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Duct quiet zones utilization for an enhancement the acoustical air-condition noise control

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ABSTRACT

This paper investigates the duct's noise distribution pattern due to the heating, ventilation, and air conditioning systems. This study is considering the longitudinal sound wave distribution that can permit a higher reduction of these heating, ventilation, and air conditioning systems duct noise. The proposed technique is depending on the lowest sound pressure level points in the duct or duct quiet zones. Moreover, each heating, ventilation, and air conditioning systems duct has several quiet zones, depending on the sound pressure level of the fan noise source and the duct length as well as the duct diameter. Furthermore, the noise standing wave has a wavelength (λ) which is the distance between two successive quiet zones. This work utilizes orthogonal acoustical noise with the standing wave via feed-forward control speakers. This system confirmed that the distance (λ) is linearly proportional to the duct source noise level. This system noise reduction enhancement has been fulfilled by installing further noise feed-forward control speakers at different duct quiet zones. The system simulation results were displaying satisfactory agreement with the field experimental results.

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1. INTRODUCTION

Many of the challenging problems of noise reduction systems are the various characteristics related to the noise source, therefore; it is difficult to develop a general solution, and with the diversity of noise in many fields, including the medical field, especially fetal ultra-sound imaging equipment, and communication system security. How to find many solutions to reduce noise in the field [1]–[3]. Most of the hosts of commercial buildings in the cities and capitals of the world complain of hearing loss, induce stress, reduce comfort, and that due to the multiplicity of noise sources in the surrounding environment, where the noise sources consist of both external and internal noise; in this study, it will shed light on the internal noise, the internal noise source in such buildings can be considered the heating, ventilation, and air conditioning (HVAC) one. Although the hearing helping system has been improved significantly, the researchers are still searching in this field for higher noise reduction of HVAC system [4]–[6]. There are several techniques for reducing environmental noise. Broadly, there are two ways to solve the noise problem, the passive and the active noise control. The passive noise control (PNC), where simulates and diffracts to attenuate the noise in the ducts, this part uses in ventilation systems in buildings such as gas conduction systems, and boilers. The PNC includes enclosures, isolation walls and always used the silencer to the reduction of HVAC noise but uses it in the high-frequency band only. However, performing PNC relatively decreases at the low frequency of the HVAC noise. So, the disadvantage of PNC is the high cost, huge size, and complexity. Therefore, it is always preferable to use active noise control (ANC) for the reduction of noise about PNC [7]–[10].

The performance of PNC reduction systems is poor, the isolation walls in PNC are indeed too thick. On the other hand, a lot of cases are heavy to be practically implemented for the desired noise reduction, many isolation wall systems have been developed, with these systems, the vibration of the thin plate is controlled by piezoelectric or electric actuators, and the noise emission of the plate is reduced. In order to control noise emissions in three-dimensional space, multiple flat panels are required. The idea of developing isolation walls to get a higher noise reduction, two panels are used but it has some disadvantages; the mass of the wall are huge and thick [11]–[13]. On the other hand, the ANC techniques, are working at low frequency noise and effect on the small device such as noise duct, depend on the destructive interference are occurs between the noise source and the controlled source. The noise source or the fan noise that a person can be exposed to during the cooling process of the air conditioners. to overcome this noise, it can be controlled or reduced in the duct quiet zones (DQZs). The duct quit zones phenomena are due to the mechanical nature of the audio standing waves, an illustration to show the example of a duct quiet zone (DQZ) produced as shown in Figure 1, determined of control speaker places are very important and are effective on noise reduction value. However, the application of ANC system are more complex structures to create and find the DQZs [14]–[16].

ANC consists of two main types: feed-forward control structures and feedback control structures. The feedback structure modeling can be done in the analog and/or digital domains. It contains one microphone (the residual error mic) uses to sense the original noise to ameliorate periodic noise signals. The feed-forward control structures are the best solve of the fan noise reduction. The feed-forward is therefore, considered in this paper for reducing the HVAC noise. The feed-forward configures of a microphone at the front of the fan as an input signal, amplifier and an output control speaker as shown in Figure 1. The feed-forward control has two mainly paths (primary, secondary), the direction of fan noise in the duct is called primary path. And the direction of speakers control signal is called secondary path as shown in Figure 2. Determined the distance between the fan noise to the reference microphone is important for the cancellation process to be completed successfully [17]–[21]. The fan front is the best position of the reference microphone in order to facilitate the controller processes such as the noise signal modifications. The higher performance of noise reduction can be achieved at the shortest time delay between the fan noise and the output of the control speaker [22]–[24]. Therefore, it is recommended to accurately calculate these times for satisfying the system best results.

