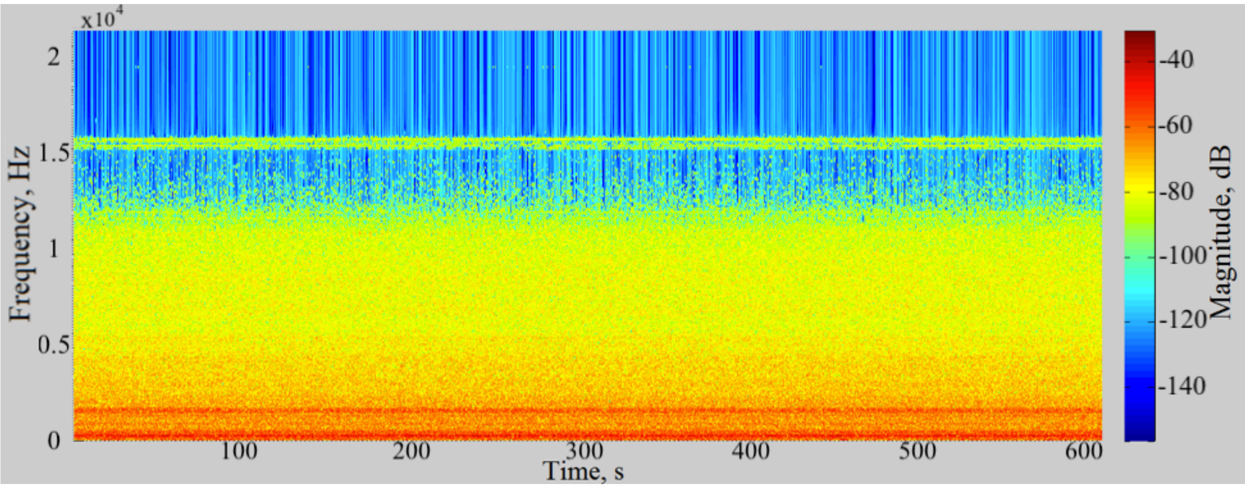
The spectrum of the noise signal at location I-19 (Figure 14(b)) clarifies the power of the signal distribution in the frequency domain. The power of the signal is primarily allocated in the frequency band of 10–120 Hz. This low-frequency band, defined as a gamma wave, and as mentioned earlier, could be a causal factor in the development of Tinnitus. The spectrogram for the noise signal is defined in Figure 14(c). The noise signal with a frequency band of 20–100 Hz has a signal power of about -50 dB to -60 dB. A noise signal with a high frequency does not carry the same level of sound and therefore does not impact the employees as much as low frequency.



(a) Time domain for the sound pressure.



(b) Frequency spectrum for the noise signal.



(c) Frequency spectrum in time domain for the noise signal.

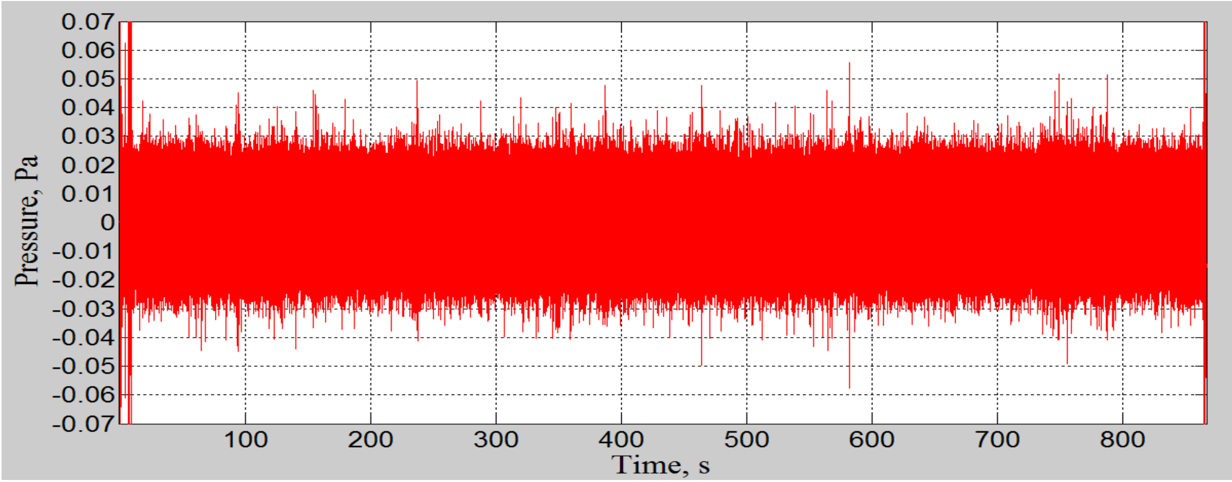
Figure 14. Noise signal analysis at I-19 location.

Sound Sources Examples with Distance	Sound Pressure Level L_p dBA	Sound Pressure p N/m^2 = Pa
Jet aircraft, 50 m away	140	200
Threshold of pain	130	63.2
Threshold of discomfort	120	20
Chainsaw, 1 m from distance	110	6.3
Dancing club, 1 m from speaker	100	2
Diesel truck, 10 m away	90	0.63
Curbside of busy road, 5 m	80	0.2
Vacuum cleaner, distance 1 m	70	0.063
Conversational speech, 1 m	60	0.02
Average home	50	0.0063
Quiet library	40	0.002
Quiet bedroom at night	30	0.00063
Background in TV studio	20	0.0002

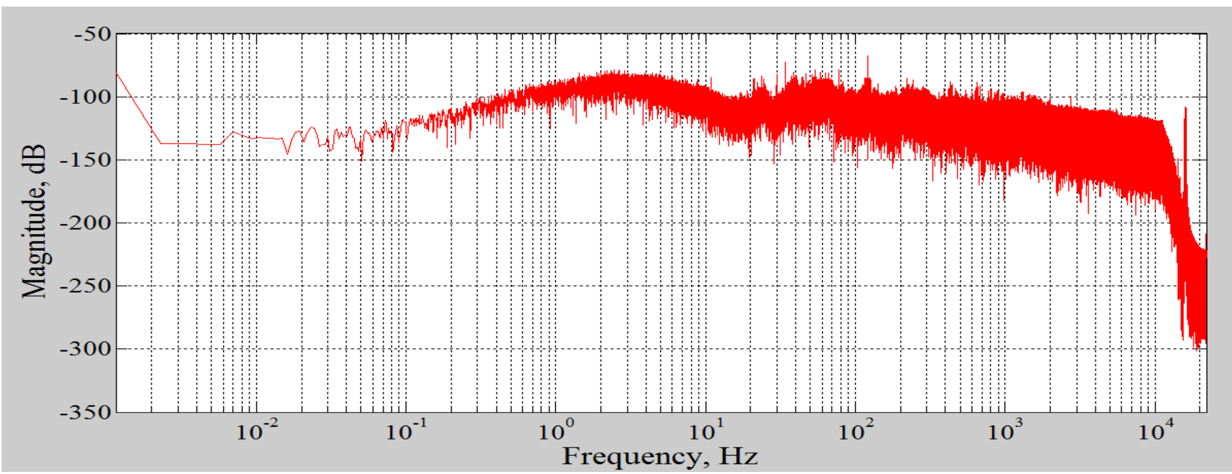
Table 3. Sound Levels (Loudness) and Corresponding Sound Pressure and Sound Intensity (Sengpielaudio, 2011).

In Table 2, Region D6-4 represents the workstation area where employees are found when they were not working specifically on the servers or performing maintenance or testing them. We found that the workstations were located in that area where the operators could perform paperwork or work on their computers with tasks that were assigned to them. The time domain, frequency spectrum, and spectrogram analysis of the recorded signal are shown in Figure 15. The sound pressure fluctuated in the range of ±0.05 Pa. Therefore, the sound pressure at that location could be over 60 dBA but not close do the maximum sound level established by OSHA. While the noise level of the signal may not be legally harmful due to the distance from the servers, it was still continuous and represented a distraction to the employees in that server room.

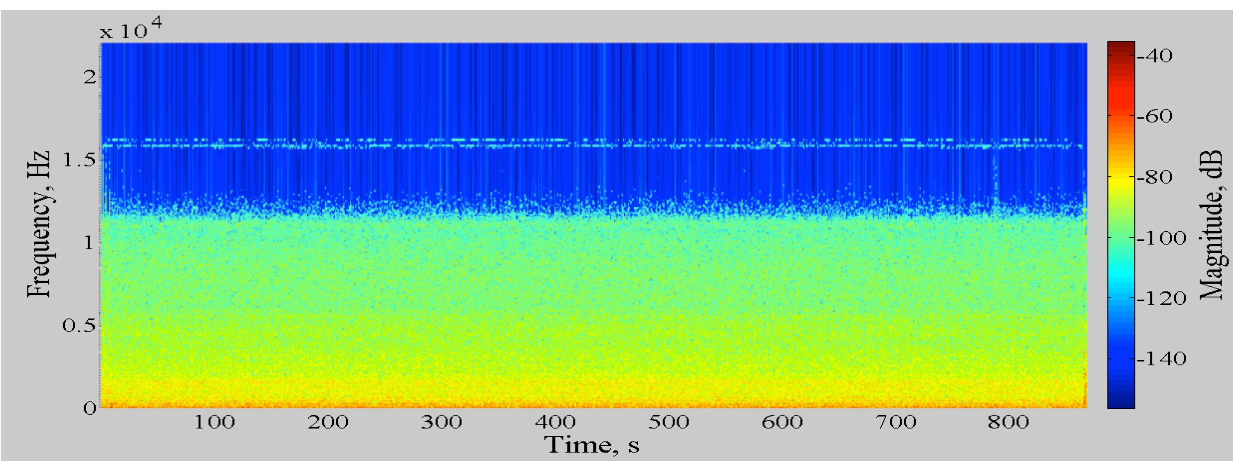
An analysis of the the frequency spectrum in Figure 15(b) reveals that the lower frequency band carries the highest power of the signal (i.e., 20–80 Hertz). This is the band that has the highest power of the signal, ranging from -35 dB to -60 dB. In Figure 15(c) we display the power distribution of the signal over the frequency in the time domain. The frequency range of 0–120 Hz for the spectrogram of Figure 15(c) is evident in Figure 16. The frequency band from 40–80 Hz has a power range that varies between -50 dB to -60 dB, as shown in Figure 16. This gamma frequency range is considered the most harmful range in terms of hearing damage. Employees within that range were exposed to a high level of power of continuous gamma frequency sound while spending the majority of their work shift in the server room to monitor the network and perform daily tasks. As stated earlier, long-term exposure in this frequency range might elicit substantial damage to the hearing system such as a chronic noise trauma (Schlee et al., 2009).



(a) Time domain for the sound pressure.



(b) Frequency spectrum for the noise signal.



(c) Frequency spectrum in time domain for the noise signal.

Figure 15. Noise signal analysis at D6-4 location.

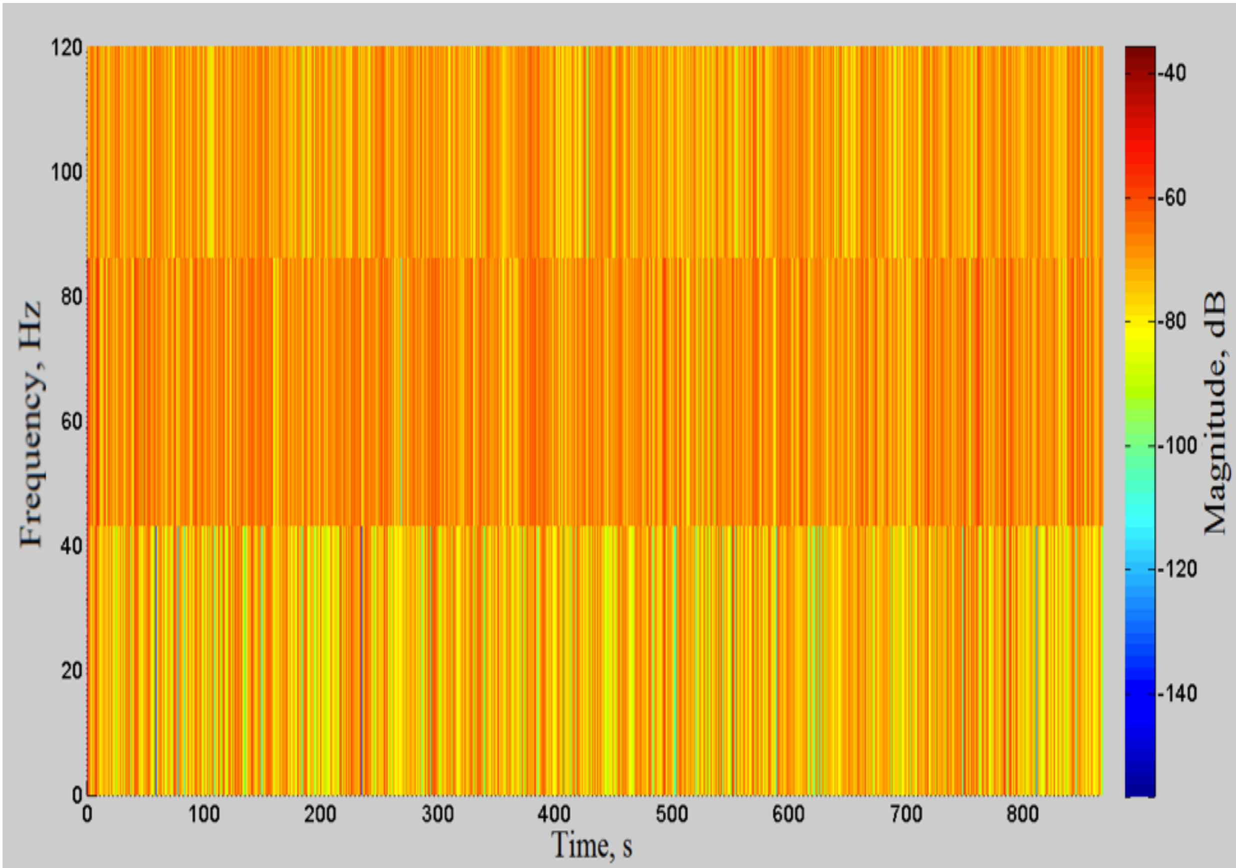


Figure 16. Spectrogram for noise signal in location R4-6.

The sound pressure level (i.e., acoustic pressure level) was plotted to show the pressure of the noise signal over time. According to Sultan et al. (2016), the sound pressure level (SPL) for a sound source with pressure (p), is defined as

$$SPL = 20 \log_{10} \frac{p}{p_{ref}} \quad .. (1)$$

where $p_{ref} = 20 \times 10^{-6}$ Pa.

