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Measurements of ultrasound from public address and voice alarm systems in public places

Beth Paxton,[a)] Jack Harvie-Clark, and Max Albert
Apex Acoustics, Design Works, Gateshead NE10 0JP, United Kingdom

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Concerns have been raised about potential health effects of public exposure to ultrasound; however, there are few published surveys of measurements taken in public places. Results are presented of measurements taken in a selection of public places including train stations, shopping centres, galleries and museums, and the difficulties of taking measurements with conventional equipment are highlighted. Tones were identified in the 20 kHz third-octave band at 8 of the 14 locations tested; the characteristics of the tones are consistent with their source being Public Address or Voice Alarm systems. The measured results do not exceed existing interim guidelines for public exposure to ultrasound, and existing research suggests that no significant undesirable effects would be anticipated following exposure to ultrasound of this nature for short periods. The measured data may be reviewed against future public exposure guidelines which consider the variation in response across the population and between continuous and pulsed sources. © *2018 Acoustical Society of America*.
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I. INTRODUCTION

Concerns have been raised about potential health effects associated with exposure to sound at ultrasonic frequencies.[1] Sources of ultrasound are increasingly prevalent and can be grouped into those where the production of an ultrasound signal is deliberate and those where emission of ultrasound is an unintentional by-product of their operation.[1]

There are inherent challenges in locating sources of ultrasound. Previous measurements in the field have been conducted in areas where there have been anecdotal reports from members of the public of ill effects attributed to ultrasound,[1] and to investigate the unintentional emission of ultrasonic tones by projectors found in school classrooms.[2]

Some animal repellent devices use very high frequency or ultrasonic emissions to drive away pests such as rodents and birds. Measurements of the emissions from these devices taken *in situ*[3,4] and in the laboratory[5] demonstrate that these devices are capable of emitting ultrasound at high sound pressure levels.

Another type of device designed to intentionally emit very high frequency noise is the Mosquito, designed to deter teenagers from loitering by producing sound at frequencies which may be audible and unpleasant to teenagers and young people but beyond the hearing range of most adults.

Since there is no legal obligation for people using these devices to register their location it is difficult to identify places where they are used and it has not therefore been possible to measure noise levels from these devices *in situ*.

Sources identified[1] as having the potential to affect very large numbers of people are Public Address (PA) and Voice Alarm (VA) systems. The dataset on the output of these sources has recently increased, Mapp[6] noting that ultrasonic signals, almost always a pure tone and typically with a frequency of around 20 kHz, are frequently used to monitor critical paths, as required by British and International Standards.

Emission of ultrasound by PA/VA systems has been selected for investigation as these sources have the potential to be a widespread cause of public exposure, and it is considered that the probability of success in locating these sources is greatest, common as they are in publicly accessible locations. Measurements have been taken in a selection of public places including train stations, shopping centres, galleries and museums, which are considered likely to use PA/VA systems.

The primary purpose of this paper is to add to those measurements that have been made previously to contribute to the body of evidence for those wishing to determine whether public exposure to ultrasound may be problematic. A secondary purpose is to highlight practical measurement issues to assist others seeking to make measurements with conventional equipment.

The author is aware of only one set of interim guideline limits concerning public exposure to ultrasound,[1] published by the International Non-Ionizing Radiation Committee of the International Radiation Protection Association (INIRC-IRPA).[7] The limits apply to "continuous exposure to the general public for up to 24 h per day." Results presented in this paper are limited to the 20 kHz third-octave band by the capabilities of the available measurement equipment. The lower limit of ultrasound is taken to be 17.8 kHz, as discussed by Leighton.[8] The INIRC-IRPA guideline limit at this frequency is 70 dB re 20 μPa.

Further research has been undertaken into the potential for undesirable effects due to ultrasound exposure from pest repellent devices.[3,4,9]

[a)]Electronic mail: beth.paxton@apexacoustics.co.uk

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FIG. 1. Measurements in progress.