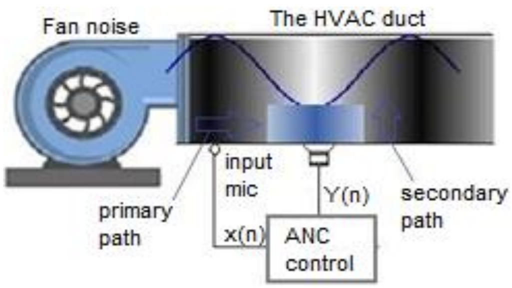


Figure 1. Block diagram of basic feed-forward ANC system

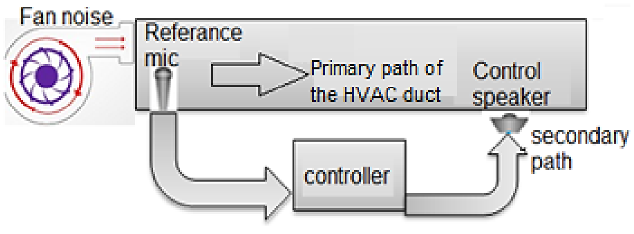


Figure 2. The paths of the HVAC duct

The HVAC acoustical noise in the duct can be considered a longitudinal wave as shown in Figure 3, that includes both of the compression and refraction states respectively [25], [26]. It has the distribution of refraction and compression zones. The wave length (complete cycle) is distance between any two consecutive compressions or refractions respectively.

The frequency of HVAC acoustical noise in the duct, can be obtained using (1), and the HVAC acoustic impedance at the duct are calculated according to (2) [27], [28]:

$$f_n = \frac{nc}{2l}, \quad (1)$$

where the parameter of n, c, and l are the mode number, the speed of sound, and the length of the duct.

$$Z_S = 0 - i\rho c \cot(kl) \quad (2)$$

Where $i = \sqrt{-1}$, ρ is the density of air, and k is the wave number.

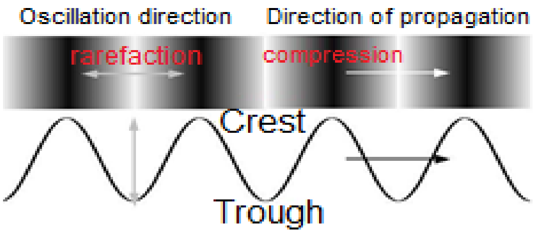


Figure 3. The HVAC acoustical fan noise

Although most of the HVAC active noise control uses a single speaker control for achieving the desired noise reduction level, the noise patterns through the HVAC ducts have not yet been investigated. This research studies the duct sound pressure level (SPL) distribution and suggests a proposed scheme for higher HVAC ducts noise reduction. The proposed methodology is based on utilizing the control speaker position for obtaining the 1,800 of the control speaker output.

2. A PROPOSED HVAC DUCTS NOISE INTERACTIVE CONTROL TECHNIQUE

This work proposes that a 3 m length, and 0.2 m diameter PVC duct to be the under-test HVAC tunnel. A type 2270 Hand-held analyzers is used as a sound pressure level meter is used for determining the refraction and the compression tunnel zones. According to the obtained duct sound pressure level, the different DQZs, and the wavelengths (λS) will be allocated as shown in Figure 4. These zones sites are depending on the duct size length, and the rated fan power and speeds.

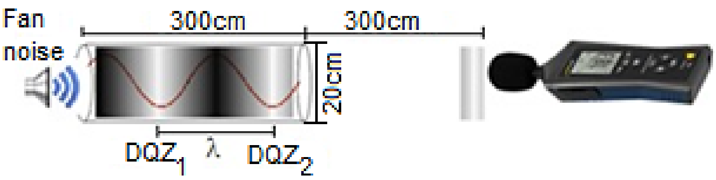


Figure 4. The DQZs of HVAC fan noise

– Case study_1

Figure 5 shown a typical SPL distribution in case of SPLfan is 100 dB, duct length is 300 cm, duct diameter is 20 cm at fixed noise source, the distance between any two consecutive DQZs is 34 cm that represents the acoustical wavelength (λ). The obtained sinusoidal SPL distribution is according to the noise nature inside the HVAC ducts. Extra located DQZs are displayed in Figure 5.

The measured sound pressure level of the prototype tunnel is displayed in Figure 6. It is noted that this study showed that the noise reduction occurs at equal distances λ which are about 34 cm, and in this case, the noise reduction of the HVAC fan is about 21 dB. Furthermore, the λ is almost linearly proportional to source SPL.

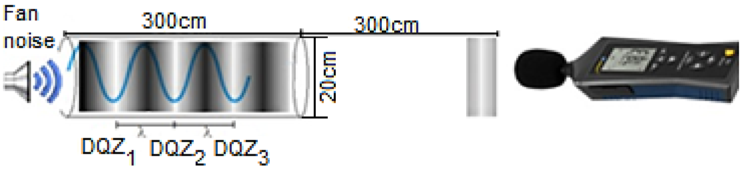


Figure 5. Duct noise form

2.1. Duct noise sources and quite zones interdependence

On the other hand, these zones have a fixed separation distance (λ), that is also depending on the duct mechanical parameters as well as the standing wave profile. However, the relation between the duct parameters, the source noise level, and the separation distance (λ), is obtained. The measured SPL is plotted in Figure 7, these measured SPL values depict an almost linear relation between the duct SPL and distance (λ) between any two successive DQZs for different noise sources.

