Analysis of Traffic Noise during Peak Office Hours in Chandigarh, India and its Reduction using Active Noise Control

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Abstract
The studies have indicated that exposure to traffic noise is resulting in adverse health effects. This calls for immediate attention to the mitigation of road noise. This study examines the traffic noise levels and their reduction using the active noise control (ANC) system at the roundabout (free-moving traffic site) and traffic lights (controlled movement traffic site) during peak office timings on working days. The study is conducted on the roads of the planned city Chandigarh (called the city beautiful) in India. It is observed that noise levels are much higher than the permissible limits at both sites and for more than 70% of measured time duration the noise level remains above the permissible limits. The frequency spectrum analysis shows that high dB noise levels have occurred at low-frequency noise.

In the second part of the study, FxLMS based ANC system is implemented in MATLAB for the reduction of recorded traffic noise signals at both sites. The results indicate that acceptable limits of noise are reached in both cases. The signal to noise ratio (SNR) and power spectral density (PSD) analysis indicates a significant decrease in noise signal amplitude throughout the frequency range. The good simulation results encouraged an application of ANC in the real environment.

Keywords: Traffic noise, Frequency spectrum, Noise mitigation, Active noise control.

Introduction

There is exponential growth in the number of vehicles on the roads resulting in increased traffic noise. This results in many health problems such as cardiovascular disease[14], hypertension[16], stroke[24], infertility[27] etc. The studies have been carried out to investigate the effects of traffic noise on health concerning different diseases affecting mankind such as cognitive impairment in children[5], diabetes in adults[23], noise annoyance[9], sleep disturbance[18], breast cancer[20]. Romeu et al[19] have studied the consequence of noise on newborn children in the Neonatal Intensive Care Unit. Khaiwal et al[12] have conducted a study on noise pollution and its effect in and around the sensitive zone in North India. The study concluded that noise was more than permitted limits in all the cases of study and 97% of respondents have blamed traffic noise as a major culprit.

In India, a fast developing country, the vehicles plying on the road constitute: (a) fast-moving vehicles and (b) slow-moving vehicles. The cars, two-wheelers (bikes, scooters, etc.), buses, trucks, passenger vehicles, three-wheelers etc. comprise fast-moving vehicles whereas slow-moving vehicles include animal carts, cycle-rickshaw, bicycle, agriculture tractors etc. The mixed nature of traffic on Indian roads is one of the causes of honking resulting in severe noisy conditions beyond 100dB(A).

The road conditions such as roundabouts, traffic lights, intersections andspecific locations (like schools, colleges, public offices and market roads) witness above the permissible noise levels. The traffic noise is subject to many factors like the number of vehicles, the presence of heavy vehicles like buses, lorries, trucks androad conditions, the speed of vehicles andthe type of vehicles in the area. The driving habits of people and office hours also contribute to the traffic noise emanating from vehicle horns.

The continuous exposure to the high traffic noise is resulting in a high-stress level in the urban area requiring an urgent solution for its reduction. The studies have been done to predict and analyze the road traffic noise levels across the world[4,7,22]. Noise mitigation strategies include reduction at source, active noise control, optimized traffic operations, better infrastructure planning[14]. Noise can be controlled by two broad techniques i.e. passive and active. The passive noise control (PNC) method uses barriers, enclosures, silencers etc. to soothe the noise. However, for low-frequency noise the thickness required for passive absorber is large. Thus, it is not feasible in many cases. In such cases, the active noise control (ANC) technique is applied which uses an adaptive algorithm[13]. In the ANC system, noise is captured and the opposite signal is generated using a control algorithm, which is overlapped resulting in noise reduction.

ANC system has been effectively implemented for noise reduction in many practical applications e.g. motorcycle helmet[2], passenger car[15], headset[26], MRI acoustic noise[11,28]. The adaptive algorithms are implemented in the ANC system to control the time-varying noise signal. The most commonly used adaptive algorithm is the Filtered reference Least Mean Square (FxLMS) algorithm[25]. In the present work, the ANC system based on the FxLMS algorithm is implemented for the reduction of traffic noise recorded during the field study at peak office hours in Chandigarh.

The noise limit for vehicles has been set by the Central Pollution Control Board of India under “The Noise Pollution

(Regulation and Control) Rules, 2000”[17]. It has a maximum noise limit of 80 dB (A) *Leq* for two-wheelers and three-wheelers, 75 dB (A) for passenger cars and85 dB (A) for commercial vehicles. The regulations also specify the daytime and night-time noise limits for different areas/zone.