II. MEASUREMENTS

A. Guidance on measurement method

Advice was sought on an appropriate measurement methodology from the Health Effects of Ultrasound in Air (HEFUA) group, a cross-UK network based at the University of Southampton,[10,11] with the aim of producing results comparable to those made previously. It is understood that previous measurements had been made according to the existing INIRC-IRPA exposure guidelines, which state that "measurement of the sound pressure levels to determine adherence to the guidelines should be made at the normal height of the ears of exposed persons,"[7] and that a field calibration should be made of measurement equipment. HEFUA advocated the identification of the specific frequency of tonal sources using a continuous spectrum and advised that the measured level should be "at least the measured amount using the on-axis sensitivity at 20 kHz combined with a 1 kHz calibration."

B. Equipment

Measurements have been made using NTi Audio (Schaan, Liechtenstein) XL2-TA sound level meters with NTi Audio MC 230 free-field equalised measurement microphones and MA 220 pre-amplifiers. The sound level meters used achieve Class 1 under BS EN 61672-1,[12] but it is noted that the upper and lower acceptable limits specified in this standard for the 20 kHz third-octave band are $(+3, -\infty)$, meaning that the meter may under-read by any amount at this frequency while still complying with Class 1.[1] Measurements were made with no wind shield to prevent unnecessary scattering and attenuation of high-frequency sound.

All sound pressure levels presented in this paper have been corrected to account for the equipment's frequency response at 20 kHz using information from the most recent calibration of the microphone and preamplifier. Since the frequency response of the microphone and A-weighting curve are not flat in this frequency band, uncertainty of approximately ± 5 dB would be expected in the measured level.

All measurements were taken indoors, often in large reverberant spaces. In most cases an individual source could not be identified and the microphone was handheld rather than fixed, therefore the angle of the sound incident on the microphone and distance from the source is unknown (see Fig. 1). BS EN 61672-1 (2013)[12] does not specify limits on deviation of directional response above 12.5 kHz, however, the microphone response is expected to be highly directional in the frequency range of interest due to diffraction and scattering effects, with the highest sensitivity at 0° incidence. The presented levels are therefore considered to be a lower limit on the sound pressure level actually present.

C. Measurement method and data processing

In order to maximise the responsiveness of the display and allow identification of any time dependency (e.g., pulsed signals) when searching for ultrasonic frequency content, the meter was set up to display a "live" fast Fourier transform (FFT) spectrum with a fast time weighting, chosen to give a high resolution in time with minimal averaging. The microphone was held at head height and moved around areas potentially occupied by members of the public, to initially identify whether ultrasonic tones were present, and to identify the worst-affected location. The frequency range over which the meter can perform FFT is 5 Hz to 20 kHz, while the measurement bandwidth is broader, with an upper limit of 23 kHz. Therefore, while identification of ultrasound was possible after processing the measurements, the presence and characteristics of tones at a frequency of 20 kHz or above could not be identified on site. This made it particularly difficult to identify whether tones at above 20 kHz were continuous or pulsed, notably the measurements at ID 1.

In places where significant frequency content was noted in the 20 kHz third-octave band, a short-term measurement was made with the sound level meter, including a WAV file recording. The meter was field-calibrated within appropriate tolerances using a Larson Davis CAL 200 calibrator before and after the measurements, with no significant drift noted. Where an individual loudspeaker was identified as the source of the ultrasound the microphone was pointed directly at the source to ensure the most meaningful reading possible.

Where sound pressure levels have been taken directly from the XL2 software, these have been measured as A-weighted values in third-octave bands and corrected to Z-weighted values using the 20 kHz third-octave band value of the A-weighting network. Ideally, raw data would be obtained using a Z-weighting; however, this was not possible with the data acquisition filter settings used on the day. The measured levels have also been corrected to account for a spectral correction factor—a setting on the sound level meter designed to account for the presence of an all-weather kit—which was activated during the measurements. The tonal frequencies were identified using an FFT spectrum generated by the sound level meter.

