Research on the Infrasound Generated by Busses

Zhou Ming[a], Cai Desuo[a,b], Wu Pangao[a] and Zhang Yongxiang[a]
[a]College of Civil Engineering and Architecture, GuangXi University, 100 Daxue Road, Nanning, Guangxi, P. R. China
[b]College of Hydraulic and Environment Engineering, Three Gorges University, 8 Daxue Road, Yichang, Hubei, P. R. China

The interior infrasonic level in a bus is an important factor that may affect the driver and the passengers. Scientists have found that high infrasound noise can have an effect on disorganizing nervous activities in a similar manner to the effects of alcohol. This may bring potential safety risk to driving. However, attention has traditionally focused on audible noise inside various modes of transportation. There has been very little spectral data reported at infrasonic frequencies for noise inside busses. In view of this, this article applies to study of infrasound signals generated by running busses. Tests were carried out on 15 busses, three groups divided according to their used time. After measurement, the time-domain signals were transformed into the frequency-domain by using the Fast Fourier Transform (FFT), the main characteristics of bus generating infrasound were discussed in terms of the frequencies. Data derived from measurements were compared with the limits specified in existing standards and/or regulations in this field in order to evaluate the effects that bus generating infrasound may cause.

1. INTRODUCTION

Infrasound is acoustic energy whose frequency is lower than 20 Hz, which can be annoying when levels exceed the hearing thresholds. It is important to note that the degree of annoyance can increase markedly for only relatively small increases in the infrasonic noise level once it is above the hearing threshold [20]. There are many sources of infrasound including volcanoes, earthquake, bolides, mini explosions, atmospheric explosions, rockets and weather systems [1-6]. Riding on busses also expose drivers and passengers to 1 to 20 Hz infrasound noise. High intensity infrasound noise in busses do not only have influence on the comfort of passengers and driver, but also can have an effect on their mental and physical health. Extended operation at a high intensity infrasound noise condition can also lead to fatigue and loss of concentration [7]. This may bring potential risk and danger to our safety.

However, in the past studies, Researchers have focused more on vehicles generating infrasound noise or audible noise [8-11]. So far, research on the busses generating infrasound has been sparse and few experiments have reported the relation between the level of bus generating infrasound and the time of their exploitation [12]. Therefore, the characteristics of infrasound generated by busses, and their nuisance evaluation are issues that require detailed research.

This article presents results obtained from 15 running busses. Aiming to clarify the relation between the level of bus generating infrasound and the time the bus has been used. The aural discomfort and disturbances that the infrasound generated by busses can cause is also evaluated.

2. METHODS

An infrasonic microphone from Chinese Academy of Sciences was used in the measurement. With a sensitivity of 50 mv/Pa in the frequency range from 2 to 4000 Hz. (which is shown in Fig. 1). This microphone is designed for high-

* Corresponding author: e-mail: choving@hotmail.com (Z. Ming)

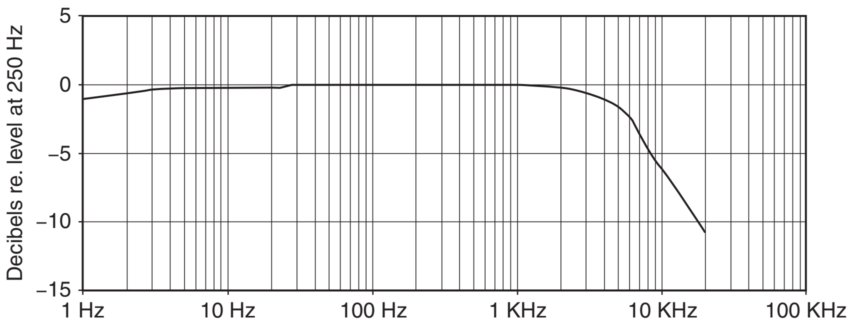


Figure 1: Frequency response curve of used microphone.

precision, acoustic measurements with a diameter of 0.52 inch. Being prepolarized, it is well suited for battery operated equipment and operation in environments with high humidity. This sensor was chosen for its frequency range, good pressure sensitivity and low inherent noise, with an operating temperature range of –40 to 120 degrees Celsius. The microphone was connected with an infrasound detecting system. This system was originally used to monitor debris flow, avalanche generating infrasound. Since there is an SD memory card to store data inside, it can also be used to measure the infrasound noise (see Fig. 2). According to the Nyquist Theorem, as the main frequencies of infrasound generated by bus lie between 0 Hz and 20 Hz, the sampling rate was set at 100 Hz in the measurements. All windows were kept closed during the measurement period.

We divide the busses into groups of three according to the time they have been used, less than 1 year used, 5 years used and 7 or more years used respectively. All buses in the three groups are rear-engined. Fig 3 is a photo of the tested busses. The infrasonic sensors were located in the front of the bus behind the driver's seat and in the back seat and the height of the sensor is greater or equal to a person's ear level which is shown in the top view in Fig. 4. Measurements were taken in a general concrete pavement which is straight and smooth. The driving speed is stabilized around 20km/h in the first gear. Each measuring-point of each bus is measured for 60 seconds. The weather condition of the testing day is shown in Table 1.