The noise files we collected were trimmed to five minutes to reduce the processing time when calculating and plotting the SPL in MATLAB. The SPL plot for the noise around location I-19 is shown in Figure 17. The SPL for the signal fluctuated between 64–76 Pa with some spikes because of an external sound source that makes SPL reach to 80 Pa.

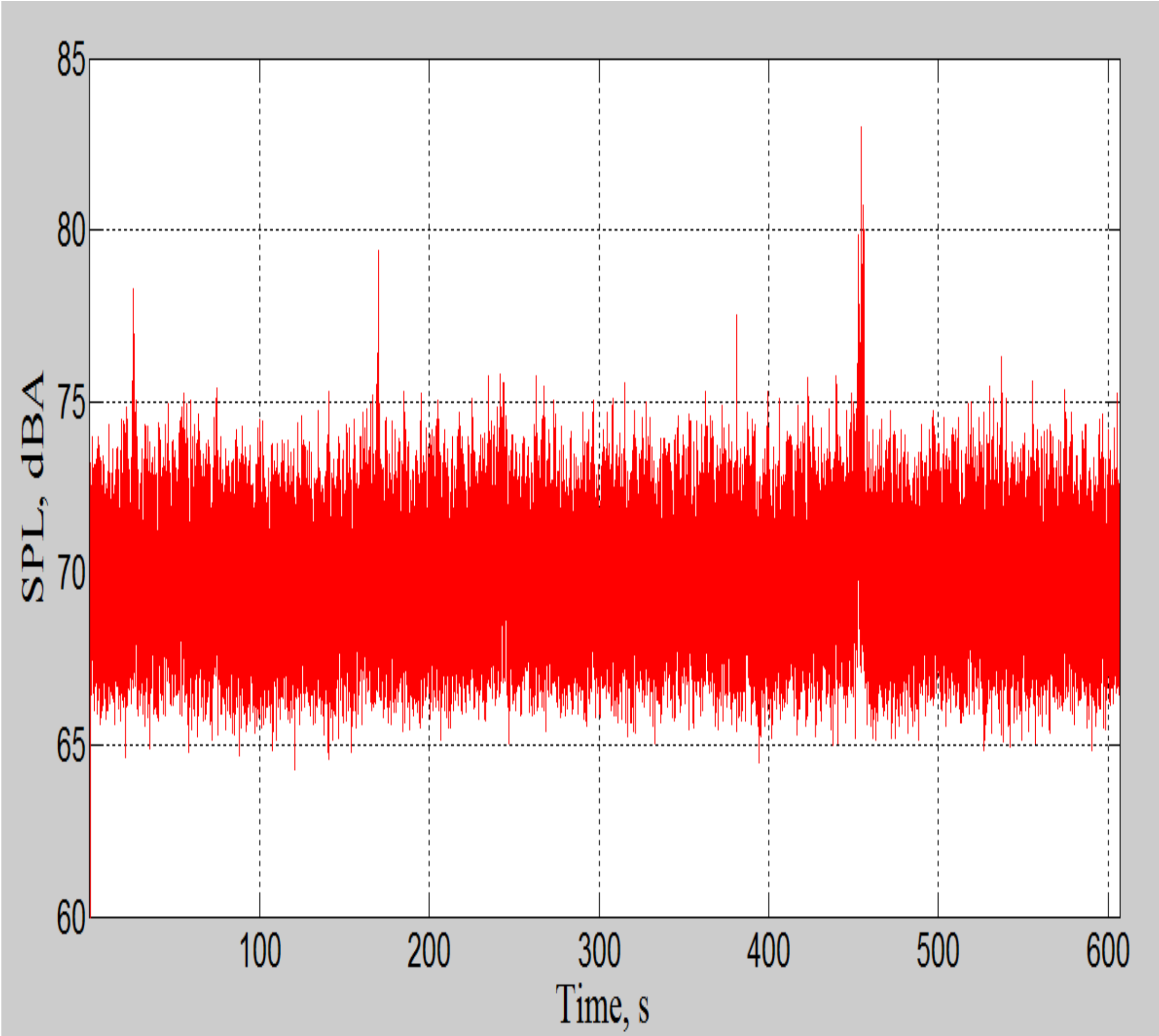


Figure 17. Sound pressure level for the noise signal I-19 location.

The SPL for the noise signal in the D6-4 office location is plotted in Figure 18. The SPL was lower than I-19 (adjacent to servers), as the signal was collected in the area that was physically further from the source of the noise. The sound pressure fluctuated between the levels of 45–63 Pa, while the number of spikes was greater in that location because the presence of more sources of noise. That was a result of activities of the employees in that area (talking, typing on the keyboard, moving their chairs, etc.), as employees had their workstations at that location.

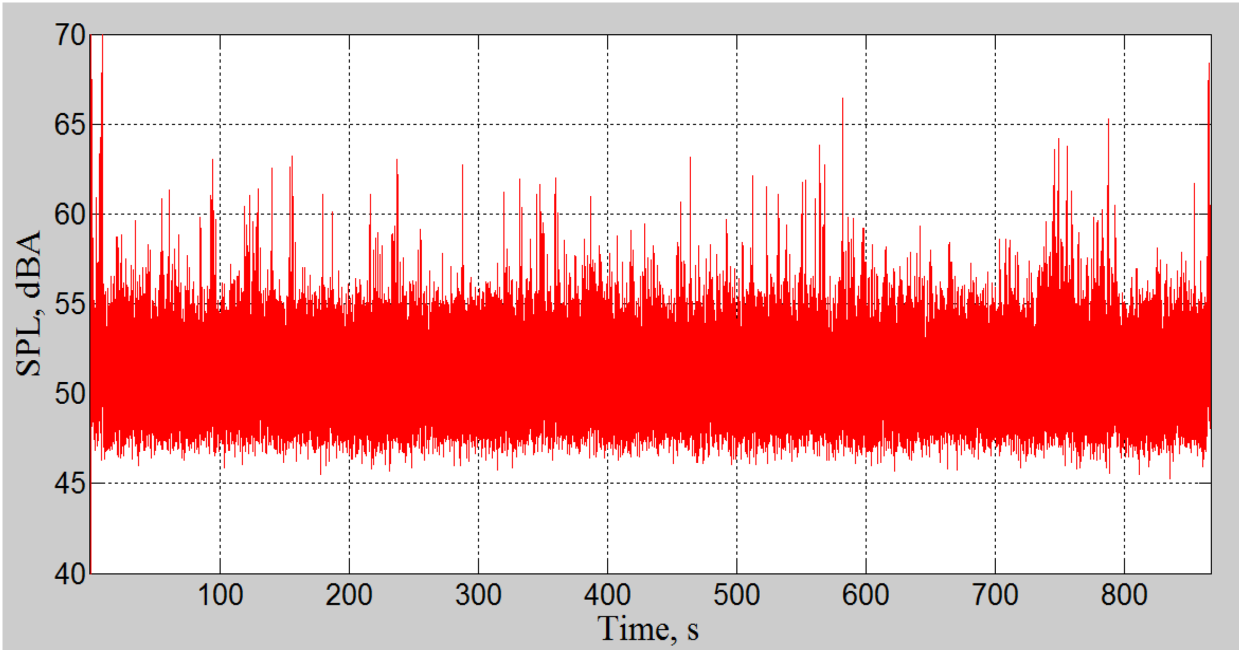


Figure 18. Sound pressure level for the noise signal D6-4 location.

The SPL was measured for the whole frequency band of the signal. Therefore, it was slightly different from the measure of the sound level meter (for noise signal analysis and SPL analysis at M-18 location, shown in Appendix B).

Experimental Study

We conducted an experimental study in the Electrical Engineering Laboratory at St. Mary's University. The study included equipment to simulate the environment in server rooms in order to simulate different server configurations, and whether the placement of "sound emitting devices" could impact the overall sound.

A summary box plot with the sound pressure values is furnished in Figure 19 for the two-, four-, and six-configuration sets of speakers at a distance of 3 feet, respectively. The speakers were placed symmetrically between the sound level meter between the meter and what else?? (i.e., in the middle of them) to maintain consistency in measurement of the sound between configuration changes. A full data summary for each configuration (two, four and six speakers) is provided in Appendices C to I. The box plot distinctly shows that increasing the number of speakers causes the overall level of noise to rise as expected. The volume of noise was increased due to the additive properties of sound. The descriptive statistics provided in Table 4 are used to compare the three steps in this experiment and to explain the level of the noise in each reading.

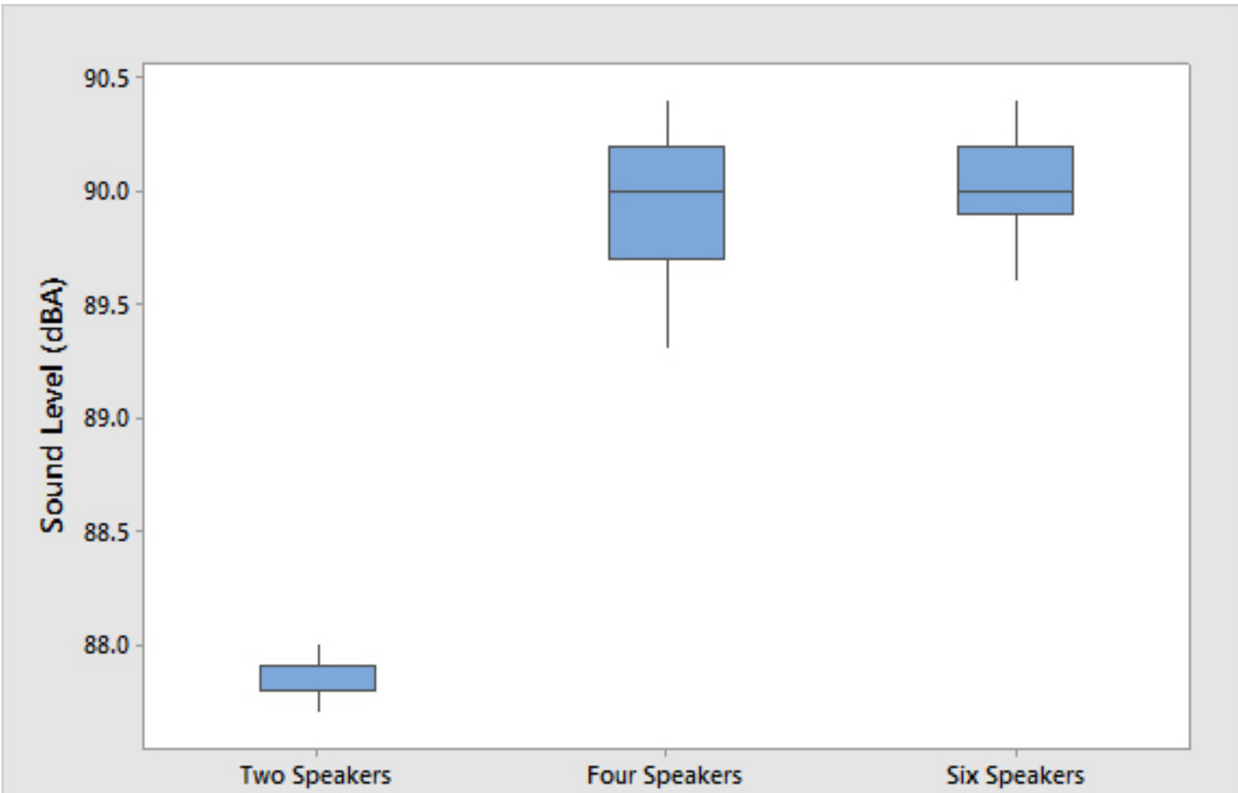


Figure 19. Sound level box plot for the speakers with 3-ft space distance between speakers.

Number of Speakers	Average (dBA)	Maximum (dBA)	Minimum (dBA)	Percentage for Sound Level over 90 dBA
Two speakers	87.8	88.1	87.1	0%
Four speakers	89.9	90.4	89.3	55%
Six speakers	89.9	90.4	89.6	68%

Table 4. Descriptive Statistics for the Sound Level with 3-ft Distance Between Speakers

The average chart in Figure 20 shows that increasing the number of racks in a server room causes an increase in the level of noise. The total signal level (in decibels) from equal signal sources can be calculated by

$$L_t = 10\log\left(\frac{nS}{S_{ref}}\right)$$

$$= 10\ log\left(\frac{S}{S_{ref}}\right) + 10\log(n)$$

$$= L_s + 10\log(n) \text{ .. (2)}$$

where L_t is a total signal level (dB), S is a signal (signal unit), S_{ref} is a signal reference (signal unit), n is number of sources, and L_s is a signal level from each single source (dB).

Hence, the noise level can reach or exceed OSHA's regulatory limit if enough servers are placed in a room due to the additive sound power of each unit. The level of sound power for four and six speakers was 89.9 dBA (Figure 20). However, the percentage of values that exceed the 90 dBA threshold in these cases varied (Figure 21). As would be expected, the percentage of sound level pressure over 90 dBA is higher for six-speaker configurations than any placement with four speakers.

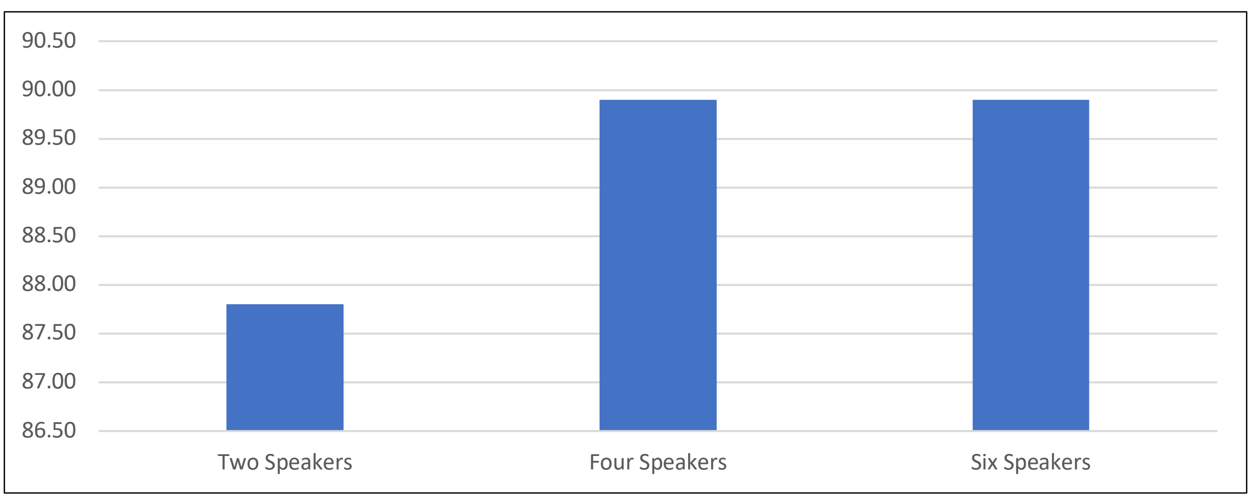


Figure 20. Average value of the noise level with 3-ft distance between speakers.

