A Simulation Based Approach of Characterizing Acoustic Feedback In Public Address System

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Abstract: - Public address system had been in use for a very long time. Since it was first developed, it has evolved from analog public address system to digital public address system. Either analog or digital public address system, its general purpose is to allow efficient communication in a large number of crowd. The object of the public address system is to amplify the received acoustic signal. However, throughout the history of public address system, it had been plagued by problems. One of the problems in public address system is the existence of positive feedback which severely affects the quality output signal. This paper examines the characteristic of acoustic feedback through simulation. The public address system and the acoustic feedback path was based on a low pass finite-impulse-response (FIR) filter. The simulation was performed by increasing slowly the gain of the public address system until the output signal grows exponentially and uncontrollably. The output signal of the public address system with the gain to which it behaves uncontrollably was compared with the output signal of the public address system with a gain 3dB lower. Simulation results show that the acoustic feedback signal has a fixed few narrow frequency components and one of its frequency components dominates the rest of time. Furthermore, it was observed that the public address system with music applied as input acoustic signal and with the existence of acoustic feedback path will have an approximate output signal that is a linear sum of the acoustic feedback signal and music signal. However, the existence acoustic feedback is unpredictable thus its characteristic is hard to quantify. With this, classical way of filtering or signal suppression is inefficient in dealing with the existence of acoustic feedback.

Key-Word: - Feedback, Acoustic Feedback Path, Acoustic Feedback, Howling, Public Address

1 Introduction

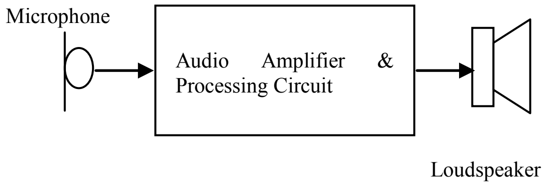


Figure 1 Structure of a basic public address system

Electronics has a very long history up to this date. It covers a wide range of application. One of the applications of electronics is communication. Since then, people always communicate with one another for the reason of trade. People communicate because they want to exchange thoughts, technology, or any form of resources. Over history, communication between people to people have grown significantly in terms of distance and numbers. To overcome the problems in communication associated with distance and numbers are that people make use of electronics. With the use of electronics, a person was now able to communicate across a distance or were able to convey an information addressing to a considerable number of people. One of the technologies that use electronics and was developed of addressing the problems in communication is public address system. [1] The public system is an electronic device that amplifies a received sound signal using microphone, amplifier, and loudspeaker.

The public address has been in use by people way back before ancient periods. However modern public address system which accepts acoustic signal, convert it to electrical energy and amplify, then convert the amplified electrical energy into acoustic energy. It was first publicly demonstrated by Jensen and Pridham of Magnavox. On the day before Christmas in the year 1915 in San Francisco CA, a Christmas concert was held on the grounds of the City Hall. The concert was attended by an estimated crowd number of 100000. To ensure that the estimated crowd number of 100000 be able to hear the music and speeches, Jensen and Pridham of Magnavox installed a electronics system composed of microphone, amplifier, and loudspeaker. Although the installed electronic system was only able to produce an estimated audio power of 10W, the use of horn loudspeakers helped ensure that the crowd heard the music and speeches with a degree of clarity and loudness. Since then public address system has been in use of conveying information to a large number of crowd in orchestras, cinemas, theatre, churches, schools, airports, and others alike.

A public address system is an electronic sound amplification and distribution system. A basic public address system is shown in Fig. 1. [2][3] It is composed of a microphone, power amplifier, audio processing circuit and a loudspeaker. The microphone captures the acoustic signal from the person addressing the crowd and convert it to electrical energy. The electrical signal will then be amplified by an electronic power amplifier. Then the amplified electrical energy will then be converted to acoustic signal using a loudspeaker. Often a public address system has an added audio processing circuit. The audio processing circuit is added to ensure a superior audio quality.