Material and Methods

To observe the actual traffic noise scenario, it is important to record the noise at different locations so that how it occurs can be observed. Keeping this in mind, the two different locations having different traffic conditions are selected for the study.

Site Selection: A field study has been conducted to observe the traffic noise at two different sites in Chandigarh city in India, during peak office hours of the day. Chandigarh, also called The City Beautiful, is the most planned city in north India and is located at 30˚44’14N (latitude) and 76˚47’14E (longitude). As per the 2011 census, the population of Chandigarh is 1.05 million[3]. Being a planned and urban city, the traffic constitutes mostly motorized vehicles andslow-moving vehicles like animal-cart, cycle-rickshaw, bicycle, etc. are minimal. The city is divided into different sectors that meet at roundabouts. With the high per capita income of Chandigarh, there is a phenomenal increase in traffic resulting in frequent traffic jams at roundabouts. The stress level of an individual is bound to increase as one is exposed to high vehicular noise levels. To cope up with the fast-rising vehicular density in the city, many steps have been taken by the administration which includes putting traffic lights on roundabouts and closing many intersections.

To measure traffic noise levels, two sites were selected based on the nature of traffic flow i.e. free flow of traffic (on the roundabout) and controlled traffic movement (on traffic lights). The sites selected for the study are as:

- Site 1: Sector 12-14 roundabout (near PGIMER and Panjab University)
- Site 2: Sector 24-25 traffic lights intersection

The permissible noise levels are 50 dB (A) *Leq* at both locations[17]. The timings for observations are peak traffic conditions during a working day when there is a rush of offices and schools i.e. morning (9:00 am to 9:30 am), afternoon (2:00 to 2:30 pm) and evening (5:00 to 5:30 pm).

Noise measurement and high noise source identification: The noise is measured in the terms of decibel dB(A) *Leq* indicates the time-weighted average of the level of sound in decibels on scale A which corresponds to human hearing. The equivalent noise level, *Leq* is specified as per equation (1)[6]:

$$L_{eq} = 10 \log \frac{1}{N} \sum_{i=1}^{N} 10^{\frac{L_i}{10}} \qquad (1)$$

where N is no. of noise sources, L_i is sound pressure levels *ith* source.

In the present study, traffic noise is measured in dB (A) *Leq* at designated sites using Type 1 sound level meter of Bruel & Kjaer (Model 2250). The sound level meter and video camera are installed at the designated sites. The video recording is made in such a manner that passing traffic and reading of sound level meter are captured simultaneously. This helps to identify the source of the high noise level. The prominent sources of high noise levels are identified from the video and it is observed that vehicle horns were majorly responsible for high noise. For overall traffic noise reduction, it is required that high dB noises must be controlled.

Analysis of Traffic Noise: The study at the designated sites gives a detailed picture of the noise and its frequency components at different time durations. The noise levels recorded at these sites are analyzed in the following sections.

Comparison of traffic noise levels: The results obtained from the traffic noise measurement at designated sites in the Indian city of Chandigarh are found to be alarming. During the peak office hours in a working day, the vehicular density is maximum and the noise level surpasses the permissible limit of 50 dB by 28 dB at traffic lights and 27 dB at the roundabout as shown in table 1.

The maximum noise level crosses 100dB and the minimum noise is 57.5 dB at the roundabout and 59.2 dB at the traffic lights respectively which is higher than permissible limits of 50 dB. This indicates a person is unintentionally being exposed to the noise beyond the permissible limits every day while commuting to and from the office.

Table 1
Traffic Noise levels at the designated site during peak office hours.

	Noise at Roundabout (dB) Site 1			**Noise at Traffic Lights (dB) Site 2**		
	LAeq	***LAFmax***	***LAFmin***	***LAeq***	***LAFmax***	***LAFmin***
Morning	78.7	97.5	68.4	77.9	102.3	61.4
Afternoon	77.3	98.2	57.5	77.3	102.6	60.7
Evening	78.2	100.4	66.8	76.9	97.3	59.2

where *LAFmax and LAFmin* indicate the maximum and minimum value of sound pressure level on scale A.
LAeq indicates the equivalent value of sound pressure level on scale A