3. ANALYSIS OF INFRASOUND DATA

Fast Fourier transform (FFT) is usually used to analyze the time series data of the sound signals. The FFT of a signal

Figure 2: Infrasound detecting system.

Figure 3: *Photo of the tested busses.*

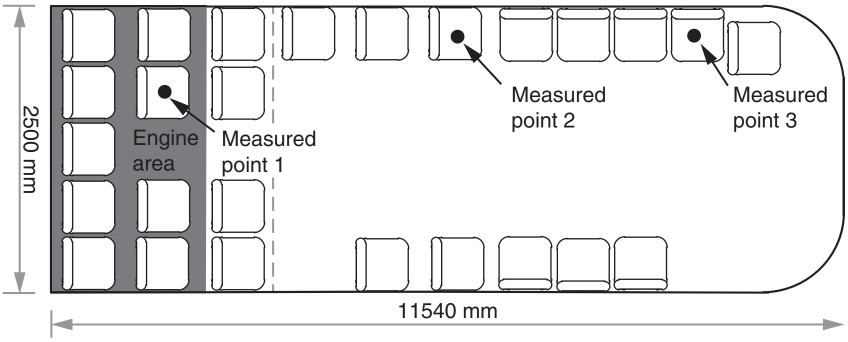


Figure 4: *Top view of the measured busses.*

Table 1: *Weather condition of the testing day*

Weather condition	Average value
Temperature	23.5°C
Humidity	66.9%
Pressure	1000.5 hPa

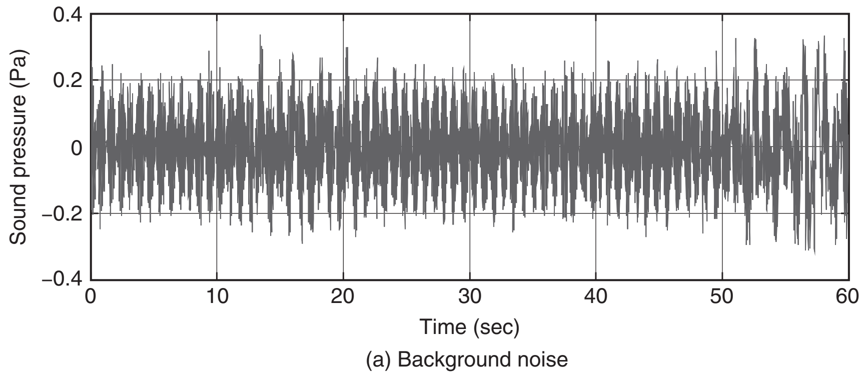
essentially decomposes, or separates the signal into a sum of sinusoids with different frequencies. This approach implies periodicity in both the time and frequency domains. It is very suitable for periodic signals. Therefore, the FFT was applied to analyze the infrasonic signals of the experiment.

In the study, the background noise was measured in order to distinguish it from the infrasound generated by bus, shown in Fig. 5(a). The buses were stationary with the engine off during the background noise measurement. Typical infrasonic signals associated with group 1 are shown in Fig. 5(b).

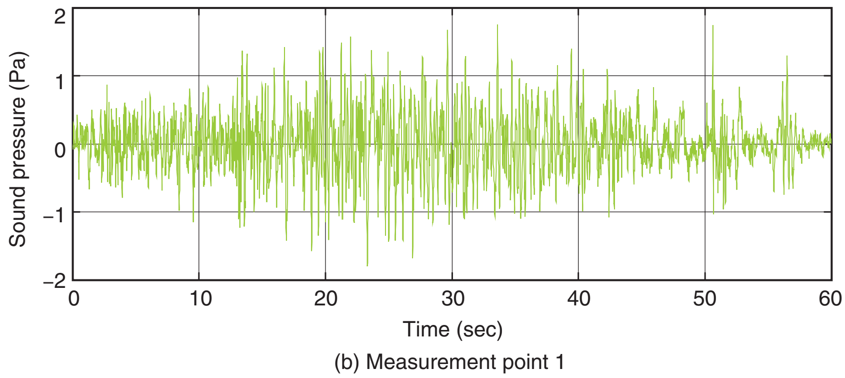
In Fig. 6 the infrasound spectrums of background noise and group 1 which was analyzed using the FFT was presented. It illustrated the frequency spectrum of the measured signal. According to the results of the analysis, the highest value of the background sound was 1 Hz and the peak frequency of all the three measured points of group 1 was 2 Hz.

In the same way, the typical infrasonic signals associated with group 2 are shown in Fig. 7.

Fig. 8 shows the infrasound spectrums of group 2. Fig. 8(a) indicates that the frequency of the sound measured at point 1 ranges between 1.5 Hz to 2 Hz and 9 Hz to 12 Hz, and the peak frequency is at about 1.7 Hz and 11.7 Hz. Comparing Fig. 8(a), Fig. 8(b) and Fig. 8(c), it is noted that the peak frequencies in all the three points are much close to one another and the peak energy of point 1 (located at engine area)



(a) Background noise



(b) Measurement point 1

Figure 5: Infrasound pressure.