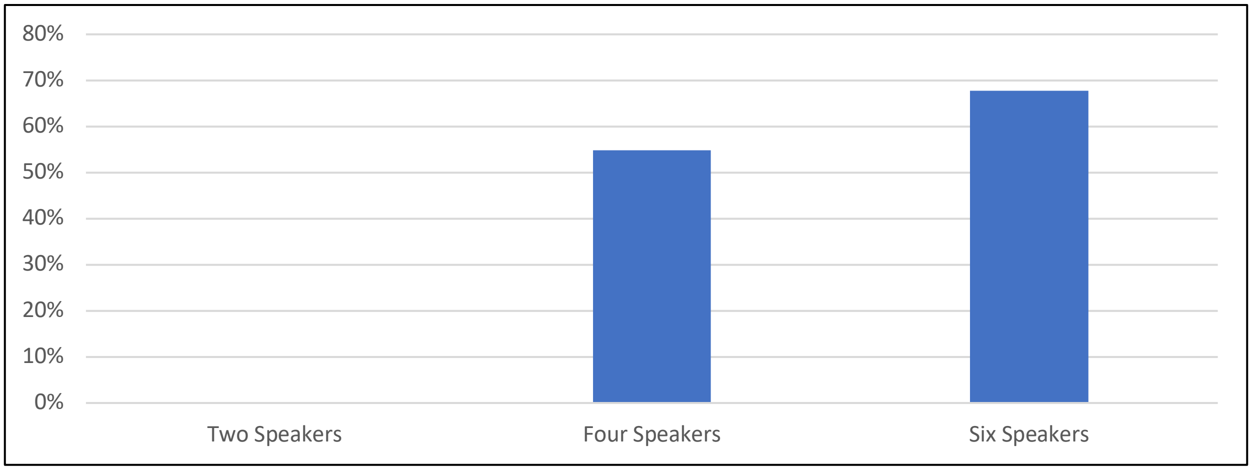


Figure 21. Percentage of sound level over 90 dBA with 3-ft distance between speakers.

A real-time measure for the level of the noise for the three cases of speakers' arrangements with 3-feet spacing between the speaker (Figure 22) is showing that the higher values in dBA occurred with four and six speakers' configurations.

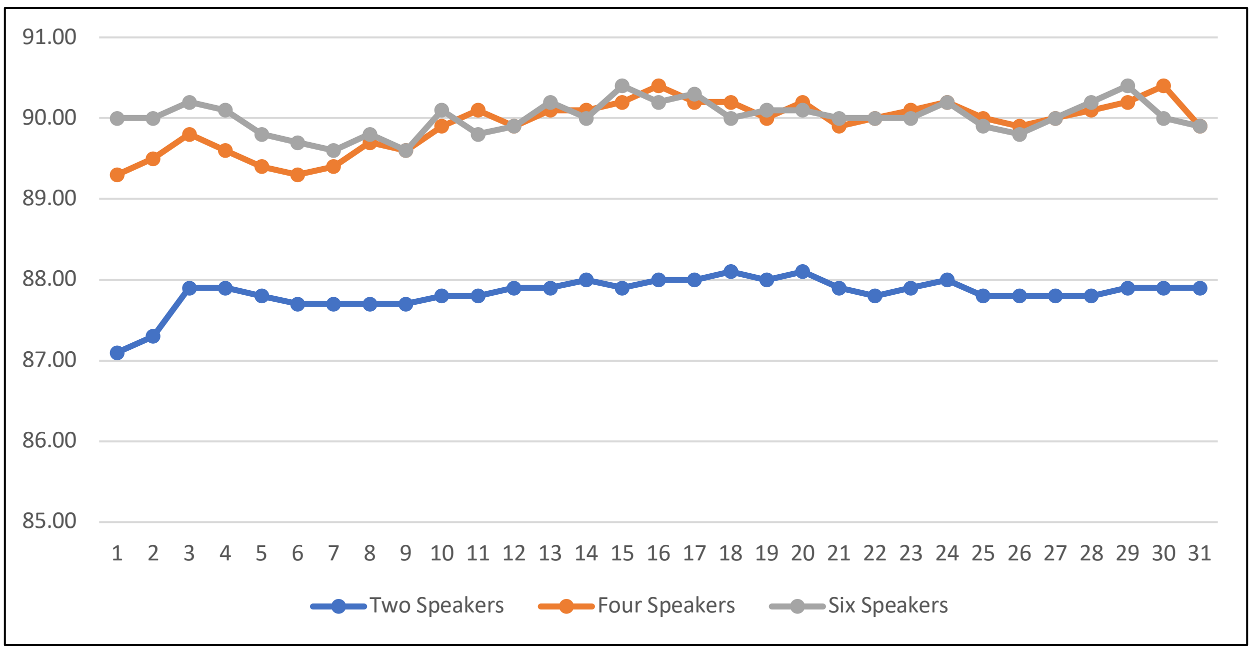


Figure 22. Real-time reading for the noise level with 3-ft distance between speakers.

CHAPTER V

CONCLUSION

Based upon the additive law of sound, it is evident that increasing the density of equipment in a server room can increase the level of sound pressure in a room or enclosure. One of the challenges faced by human factors engineers is to comply with the regulatory standards in their respective countries, and to promote the health and well-being of employees and individuals in general in products or environments that they design or analyze. As with any emerging technology, the actual health or safety implications are not always known beforehand. This provides the opportunity for researchers to investigate the workplace or environment by applying theoretical knowledge to solve real-world problems. Sometimes health hazards are referenced in epidemiological data, and sometimes this is not available as this research and information is expensive to gather and to perform.

The initial analysis of the sound in the server room provided no concern from a regulatory perspective as the sound levels were below 90 dBA. The data collected from the data center had a maximum sound level of 82.7 dBA. The area where the network engineers and technician congregated to monitor the network had a lower noise level of 66.5 dBA. However, employees expressed concerns in that area that they were developing headaches associated with the equipment in that region.

We hypothesized that low frequency sound can have a deleterious effect on individuals exposed to it for extended periods. Some evidence supports this theory, and this thesis summarizes similar facts. Our purpose was to facilitate this discussion and to promote more investigative work in this area, however no medical investigation on the employees was performed.

The experimental study provided us with an opportunity to explore if changes in configuration would improve the human experience. It was theorized, and subsequently confirmed, that we could have some potential sound cancellation opportunities with the sound power in server rooms (assuming one primary frequency) by strategic placement of servers. The experiment has design implications regarding sound attenuation and decreasing equipment sound or vibration. It is important to understand that sound characteristics (power and frequency) affect the method of sound attenuation, while still providing a potential source of improvement in design.

Sound level is not the only parameter that should be considered to define the impact of noise on job performance. Frequency can play a major role in Human Factors as it might influence a person's hearing ability and even mental functionality. We recommend that employees in work environments similar to the work data center studied in this research effort wear personal protective equipment until an appropriate engineering solution can be implemented to reduce noise levels.

Future research is recommended to collect additional data in server rooms with different configurations. This can help to investigate and validate the placement of servers and their impact on human performance in occupational environments.

References

Acoustics First Corporation. (2003). *Acoustic myths and realities: Foam flammability*. Retrieved February 15, 2017, from http://www.acousticsfirst.com/acoustical-foam-flamibility-fire-ratings.htm

Air-Met Scientific. (2017). *Heat stress software*. Retrieved December 29, 2017, from https://www.airmet.com.au/product/detection-management-software-dms

All Safe Industries. (1996). *Sound Pro Sound Level Meter*. Retrieved February 2018 from https://www.allsafeindustries.com/store/p/5191-Sound-Pro-Sound-Level-Meters.aspx.

Bryant, R. E., & O'Hallaron, D. R. (2015). *Computer systems: A programmer's perspective.* (3rd ed.). Prentice Hall 4 Class Meetings Section Time Days Classroom Date Range.

Carstenpxi. (2010, 5 25). *Youtube*. Retrieved December 29, 2017, from https://www.youtube.com/watch?v=1H0Ya07BhBQ

Concha-Barrientos, M., Steenland, K., Prüss-Üstün, A., Campbell-Lendrum, D. H., Corvalán, C. F., Woodward, A., & World Health Organization. (2004). Occupational noise: Assessing the burden of disease from work-related hearing impairment at national and local levels. Geneva, Switzerland: World Health Organization.

Fehrenbacher, K. (2012, August 17). *A rare look inside Facebook's Oregon data center*. Retrieved August 14, 2017, from https://gigaom.com/2012/08/17/a-rare-look-inside-facebooks-oregon-data-center-photos-video/

HSE. (2014). *Noise: Frequently asked questions.* Retrieved February 2017 from http://www.hse.gov.uk/noise/faq.htm#q11

HaSPA. (2012). *The core body of knowledge for generalist OHS professionals.* Tullamarine, VIC: Safety Institute of Australia.

Jerome, M. (2010). Sound of computers in a data center [Recorded by Free Sound].

Johnson, P. T. (2014). *Noise exposure: Explanation of OSHA and NIOSH safe-exposure limits and the importance of noise dosimetry.* Etymotic Research, ER078114 –B.

Kuo, S. M., & Morgan, D. R. (1999). Active noise control: A tutorial review. *Proceedings of the IEEE, 87*(6), 943–973.

Leaver, A. M., Renier, L., Chevillet, M. A., Morgan, S., Kim, H. J., & Rauschecker, J. P. (2011). Dysregulation of limbic and auditory networks in tinnitus. *Neuron*, *69*(1), 33–43.

Mahoney, C. J., Rohrer, J. D., Goll, J. C., Fox, N. C., Rossor, M. N., & Warren, J. D. (2011, November). Structural neuroanatomy of tinnitus and hypercusis in semantic dementia. *Journal of Neurology, Neurosurgery and Psychiatry*, *82*(11), 1274–1278.

MathWorks, Inc. (2017). *MATLAB*. Retrieved April 22, 2017, from https://www.mathworks.com/products/matlab.html?s_tid=hp_ff_p_matlab

McDonough, J. M. (2007). Introductory lectures on turbulence: Physics, mathematics and modeling. Retrieved from https://uknowledge.uky.edu/me_textbooks/2/

Miljković, D. (2016). *Noise within a data center.* Opatija: 2016 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO).

Minitab. (2017). *About us*. (M. 17, Producer). Retrieved April 22, 2017, from http://www.minitab.com/en-us/company/

Mühlau, M., Rauschecker, J. P., Oestreicher, E., Gaser, C., Röttinger, M., Wohlschläger, A. M., Simon, F., Etgen, T., Conrad, B., & Sander, D. (2005). Structural brain changes in tinnitus. *Cerebral Cortex, 16(9)*, 1283–1288.

NIOSH. (1998). *Criteria for a recommended standard: occupational noise exposure. Revised criteria 1998.* Cincinnati, OH: National Institute for Occupational Safety and Health.

OSHA. (2014). *Occupational noise sxposure*. Retrieved February 2017, from https://www.osha.gov/SLTC/noisehearingconservation/

Pinosova, M., Andrejiova, M., Kralikova, R., Hricova, B., Lumnitzer, E., & Wessely, E. (2015). Assessment of hearing impairment risk from the point of view of long-term exposure to noise in working environment. In B. Katalinic (Ed.), *DAAAM International Scientific Book 2015* (pp. 345–358). Vienna, Austria: DAAAM International.

Rauschecker, J. P., Leaver, A. M., & Mühlau, M. (2010). Tuning out the noise: Limbic-auditory interactions in tinnitus. *Neuron, 66*(6), 819–826.

Schlee, W., Mueller, N., Hartmann, T., Keil, J., Lorenz, I., & Weisz, N. (2009). Mapping cortical hubs in tinnitus. *BMC Biology*, *7*(1), 80.

Sedley, W., Friston, K. J., Gander, P. E., Kumar, S., & Griffiths, T. D. (2016). An integrative tinnitus model based on sensory precision. *Trends in Neurosciences, 39(12)*, 799–812.

Sengpielaudio. (2011). Loudness comparison chart. Retrieved December 29, 2017, from http://www.siue.edu/~gengel/ece476WebStuff/SPL.pdf

Sensear. (2016). *High noise communication headset products*. Retrieved December 29, 2017, from http://www.sensear.com/communication-headsets-product-range

Sharma, M. K., & Vig, R. (2014, March). Server noise: Health hazard and its reduction using active noise control. In *2014 Recent Advances in Engineering and Computational Sciences (RAECS)* (pp. 1–5). IEEE.

Sultan, H., Katiyar, A., & Smruti , S. R. (2016, June). Noise aware scheduling in data centers. *Proceedings of the 2016 International Conference on Supercomputing. ACM.*, (p. 13). New York, NY: ACM.

IOSH. (2006). *Hearing protection - Ear infections* . Retrieved December 29, 2017, from http://forum.iosh.co.uk/posts/t76341-Hearing-Protection-Ear-Infections

Appendix A:

Potential Health Effects of Gamma Frequency

Tinnitus is characterized as a common auditory disorder in the population. The disease associations and anatomical substrates still continue to be defined. However, (SemD) Semantic Dementia patients frequently report Tinnitus as a symptom (Mahoney et al., 2011). Therefore, the prevalence or potential onslaught of Tinnitus may be a significant issue in SemD. The evidence of SemD can support previous work implicating of limbic network and a distributed cortico-subcortical auditory in the pathogenesis of these abnormal auditory percepts (Mahoney et al., 2011).