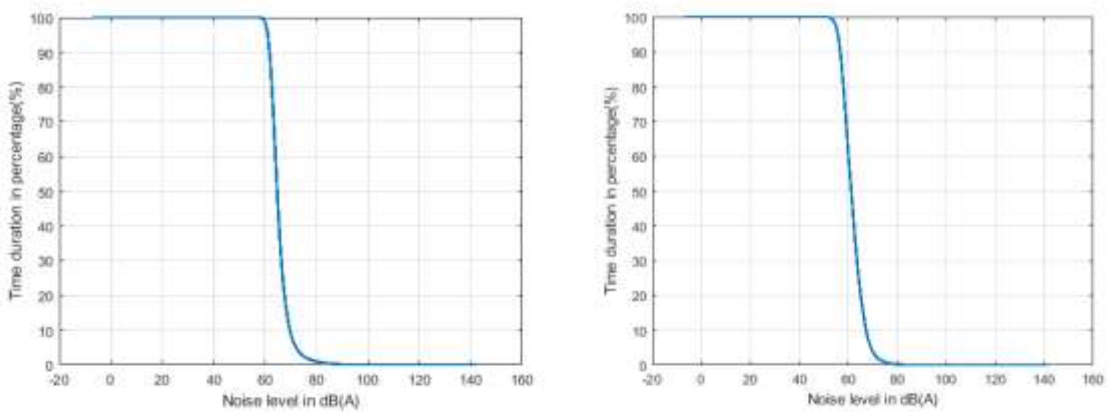
The exposure to such high noise levels leads to an adverse effect on the health of an individual and his working efficiency is affected. It is further seen that maximum values of noise (*LAFmax*) are high at traffic lights (site 2) probably due to honking by drivers in an attempt to cross the lights before it changes to red. This site also observed low *LAFmin* which indicates that drivers are patiently waiting for the traffic light to turn from red to green. On the other hand, *LAFmin* noise levels are higher at the roundabout (site 1) where there is a free flow of traffic as compared to traffic lights. This points to that there is a continuous high value of noise (above the permissible limits) existing on the roundabout. It can be concluded that the roundabout (site 1) is a more noisy location than the traffic lights intersection (site 2).

Time duration Vs noise level: Figure 1(a) and figure 1(b) show the time percentage versus noise level (in dB) plot which indicate that the noise level of more than 60 dB is observed for 70 % of time duration at the traffic lights in the evening (figure 1(a)). However, the same dB level exists for 98% of the time duration at the roundabout in the morning. (figure 1(b)).

This suggests that most of the time noise level is above the permissible limit of 50 dB (A) at both sites during peak office hours. Thus, a person, during approximately 70% of his commuting time, faces a high dB level of noise which makes him prone to many diseases in the long run.

Frequency spectrum analysis of traffic noise levels: The frequency spectrum analysis of the recordings at roundabout and traffic lights during peak working timing of the day is shown in figure 2 and figure 3 respectively. The observations indicate that for most of the frequency range the noise dB(A) Leq is higher than the permissible limit of 50 dB(A). Further, the peak noise dB (A) is observed in the low-frequency range.

The noise level higher than 70dB (A) corresponds to the low-frequency range of 25 Hz to 200Hz. The low-frequency noise has greater penetration and difficult to suppress using an enclosure, barriers, etc. This makes a good case for the implementation of an active noise control system as it has been successfully applied for low-frequency noise reduction applications[10].



(a) **(b)**

Figure 1: Time percentage versus noise level (dB) plot at: (a) roundabout during morning timings (b) traffic lights during evening timings

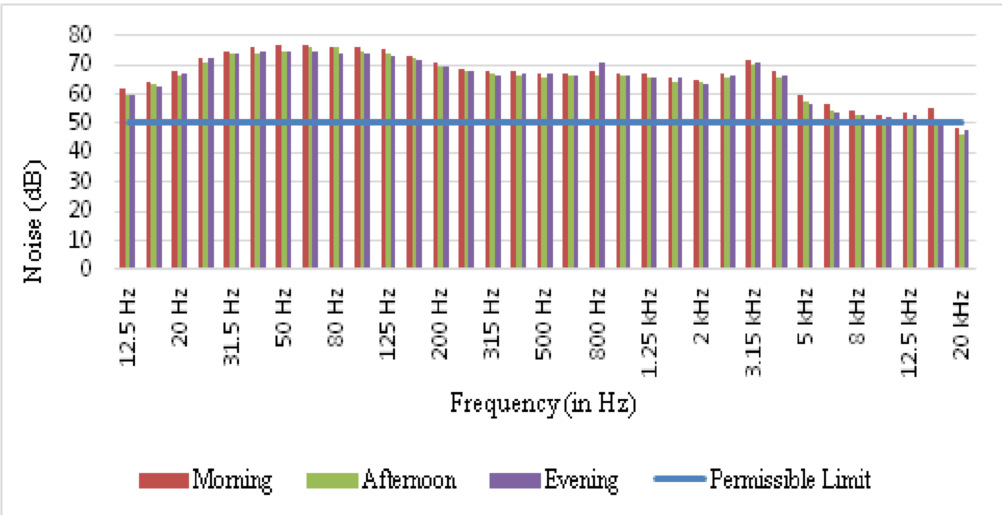


Figure 2: Noise level (dB) versus frequency (Hz) plot at the roundabout during peak hours of the working day