[4][5]The public address system can be mathematically modeled as a low pass filter as shown in equation (1). Equation (1) is a mathematical expression of a finite-impulse-response (FIR) filter. With its coefficients has to be set first in order to act as a low pass filter.

$$G(z) = \sum_{k=0}^{K} g_k z^{-k} \tag{1}$$

With the development of discrete electronics and with its rapid decrease in cost, it resulted in the development of digital devices from analog ones. Among those is a digital public address system. Digital public address system is now widely used in the society. [1] Compared to the traditional public address system, modern digital public address system has an added digital audio processing circuit intended to increase the fidelity and signal-to-noise ratio of the said system. The audio digital signal processor in public address system may perform audio enhancement and noise filtering and cancellation. [1] Some modern digital public address system also supports multicast oriented addressing broadcasting, which can achieve environmental broadcasting requirement. While other public address systems now support wireless communication protocols, text-to-speech and voice recognition capability. The use of some advancement, allows public address system to be used in a metropolitan wide disaster risk reduction management. [3] An example of this is in Korea. In Korea building are required by the government to have an installed public address system to be used in case of emergency.

For a century of history of public address system, modern public address system is still plagued by problems which affect its fidelity, amplification, sound integrity and quality. One of this problem that severely affects the performance of public address system is the presence of a positive feedback.

This paper is intended to present the effects of positive feedback in public address system. The structure of this paper is as follows. In section 2, a review of acoustic feedback in public address system is discussed. Section 3 discusses the methodology used to simulate characterize the acoustic feedback in public address system. The results of the simulation are presented in section 4 and finally, a conclusion is drawn in section 5.

2 The Acoustic Feedback

Using public address system, received acoustic signal by the microphone is amplified by a power amplifier then converted back to an acoustic signal by a loudspeaker with much larger energy compared to the received acoustic signal by the microphone. Because of the acoustic signal has a huge amount of energy coming from the loud speaker, most of this is being feedbacked to the microphone.

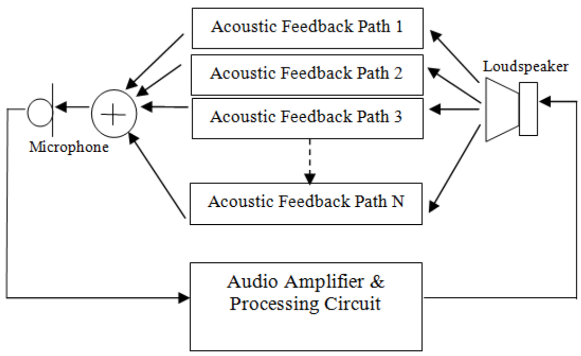


Figure 2 Acoustic feedback in public address system

[6]Usually, microphones and the loud speakers are placed in such a way that the acoustic signal from the loudspeaker is not being picked up by the microphone. [4]However, it is inevitable that the acoustic signal from the loudspeaker sound will be not be reflected by the boundaries such as walls and ceilings. These reflections are sometimes being picked by the microphone which causes acoustic feedback. Acoustic feedback is a positive feedback that occurs when the acoustic signal from the loudspeaker is being picked up by the microphone through acoustic feedback paths as shown in Fig. 2. Acoustic feedback paths are of finite numbers that are classified as direct acoustic feedback path and others are indirect acoustic feedback paths. [7]Acoustic feedback path also includes the

characteristic of the microphone, the loud speaker, the audio processing circuit and the audio amplifier. Direct acoustic feedback path directly couple the microphone and the loudspeaker in which it offers a direct path of the acoustic signal from the loudspeaker to the microphone. While indirect acoustic feedback paths are those acoustic feedback path that permits acoustic signal from the loudspeaker to be reflected several times before is being picked up by the microphone. [8] On the other hand, the forward path includes the characteristic of the amplifier as well as of any other devices within the microphone and the loudspeaker.

[7]The acoustic feedback path is composed of a direct acoustic feedback and several acoustic feedback path. Equation (2) describes that the acoustic feedback path F(z) is a linear sum of several acoustic feedback path $F_N(z)$ which consist of direct feedback path and N numbers of the indirect acoustic feedback path. [7]Meanwhile, the acoustic feedback $F_N(z)$ is usually represented by a finite-impulse-response (FIR) low pass filter and is described in equation (3). Thus, using equation (2) which defines the acoustic feedback path as the linear sum of the direct and several indirect acoustic feedback path and equation (3) which describe the acoustic feedback path as an FIR low pass filter, the overall acoustic feedback path is presented in equation (4) and can be in matrix form as shown in equation (5). Where $f_{N,M}$ are coefficients of the room-impulse-response (RIR).