In general, Tinnitus is caused by central and peripheral mechanisms such as a reorganization of central auditory pathways, peripheral injury, and/or anomalies in the limbic system that produce an emotional content of sensory experiences (Mühlau et al., 2005). There is more than one hypothesis to explain the reason of Tinnitus. Some evidence suggests that Tinnitus is pathophysiology that involves damage either peripheral or central pathway or both (Leaver et al., 2010). Another Hypothesis suggested that Tinnitus is caused by tonotopic maps. Tonotopic maps are recognized in the auditory cortex and leads to a sensation of Tinnitus frequencies (Mühlau et al., 2005). Previously, there was a suggestion that the causes of chronic Tinnitus are coming by a compromised limbic corticostriatal circuit that leads to a disordered evaluation of the Tinnitus sensation's perceptual and causes a disordered gain control in a percept of the Tinnitus (Leaver et al., 2010). On the other hand, anomalies related to Tinnitus are inter-correlated between limbic and primary auditory and/or two limbic area and indicates necessity of interactions of auditory-limbic in Tinnitus as shown in Figure I. Although, the exact role of the limbic contributions nature to the Tinnitus is not yet known (Leaver et al., 2010). Auditory-Limbic shown in Figure I elaborate the interaction in Tinnitus where the sensory input is originated subcortically then enters both limbic and auditory circuits through Medial Geniculate Nucleus (MGN).

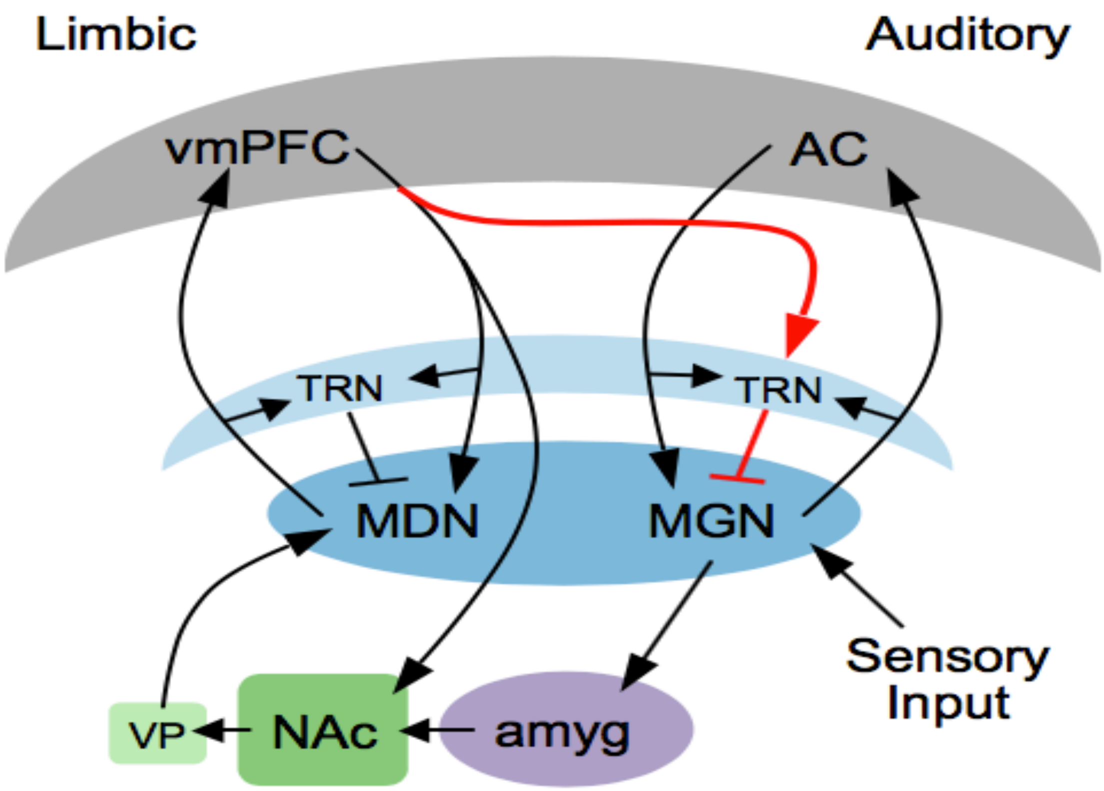


Figure I. Auditory-limbic interaction in Tinnitus (Leaver et al., 2010).
Medial Dorsal Nucleus (MDN),
Ventral Pallidum (VP),
amygdala (amyg),
Auditory Cortex (AC),
Medial Geniculate Nucleus (MGN).

Normally, the limbic system is identifying a sensory signal as perceptually irrelevant such as transient Tinnitus followed by exposure to loud noise. Then inhibit an unwanted signal into MGN through projections from the ventromedial Prefrontal Cortex (vmPFC) to the auditory thalamic reticular nucleus (TRN, red pathway). Therefore, an unwanted signal can be reduced in either circuit. In the case of Tinnitus, an inefficient vmPFC output can prevent hosting of Tinnitus signal and thalamocortical activity. The structures of cortical are noted in gray, basal ganglia noted in green, thalamus in blue, and amygdala is noted in lavender.

Mapping the hubs of cortical in Tinnitus it has been reported that there are fundamental group differences over the global networks, especially in the range of gamma frequency (Schlee et al., 2009).

Typically, Tinnitus is associated with a damage that occurs in the hearing system such as chronic noise exposure or a noise trauma (Schlee et al., 2009). Such damage can lead to plastic changes at different levels of the central auditory system. As a result, enhance spontaneous firing rate and neural synchrony within the central auditory system. Those changes have been reported in both human and animal studies and could be caused by various pathologies (Schlee et al., 2009).

Another suggestion about the cause of the chronical Tinnitus stated that it might be originated from the plastic reorganization of auditory cortex followed by peripheral deafferentation. Based on this hypothesis the process of reorganization is usually causing a loss in hair cells in the inner ear, Sensorineural Hear Losing (SNHL) might lead in some cases to cochlear lesion because of acoustic trauma (i.e., an exposure to a load noise with a certain level of frequency range or age-related degeneration of the hair-cell.

Furthermore, corresponding frequency range can cause an elevation in lesion thresholds. In addition, the neighbor frequencies become more amplified because of the central representation expansion in a vacant frequency range (Rauschecker et al., 2010).
In fact, some basic findings from human Positron Emission Tomography (PET) studies show that a correspond frequencies to the perceived Tinnitus frequencies can lead to a frequency expansion in the auditory cortex (Rauschecker et al., 2010).

While Tinnitus is usually considered as heterogeneous condition, most of the patient who suffered from Tinnitus they have reported a complaint a sensation of an auditory phantom.

Regarding the brain mechanism for the Tinnitus sufferers, most of the present data show a highly significant gray matter shrinking in the subcallosal area as shown in Figure II (Mühlau et al., 2005).

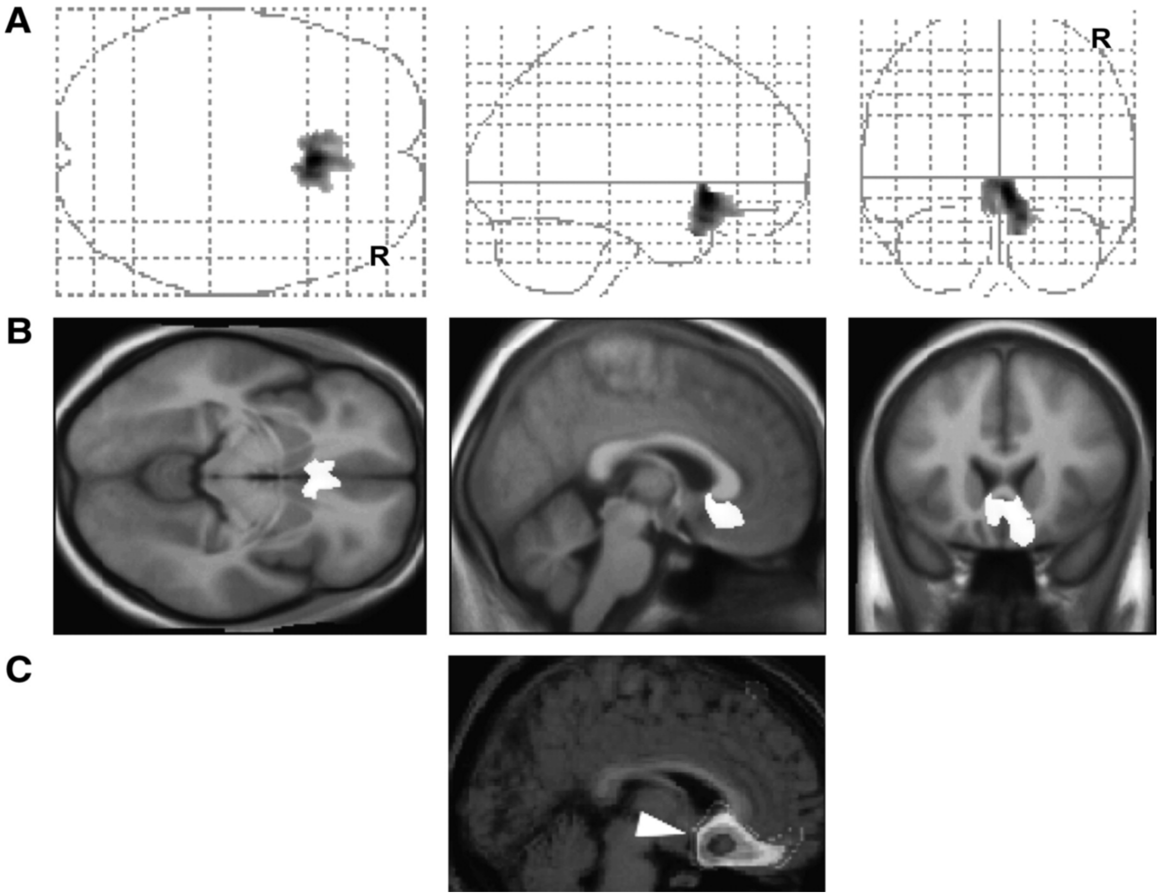


Figure II. Gray-matter volume decreases in addition to the changes throughout the whole brain (Mühlau et al., 2005).

Moreover, it was found that there is an expansion in the gray-matter concentration for the auditory thalamus of the Tinnitus group as shown in Figure III (Mühlau et al., 2005).

Tinnitus-related subcallosal region structural changes finding is important for different reasons such as the activity in the region of subcallosal is correlated to an unpleasant auditory sensation that comes from different amounts of dissonance harmonies, specifically at the region where the gray-matter shrink (Mühlau et al., 2005).

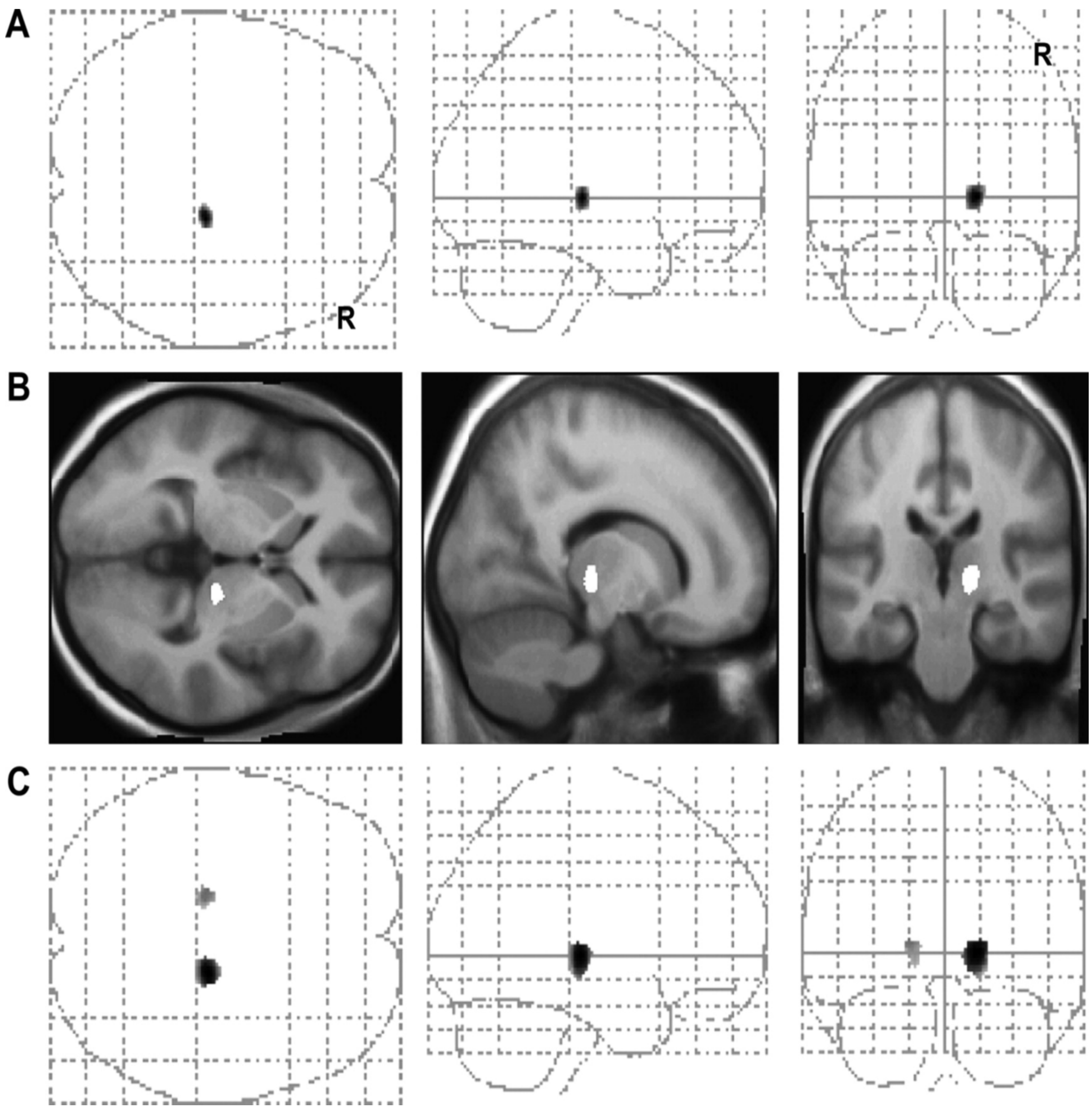


Figure III. Gray-matter concentration increases (Mühlau et al., 2005).