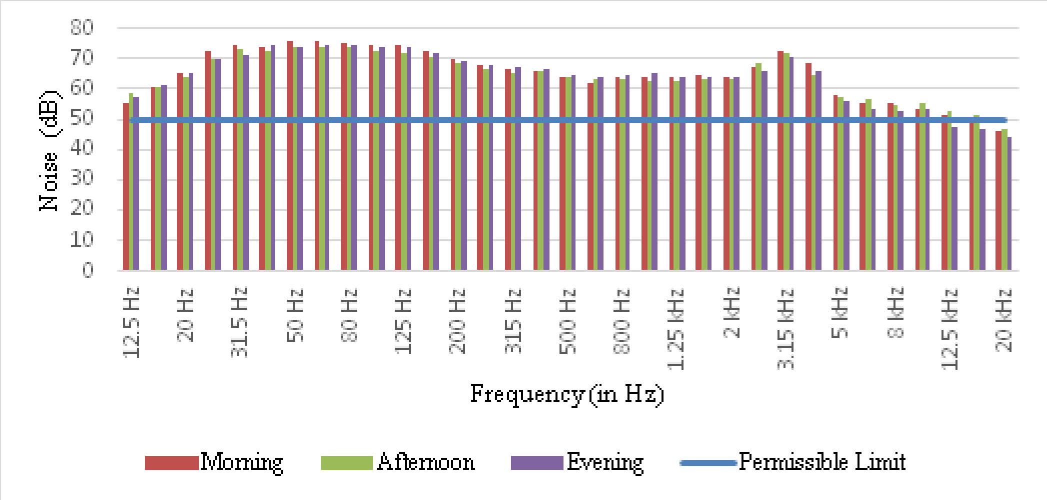


Figure 3: Noise level (dB) versus frequency (Hz) plot at traffic lights during peak hours of the working day.

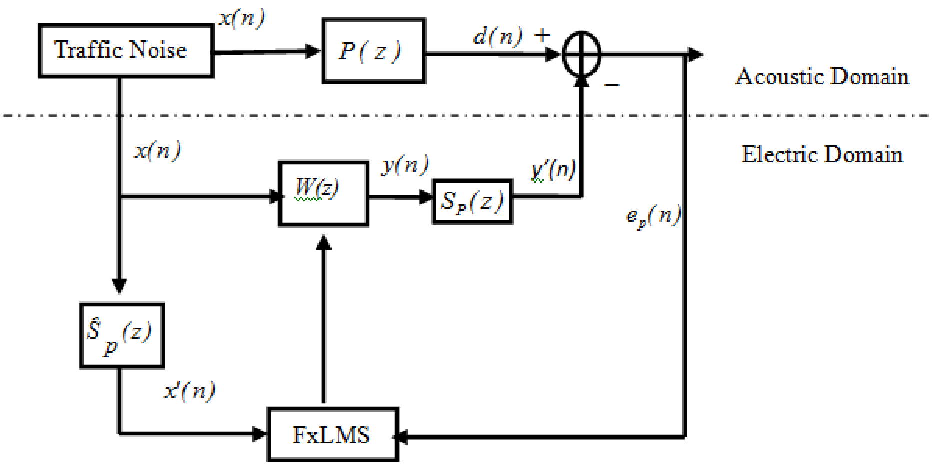


Figure 4: Block diagram of the ANC system using the FxLMS algorithm.

Noise Mitigation using ANC System: Figure 4 describes the different blocks of the ANC system[8,13]. As depicted, the noise signal is passed through the primary acoustic path *P(z)* and disturbance signal *d(n)* is obtained. The noise signal *x(n)* is filtered through a secondary path estimate $\widehat{\boldsymbol{S}}_{\boldsymbol{p}}(\boldsymbol{z})$ to obtain a filtered reference signal which is used for weight updation of the FxLMS algorithm.