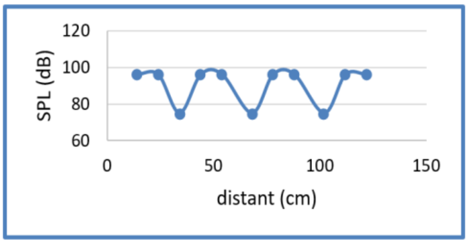


Figure 6. Duct SPL vs different duct places at a fixed noise source

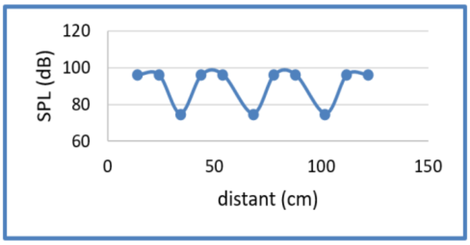


Figure 7. The measured SPL vs distance (λ) for different noise source

2.2. A proposed feed-forward noise control

The proposed system includes the different schemes for the duct noise control as below. The input microphone is used in front of the fan while the speaker is allocated at the DQZs. The fan noise waveform without control speaker and the control speaker waveform as shown in Figure 8.

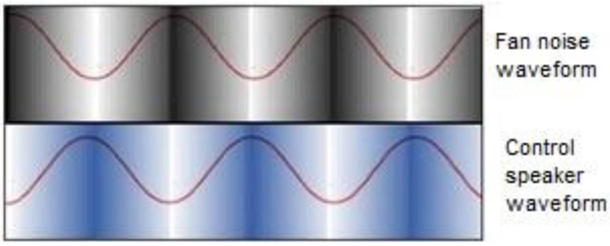


Figure 8. The fan noise waveform with the control speaker waveform

2.2.1. Single control speaker at one of multi-DQZs centers

The DQZs centers appear at many fixed distances (λ), this work proposes a single noise control speaker that can be installed at any of the DQZs centers as shown in Figure 9. The control speaker wave at the first DQZ can decrease the noise level to about 25% as shown in Figure 9(a). The same situation at either the second DQZ as shown in Figure 9(b) or the third DQZ as shown in Figure 9(c). The distance (λ) between the second DQZ and the first DQZ is equal to the distance between any two successively different DQZs as shown in (3).

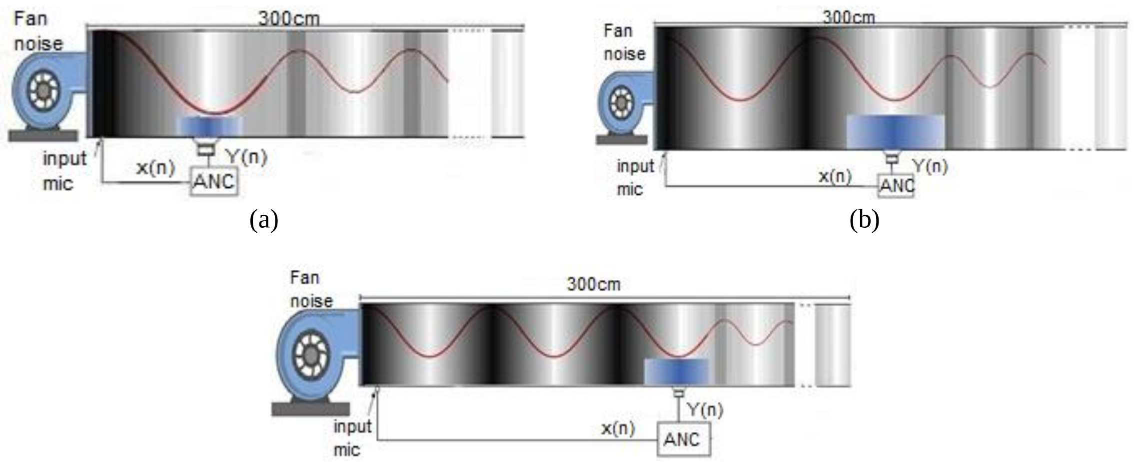
$$DQZ_2 - DQZ_1 = DQZ_3 - DQZ_2 = \ \dots \ \dots \ \dots . = DQZ_n - DQZ_{n-1} = \lambda \qquad (3)$$

2.3. Enhancement of the proposed feed-forward noise control

This paper displayed that higher noise reduction can be achieved by adding further control speakers at different quiet zones. This can be implemented in several arrangements of the control speakers' installation. Some of these installation schemes are demonstrated:

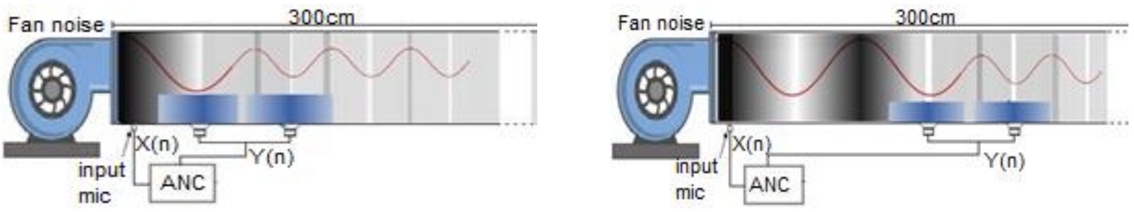
2.3.1. Double control speakers at two of the multi-DQZs centers

Two configurations of the system will be implemented; the double stage noise control is content on two control speakers at two different DQZs, as shown in Figure 10. The control speakers at the first and second DQZs as shown in Figure 10(a), and the control speakers at second and third DQZs as shown in Figure 10(b). Note that in the two cases has the performance where the noise level is decreased by around 30% from total HVAC noise.



(a) (b) (c)

Figure 9. The proposed HVAC noise control (a) the first DQZ, (b) the second DQZ, and (c) the third DQZ



(a) (b)

Figure 10. Enhancement of the proposed system (a) first and second DQZs and (b) second and third DQZs

2.3.2. Triple speakers at three of multi-DQZs centers

In this case, the triple control speakers as shown in Figure 11. They are sequentially installed where the 35% noise reduction can be achieved. However, they are consecutively installed, they can successfully perform the same reduction at different quit zones.

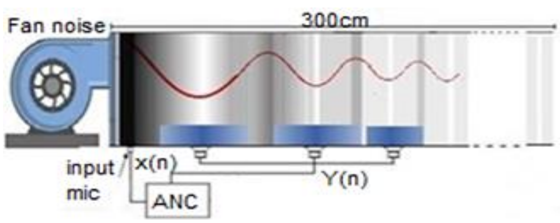


Figure 11. Triple-stage noise control

3. THE SIMULATION

A Proteus program is developed and implemented to validate the system concept the signal. The system simulation has been archived as shown in Figure 12, the fan noise simulated by a recorded fan sound file. Furthermore, the fan noise control signal is 1,800 shifted compared to the fan noise signal. A summer circuit is used to simulate the net duct noise as shown in Figure 13.