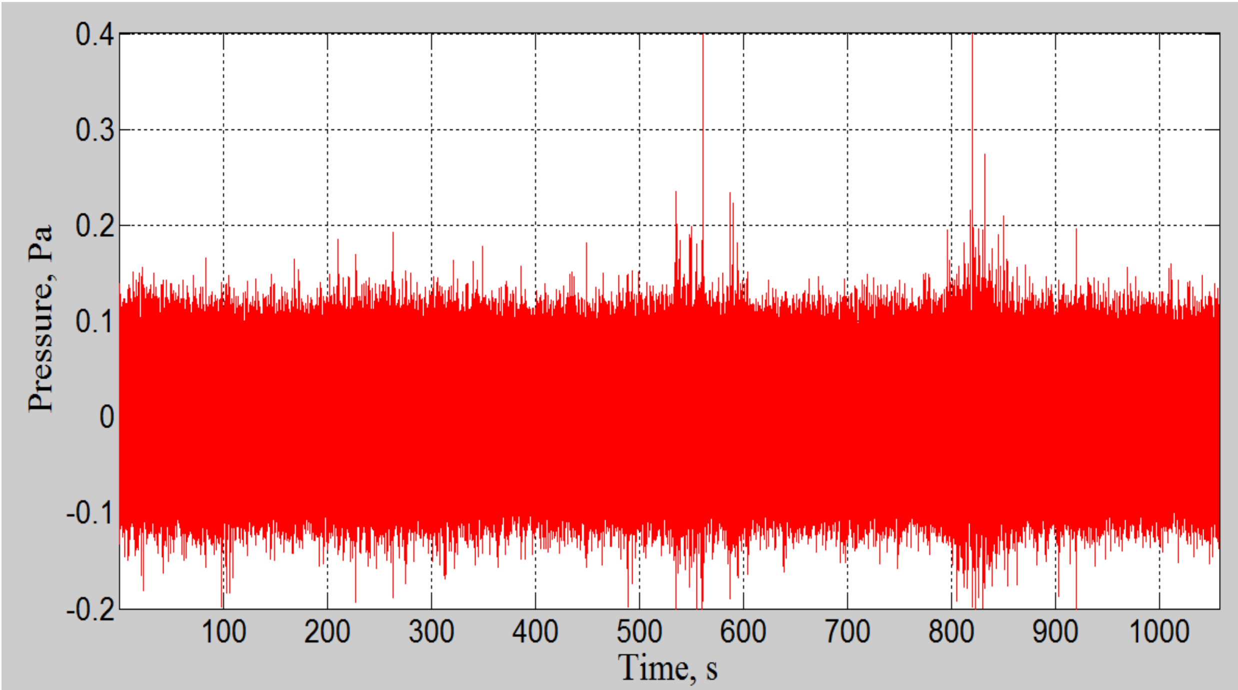
The main role for the area of subcallosal and posterior thalamus in Tinnitus pathogenesis is the combined changes in both regions. In other words, those changes seem to bring about the Tinnitus sensation. Mühlau et al. (2005) model suggested that

1. Neural based Tinnitus activity is primarily located in MGN and resulted from reorganization after peripheral hear losing.

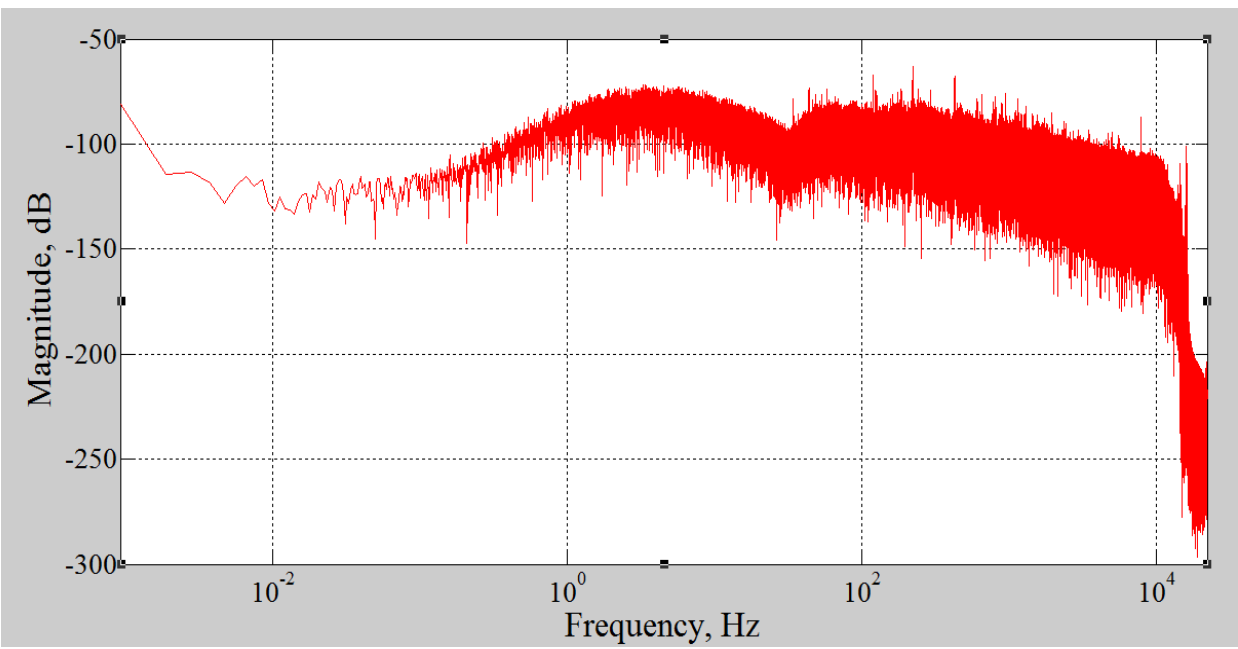
2. Inhibitory feedback from the area of the subcallosal may help in tuning out the neural activity because of Tinnitus.
3. The gray-matter shrinking in the subcallosal area may reduce this inhibitory feedback. Because of that, people with peripheral hear losing might be in health hazard of developing Tinnitus.

Appendix B:

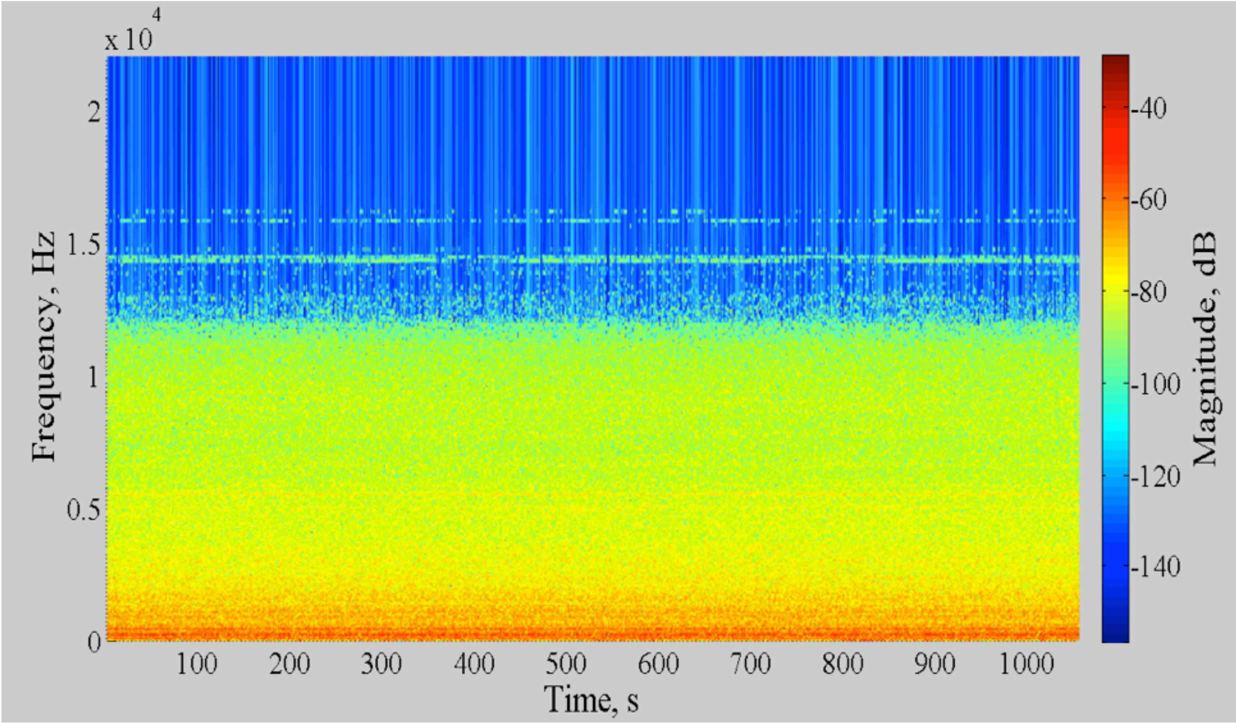
Noise Signal Analysis at M-18 Location



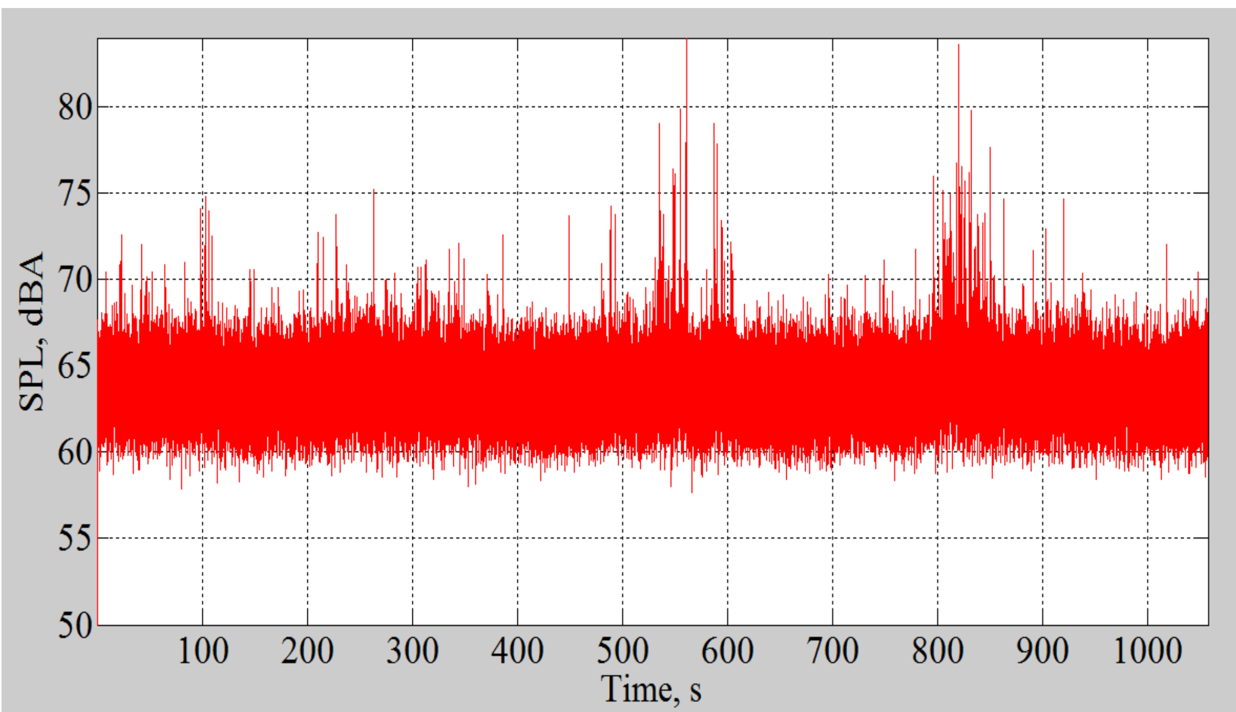
Time domain for the sound pressure.



Frequency spectrum for the noise signal.



Frequency spectrum in time domain for the noise signal.



Sound pressure level for the noise signal M-18 location.

Appendix C:

Data Collection for Two Speakers Measured Individually

Left Speaker	Right Speaker
82.00	83.10
82.00	83.20
82.00	83.20
82.00	83.20
81.80	83.10
81.70	83.00
81.70	82.90
81.70	83.00
81.70	83.00
81.80	83.10
81.90	83.10
81.90	83.20
81.90	83.20
82.00	83.20
82.00	83.30
82.10	83.30
82.00	83.30
82.20	83.40
82.10	83.30
82.20	83.40
81.90	83.30
81.80	83.10
81.90	83.20
82.00	83.30
81.90	83.20
81.80	83.10
81.90	83.10
81.90	83.10
82.00	83.20
81.90	83.10
81.90	83.10

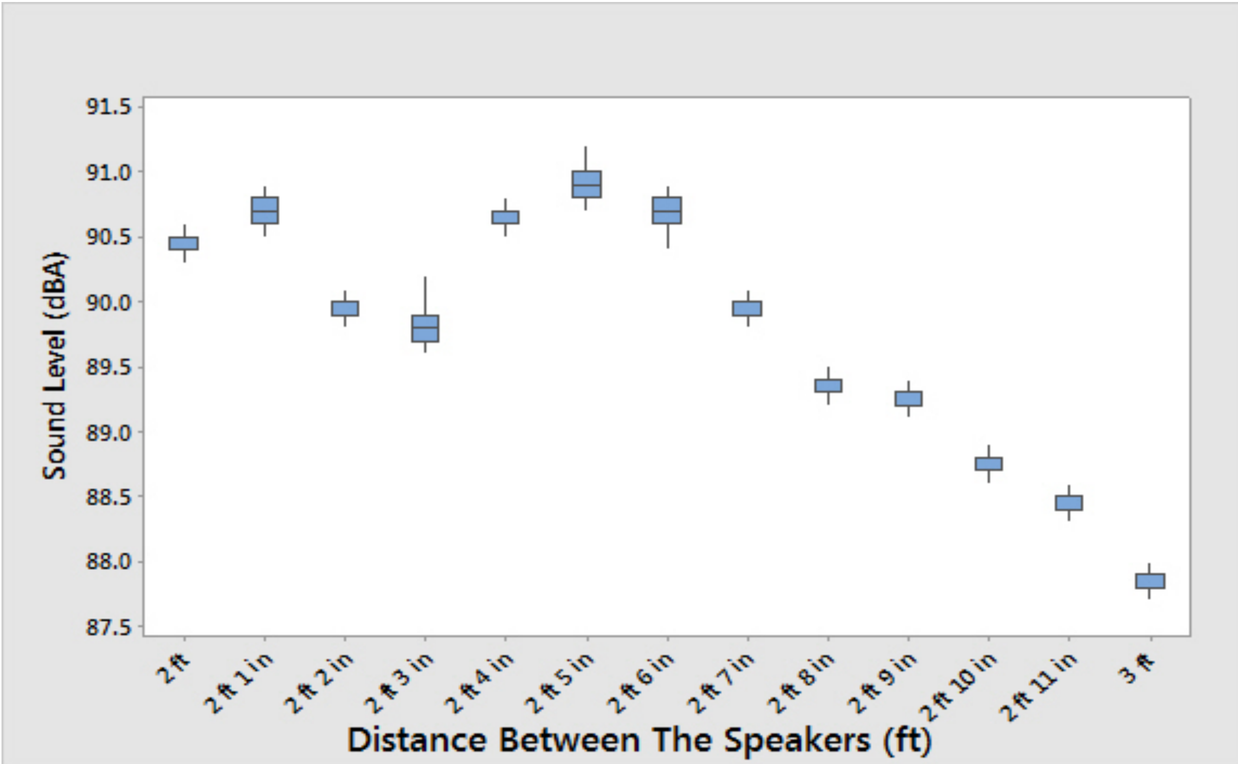
Appendix D:

Data Collection for Two Speakers at Different Space Distance

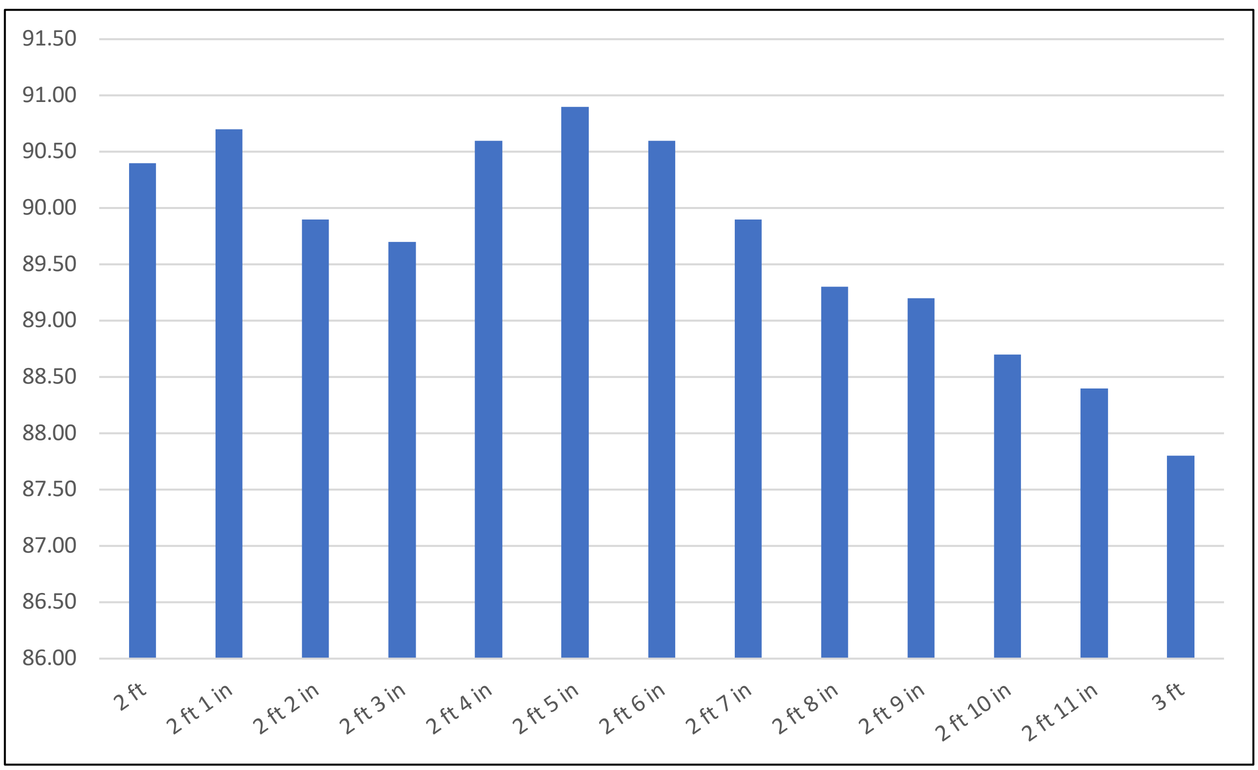
2ft	2ft 1in	2ft 2in	2ft 3in	2ft 4in	2ft 5in	2ft 6in	2ft 7in	2ft 8in	2ft 9in	2ft 10in	2ft 11in	3ft
90.50	90.70	89.20	90.00	90.50	91.00	90.80	89.90	89.30	89.00	87.40	88.00	87.10
90.50	90.80	90.20	90.10	90.70	90.90	90.70	89.90	89.40	89.20	88.00	88.40	87.30
90.50	90.80	90.00	90.20	90.80	90.90	90.80	90.00	89.40	89.30	88.60	88.50	87.90
90.40	90.70	90.00	90.10	90.70	91.00	90.70	90.00	89.40	89.30	88.60	88.50	87.90
90.30	90.60	89.80	89.90	90.50	90.90	90.60	89.90	89.20	89.20	88.80	88.40	87.80
90.20	90.50	89.80	90.00	90.40	90.70	90.40	89.80	89.20	89.00	88.80	88.20	87.70
90.10	90.60	89.80	89.90	90.40	90.70	90.50	89.80	89.10	89.10	88.80	88.20	87.70
90.30	90.50	89.80	89.20	90.50	90.70	90.50	89.70	89.20	89.00	88.90	88.20	87.70
90.30	90.50	89.90	89.60	90.50	90.70	90.50	89.80	89.20	89.00	88.80	88.20	87.70
90.40	90.60	90.00	89.70	90.60	90.80	90.60	89.80	89.30	89.10	89.00	88.30	87.80
90.40	90.70	90.00	89.70	90.60	90.80	90.60	90.00	89.30	89.20	88.90	88.40	87.80
90.40	90.80	90.00	89.70	90.60	90.90	90.60	89.90	89.30	89.20	89.00	88.40	87.90
90.50	90.70	90.00	89.80	90.70	90.80	90.60	89.90	89.40	89.20	88.80	88.40	87.90
90.50	90.80	90.00	89.80	90.70	91.00	90.80	90.00	89.30	89.30	88.70	88.50	88.00
90.60	90.80	90.10	89.90	90.80	91.00	90.70	90.00	89.50	89.30	88.80	88.50	87.90
90.50	90.90	90.00	89.90	90.80	91.10	90.80	90.10	89.40	89.40	88.80	88.60	88.00
90.60	90.80	90.20	89.90	91.00	91.10	90.80	90.00	89.60	89.40	88.80	88.60	88.00
90.60	90.90	90.00	89.90	90.90	91.20	90.90	90.20	89.50	89.50	88.60	88.70	88.10
90.50	90.80	90.20	89.90	90.90	91.00	90.80	90.00	89.50	89.30	88.70	88.50	88.00
90.50	90.90	90.00	89.80	90.80	91.20	90.90	90.10	89.50	89.50	88.70	88.70	88.10
90.40	90.70	89.90	89.80	90.70	90.90	90.70	90.00	89.30	89.30	88.80	88.50	87.90
90.40	90.70	90.00	89.70	90.70	90.90	90.70	89.90	89.40	89.20	88.70	88.40	87.80
90.40	90.80	90.10	89.80	90.70	90.90	90.70	90.00	89.40	89.30	88.70	88.50	87.90
90.50	90.80	89.90	89.70	90.70	91.00	90.70	90.00	89.40	89.30	88.80	88.50	88.00
90.30	90.60	89.80	89.60	90.60	90.90	90.60	90.00	89.30	89.20	88.90	88.40	87.80
90.30	90.60	89.90	89.80	90.70	90.80	90.60	89.90	89.20	89.10	88.70	88.30	87.80
90.40	90.70	90.00	89.70	90.60	90.90	90.70	89.90	89.30	89.20	88.80	88.40	87.80
90.50	90.70	90.00	89.70	90.70	90.90	90.60	89.90	89.40	89.20	88.60	88.40	87.80
90.50	90.80	90.00	89.70	90.60	90.90	90.70	90.00	89.30	89.30	88.80	88.50	87.90
90.50	90.80	90.00	89.70	90.60	90.80	90.60	90.00	89.30	89.20	88.80	88.40	87.90
90.40	90.70	90.00	89.80	90.70	90.90	90.60	89.90	89.40	89.20	88.70	88.40	87.90

Appendix E:

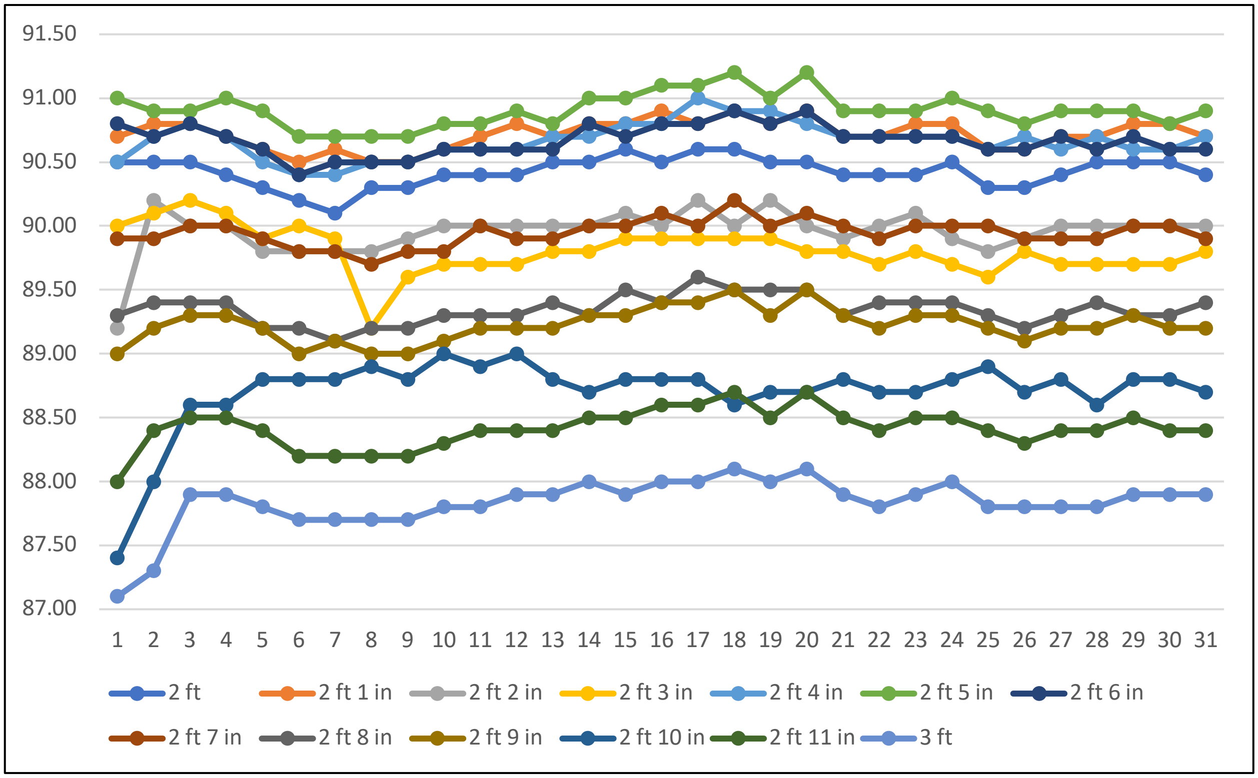
Two Speakers Noise Level Analysis



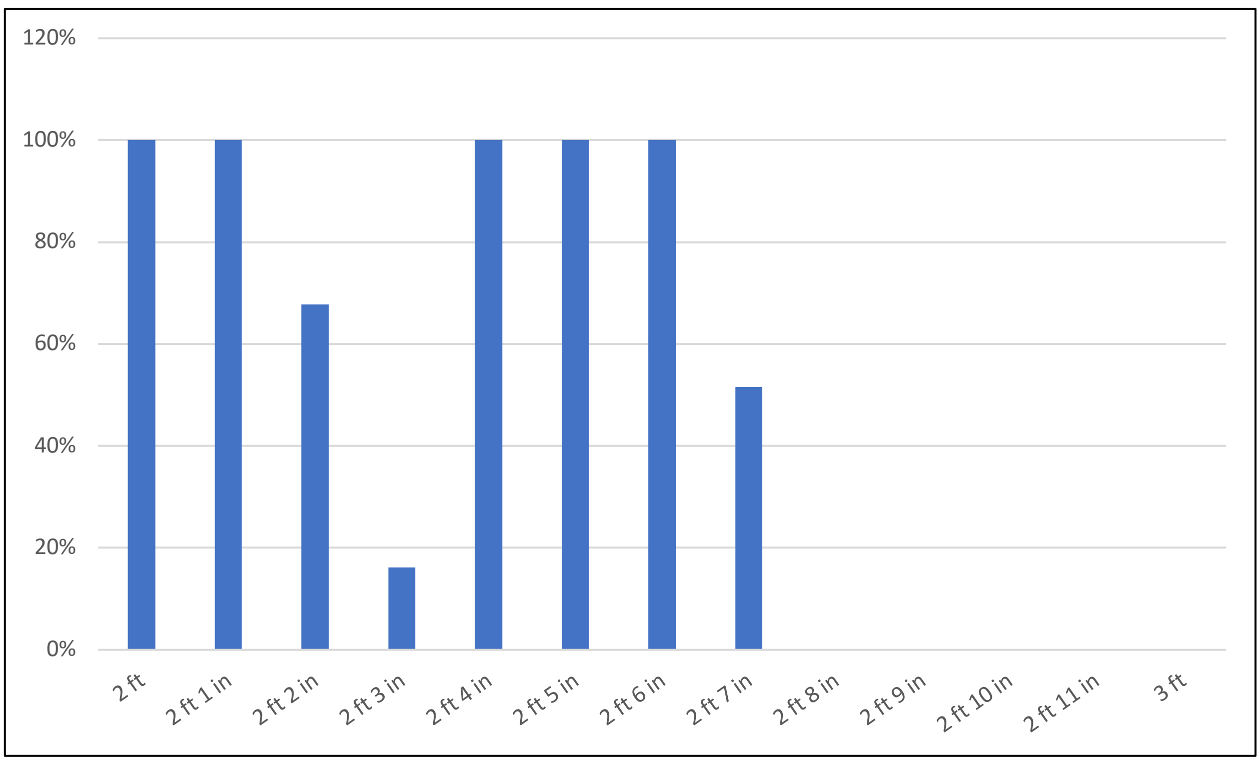
Box plot for sound level between two speakers.



Average value of the noise level for two speakers.



Real-time reading for the noise level of two speakers.



Percentage of sound level over 90 dBA for two speakers.