The path between the error microphone and a secondary speaker constitutes secondary path *Sp(z)*. The anti-noise signal *y'(n)* is obtained from the secondary loudspeaker and combined with *d(n)* to obtain the error signal *e(n)* called residual noise. The error signal is fed to the controller to update the weights to get the desired anti-noise signal, *y'(n)*.

x(n) is a reference signal, *w(n)* is a weight vector and $S_p(n)$ indicates impulse response of secondary path $S_p(z)$. The controller output signal, *y(n)* and secondary loudspeaker output, *y'(n)* and error *e(n)* is obtained as per equation (2), (3) and (4).

$$y'(n) = S_p'(n)y(n) \quad (2)$$

$$y(n) = w'(n)x(n) \quad (3)$$

$$e(n) = d(n) - y'(n) \quad (4)$$

The weights are modified as per the Normalized Filtered-reference-LMS (FxLMS) algorithm as per equation (5):[1,21]

$$w(n+1) = w(n) + \frac{\alpha}{(N+M)P_{x'}(n)} x'(n-i)e(n), i = 0,1, \dots . N-1 \quad (5)$$

where
$x'(n) = \hat{S}_p(z) * x(n)$
M is filter length, α is the learning rate.

$P_{x'}(n)$ is the power of the filtered reference signal and is updated as:

$$P_{x'}(n+1) = \beta P_{x'}(n) + (1+\beta)x'^2(n), \quad 0 < \beta < 1 \quad (6)$$

where β is the forgetting factor.

Performance analysis of ANC for vehicle noise reduction: The performance analysis of the ANC system is done based on error response, signal to noise ratio (SNR) andpower spectral density (PSD).

Error Response: The scheme for the ANC system is implemented as per the figure 4. The behavior of the algorithm to the input traffic noise signal is characterized by an error response obtained. The error response indicates how fast an algorithm can reduce the error and is evaluated as per equation (4). The disturbance signal *d(n)* is obtained as the input signal, *x(n)* is passed through the acoustic path *P(z).*

Signal to Noise Ratio (SNR): When ANC is applied, the noise is reduced which is a logarithmic difference of signal with ANC ON and OFF. The noise reduction is represented by signal to noise ratio (SNR) given by equation (7):

$$SNR = 10\log_{10}\left[\frac{\sum d^2(n)(ANC\ OFF)}{\sum e^2(n)(ANC\ ON)}\right] \quad (7)$$

Power Spectral Density (PSD): The power of a signal over different frequencies is described by power spectral density (PSD). The power can be defined as the squared value of the signal *x(t)*. It is given by equation (8) over the average time.

$$P = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} x(t)^2.\,\mathrm{d}t \quad (8)$$

In the analysis, it is used to express the reduction of the power of the noise signal over the range of frequencies using the ANC system.

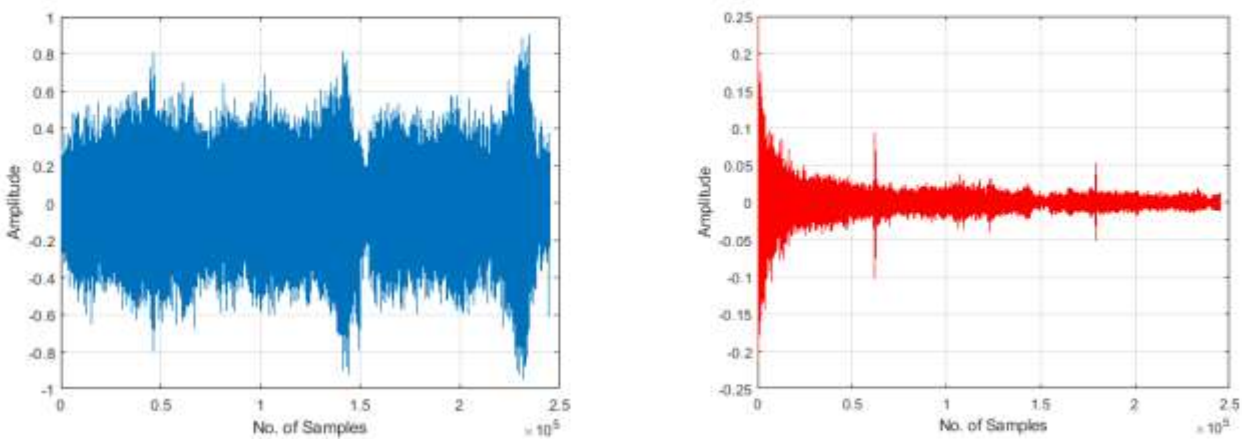
Noise Reduction of Traffic Noise Signals: The recorded real-time traffic noise signals at both the sites (at the roundabout and traffic lights) are considered for analysis. The video recordings of the vehicles crossing the sites and dB values measured using a sound level meter indicate that the use of vehicle horns results in noise peaks in addition to the continuous noise of usual traffic. In the present work, real-time traffic noise signals are obtained from the recordings made at both sites. ANC system is implemented in MATLAB on the recorded traffic noise signals to reduce the noise.

