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Trends in Acoustic Feedback Suppression Methods

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Abstract: In audio amplifier systems, the acoustic feedback causes howling noise, which affects the quality of the audio signal. Detection and suppression of this howling noise is a requirement in Public Addressing (PA) systems, hearing aids, and telecommunication systems. The nature of howling signals, their spectrum, and effects on speech signal have been studied and presented in this paper. This paper also reviews the methods used for howling detection, and suppression in an acoustic environment. By adjusting the gain and altering the positions of the microphone, and speakers are the manual methods used to avoid howling. Automatically adjusting the parameters of the system, and not allowing it to enter into an unstable state is a crucial thing in audio system. Howling can be identified from the input signal using its temporal & spatial parameters. The commonly used method makes use of notch filters for suppressing the howling noise. Other methods include automatic equalization, automatic gain control, etc.

Keywords: Acoustic feedback, Howling, Adaptive filter.

I. INTRODUCTION

In the acoustic feedback system, howling is a common trouble that annoys the speaker and the audience. A public addressing (PA) system shown in figure 1 is a sound amplification and distribution device which consists of a microphone, an amplifier, and one or more loudspeakers. The amplified signal from the loudspeakers is again fed into the microphone forming a closed-loop path with positive feedback. In positive feedback, sustained oscillations occur if the feedback signal is in phase and has a larger amplitude than the original signal at one or more frequencies. So the system becomes unstable at any frequency if the loop gain exceeds unity, and the signal in the feedback loop starts growing unboundedly. The feedback results in an unpleasant and disturbing whistling sound called howling. The positions of microphones and loudspeakers, room shape and arrangement are some of the parameters that affect howling. The position and movement of talker and the room temperature also affect howling. Therefore, it is challenging to predict howling. Before hearing the howling sound, we cannot distinguish between the original speech signal and the howling signal.

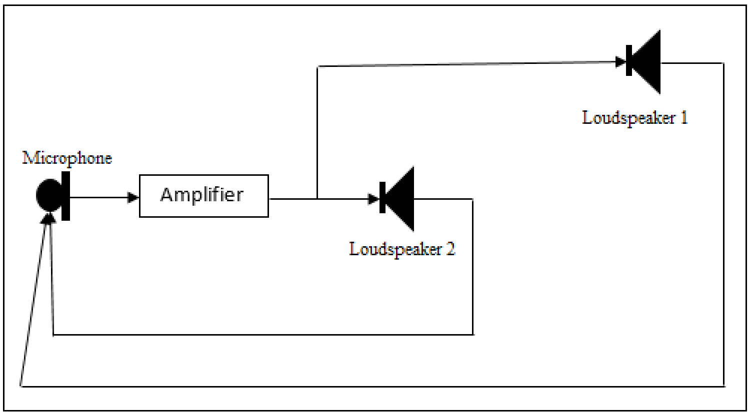

Figure 1: Acoustic feedback system

Figure 2(a) shows a speech signal with duration of 14 seconds approximately. According to the words spelled, there are variations in the amplitude of the signal. The maximum amplitude appears at the instant of vowels, and the consonants have a lesser amplitude. The significant frequency components extend up to 2 kHz approximately. While analyzing the howling signal, it is observed that howling signal does not affect the whole portion of the audio signal. It occurs only at some instants if the parameters mentioned above vary. Howling is a periodic signal which starts with low amplitude, and reaches high amplitude after some duration. This is heard as a low whistling sound that gradually grows up to a larger one as it reaches the saturation level, and is shown in figure 2(c). The howling signal has just a single significant component present in it. This is evident from the corresponding spectrum, which is shown in figure 2(d). There is a peak in the spectrum at around 1 kHz, and its magnitude is greater than that of the speech signal. Figure 2(e) depicts a speech signal with the howling noise present in it. The signal consists of high amplitude howling noise with

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variations in the peak values, which are proportional to the speech input. Figure 2(f) shows the spectrum of the speech signal with howling noise. It includes the frequency component of speech as well as the howling noise, which appear as peaks in the spectrum.