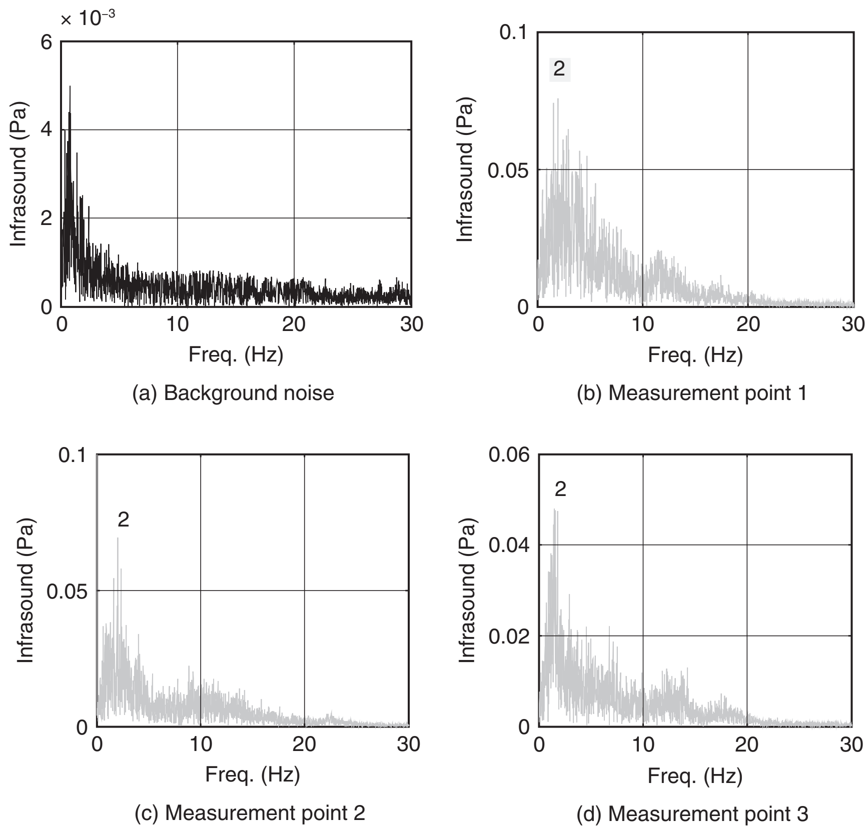


Figure 6: Infrasound spectrums.

is a little higher than point 2 and point 3. This result seems to indicate that the infrasound is mainly generated by the engine area and the propagation process of pressure has certain attenuation, but the loss is little. This phenomenon is