$$F(z) = \sum_{n=0}^{N} F_n(z) \tag{2}$$

$$F_N(z) = \sum_{m=0}^{M} f_{N,m} z^{-m} \tag{3}$$

$$F(z) = \sum_{n=0}^{N} \sum_{m=0}^{M} f_{n,m} z^{-m} \tag{4}$$

$$F(z) = \begin{bmatrix} f_{0,0} & f_{0,1} & \cdots & f_{0,M} \\ f_{1,0} & f_{1,1} & \cdots & f_{1,M} \\ \vdots & \vdots & \vdots & \vdots \\ f_{N,0} & f_{N,1} & \cdots & f_{N,M} \end{bmatrix} \begin{bmatrix} 1 \\ z^{-1} \\ \vdots \\ z^{-M} \end{bmatrix} \tag{5}$$

The occurrence of acoustic feedback is a problem in public address system because it is very annoying. [9] It affects system's performance by limiting the gain of the amplifier and deteriorates sound quality. [10] Also, the occurrence of acoustic feedback is unpredictable and usually varies with time. This is because of the direct and several multiple acoustical paths between the microphone and loudspeaker.

The acoustic feedback path model F(z) is linear, time varying, and of finite order. F(z) is said to be linear since the effects of sound propagation and reflections in the acoustic environment are quasi-level independent. While it said to be of finite order because typical room impulse response (RIR) has an exponentially decaying envelope such that it can be truncated.

Consider a single a channel public address system G(z) with a direct acoustic feedback path F(z) and the indirect acoustic feedback path is assumed to be negligible. The closed loop transfer function of the said system is shown in equation (6). Where *v*(z) is the acoustic input signal and *y*(z) is loudspeaker output signal.

$$\frac{v(z)}{y(z)} = \frac{G(z)}{1 - G(z)F(z)} \tag{6}$$

According to Nyquist, a system is said to be stable if the magnitude of the open-loop transfer function is not greater than or equal to one or the overall phase shift is not an integer multiple of 2π. However, the system is said to be unstable when the magnitude of the open loop transfer function of the public address system is greater than or equal to 1 and the overall phase is an integer multiple of 2π. Equation (7) and equation (8) are the two conditions of Nyquist that needs to be satisfied in order for a system to be unstable.

$$|G(z)F(z)| \geq 1 \tag{7}$$

$$\angle G(z)F(z) = 2\pi \tag{8}$$

Equation (7) shows that when an acoustic signal from the loudspeaker does not decay over time because when the microphone pickups the acoustic signal from the loud speaker, it will then again re-amplified and restore its magnitude larger than before by a power amplifier. Thus, the acoustic signal will grow larger and uncontrollably as it goes with the cycle over time. Meanwhile, if the overall phase shift of the system is an integer multiple of 2π, this will cause the acoustic feedback and the acoustic input signal to add up before it will be picked up by the microphone. Since acoustic feedback and the acoustic input signal are said to be highly correlated, the result when the overall phase shift is an integer multiple of 2π is the tendency to reproduce of a much larger acoustic signal at the loudspeaker and will grow larger and uncontrollable. This is because the acoustic feedback signal and the acoustic input signal aids with one another before it will be picked up by the microphone then amplified to a much larger amplitude by the power amplifier.

Acoustic feedback is classified as an unwanted signal that is very noisy and annoying to the talker and the listener. [10] The difference between the acoustic feedback signal and the acoustic input signal of the public address system is that acoustic input signal shows randomly distributed periods, while acoustic feedback signal is consistently repeated periods. This means that when acoustic feedback occurs, the audible annoying acoustic signal is a monotone in which the loudness increases uncontrollably.