Case 1: Traffic noise signal at the roundabout: As observed earlier, the roundabout is a noisier site than the traffic lights intersection; the traffic noise signal considered has a peak noise level of 93 dB. The actual noise signal is shown in figure 5(a) and the residual noise signal after implementation of ANC is shown in figure 5(b).

It indicates a considerable reduction in the amplitude of noise level which is validated by SNR of 29.38 dB. The power spectral density shows the variation of the noise level in dB over the frequency range. Figure 6 indicates that the noise level is reduced significantly throughout the frequency range with some shoot ups in between.

Case 2: Traffic noise signal at traffic lights: The noise at traffic lights has LAF_{max} value due to the tendency of drivers to cross the traffic lights before it changes from green to red and in the process, they tend to honk. The traffic noise signal considered at traffic lights has a peak dB level of 98 dB. The actual signal (ANC OFF) and reduced noise signal (ANC ON) at site 2 are shown in figure 7(a) and figure 7(b) respectively. The SNR obtained is 33.1 dB which can bring the noise to a moderate level.

Thus, the ANC system has successfully reduced traffic noise to a comfortable zone. The PSD plots (figure 8) of the traffic noise signal (ANC OFF) and reduced noise signal (ANC ON) show a reduction in dB over the complete frequency range except at the 1000 Hz frequency. This is because the high dB noises have higher components of the lower frequency generally between the range of 700 Hz to 1000 Hz. As the noise at traffic lights has higher peaks, so the PSD curve with ANC ON has a comparatively lesser reduction at around 1000Hz frequency. However, the performance is better in the rest of the frequency range. This illustrates the effectiveness of the ANC system for noise reduction.



(a) **(b)**

Figure 5: (a) The plot of traffic noise signal (ANC OFF) and (b) residual traffic noise signal (ANC ON)

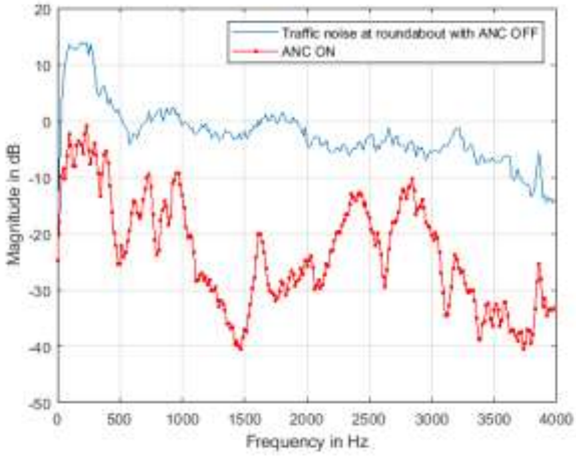


Figure 6: The plot of PSD of the traffic noise signal and residual noise signal at the roundabout at the roundabout