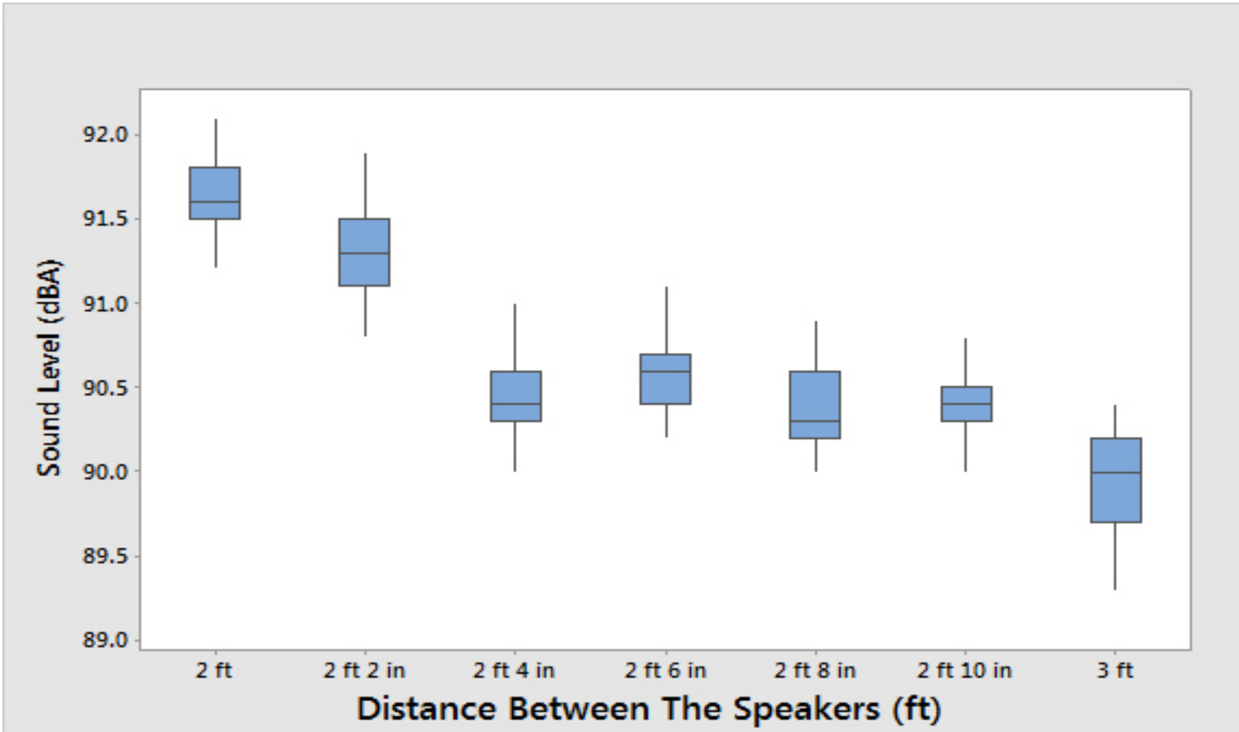
Appendix F:

Data Collection for Four Speakers at Different Space Distance

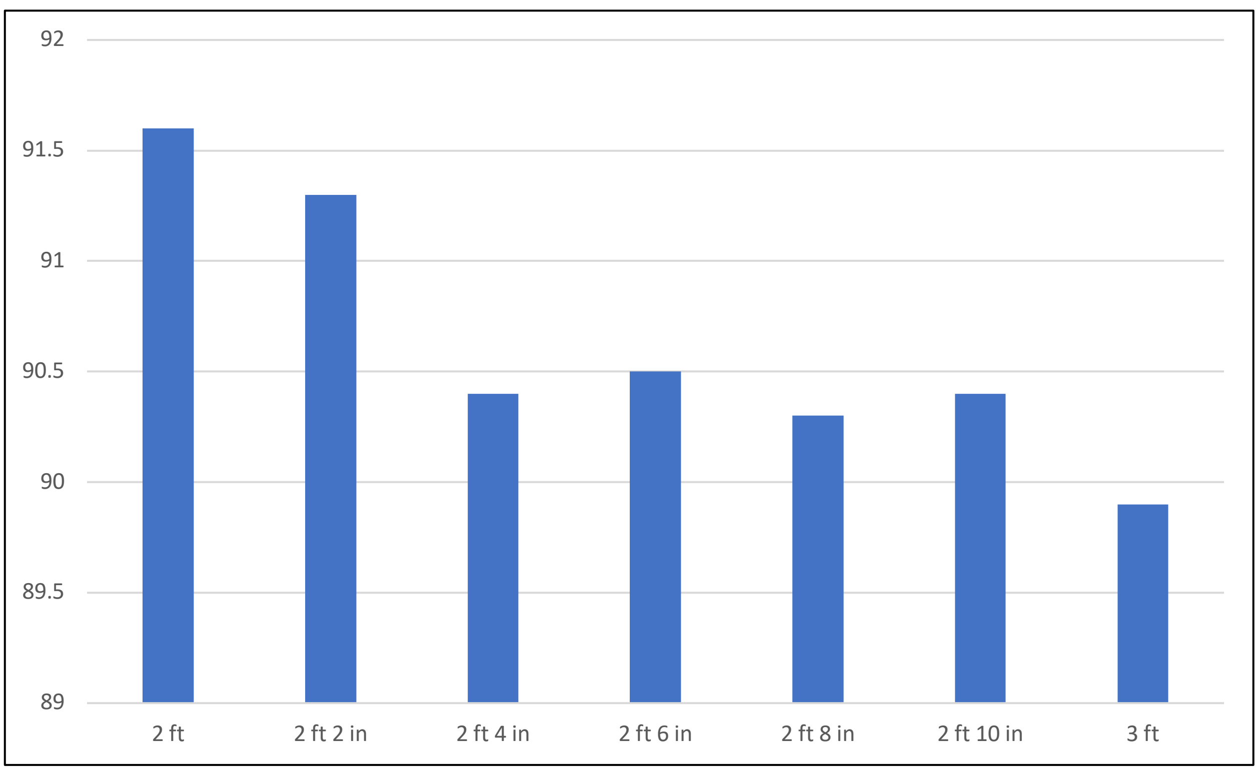
2ft	2ft 2in	2ft 4in	2ft 6in	2ft 8in	2ft 10in	3ft
91.50	91.10	90.40	90.30	90.40	90.20	89.30
91.60	91.30	90.40	90.70	90.60	90.30	89.50
91.90	91.60	90.50	90.80	90.30	90.70	89.80
91.50	91.30	90.60	90.60	90.10	90.40	89.60
91.40	91.10	90.30	90.40	90.10	90.30	89.40
91.30	91.00	90.10	90.30	90.00	90.10	89.30
91.20	90.90	90.10	90.20	90.00	90.10	89.40
91.20	90.90	90.10	90.30	90.10	90.10	89.70
91.20	90.80	90.00	90.30	90.50	90.00	89.60
91.60	91.10	90.10	90.80	90.30	90.30	89.90
91.60	91.50	90.60	90.40	90.20	90.50	90.10
91.50	91.20	90.30	90.50	90.50	90.30	89.90
91.90	91.40	90.20	90.80	90.40	90.50	90.10
91.50	91.40	90.60	90.60	90.90	90.40	90.10
92.00	91.50	90.40	91.20	90.40	90.70	90.20
92.00	91.80	91.10	90.60	90.60	90.80	90.40
91.90	91.40	90.60	90.90	90.30	90.60	90.20
91.70	91.50	90.80	90.50	90.60	90.50	90.20
91.60	91.20	90.40	90.80	90.30	90.50	90.00
91.60	91.40	90.70	90.60	90.20	90.50	90.20
91.50	91.10	90.40	90.50	90.50	90.30	89.90
91.60	91.20	90.40	90.60	90.60	90.40	90.00
91.70	91.40	90.60	90.70	90.30	90.40	90.10
91.80	91.40	90.70	90.70	90.10	90.60	90.20
91.40	91.20	90.40	90.30	90.30	90.30	90.00
91.40	91.20	90.20	90.40	90.50	90.30	89.90
91.60	91.20	90.40	90.70	90.60	90.40	90.00
91.80	91.50	90.60	90.70	90.80	90.50	90.10
91.90	91.60	90.70	91.10	90.20	90.60	90.20
92.10	91.90	91.00	90.50	90.30	90.80	90.40
91.50	91.20	90.40	90.50	90.60	90.30	89.90

Appendix G:

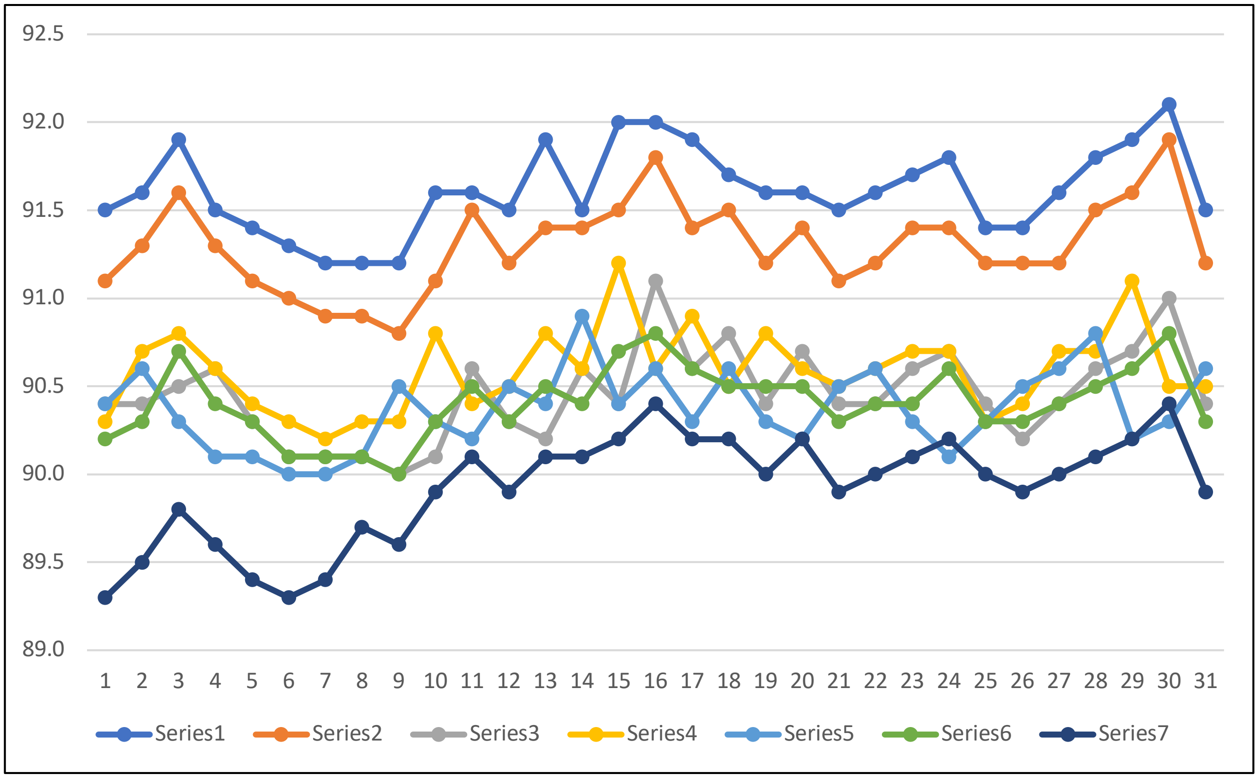
Four Speakers Noise Level Analysis



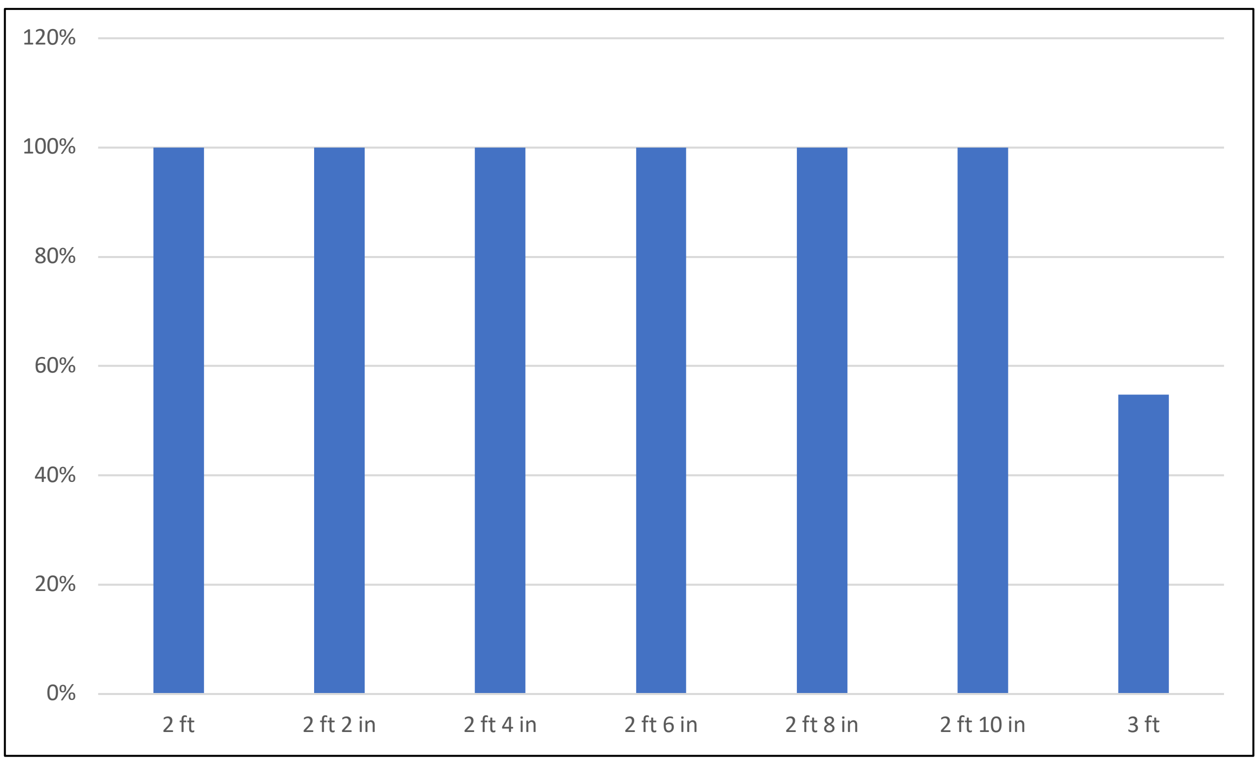
Box plot for sound level between four speakers.



Average value of the noise level for four speakers.



Real-time reading for the noise level of four speakers.



Percentage of sound level over 90 dBA for two speakers.