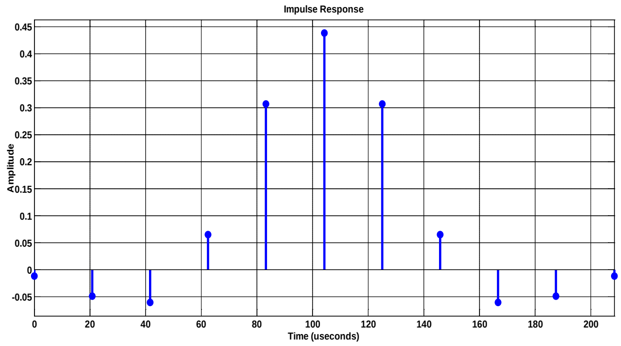
3 Methodology

In this paper, the effect of acoustic feedback on the performance of the public address system will be investigated using a simulation model. The model of the public address system used in the simulation was based on a low pass 10th order FIR filter G(z). The low pass filter that serves as a model of G(z) has a cutoff frequency of 10kHz. The impulse response and Bode plot of G(z) are shown in Fig. 3.

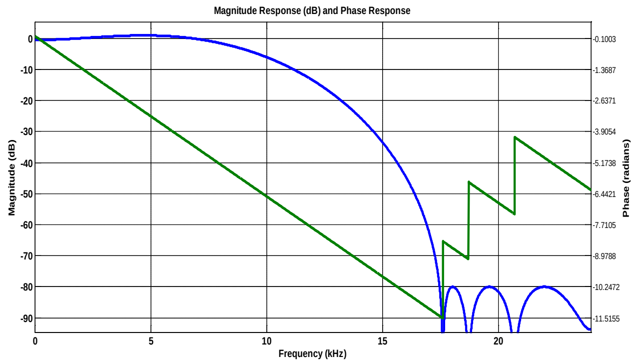
Meanwhile, the simulation considers the acoustic feedback as the sum of direct feedback path and indirect feedback paths as described in equation (2). With each feedback path can be modeled as a low-pass FIR filter as described in equation (3). Then the overall acoustic feedback path can be modeled as a low pass FIR filter. The model of the acoustic feedback path used in this paper was assumed to be on a 300th order low pass FIR filter with the impulse response and Bode plot shown in shown in Fig. 4.

During simulation, the public address system G(z) takes it input from the linear sum of the acoustic feedback signal *f*(z), audio input signal *v*(z). The sum will pass through public address system G(z) and will be amplified. The output of the public address system will be sum up with noise signal *n*(z) and will pass through acoustic feedback path F(z).

Without input signal, the gain of the public address system G(z) was slowly increased. As the gain of G(z) was slowly increased until the overall system exhibit an unstable behavior, the signal *y*(z) was then recorded and observed through spectrograph and spectrum analyzer for analysis on the performance of public address system and visualization of the characteristic of the acoustic feedback signal. Then the output signal of the public address system with a gain of G(z) that makes it unstable was be compared with an output signal of G(z) 3dB lower to its previous gain. In addition, the output signal under the influence of acoustic feedback signal was visualized using spectrum analyzer and spectrograph to characterize the acoustic feedback signal.

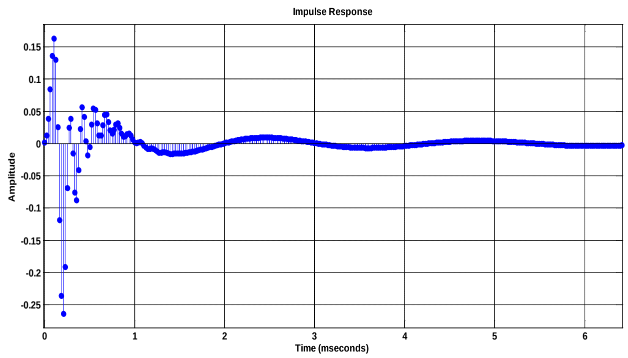


(a)



(b)

Figure 3 (a) Impulse Response of G(z), Bode plot of G(z)



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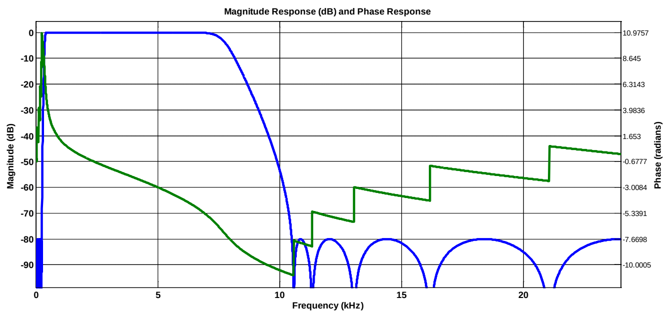


(b)