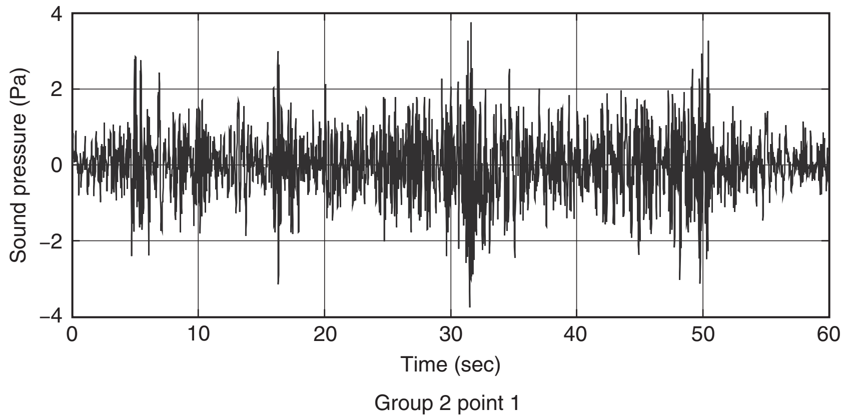


Figure 7: *Typical Infrasound Pressure of Group 2.*

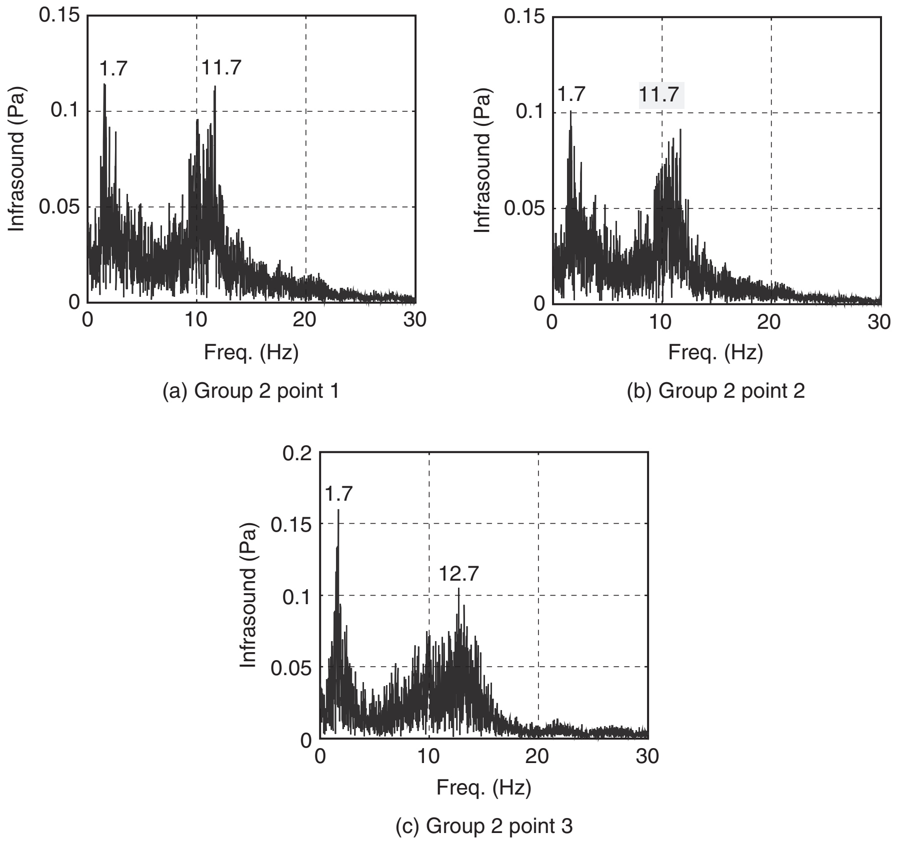


Figure 8: *Infrasound Spectrums of Group 2.*

consistent with previous research of Sandberg [13] and Sand [14].

Infrasound spectrums of Group 3 are shown in Fig. 9.

Fig. 10 displays the infrasound spectrums of group 3. The frequency of the infrasound ranges between 1.5 Hz to 2 Hz and 9 Hz to 12 Hz, and the peak frequency is at about 1.5 Hz and 10 Hz.

Comparing the spectrums of the three groups, it is noted that as the usage time increases, the frequency band from 9 Hz to 12 Hz gradually increases in this type of bus. There are many reasons that may cause infrasound noise in the bus, such as the running engine, component loosening, fasteners missing, etc. Since the driving speed and road condition are the same in these experiments, besides, a peak at the frequency of 1.5 Hz approximately was persistent in overall tested buses, it can be assumed that the frequency of 1.5 Hz occurring in the three group buses may be caused by the running engine. While the increasing sound pressure levels