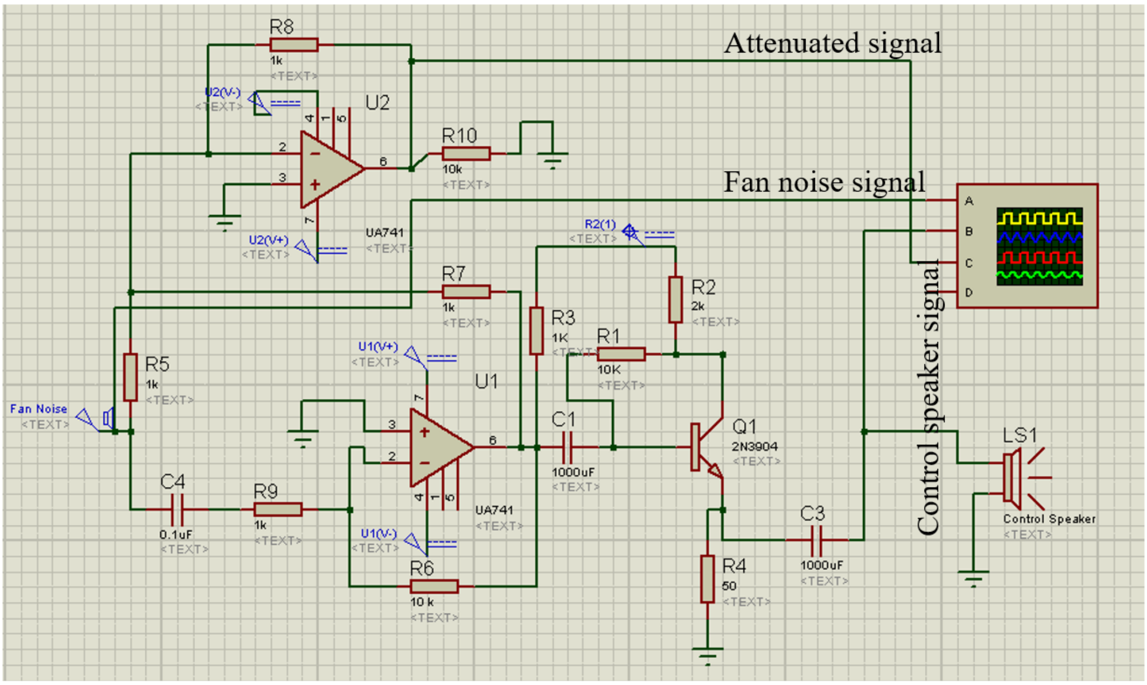


Figure 12. Active noise control proteus

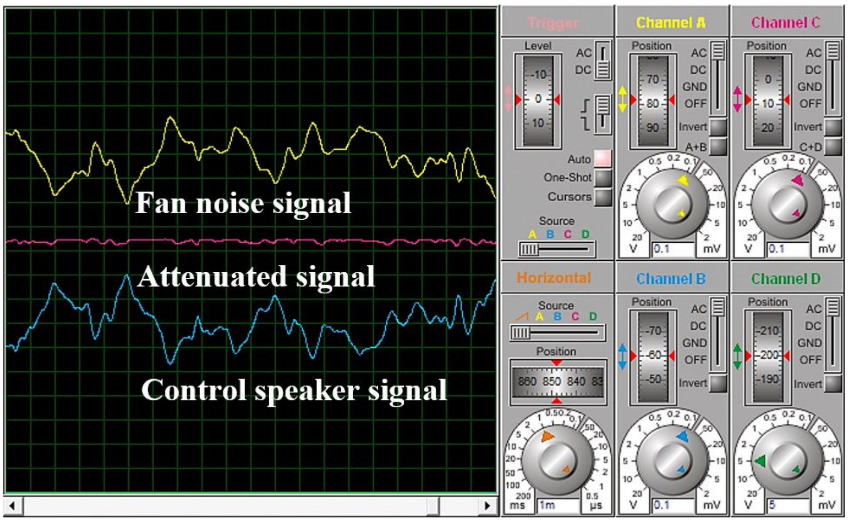


Figure 13. The simulation results

4. THE EXPERIMENTAL WORK

The experimental set-up shown in Figure 14, includes the 3 meters duct accompanied with three control speakers in addition to the generating noise speaker and noise reader microphone (the best position of mic is front the generating noise speaker. The duct length (L) is 3 m, the diameter (D) is 0.20 m, the distance between any two consecutive control speakers is 0.34 m, the control speaker’s impedance is 4 Ω and the power rate 16 w. A 100 dB fan noise generator is used for this experimental work. In the next paragraphs, the procedures of noise control will be discussed.

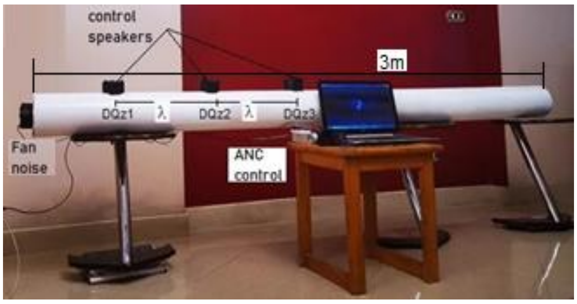


Figure 14. The proposed ANC prototypes

4.1. DQZs determination

The porotype tunnel accompanied with the proposed control devices/elements are depicted in Figure 14. Using a sound pressure meter with slight movement along the duct one can determine the total quiet zones of the duct. This system has DQZ at every 0.34 m along the duct.

4.2. Noise control models

The control speakers can be used in three different models; single, double, and triple according to both the noise source level and/or the desired reduction level. However, the noise control speakers are installed. This work applies the compensation noise signals through three different states. Single control speaker is fixed at any DQZs, the places of DQZs in the duct are changed whenever change SPLfan and you must choose a correct place of DQZs to get on the best reduction of noise. The double control speaker's model, it should be fixed the double speakers at any two points. This mode to give a reduction of noise better than single control speaker. The triple control model is the best solution for the noise reduction. The best choice for the noise reduction of the duct is depending on the distance between the speaker is equal (λ).

5. RESULTS AND DISCUSSION

Figure 15 shown the SPL at different operational frequencies after and before ANC. The best reduction at frequency 250 Hz, 500 Hz, and 1000 Hz are equal approximation 14~21 dB. The measurement point is about 3 meters from the noise source at single control speaker. The reduction with double control speakers is equal 19~26 dB at frequency 250 Hz, 500 Hz, and 1,000 Hz, and 24~31 dB of reduction at triple control speakers.

We found a thorough result and measurement of the noise-canceling experiment, the maximum reading fan noise before noise control is an equal approximation of 96 dB at a frequency of 1,000 Hz at distance 3 m from fan noise source and equal, 86 at distance 6m from fan noise source, as shown in Table 1. At the same fan noise source, and fixed at single control speaker, it has found that the cancellation equals to about 21 dB. This is takes place at distance 3 m at the end of the tunnel as listed in Table 2. At 1.5 m and 3 m from the end of the tunnel, the noise level is decaying to 70.5 dB and 66 dB respectively.