Figure 4 (a) Impulse Response of F(z), Bode plot of F(z)

The simulation of the public address system without input signal was redo twice at different gains, this time with recorded input signal. The gain of the public address system was set to which howling will occur and at 3dB lower. The output of the public address system was then observed using a spectrogram and results were compared. This will show how the acoustic feedback affect affects the information signal applied on t he public address system

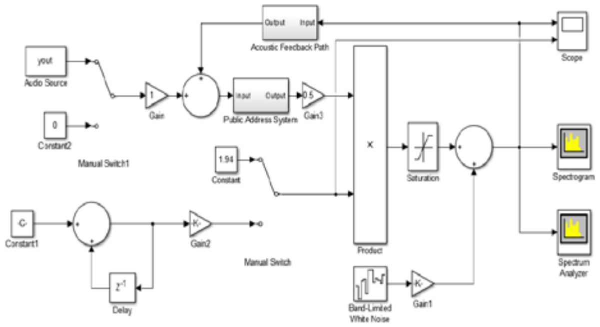


Figure 5 The simulation setup

4 Results

The public address system takes an input from the sum of the noise signal and the acoustic feedback signal. The noise signal at the output of the public address system, represent the noise signal that affects the output of the loud speaker. The output signal of the public address system with the noise signal is inputted to the acoustic feedback path.

The block diagram in Fig. 5 was then simulated using Simulink with a sampling frequency of 48kHz, Then the gain of the public address system was slowly increased by 0.5/s. The output of the public address system was recorded and observed with respect to the input signal and the gain of the public address system. The output signal of the public address system is shown in Fig. 6. Simulation results in Fig. 6 show that at less than 3.0s the output signal of the public address system does not grow exponentially even as the gain of the public address system is slowly increased. Simulation results in Fig. 6 also show that the output signal of the public address system nearly maintains a constant amplitude. However, when simulation time reaches 3.5s, results in Fig. 6 shows that the amplitude of the public address system's output signal grows exponentially and at 4.2s Fig. 6 shows that the output signal grows uncontrollably. This means that the public address system G(z) used in this simulation if it had a gain of greater than or equal to 2.0, i t will exhibit an unstable and an uncontrollable behavior.

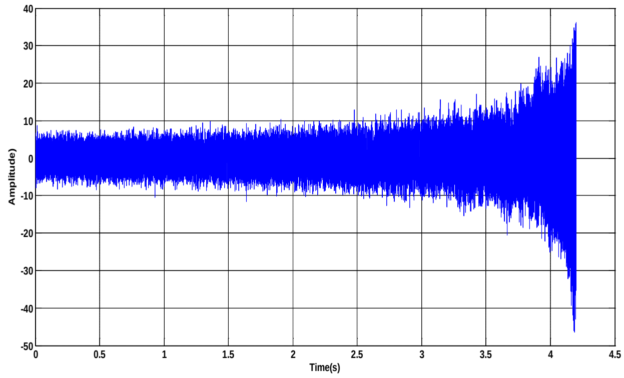
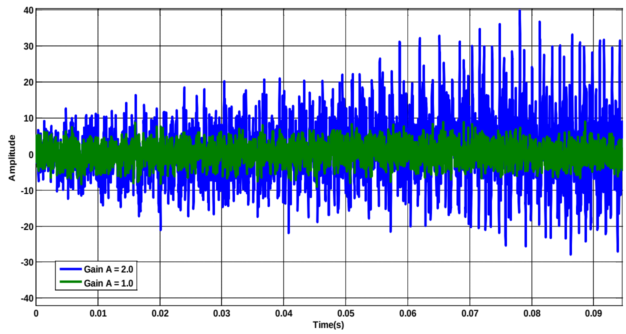


Figure 6 Public address system output with gain increases at 0.5/s



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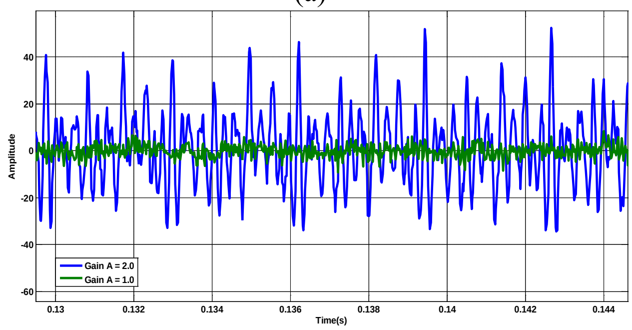