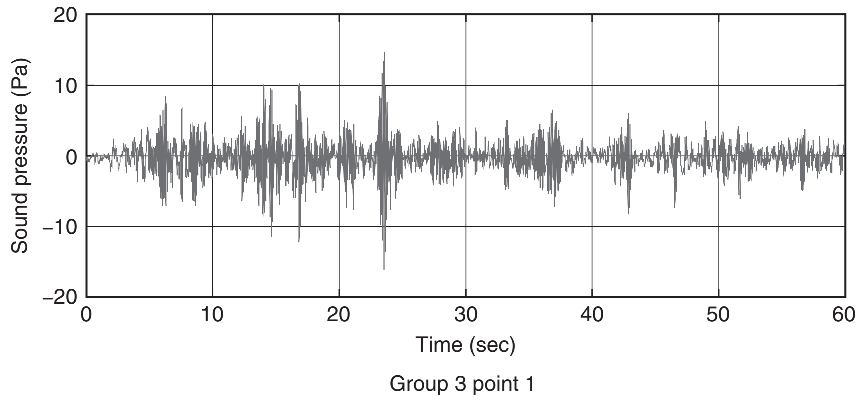


Figure 9: *Infrasound pressure of point 3.*

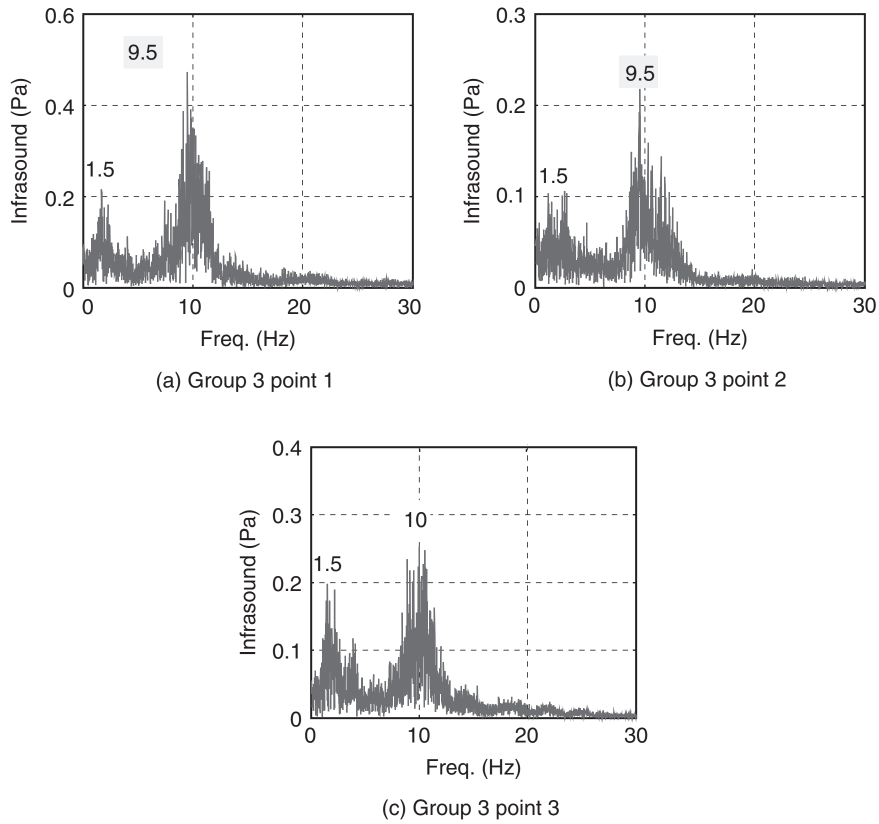


Figure 10: *Infrasound spectrums of Group 3.*

around 10 Hz in the second and third group buses may be due to component loosening.

Since measurement point 1 in each bus was located right in the engine area, and according to the frequency domain analysis, the running engine plays an important role in leading to a high infrasound noise level, here we present the Leq for each measurement in Table 2.

In order to evaluate the effects that bus generating infrasound may cause, occupational exposure limits should be presented first. Over years, there are exposure criteria in use or proposed in the United Kingdom, Germany, Sweden, Denmark, the Netherlands, Australia, and Poland based on the threshold of perception [15-18]. ISO 7196 [19] states that “sound pressure levels below 90 dB (G) will not be significant for human perception”, so that it is unlikely to produce any effects. Andresen and Moller [20] proposed a criterion of 95 dB(G) based on the onset

Table 2: Leq for each measurement

Category	Num.	Leq. at measured point 1, dB
	1	79
Buses being used	2	79
less than one year	3	80
(Group 1)	4	81
	5	80
	1	91
Buses being used	2	87
for five years	3	87
(Group 2)	4	92
	5	89
	1	97
Buses being used	2	96
for seven or more	3	97
years	4	98
(Group 3)	5	101

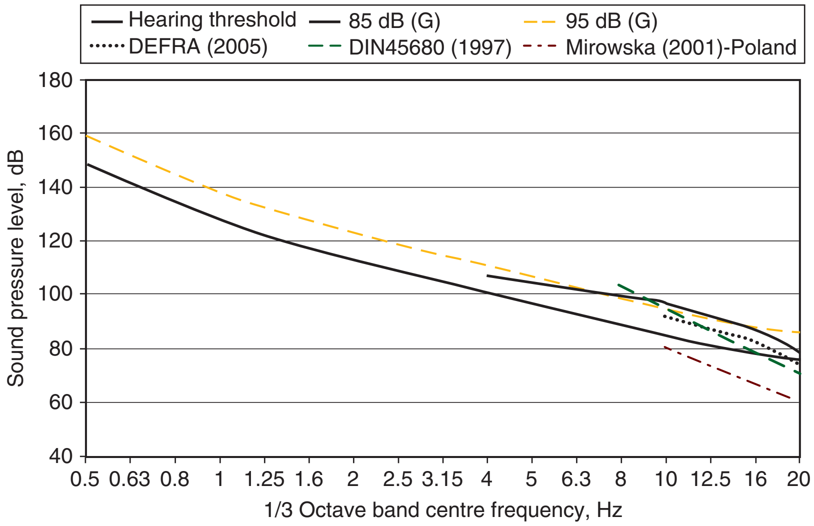


Figure 11: Comparison of infrasound assessment criteria.

of annoyance from perceptible infrasound. In Denmark, Jakobsen [21] recommended a noise limit of 85 dB(G) for dwelling. Unfortunately, none of them is widely accepted. In order to find out which criterion is more relevant for assessment of the low frequency sound inside the buses. The proposed 85 dB(G), 95 dB(G), the low frequency hearing threshold from Watanabe and Møller [22] and other low frequency noise assessment criteria between 0.5 Hz and 20 Hz were compared in Fig. 11. These assessment criteria allow measured infrasound levels as part of the present study to be placed in context. It is noted that the 95 dB(G) criterion is closer to the mean threshold and the aim of this study is to investigate the infrasound levels in running buses rather than against the assessment criteria for dwellings. It is important to recognize that levels below 95 dB(G) would be unlikely to cause adverse response in bus passengers and the driver.

In order to determine the levels of infrasound that people are most commonly exposed to within this environment, the one-third octave band frequency analysis was applied. The sum of G-weighted third octave level was also calculated for comparing with the criterion.

Fig. 12(a) presents the 1/3 octave frequencies of infrasound measured in group 1. It can be seen that the octave band sound levels with G-weighting reveal an increasing trend as the frequency of sound increases. This is because the G-weighting function negatively weighs sound at lower frequencies. The maximum G-weighted sound pressure level of this group is approximately at 73 dB(G). Summing all G-weighted values in the 1/3 octave band logarithmically, the total G-weighted level of 78 dB(G) thus obtained is shown in Fig. 12(a). Comparing this value with the reference value, it would be reasonable to indicate that the level of infrasound produced by group 1 is below the threshold of human perceptibility which means it is permissible.