Where the measurements have been processed using Audacity, an FFT spectrum with bin size of approximately 47 Hz was generated from the recorded WAV file using a Hanning time window, and the tonal frequencies identified. To calibrate the spectrum, the measured single-octave band sound pressure level at 1 kHz was taken from the NTi software, corrected for the spectral correction factor, and compared with the sum of the Audacity spectrum bins with frequencies within the octave band to calculate a calibration factor. The third-octave band sound pressure levels presented in Table I are the sum of the calibrated spectral contributions from bins in the relevant frequency range. The calibration factor was also calculated for the 4 kHz octave band (with the additional step of correcting the NTi software generated sound pressure level for A-weighting); there was a 0.3 dB difference between the 1 and 4 kHz calibration factors. Some uncertainty can be attributed to the fact that the bin frequencies do not align exactly with the octave band cutoff frequencies.

The sound pressure level of a pulse of ultrasound was calculated by inspecting the time history of the 20 kHz third-octave band and the time/frequency spectrogram in the NTi software to identify time periods when the source was active. Noise events with broadband spectral content were presumed to originate from a different source. Measured sound pressure levels are presented both for times when the source was operating and over the entire measurement period. It was considered important to present both values due to uncertainty about the mechanism for potential ill effects; it is not known whether the dose-response relationship for ultrasound emission obeys an equal energy principle.

III. RESULTS

A summary of the results of the surveys are shown in Table I.[13] Where no ultrasonic tones were detected, the 20 kHz third-octave band level is not presented.

Measurements were taken in three different areas of Location 2; at each position, the frequency of the tone was the same, suggesting that they shared the same source or type of source. Searching around with the microphone to find the location of the highest sound pressure level identified the source in one area to be a loudspeaker. A difference of approximately 30 dB was calculated between the level measured in general circulation areas and the level measured at a distance of approximately 1.5 m from the loudspeaker, reflecting the rapid reduction in sound pressure level

TABLE I. Summary of measurement results.

Location ID	Location type	Date of measurements	Character of source	Frequency of source, kHz	Sound pressure level in 20 kHz third-octave band
1	Railway station	06/2005/17	Tone, unknown if constant or pulsed	20.8	65[a,b]
				18.0	
2a	Library	06/05/17	Constant tone	19.2	36[c]
2b	Library	06/05/17	Constant tone	19.2	35[c]
2c	Library	06/05/17	Constant tone	19.2	62 [c,d]
3	Museum/gallery	06/05/17	—	—	—
4	Museum/gallery	06/05/17	—	—	—
5	Foyer of concert venue	06/05/17	—	—	[e]
6	Railway station	15/05/17	Constant tone	20.0	49[a,d]
7	Museum/gallery	15/05/17	—	—	—
8	Shopping centre	15/05/17	—	—	—
9	Library	15/05/17	—	—	—
10	Sports stadium	15/05/17	—	—	—
11	Foyer of concert venue	15/05/17	Tonal pulses every 20 seconds	19.4	32[c,f]
				19.2	2[c,g]
12	Museum/gallery	15/05/17	Constant tone	19.1	46[c]
13	Museum/gallery	19/05/17	Two/three tonal pulses every 30 s	19.4	43[c,f]
					34[c,g]
14	Museum/gallery	19/05/17	—	—	-

[a]Sound pressure level presented has been calculated from Audacity FFT spectrum.
[b]Tone at 20.8 kHz dominates the third-octave band.
[c]Sound pressure level presented has been taken from NTi software.
[d]Measurements taken with a microphone pointed directly at an identified source at the closest potentially occupied position.
[e]A potential tone was identified at the limit of the meter's FFT display at 20 kHz. Site constraints at that location meant that a time series recording was not taken, so the presence of ultrasound could not be investigated further.
[f]Period when tones are present.
[g]Entire measurement period.