(b)

Figure 7 Comparison of two public address system output signal with gains at 2.0 and 1.0

Comparing the output signal of the public address system with fixed gains, one is set at 2.0 which makes the public address system unstable and the other gain is 1.0. The result is then shown in Fig. 7. In F ig. 7a shows that the public address system with a gain of 1.0 ha s an output signal that is bounded. While the public address system with a gain of 2.0, Fig. 7a shows that the output signal gradually increases with time and shows no sign of having a stable output signal. Furthermore, looking at a narrow time frame on t he comparison of between two public address system, its shows that as the output signal of the public system with a gain of 2.0 g rew larger, the output signal becomes periodic as shown in Fig. 7b. This shows that the output signal of the public address system with of

2.0 have some sinusoidal components that do decay and remains dominant throughout time.

Taking the frequency spectrum at 2.0s and spectrogram of the output signal of the public address system with a gain of 2.0, results are shown in Fig. 8 and Fig. 9. Results show that there are only few frequency components that dominate the audible frequency band. In addition, these dominant frequencies will continue to grow over time until the public address system saturates. This is because the overall system satisfies the two Nyquist criterion for instability. However, there is only a single frequency that dominates the rest as shown in Fig. 8. The dominant frequency components as shown in Fig. 8 are the components of the acoustic feedback signal. If implemented in real time, these dominant frequency components are the audible monotone annoying signal.

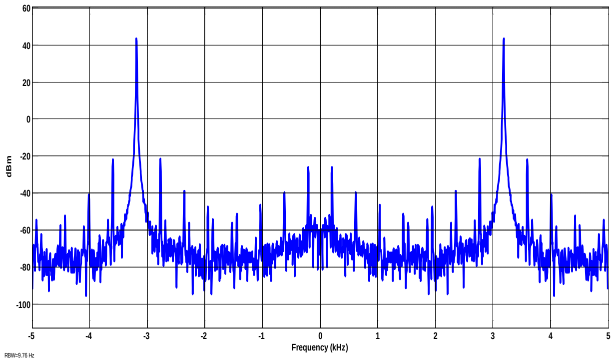

Figure 8 Frequency spectrum of the output signal of the public address system at 2.0s.

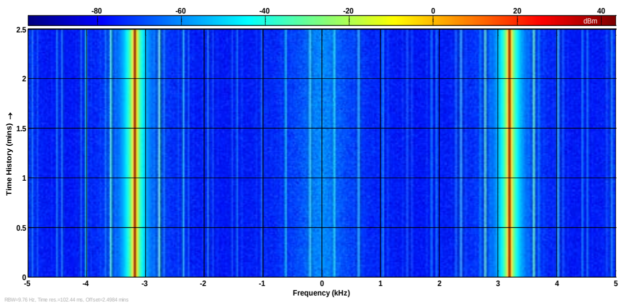

Figure 9 Frequency spectrum of the output signal of the public address system at 2.0s.

Simulation results in Fig. 9 further show that the frequency components of the acoustic feedback signal remain dominant over time. When compared to the acoustic input signal shown in the background of Fig. 9, it shows that the magnitude of each frequency components varies with time and does not remains constant over a long period of time. In addition, considering the magnitude of the frequencies shown in Fig. 8, simulation results show that the acoustic feedback signal at specific frequency components overshadows the acoustic input signal of the public address system. However, in reality, acoustic feedback path may change unpredictably as the talker may walk from one place to the other. This means that acoustic feedback signal frequency components may unexpectedly change as the talker moves from one place to the other

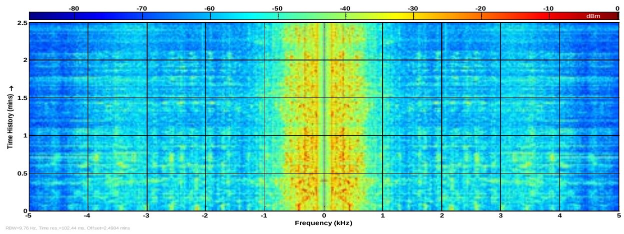

Figure 10 Spectrograph of the music signal of the public address system without howling signal based on simulation