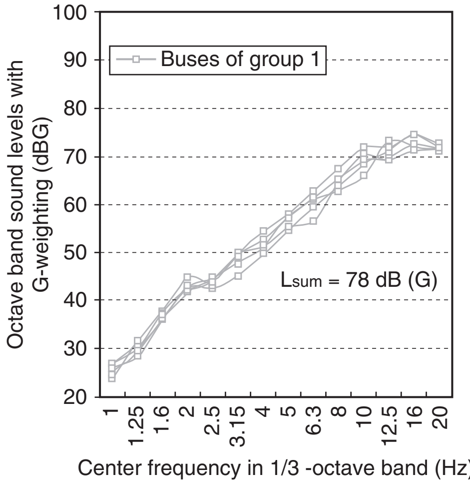
Fig. 12(b) shows the 1/3 octave frequencies of infrasound measured in group 2. Identified from Fig. 8, the characteristics of frequencies of this group were at 1.5 Hz to 2 Hz and 9 Hz to 12 Hz. Since G-weighting applied at the third-octave frequencies of 1.6 Hz and 10 Hz are –32.6 dB and 0 dB respectively, the peak at 1.6 Hz, 10 Hz which are 83 dB, 84 dB approximately, were less obvious in the G-weighted octave band sound pressure levels. Comparing Fig. 12(b) with Fig. 12(a), it can be seen that group 2 appears to generate relatively high level sound pressure levels at the third-octave frequency bands. Similarly, logarithmically summing the G-weighted level in each 1/3 octave band, the G-weighted level in group obtained is approximately 93 dB(G). Therefore, it is reasonable to indicate that the infrasound pressure levels of the 5 year exploited buses are still below the threshold of perception.

Fig. 12(c) presents the 1/3 octave frequencies of infrasound measured in group 3, which produced peaks with the greatest sound pressure levels of the three groups according to Fig. 10. Viewing from Fig. 10, the peak sound pressures of this group occur at frequencies 1.6 Hz, 10 Hz and 12.5 Hz respectively. However, since the G-weighting applied at the frequencies of 1.6 Hz, 10 Hz and 12.5 Hz are –32.6 dB, 0 dB and 4 dB, the un-weighted sound pressure levels of these peaks are 88 dB, 98 dB and 91 dB. It is important to note that, while the threshold of perceptibility of sound pressure levels at the frequency of 1.6 Hz has not been well defined, available evidence of the threshold at a frequency of 2.5 Hz suggests that it would be at least 110 dB. Thus, it would be reasonable to assume that the threshold of perception at frequencies lower than 2.5 Hz would be higher than this. Therefore, the level of infrasound at 1.6 Hz of the third group is below the threshold of perceptibility. Thus, it is unlikely to produce any effects. However, calculating all the third octave levels, the total G-weighted level which is approximately 100 dB(G) obviously exceeds the acceptable value of 95 dB(G). Particular attention should be paid to this type of buses.

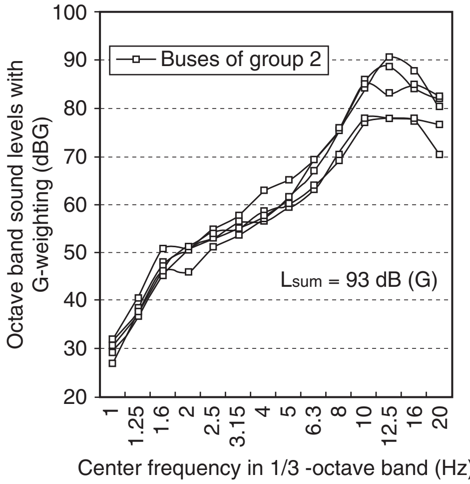
4. CONCLUSIONS AND SUGGESTIONS

Vehicles type tests conducted in the past studies, according to the UN European Economic Commission Regulations [15, 16], encompass only assessment of the vehicle generating noise, specifically audible noise. The effect that infrasound produces on passengers and driver in a bus need to be recognized in detail.

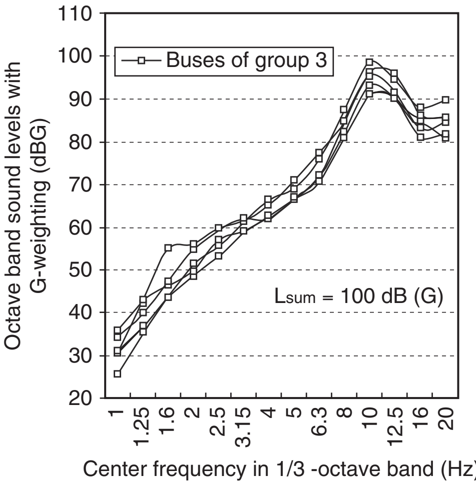
Measurements were presented by using 15 busses to investigate the main characteristics of bus generating infrasound. The fast Fourier transform was applied to analyze the infrasound signals. Its impact and nuisance were also evaluated based on standards and regulations in this field. The experimental results support the following conclusions:



(a) Infrasound in 1/3 octave band spectrum of group 1



(b) Infrasound in 1/3 octave band spectrum of group 2



(c) Infrasound in 1/3 octave band spectrum of group 3

Figure 12: Infrasound in 1/3 octave band spectrum.