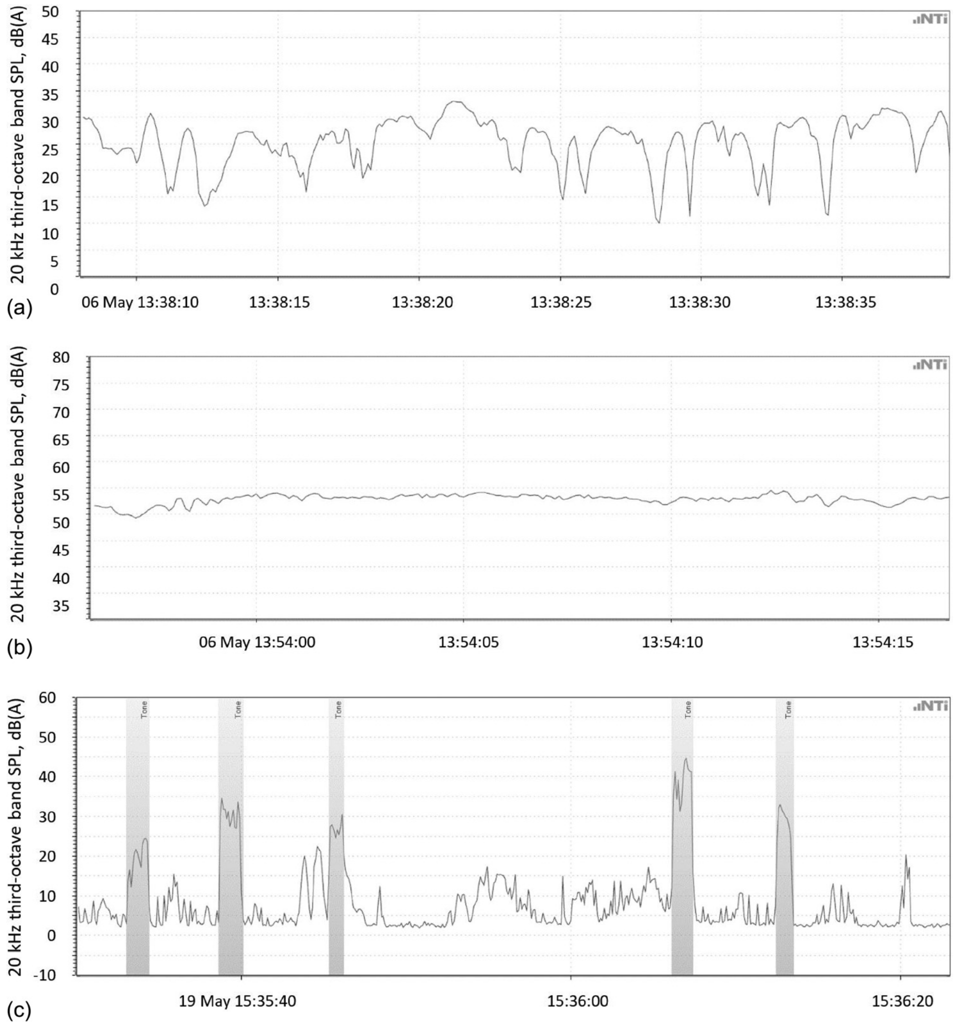

FIG. 2. Time histories of the 20 kHz third-octave band at (a) Location 2 a, (b) Location 2 c, and (c) Location 13.

expected to occur with distance from the source.[6] Figure 2(b) shows the time history of the 20 kHz third-octave band at Location 2c, close to the loudspeaker. The measured sound pressure level is considerably steadier than initially measured at a greater distance from the loudspeaker [as shown in Fig. 2(a)]. Drop-outs in level may be caused by slight changes in the position and angle of the handheld microphone, scattering due to air turbulence, or an intermittent shielding effect between source and receiver. A pulsed signal was measured at Location 13. The time periods marked as tones [shaded in gray in Fig. 2(c)] showed a similar variation in level as that measured at Location 2a.

Example frequency spectra are shown in Fig. 3. Tones at two distinct frequencies were identified at Locations 1 and 11. At Location 1, the tone at 20.8 kHz provided the dominant contribution to the third-octave band level. The lower frequency tone is considered likely to have a different source; however, this was not identified. At Location 11, the tones had similar frequencies and similar amplitudes, indicating that their sources may have been similar—two loudspeakers in the same system, for example.