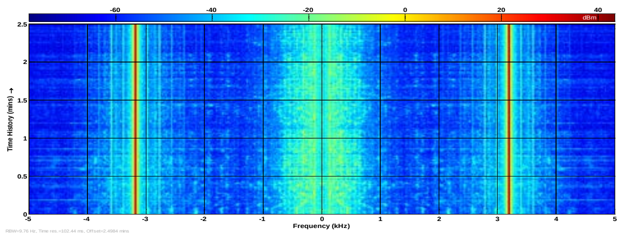

Figure 11 Spectrograph of the music signal of the public address system with howling signal based on simulation

A recorded music signal was then applied to the model of the public address system with a gain of 1.0. The output signal was then observed by a spectrogram and the result is shown in Figure 10. Comparing Fig. 10 with Fig. 9, it can be seen that howling characteristic observed in Fig. 9 could not be found in Fig. 10. In Fig. 10, spectrogram results of the music signal without howling shows that the dominant frequency components within a period of 2.5 minutes were spread within the frequency band of approximately 100Hz to 600Hz for a short period of time. This means that none of the frequency components within the frequency band of 100Hz to 600Hz remains dominant for a long period of time. On the other hand, when the gain of the public address system was increased to 2.0 and the music signal was reapplied, the spectrograph of the output signal is shown in Fig. 11. Result in Fig. 11 shows that the narrow frequency band with a very high magnitude observed in Fig. 9 is seen on the same frequency band with exactly the same characteristic. Furthermore, it was observed that result in Fig. 11 is approximately as the linear sum of the results observed in Fig. 9 and Fig. 10. Thus it can be seen in Fig. 11 that acoustic feedback signal neither eliminate nor suppressed the information signal but rather it only overshadows the information signal during its existence. With this, eliminating only the frequency band to which acoustic feedback signal by incorporating acoustic feedback cancellation methodologies may further improve the intelligibility of the information signal at higher gain of the public address public address system.

5 Conclusion

In public address system, the acoustic signal from the talker is being received by the microphone. Then it will be amplified by the power amplifier. The amplified signal will then be converted back to an acoustic signal by a loudspeaker, this time with much larger compared to the input signal. Because the output signal of the loudspeaker has a greater amount of energy, some of it is being picked up by the microphone and adds up t o the acoustic input signal and be amplified by the power amplifier. Then an output signal with the component of the feedback signal will be outputted by the loudspeaker.

Simulation results shown in this paper shows that when the gain of the public address system is continuously increased, there is a point in time where the public address system's gain is sufficient enough to produce an output signal that can be picked up by the microphone, thereby producing a positive feedback. T he existence of the positive feedback in public address system causes the system to exhibit an unstable behavior. Thereby, producing an uncontrollable output. Simulation results further show that this uncontrollable output of the public address during the existence of positive feedback have a few frequency components that dominate the rest of the frequencies in the audible band. It further shows during simulation that the frequency components that dominate the rest of the audible band during the existence of positive feedback remain fixed over time. It also shows the frequency components that dominate the rest of the audible frequency band, there is a single frequency component that dominates all and remains fixed over time. These frequency components that dominate the rest of the audible frequency band overshadow the acoustic input signal which causes severe acoustic interference and is very annoying.

Simulation results in this paper show that the acoustic feedback signal frequency components remain fixed over time. However, it is quite difficult to eliminate the annoying acoustic feedback signal using only the classical method of filtering and signal suppression because it hard to determine the gain of the public address system to which a positive feedback will occur. A lso, acoustic feedback path may vary with time due to the movement and position of the talker, environmental conditions, and characteristics of the room. Furthermore, it is hard to quantify the frequency component of the acoustic feedback signal.

Acknowledgement
The authors of this paper would like acknowledge the contribution of Altera Inc. now Intel FPGA. Altera Inc. provides development boards and software licenses which was extensively used on this work and make this work possible. This work was carried out at the Special Application Laboratory of the Department of Electronics and Electrical Engineering of the University of San Carlos. This work was also in collaboration of the faculties of the Department of Electronics and Electrical Engineering of the University of San Carlos in Cebu City and Eastern Visayas State University in Tacloban City Philippines.

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