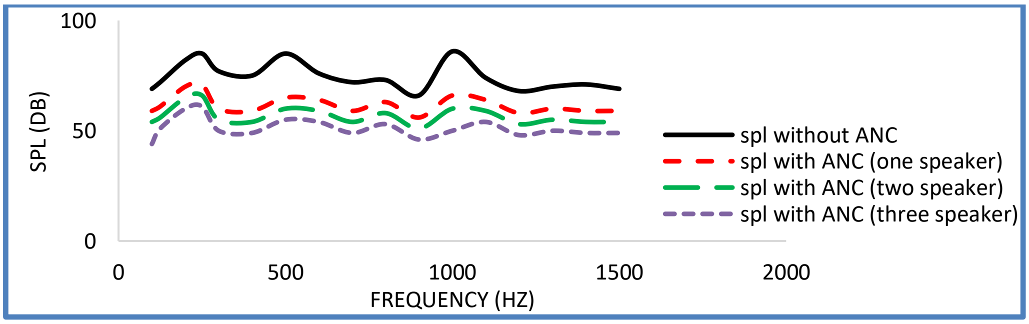


Figure 15. Relationship between SPL and frequency after and before ANC

Table 1. SPL of fan noise vs the distance (@ no control speaker)

Distance (m)	0	3	4.5	6
SPL of fan noise (dB) @ no control speaker	100	96	91	86

Table 2. SPL vs the distance (@ a single control speaker)

Distance (m)	0	3	4.5	6
SPL (dB) @ a single control speaker	100	75	70.5	66

In the case of double control speaker's, the fan noise reduction is equal approximation 30 dB at distance 3 m from noise source, as listed in Table 3. While the reduction has been improved at 4.5 m distance from the source to be 35.5 dB. The noise level has been reduced to be 60 dB at 3 m distance from the end of tunnel. With triple control speaker's, the noise reduction equal approximation 35 dB at the end of the tunnel. The noise level in near free space has been decayed to 61 dB and 57 dB at distances 1.5 m and 3 m respectively from the end of the tunnel. These results are listed in Table 4. Table 5 is presenting summarized lists of results. A group depicts the difference between the SPL reductions at different operational cases. The single, double and triple control speakers and the different measurement distances from fan noise are equal 3, 4.5 m and 6 m respectively.

Table 3. SPL vs the distance (@ a double-control speakers)

Distance (m)	0	3	4.5	6
SPL (dB) @ double-control speakers	100	70	64.5	60

Table 4. SPL vs the distance (@ a triple-control speakers)

Distance (m)	0	3	4.5	6
SPL (dB) @ triple- control speakers	100	65	61	57

Table 5. SPL reduction (@ control speakers) vs the distance

@100 dB (1000 Hz)			
@Single control speaker (dB)	@Double control speakers (dB)	@Triple Control speakers (dB)	Distance (m)
21	26	31	3
20.5	26.5	30	4.5
20	26	29	6

At the beginning of the duct, the measured of fan noise was equal 100 dB. The measured fan noise at the end of the duct was about 96 dB. This noise decreases by about 10 dB at distance 3 m from end of the tunnel as shown in Figure 16. This extra reduction of the free space is due to the near interferences.

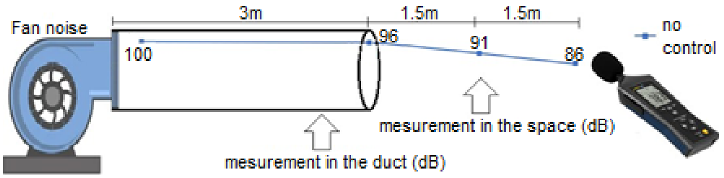


Figure 16. SPL of fan noise (no control speaker)

In case of a single- control speaker, the distance between fan and control speaker λ is equal 34 cm. The fan noise reduction in this case is equal 25 dB at distance 3 m (duct length) from the fan. While, the noise level of Figure 17 reached around 66 dB at 3 m distance from the end of the tunnel. The double-control speakers technique is higher noise reduction compared to the single speaker. The reduction is around 30 dB at the end of the tunnel. While the noise level decayed to about 60 dB at 3 m distance from the end of the tunnel as shown in Figure 18. The last case of noise control is the triple control speakers shown in Figure 19. This is the best case for noise reduction. The noise level is about 65 dB at 3 m distant from fan. It is about 57 dB at 3 m distance from the end of the tunnel as shown in Figure 19.