1. Based on the analysis conducted, the frequency of the infrasound generated by this type of bus mainly ranges from 9 Hz to 12 Hz, main frequency at 10 Hz.
2. Comparing with the 1/3 octave band frequencies of the infrasound level for the three groups
   a) Group one, which were composed of busses that were less than 1 year

exploitation, were affected by the infrasound with frequencies at about 2 Hz. But the noise level is permissible according to the guidance.

b) Group two, which were composed of busses used for 5 years, influenced by the infrasound at frequencies in the range of 1.5 Hz to 2 Hz and 9 Hz to 12 Hz, and the peak frequencies are at about 1.7 Hz and 11.7 Hz.

c) Group three, which were composed of busses used for 7 years or more, were influenced by the infrasound frequencies in the range of 1.5 Hz to 2 Hz and 9 Hz to 12 Hz, and the peak frequencies are at about 1.5 Hz and 10 Hz, and the infrasound noise level exceeds the recommended value at these frequencies which may give symptoms of strenuousness like drowsiness and sluggishness.

3. Reasons that may lead to the increase of the bus generating infrasound level are various. Working engine, pulsating air, or the road surface can cause such noise. Furthermore, according to these experiments, it appears that, the time that the bus has been used can also be a factor in the increase of inside-bus infrasound level. Further research should be conducted in order to recognize the fact of endangering drivers and passengers by their exposure to the infrasound in the riding environment and formulate appropriate countermeasures.

REFERENCES

[1] Garces. M., Hetzer. C., Merrifield M., Willis M. and Aucan J. Observations of surf infrasound in Hawai'i, Geophysical Research Letters, 2003, **30**, 2264.

[2] Jakobsen J. Infrasound Emission from Wind Turbines, Journal of Low Frequency Noise, Vibration and Active Control, 2009, **24**, 145–155.

[3] Assink J. D., Evers L. G., Holleman I. and Paulssen H. Characterization of infrasound from lightning, Geophysical Research Letters, 2008, **35**, L15802.

[4] Petersen T., De Angelis S., Tytgat G. and McNutt S. R. Local infrasound observations of large ash explosions at Augustine Volcano, Alaska, during January, Geophysical Research Letters , 2006, **33**, L12303.

[5] Olson J. V., Wilson C. R. and Hansen R. A. Infrasound associated with the 2002 Denali fault earthquake, Alaska, Geophysical Research Letters, 2003, **30**, ASC6.

[6] Klaczynski. M. and Wszolek T. Detection and Classification of Selected Noise Sources in Long-Term Acoustic Climate Monitoring, ACTA Physica Polonica A, 2012, **121**, 179–182.

[7] Qibai C. Y. H. and Shi H. An Investigation on the Physiological and Psychological Effects of Infrasound on Persons, Journal of Low Frequency Noise, Vibration and Active Control, 2005, **4**, 25–30.

[8] Namba S. and Kuwano S. Kinoshita A, Hayakawa Y, Psychological Evaluation Of Noise In Passenger Cars, Journal of Sound and Vibration. 1997,**205**, 427–433.

[9] Xiaojun L., Jie L. and Jilin W. D. An Investigation of Inner Infrasound of Vehicles, Automotive Engineering. 2001, **23**, 266–269.

[10] Roberts C. Low Frequency Noise from Transportation Sources, Proceedings of 20th International Congress on Acoustics, 2010, 23–27.

[11] Jung S. S, Kim Y. T and Lee Y. B. "Spectrum of Infrasound and Low-frequency Noise in

Passenger Cars", Journal of the Korean Physical Society, 2009, **55**, 2405–2410.

[12] Nyunin B. N, Pletnev A. E and Yudin S. I, "Calculation-experimental study as a mean of infrasound and low-frequency noise in the bus cabin", Avtomob. Prom, 2002, 36–38.

[13] Sandberg U. "Tyre/road noise—myths and realities" (plenary paper), Proceedings of the International Congress and Exhibition on Noise Control Engineering, The Netherlands, 2001.

[14] Sand O, Karlsen HE. "Detection of infrasound by the Atlantic cod". J. Exp. Biol. 1986,**125**, 197–204.

[15] Pawlaczyk-Luszczynska, M. et al. "Proposal of New Limit for Occupational Exposure to infrasonic noise in Poland". Journal of Low Frequency Noise, Vibration And Active Control, 2000, **19**, 183–193.

[16] Department of Food, Environment and Rural Affairs. "Proposed criteria for the assessment of low frequency noise disturbance", report prepared by University of Salford, DEFRA, 2005, London.

[17] Mirowska M. "Evaluation of Low-Frequency Noise in Dwellings. New Polish Recommendations", Journal of Low Frequency Noise, Vibration and Active Control, 2001, **2**, 67–74.