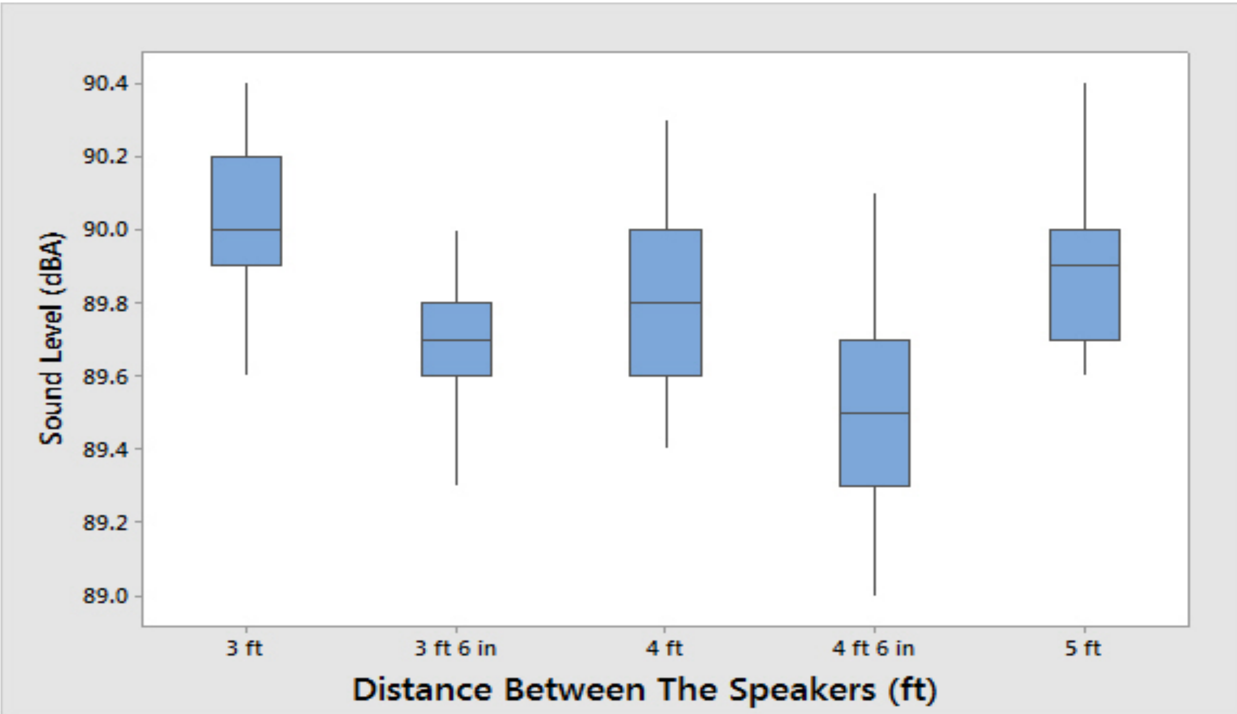
Appendix H:

Data Collection for Four Speakers at Different Space Distance

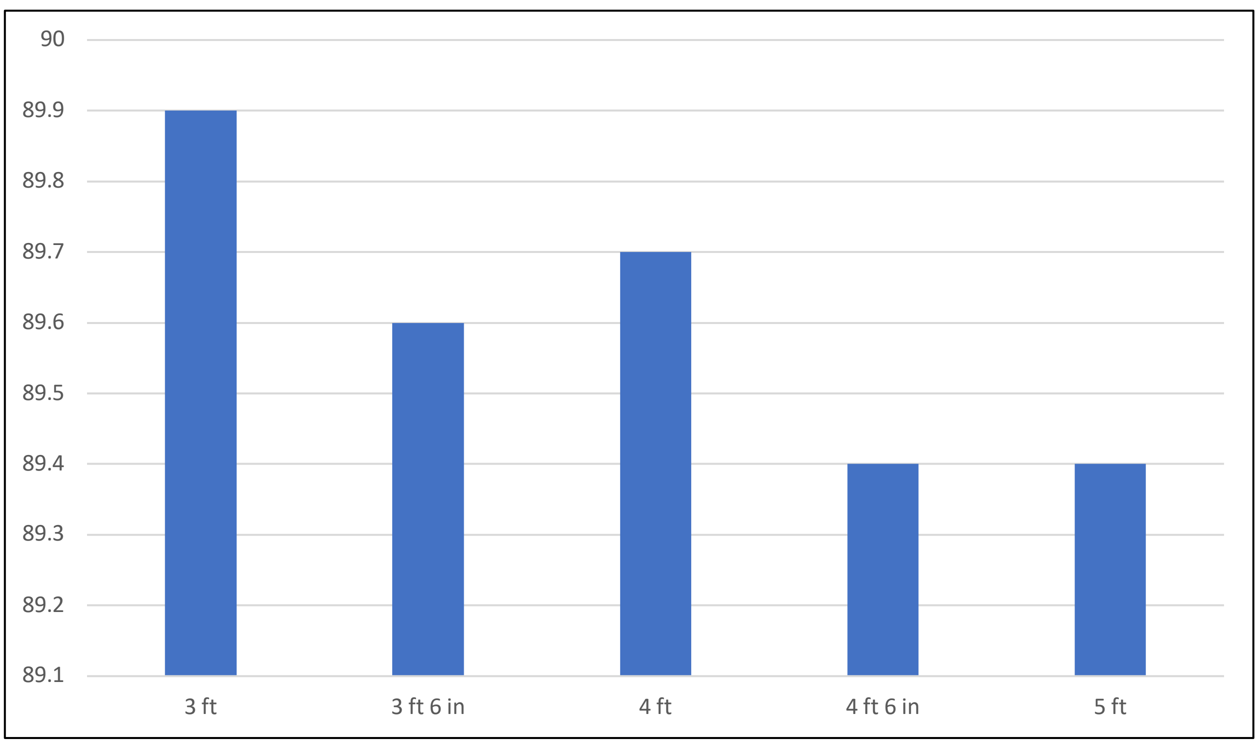
3ft	3ft 6in	4ft	4ft 6in	5ft
90.00	89.60	89.70	88.20	90.50
90.00	89.70	89.80	89.40	90.40
90.20	89.90	89.40	89.50	90.30
90.10	89.60	89.50	89.60	90.20
89.80	89.50	89.50	89.30	90.10
89.70	89.30	89.40	89.20	90.10
89.60	89.30	89.40	89.10	90.10
89.80	89.40	89.60	89.10	90.00
89.60	89.20	90.00	89.00	90.00
90.10	89.60	89.80	89.20	90.00
89.80	89.80	89.70	89.70	90.00
89.90	89.60	90.00	89.50	89.90
90.20	89.90	89.90	89.40	89.90
90.00	89.70	90.30	89.80	89.90
90.40	89.90	89.90	89.50	89.90
90.20	90.00	90.10	90.00	89.90
90.30	89.80	89.70	89.60	89.90
90.00	89.80	90.00	89.70	89.80
90.10	89.70	89.80	89.40	89.80
90.10	89.80	89.60	89.60	89.80
90.00	89.60	89.90	89.50	89.80
90.00	89.60	90.00	89.30	89.80
90.00	89.80	89.60	89.70	89.80
90.20	89.70	89.60	89.70	89.70
89.90	89.40	89.80	89.30	89.70
89.80	89.60	90.00	89.30	89.70
90.00	89.60	90.00	89.40	89.70
90.20	89.80	90.30	89.70	89.70
90.40	89.90	89.80	89.70	89.60
90.00	90.20	89.80	90.10	89.60
89.90	89.60	90.00	89.40	89.60

Appendix I:

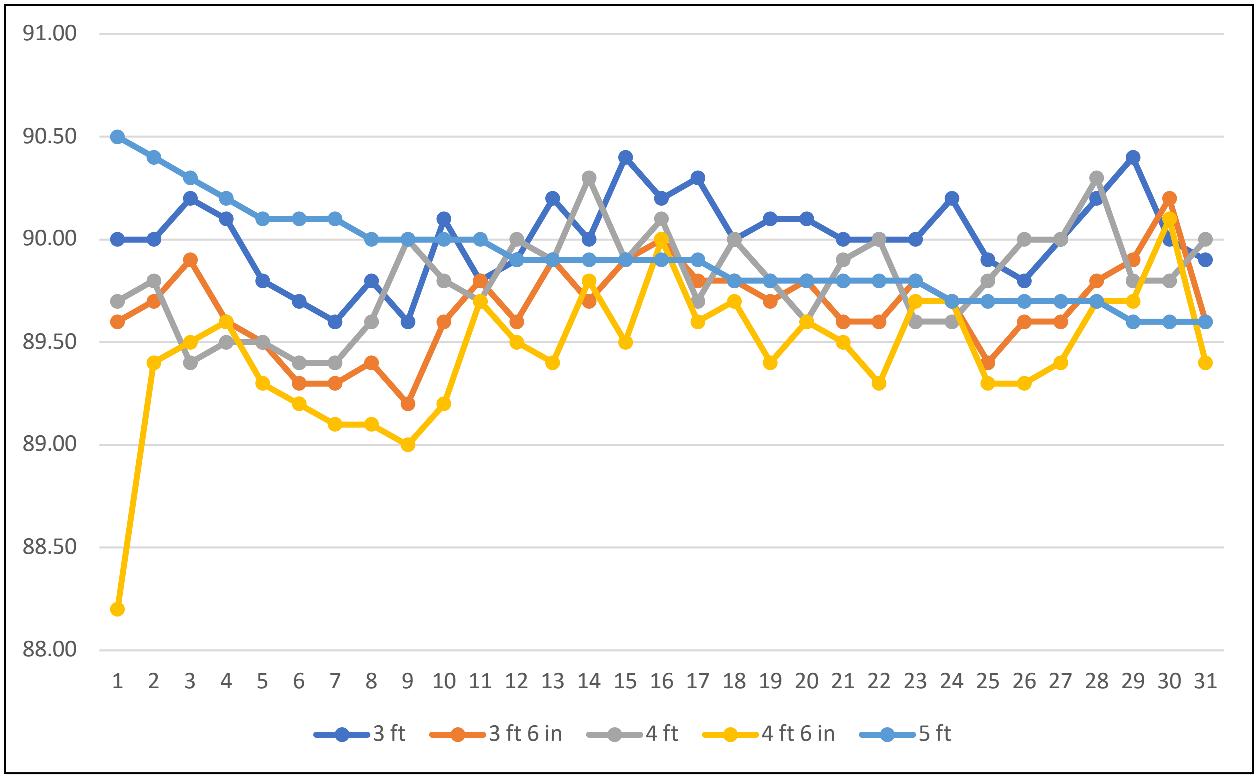
Six Speakers Noise Level Analysis



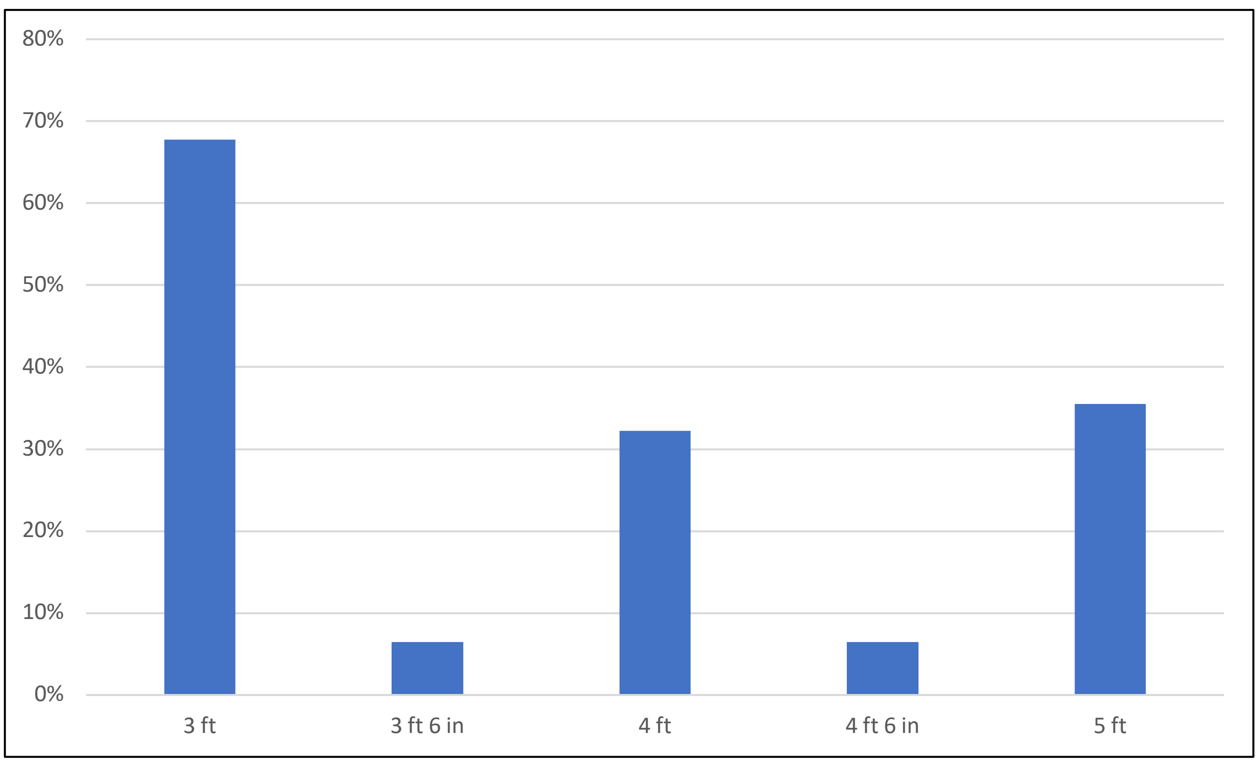
Box plot for sound level between six speakers.



Average value of the noise level for six speakers.



Real-time reading for the noise level of six speakers.



Percentage of sound level over 90 dBA for six speakers.

VITA

Ahmed Noori Al-Naami
12800 Harrisglenn Drive
Austin, Texas, 78753
(512) 971-0465

Education

St. Mary's University San Antonio Texas
Master of Science in Engineering System Management - December, 2017

National University Malaysia
Doctorate of Philosophy in Electrical Electronic and System Engineering - December, 2011

Al-Nahrain University
Master of Science in Communication Engineering - December, 2006

Al-Nahrain University
Bachelor of Science in Electronic and Communication Engineering - September, 2003

Work Experience

MEC College, Muscat, Oman
January 2013 – February 2015
Assistant Professor

Al-Madinah International University, Selangor, Malaysia
October 2010 – January 2013
Assistant Professor