Tones with their frequency in the 20 kHz third-octave band were identified in eight venues out of 14 surveyed. The character and frequency of the tones was consistent with the source being PA/VA systems and the measured sound pressure levels fell within the range of levels surveyed by Mapp.[6] Measured levels were not found to exceed the INIRC-IRPA guidelines for public exposure to ultrasound in the 20 kHz third-octave band. Results from van Wieringen[9] suggest that 20 min of exposure to ultrasound emissions at sound pressure levels lower than 70 dB does not lead to significant undesirable effects in young and middle aged people with normal hearing, but may be considered to be disturbing if perceived.

IV. CONCLUSIONS

Ultrasonic tones have been measured in several public places, supporting claims that public exposure to ultrasound is widespread[1] and claims that typical PA/VA systems are capable of reproducing frequencies of around 20 kHz at an appreciable sound level.[6]

Sound pressure levels considered to be a lower limit on actual exposure at potentially occupied positions have been measured and compared with the only existing guideline for public exposure to ultrasound in the 20 kHz third-octave band. The INIRC-IRPA guideline was not found to be exceeded at any locations potentially occupied by members of the public. One study[9] suggests that a short period of exposure to ultrasound at approximately the frequencies and sound pressure levels identified in this paper does not lead to

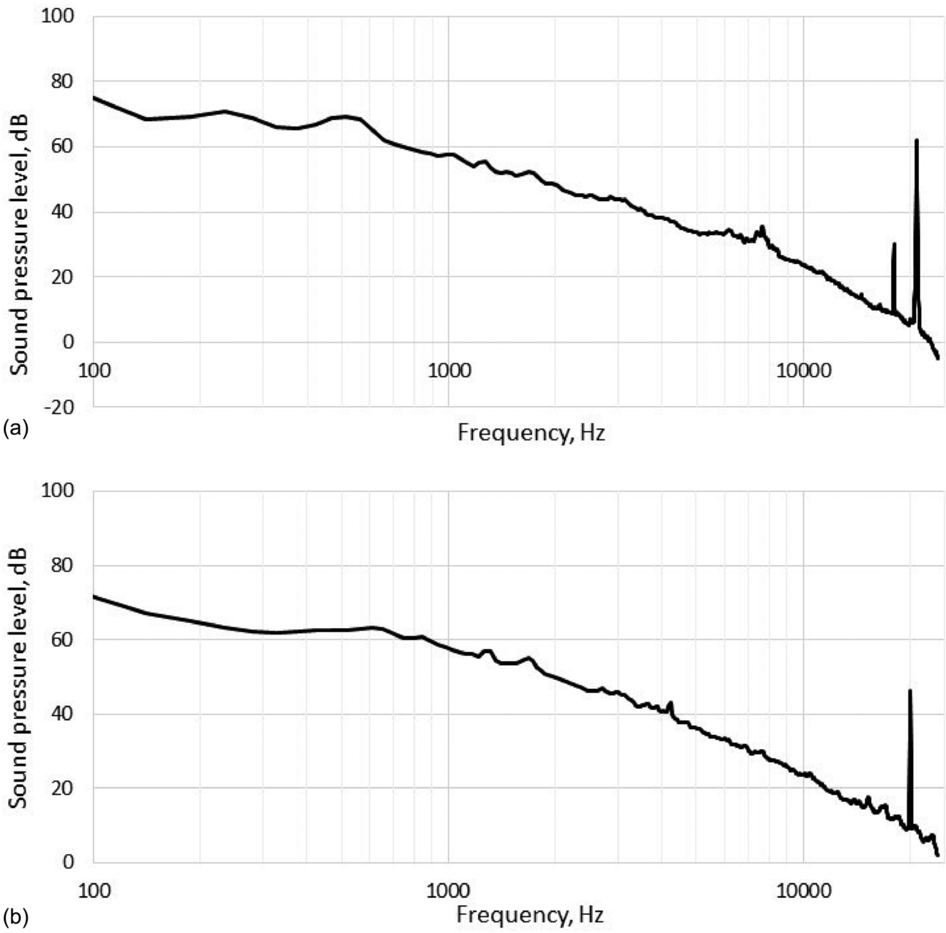

FIG. 3. Frequency spectrum at (a) Location 1 and (b) Location 6.