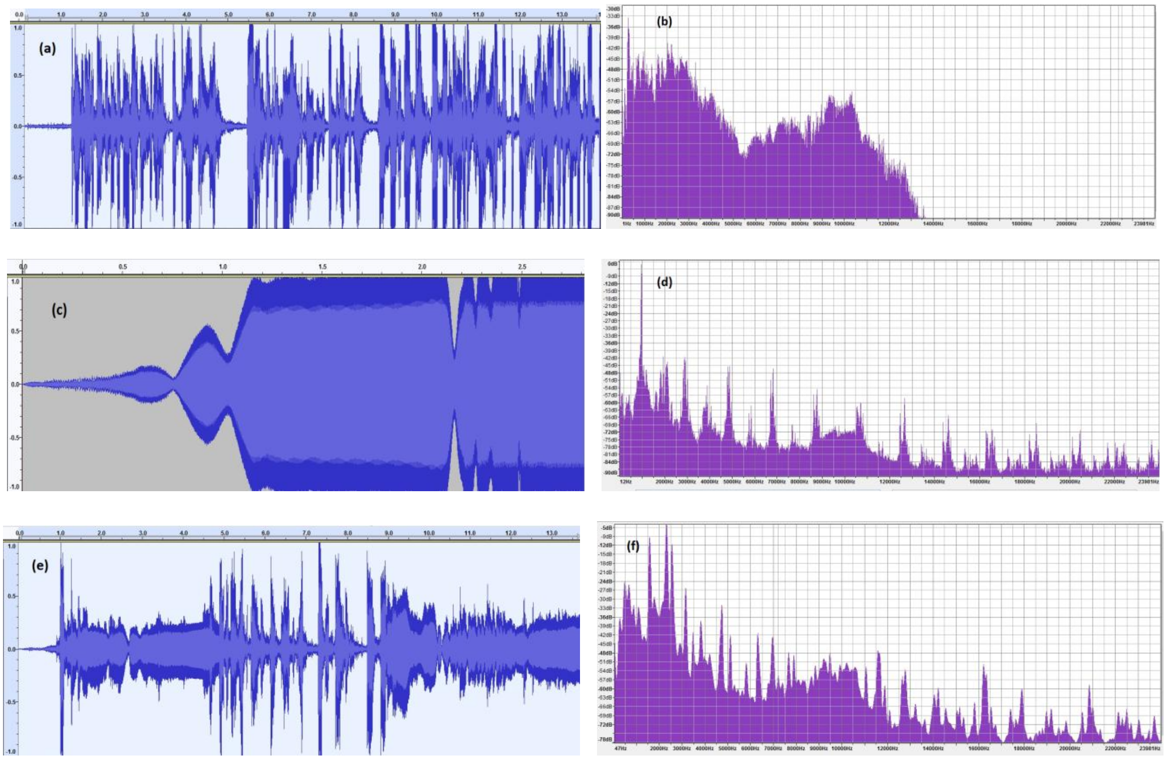

Figure 2: (a) Speech signal (b) Spectrum of the speech signal (c) Howling Noise (d) Spectrum of the howling noise (e) Speech signal with howling noise and (f) Spectrum of the speech signal with howling

II. RELATED WORKS

Several methods have been developed for the detection and suppression of acoustic feedback. Reduction of the gain of the amplifier or altering the positions of the microphone and loudspeakers are the manual methods to minimize the howling noise. Detection and suppression of the noise due to acoustic feedback without distorting the speech signal in an automatic way are very crucial in PA systems. Frequency shifting is used for howling noise suppression in [1] and [2], which ends up in a complicated modulation device. Later many of howling suppression algorithms have been developed using adaptive notch filters.

Adaptive Periodic Noise Cancellation (APNC) [3] is another technique adopted for reducing the effect of howling. This approach is primarily based on the FIR filter, which requires only a small number of filter taps driven through the LMS algorithm. In order to achieve accurate overall performance from this system, the bandwidth of the clear-out should be very narrow. This approach reduces the residual noise and is viable to realize the system on a single digital signal processing chip. The performance of the system doesn't degrade with small variations in parameter settings for LMS step-size, time delay, or number of filter out stages.

A DSP-based acoustic feedback canceller was suggested by Er et. al [4]. In this approach, the discrimination of speech and acoustic feedback signal was done by making use of their characteristics. The acoustic feedback is a natural tone and has no higher harmonics. Due to the overtones in a human vocal chord, human speech contains very high even-order harmonic content. This system is subdivided into two phases, hardware design, and firmware design. The hardware design includes the layout and development of the hardware for the cancellation of the feedback signal. By processing a microphone signal, the acoustic feedback is located and cancelled. The original signal is then reconstructed. The firmware is the software program that manages the feedback canceller system. It converts a block of samples from the time domain to the frequency domain and determines whether or not acoustic feedback is present. The acoustic feedback signal is removed using a second-order IIR notch filter.