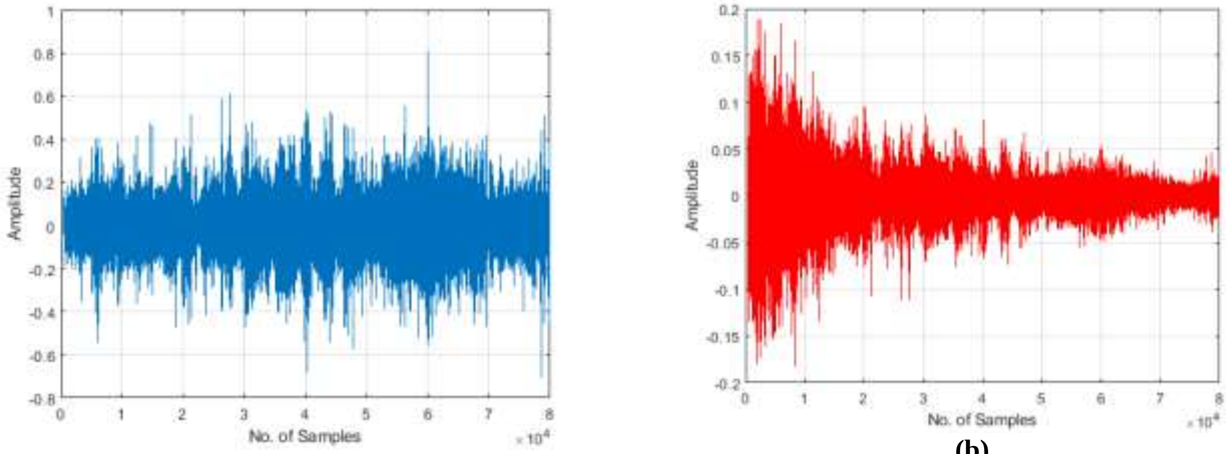


Figure 7: (a) The plot of traffic noise signal (ANC OFF) and (b) residual traffic noise signal (ANC ON) at the traffic lights.

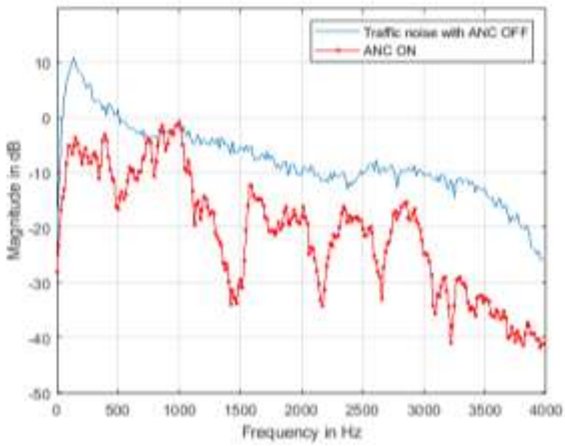


Figure 8: The plot of power spectral density (PSD) of the traffic noise signal and residual noise signal at the traffic lights

Conclusion

This present study aims to investigate traffic noise levels during peak office hours in Chandigarh, India andits reduction using the ANC system. A study was conducted to record the noise level at the peak office hours using B and K Sound Level Meter at two sites: 1) at roundabout having free traffic movement and 2) at traffic lights having controlled traffic movement. The observations indicate that there are many reasons for the use of horns which include traffic congestion, improper stoppage, driver habit, peak office hours etc.

The noise levels are higher than permissible limits of 50 dB at both sites for most of the time duration. The analysis shows that high noise has primarily low-frequency components. The implementation of noise reduction techniques is the need of the hour to safeguard ourselves from the rising traffic noise conditions. For mitigation of low-frequency noise ANC system is applied as passive noise control is not always feasible. In the present work, FxLMS based ANC system is implemented in MATLAB for the reduction of recorded traffic noise signals at both sites. The ANC system is successful in reducing the traffic noise, by 29 dB(A) at the roundabout and by 33 dB(A) at the traffic lights bringing the noise to comfortable levels.

The significant reduction of traffic noise gives the direction for the physical implementation of an active noise control system in cars, buses etc. near driver or passenger seat and on the helmet for two-wheeler drivers to generate a quieter zone. The digital signal processor can be used for hardware implementation of the ANC system in real-time.

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References
1. Bismor P., Czyz K. and Ogonowski Z., Review and comparison of variable step-size LMS algorithms, *Int. J. Acous. and Vib.*, **21(1)**, 24-39 **(2016)**

2. Castae-Selga R. and Pea R., Active noise hybrid time-varying control for motorcycle helmets, *IEEE Trans. Contr. Syst Technol*, **18(3)**, 602–612 **(2010)**

3. Chandigarh Population Census data, http://www.census2011.co.in/census/state/chandigarh.html, accessed 03.03.20 **(2011)**

4. Chew Y.R. and Wu B.S., A soundscape approach to analyze traffic noise in the city of Taipei, Taiwan, *Comp., Environ. and Urban Sys.*, **59**, 78-85 **(2016)**

5. Clark C. and Stansfeld S.A., The effect of transportation noise on health and cognitive development: a review of recent evidence, *Int. J. Compar. Psychol.*, **20**, 145–158 **(2007)**

6. Crocker M.J., Handbook of Noise and Vibration Control, New Jersey, John Wiley & Sons, Inc. **(2007)**

7. Garg N. and Maji S., A critical review of principal traffic noise models: strategies and implications, *Environ. Impact Asses*, **46**, 68-81 **(2014)**

8. George N.V. and Panda G., Review: Advances in active noise control: A survey, with emphasis on recent nonlinear techniques, *Sig. Process*, **93(2)**, 363-377 **(2013)**