[18] German Institute for Standardization (DIN). "DIN 45680 Measurement and assessment of low-frequency noise immissions in the neighbourhood" (in German), DIN, 1997, Berlin.

[19] International Organization for Standardization, "ISO 7196 Acoustics – Frequency-weighting characteristic for infrasound measurements", ISO, 1995, Geneva.

[20] Andresen J and Møller H. "Equal Annoyance Contours for Infrasonic Frequencies", Journal of Low Frequency Noise and Vibration, 1984, **3**, 1–9.

[21] Jakobsen J. "Danish guidelines on environmental low frequency noise, infrasound and vibration", Journal of Low Frequency Noise, Vibration and Active Control, 2001, **20**, 141–148.

[22] Watanabe T and Møller H. "Low Frequency Hearing Thresholds in Pressure Field and in Free Field", Journal of Low Frequency Noise and Vibration, 1990, **9**, 106–115.

PROTESTS AGAINST UNNECESSARY NOISE BARRIER

People in Bakewell, Derbyshire, fear their views of the Peak District will be spoiled if plans to build a noise barrier go ahead. In 2012 Derbyshire Dales District Council was given permission for the 5.5m (18ft) high and 97m (318ft) long barrier at the livestock market. The council said noise assessments showed it was needed to screen noise from people living nearby. A meeting was held this month in a bid to reach a compromise with residents. Diane Gilmore, who lives on Coombs Road next to the market, also known as Bakewell Agricultural Business Centre, said: "The proposal for the barrier is a solution to a problem that doesn't exist. Noise outside and inside isn't a problem for us at all, but the visual impact will be devastating." Paul Morgans, the town's mayor, said the barrier "doesn't sit right" in the area. "There's absolutely no need for it," he said. Derbyshire Dales District Council said discussions about the barrier - which residents believe could cost the authority £100,000 - will take place again at a meeting in February.

HEMEL HEMPSTEAD PENSIONER'S TELLY SEIZED

A virtually housebound pensioner says council chiefs have taken away his only link to the outside world - his television. Peter Keen, who suffers from angina and rarely ventures outside, says three council workers and a police officer came to his Hemel Hempstead home and took his two televisions as well as a stereo system. "I'm practically housebound, the only thing I have got is my television and they have taken it," said 63 year old Mr Keen. He is locked in a row over noise with his neighbour and council officials have stepped in to put an end to it. But Mr Keen, who is on anti-depressant medication, feels he is being treated unfairly. "I'm getting to the stage where I literally can't take anymore," he said. "To take the television is a step too far. Sometimes my music has been loud but it has not been loud during the night. I'm not making myself out to be innocent but during the day I can't see a problem, it has not gone on late at night. They can do what they like with my music system but to take my television, my only enjoyment is a step too far." Dacorum Borough Council's team leader for environmental health Nicholas Egerton said they usually take an informal approach where possible to resolve noise complaints in the borough. But if the problem persists then legal action is taken. "Before serving a noise nuisance notice the environmental health department will establish that there is, or is likely to be, a statutory nuisance - a noise that is thought to have a significant impact on the health and wellbeing of those affected," said Mr Egerton. "Once a notice is served we try to witness any breach of the notice. Where a breach is witnessed we can prosecute offenders. Where it is considered that the noise is serious we will apply to the court for a warrant to enter and seize noise-making equipment (like stereos and TVs). Upon prosecution, we will also ask the courts for a forfeiture order for the equipment, allowing us to permanently confiscate the equipment."

UT AUSTIN ENGINEERS BUILD FIRST NONRECIPROCAL ACOUSTIC CIRCULATOR: A 1-WAY SOUND DEVICE

Researchers at The University of Texas have built the first-ever circulator for sound. The team's experiments successfully prove that the fundamental symmetry with which acoustic waves travel through air between two points in space can be broken by a compact and simple device "Using the proposed concept, we were able to create one-way communication for sound traveling through air," said Associate Professor Andrea Alù, who led the project. "Imagine being able to listen without having to worry about being heard in return." An electronic circulator, typically used in communication devices and radars, is a nonreciprocal three-port device in which microwaves or radio signals are transmitted from one port to the next in a sequential way. When one of the ports is not used, the circulator acts as an isolator, allowing signals to flow from one port to the other, but not back. The UT Austin team realized the same functionality is true for sound waves traveling in air, which led to the team's building of a first-of-its-kind three-port acoustic circulator. Romain Fleury, a Ph.D. student in Alù's group, said the circulator "is basically a one-way road for sound. The circulator can transmit acoustic waves in one direction but block them in the other, in a linear and distortion-free way." The scientific knowledge gained from successfully building a nonreciprocal sound circulator may lead to advances in noise control, new acoustic equipment for sonars and sound communication systems, and improved compact components for acoustic imaging and sensing. "More broadly, our paper proves a new physical mechanism to break time-reversal symmetry and subsequently induce nonreciprocal transmission of waves, opening important possibilities beyond applications in acoustics," Alù said. "Using the same concept, it may actually be possible to construct simpler, smaller and cheaper electronic circulators and other electronic components for wireless devices, as well as to create one-way communication channels for light."