significant ill effects in adults with normal hearing. However, further research is needed to quantify the potential impact of exposure over longer periods of time, such as may be experienced by an employee working in a venue with a PA/VA system.[8]

These measurements have served to underline the difficulty of accurately measuring ultrasound exposure and identifying ultrasound sources using standard measurement equipment. While it would be far preferable to use specialist equipment which has been designed to measure at ultrasonic frequencies, it is considered that measurements with widely available equipment designed to measure noise in the audio frequency range may be sufficient to detect tones emitted by PA/VA systems in the 20 kHz third-octave band, and to estimate exposure levels if information is available about the frequency response of the equipment. Access to an affordable measurement system able to display a real-time narrowband spectrum may be particularly valuable to those wishing to investigate a complaint, such as an Environmental Health officer; measurements with a typical audio-range sound level meter may be useful as a preliminary survey, and additional measurements with specialist measurement equipment may be necessary should there be a potential exceedance of the guidelines.

A full set of guidelines based on sufficient evidence about human response to ultrasound exposure should be published to replace the existing interim guidelines, including additional guidance on their application to pulsed and intermittent sources. The results of this study may be compared with this up to date guidance when available. Formalised guidance on the measurement of public exposure to ultrasound should be developed, and should include the measurement of intermittent sources.[13]

[1]T. G. Leighton, "Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air?," Proc. R. Soc. A **472**, 20150624 (2016). Available from http://eprints.soton.ac.uk/385213/ (Last viewed July 26, 2016).
[2]B. Paxton and J. Harvie-Clark, "Public exposure to very high frequency sound and ultrasound: Do we know the risks?," Proc. Inst. Acoust. **38**(Part 1), 400–406 (2016).
[3]M. Ueda, A. Ota, and H. Takahashi, "Investigation on high-frequency noise in public space. We tried noise abatement measures for displeasure people," in *Proceedings of the 7th Forum Acusticum*, Krakow, Poland (September 7–12, 2014), p. 148.
[4]M. Ueda, A. Ota, and H. Takahashi, "Investigation on high-frequency noise in public space," in *Internoise 2014*, Melbourne, Australia (November 16–19, 2014), 7 pp.
[5]C. Glorieux, "Undesirable effects as a result of short-term exposure to an ultrasonic repellent device. Part I—Acoustic measurements," Assignment No. DGS/PB_PP/IVC/13026 from the Federal Public Service in Belgium for Health, Food Chain Safety and Environment (July 28, 2014).
[6]P. Mapp, "Ultrasonic surveillance monitoring of PA systems, a safety feature or audible hazard?," Proc. Inst. Acoust. **38**(Part 2), 1–16 (2016).
[7]International Non-Ionizing Radiation Committee of the International Radiation Protection Association (INIRC-IRPA), "Interim guidelines on the limits of human exposure to airborne ultrasound," Health Phys. **46**, 969–974 (1984).
[8]T. G. Leighton, "Comment on 'Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air?,' " Proc. R. Soc. A **473**(2199), 20160828 (2017).
[9]A. van Wieringen, "Undesirable effects as a result of short-term exposure to an ultrasonic repellent device. Part II—Exposure of volunteers," Assignment No. DGS/PB_PP/IVC/13026 from the Federal Public Service in Belgium for Health, Food Chain Safety and Environment (July 28, 2014).

[10]Health Effects of Ultrasound in Air (2017), website https://sites.google.com/site/hefua2/ (Last viewed October 30, 2017).
[11]Health Effects of Ultrasound in Air (2017) website https://www.southampton.ac.uk/populationhealth/partners/HEFUA.page (Last viewed October 30, 2017).
[12]BS EN 61672-1:2013. "Electroacoustics—Sound level meters—Part 1: Specifications" (British Standards Institute, London) (2013).
[13]See supplementary material at https://doi.org/10.1121/1.5063811 for the raw measurement data.