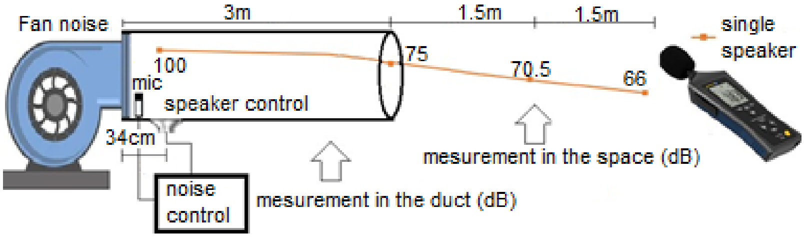


Figure 17. SPL vs number of noise control speakers (single-speaker)

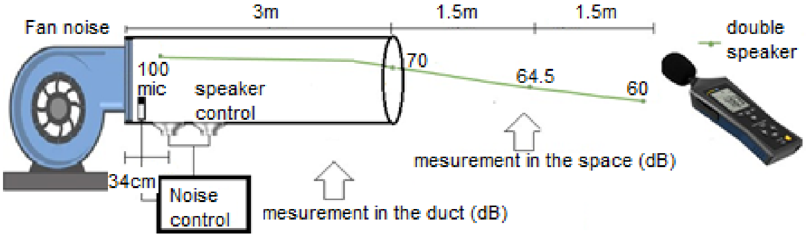


Figure 18. SPL vs number of noise control speakers (double-speakers)

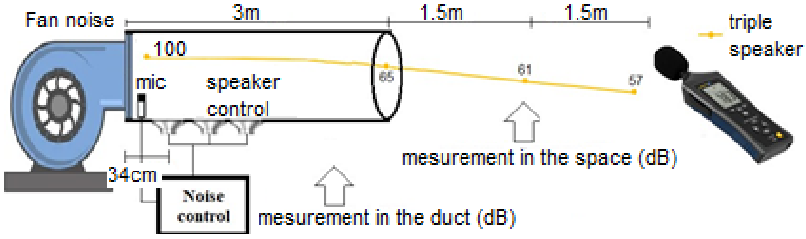


Figure 19. SPL vs number of noise control speakers (triple-speakers)

6. CONCLUSION

Heating, ventilation, and air conditioning (HVAC) multi-level noise control has been presented. The noise longitudinal wave nature is a key factor for allowing a significant reduction of these HVAC ducts noise. The DQZs have been allocated and used for installing at which the noise control speakers. This system proved that the distance λ is linearly proportional to the duct source noise level. Enhancement the noise reduction has been achieved installing further noise feed-forward control speakers at different duct DQZs. According to the proposed system multi-level of noise reduction has been implemented. A 21 dB and 26 dB noise reduction at single and double noise control speakers respectively. The system maximum reduction was about 31 dB at triple speakers control with wavelength λ is 34 cm. The results of both the system simulation and the field experimental work were in a satisfactory agreement.

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REFERENCES

[1] N. Bhat, U. Eranna, and M. K. Singh, "Pattern approximation based generalized image noise reduction using adaptive feedforward neural network," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 6, pp. 5021–5031, Dec. 2018, doi: 10.11591/ijece.v8i6.pp5021-5031.

[2] F. A. Hermawati, H. Tjandrasa, and N. Suciati, "Hybrid speckle noise reduction method for abdominal circumference segmentation of fetal ultrasound images," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, pp. 1747–1757, Jun. 2018, doi: 10.11591/ijece.v8i3.pp1747-1757.

[3] E. A. R. Hussein, M. K. Khashan, and A. K. Jawad, "A high security and noise immunity of speech based on double chaotic masking," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 4, pp. 4270–4278, Aug. 2020, doi:

10.11591/ijece.v10i4.pp4270-4278.
[4] H. Liu, S. Liu, A. A. Shkel, and E. S. Kim, “Active noise cancellation with MEMS resonant microphone array,” *Journal of Microelectromechanical Systems*, vol. 29, no. 5, pp. 839–845, Oct. 2020, doi: 10.1109/JMEMS.2020.3011938.
[5] N. Rekha and F. Jabeen, “A novel and integrated architecture for identification and cancellation of noise from GSM signal,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 5, pp. 4010–4019, Oct. 2019, doi: 10.11591/ijece.v9i5.pp4010-4019.
[6] E. M. Picou, “MarkeTrak 10 (MT10) survey results demonstrate high satisfaction with and benefits from hearing aids,” *Seminars in Hearing*, vol. 41, no. 01, pp. 21–36, Feb. 2020, doi: 10.1055/s-0040-1701243.
[7] C. Shi, Z. Jia, R. Xie, and H. Li, “An active noise control casing using the multi-channel feedforward control system and the relative path based virtual sensing method,” *Mechanical Systems and Signal Processing*, vol. 144, Oct. 2020, doi: 10.1016/j.ymssp.2020.106878.
[8] B. Lam, W.-S. Gan, D. Shi, M. Nishimura, and S. Elliott, “Ten questions concerning active noise control in the built environment,” *Building and Environment*, vol. 200, Aug. 2021, doi: 10.1016/j.buildenv.2021.107928.
[9] S. M. Kuo and D. R. Morgan, “Active noise control: a tutorial review,” *Proceedings of the IEEE*, vol. 87, no. 6, pp. 943–975, Jun. 1999, doi: 10.1109/5.763310.
[10] D. I. Ibarra-Zarate, G. Navas-Reascos, and A. L. Padilla-Ortiz, “Passive noise control in buildings: An engineering case study of ducted systems,” *Building Services Engineering Research and Technology*, vol. 42, no. 6, pp. 751–762, Nov. 2021, doi: 10.1177/01436244211019635.
[11] K. Mazur, S. Wrona, and M. Pawelczyk, “Performance evaluation of active noise control for a real device casing,” *Applied Sciences*, vol. 10, no. 1, Jan. 2020, doi: 10.3390/app10010377.
[12] M. Azimi, “Noise reduction in buildings using sound absorbing materials,” *Journal of Architectural Engineering Technology*, vol. 6, no. 2, 2017, doi: 10.4172/2168-9717.1000198.
[13] J. Yuan, J. Li, A. Zhang, X. Zhang, and J. Ran, “Active noise control system based on the improved equation error model,” *Acoustics*, vol. 3, no. 2, pp. 354–363, May 2021, doi: 10.3390/acoustics3020024.
[14] H. M. Lee, Y. Hua, Z. Wang, K. M. Lim, and H. P. Lee, “A review of the application of active noise control technologies on windows: challenges and limitations,” *Applied Acoustics*, vol. 174, Mar. 2021, doi: 10.1016/j.apacoust.2020.107753.
[15] Y. Kajikawa, W.-S. Gan, and S. M. Kuo, “Recent advances on active noise control: open issues and innovative applications,” *APSIPA Transactions on Signal and Information Processing*, vol. 1, no. 1, 2012, doi: 10.1017/ATSIP.2012.4.
[16] T. Xiao, X. Qiu, and B. Halkon, “Ultra-broadband local active noise control with remote acoustic sensing,” *Scientific Reports*, vol. 10, no. 1, Dec. 2020, doi: 10.1038/s41598-020-77614-w.
[17] C. Shi, R. Xie, N. Jiang, H. Li, and Y. Kajikawa, “Selective virtual sensing technique for multi-channel feedforward active noise control systems,” in *ICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, May 2019, pp. 8489–8493, doi: 10.1109/ICASSP.2019.8682705.
[18] S. J. Elliott, “Multichannel control of tonal disturbances,” in *Signal Processing for Active Control*, Elsevier, 2001, pp. 177–232.
[19] R. F. Nunes, J. R. D. F. Arruda, and J. M. C. Dos Santos, “Active noise control in a Y-shaped duct: simulation and experimental results,” *Building Acoustics*, vol. 5, no. 1, pp. 17–25, Mar. 1998, doi: 10.1177/1351010X9800500102.
[20] H. Meng and S. Chen, “A modified adaptive weight-constrained FxLMS algorithm for feedforward active noise control systems,” *Applied Acoustics*, vol. 164, Jul. 2020, doi: 10.1016/j.apacoust.2020.107227.
[21] T. Suman and M. Venkatanarayana, “Active noise control for PVC duct using robust feedback neutralization F×LMS approach,” *Journal of Control, Automation and Electrical Systems*, vol. 32, no. 5, pp. 1189–1203, Oct. 2021, doi: 10.1007/s40313-021-00753-6.
[22] D. Shi, W.-S. Gan, B. Lam, and S. Wen, “Feedforward selective fixed-filter active noise control: algorithm and implementation,” *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, 2020, doi: 10.1109/TASLP.2020.2989582.
[23] C.-R. Huang, C.-Y. Chang, and S. M. Kuo, “Directional dependency for feedforward active noise control systems with in-ear headphones,” in *2021 International Conference on System Science and Engineering (ICSSE)*, Aug. 2021, pp. 185–188, doi: 10.1109/ICSSE52999.2021.9537943.
[24] X. Kong and S. M. Kuo, “Study of causality constraint on feedforward active noise control systems,” *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, vol. 46, no. 2, pp. 183–186, 1999, doi: 10.1109/82.752950.
[25] M. Suzuki and I. S. Suzuki, “Lecture note on oscillations and waves.” Department of Physics, State University of New York at Binghamton, Binghamton, New York, 2009.
[26] L. F. Khilyuk, G. V Chilingar, J. O. Robertson, and B. Endres, “Magnitude and intensity of earthquakes,” in *Gas Migration*, Elsevier, 2000, pp. 133–143.
[27] F. Dunn, T. Rossing, W. M. Hartmann, D. M. Campbell, and N. H. Fletcher, Eds., *Springer handbook of acoustics*, 2nd ed. Springer, 2015.
[28] W. R. Bennett, “Wave motion,” in *The Science of Musical Sound*, Cham: Springer International Publishing, 2018, pp. 1–30.

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