9. Jakovljevic B., Pauovic K. and Belojevic G., Road-traffic noise and factors influencing noise annoyance in an urban population, *Environ. Int.*, **35**, 552-556 **(2009)**

10. Kajikawa Y., Gan W.S. and Kuo S.M., Recent advances on active noise control: open issues and innovative applications, *APSIPA Trans. on Sig. and Inform. Process*, **1**, 1-21 **(2012)**

11. Kannan G., Milani A.A., Panahi I. and Briggs R.W., An efficient feedback active noise control algorithm based on reduced-order linear predictive modeling of fMRI acoustic noise, *IEEE Trans Biomed. Eng.*, **58(12)**, 3303–3309 **(2011)**

12. Khaiwal R., Tanbir S., Jaya P.T., Mor S., Munjal S., Patro B. and Panda N., Assessment of noise pollution in and around a sensitive zone in North India and its non-auditory impacts, *Sci. Total Environ.*, **566-567**, 981-987 **(2016)**

13. Kuo S.M. and Morgan D.R., Active noise control: a tutorial review, Proc. of the IEEE, **87(6)**, 943–973 **(1999)**

14. Min K. and Min J., Exposure to environmental noise and risk for male infertility: A population-based cohort study, *Environ. Poll.*, **226**, 118-124 **(2017)**

15. Misol M., Algermissen S. and Monner H., Experimental investigation of different active noise control concepts applied to a passenger car equipped with an active windshield, *J. Sound Vib.*, **331**, 2209–2219 **(2012)**

16. Munzel T., Gori T., BabischW. and Basner M., Cardiovascular effects of environmental noise exposure, *Eur. Heart J.*, **35(13)**, 829-836 **(2014)**

17. Noise pollution (regulation and control) rules, Central Pollution Control Board, Ministry of Environment and Forests, Government of India, http://cpcb.nic.in/divisionsofheadoffice/pci2/noise_rules_2000.pdf **(2000)**

18. Pal D. and Bhattacharya D., Effect of Road Traffic Noise Pollution on Human Work Efficiency in Government Offices, Private Organizations andCommercial Business Centres in Agartala City Using Fuzzy Expert System: A Case Study, *Adv. in Fuzzy Sys.*, **2012**, 1-9 **(2012)**

19. Romeu J., Cotrina L., Perapoch J. and Linés M., Assessment of environmental noise and its effect on neonates in a Neonatal Intensive Care Unit, *Appl. Acous.*, **111**, 161-169 **(2016)**

20. Roswall N., Pernille E.B., Ole R.N., Steen S.J., Anja O. and Mette S., Residential road traffic noise exposure and survival after breast cancer – A cohort study, *Env.Res.*, **151**, 814-820 **(2016)**

21. Sharma M.K., Vig R., Pal R. and Shantharam V., Quiet zone for the patient in an ambulance: Active Noise Control Technology for Siren Noise Reduction, *Arch. Acoust.*, **43(2)**, 275–281 **(2018)**

22. Singh D., Nigam S.P., Agrawal V.P. and Kumar M., Vehicular traffic noise prediction using soft computing approach, *J. Env. Manage.*, **183**, 59-66 **(2016)**

23. Sorensen M., Andersen Z.J., Nordsborg R.B., Becker T., Tjonneland A., Overvad K. and Ole R.N., Long-term exposure to

road traffic noise and incident diabetes: Acohort study, *Environ. Health Perspect.*, **121**, 217–222 **(2013)**

24. Sorensen M., Hvidberg M., Andersen Z.J., Nordsborg R.B., Lillelund K.G., Jakobsen J., Tjonneland A., Overvad K. and Ole R.N., Road traffic noise and stroke: A prospective cohort study, *Eur. Heart J.*, **32**, 737–744 **(2011)**

25. Widrow B. and Stearns S.D., Adaptive Signal Processing, Englewood Cliffs, NJ, Prentice-Hall **(1985)**

26. Yang Z., Gu Z., Tu J., Dong G. and Wang Y., Numerical analysis and passive control of a car side window buffeting noise based on scale-adaptive simulation, *Appl. Acoust.*, **79**, 23–34 **(2014)**

27. Zeeb H., Hegewald J., Schubert M., Wagner M., Dröge P., Swart E. and Seidler A., Traffic noise and hypertension – results from a large case-control study, *Environ. Res.*, **157**, 110–117 **(2017)**

28. Zhang L. and Qiu X., Causality study on a feedforward active noise control headset with different noise coming directions in free field, *Appl. Acoust.*, **80**, 36–44 **(2014)**.

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