LMS adaptive notch filter and digital Phase Locked Loop (PLL) have been used in [5], which offers a feedback suppression system with very low complexity. The delay in the detection of howling is also minimum. Here higher-order FIR filter is used to implement a 90^0 phase shifter having a high quality phase-shifting effect. A PLL is used to lower the computational complexity. The PLL comprises a Phase Detector, Low Pass Filter, and Voltage Controlled Oscillator. The phase detector compares the reference input signal and the output signal of voltage controlled oscillator. Successively, the phase detector provides an error voltage signal which is proportional to the phase difference. The output of the phase detector is then passed through the low pass filter in the loop, which is then fed to the voltage-controlled oscillator. The output frequency of the voltage-controlled oscillator would be the same as that of the reference input signal. Simulations showed that this method is very effective in detecting howling signal.

The Adaptive Howling Suppression (AHS) [6] uses a variable momentum least mean square (VMLMS) algorithm for an adaptive system which affords a high convergence rate. It acts as a narrow-band notch filter between the preamplifier and the power amplifier section. The system consists of adaptive and non-adaptive FIR filters. The Adaptive FIR filter is based on an adaptive periodic noise canceller, which treats the speech signal as a broadband signal, and the howling signal is treated as a narrow band signal. Both the signals are passed through the delay unit to convert them into uncorrelated signals. The adaptive FIR filter attempts to minimize the error power. The coefficients of the adaptive FIR filter is copied to a non-adaptive FIR filter when it reaches the most appropriate estimate of periodic components. Thus the output of AHS consists of the speech components alone. This system offers a lower Mean Square Error, narrow bandwidth of notch features, and decreases distortion of the speech signal.
In Notch Filter based howling noise suppression (NHS) [7], the gain of the amplifier is reduced in a narrow frequency band. The frequency band is selected, such that the loop gain is close to 1. The second-order IIR filter structure is the one that is used as the notch filter structure in NHS. In order to differentiate between the original signal and the howling signal, spectral and temporal features of the signal are used. The features are Peak-to-Threshold Power Ratio (PTPR), Peak-to-Average Power Ratio (PAPR), Peak-to-Harmonic Power Ratio (PHPR), Peak-to-Neighbouring Power Ratio (PNPR), Inter-frame Peak Magnitude Persistence (IPMP), and Inter-frame Magnitude Slope Deviation (IMSD). The system provides higher reliability but lacks in sound quality.
FFT and Chirp-z transform has been applied in [8] for howling detection. Using FFT algorithm in every frame of the input signal, the power spectrum of the signal is obtained. Chirp-Z algorithm analyses the frequency spectrum and picks up the howling frequency. After picking up the howling frequency, a signal which has the same amplitude and frequency of that of the howling signal, but with a phase shift of 180^{o} is prepared. By adding this wave to the input signal, the feedback is removed. This system has improved frequency resolution with the requirement of very few arithmetic steps and memory space.
Howling frequency detection using statistical analysis of temporal power spectra [9] provides less complexity than the existing LMS algorithms. In this method, the temporal variations of power spectra was observed first, and it was noticed that it varies continuously at a stable state and gets smaller at a particular frequency in howling condition. So the standard deviation of the temporal variation values is used to detect howling frequency.
Automated detection and suppression of howling using a sinusoidal model-based analysis/synthesis system are given in [10]. Here there are three stages: Howling Detection Stage, Gain Selection Logic, and Howling Noise Suppression Stage. At the howling detection stage, speech is modelled using a sum of sinusoids of varying amplitudes, frequencies, and phases. Estimation of the model parameters is performed by selecting significant peaks in the spectrum.
Most of the methods, which are explained above, lack a complete suppression of the howling noise. Even though some papers claim to have a real-time implementation, most of them were restricted to detection only. After detection of the howling in a frame, all the samples were made zeros, suppressing howling as well as the speech signal. Delays were reported in the case of real-time implementations.

III. CONCLUSION

The main problem in the public addressing system is the howling noise formed by the acoustic feedback of the system. This makes the system unstable, producing a low-quality audio signal. This problem is also faced in hand-free communication systems and hearing aids. In order to overcome this problem, howling detection and suppression systems are used. Detection of howling is done from temporal and spectral features of the signal. Automatic gain control, automatic equalization, notch filter-based howling suppression are the methods used for howling suppression. A notch filter is a commonly used method rather than other methods. A detailed study about the howling signals and their effects on speech signals have been carried out. Methods are yet to be developed, which provide 100% suppression of the howling noise without distorting the speech signal in real-time.

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