PUBLIC EXPOSURE TO VERY HIGH FREQUENCY SOUND AND ULTRASOUND: DO WE KNOW THE RISKS?

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1 ABSTRACT

Literature has linked very high and ultrasonic frequency sound in air to tinnitus and other "subjective" effects, including headache and nausea, for over 40 years. Very little attention has been paid to the subject in the last 30 years, however the use of these frequencies is rapidly becoming more common, and increasing numbers of adults and children are exposed to these frequencies daily, often without their knowledge. Scientific study is emerging in the health effects of prolonged exposure to these frequencies, and the safety legislation that should surround them. National and international research currently being carried out to investigate the hearing abilities of different groups, and the potential impact of exposure, is described. Safety guidelines, especially for those with more sensitive hearing such babies, children and those with hyperacusis, and also some people prone to migraine, are of particular importance.

This paper considers some of the equipment in regular daily use in the home and the workplace that produce constant tones at VHF / US frequencies. It summarises the current legislative position in the UK for very high and ultrasonic frequencies, looks at current work in safety around these frequencies of sound and looks at some of the major questions on the impact of these frequencies on the general public, and sensitive individuals in particular.

This paper details preliminary investigations into claims that data projectors found in school classrooms can inadvertently produce very high frequency tones and finds no evidence of this from the very limited sample tested. Measurements of very high frequency sound taken using a variety of measurement systems have revealed discrepancies in measured sound pressure level, which also varies significantly with angle to the source.

2 INTRODUCTION

Public exposure to ultrasonic (US) sound, usually defined as sound with a frequency above 20 kHz, and very high frequency (VHF) sound, generally taken to cover the 10-20 kHz range, has increased dramatically in recent years. Research conducted over the past 40 years has linked exposure to sound in the VHF / US range to various subjective health effects including annoyance, tinnitus, persistent headaches, fatigue, nausea, dizziness and migraine. Existing guidelines for exposure to VHF / US sound are inadequate for modern patterns of exposure and measurement methods are not standardised. This paper summarises past research into the subject and by investigating claims that VHF tones are inadvertently produced by equipment commonly used in schools, seeks to draw attention to some of the problems inherent in measuring VHF / US sound.

3 SOURCES OF VHF / US SOUND

Increasingly, the general public are exposed to VHF / US sound without their knowledge from a variety of sources. Public address voice alarm (PAVA) systems are common in public places such as train stations, airports, sports stadia and shopping centres. EU legislation[1] requires that evacuation systems must be monitored, and constant or pulsed 20 kHz tones are frequently emitted to achieve this. The wide variety of public locations perhaps gives this source the potential to affect the largest numbers of people on a daily basis. Many of the locations where these systems are used have a footfall of millions of people per year, and only a tiny proportion of these will have any awareness of their exposure. As manufacturing costs have fallen, the number of ultrasonic pest deterrent devices and VHF emitting 'Mosquito' devices in use has also increased substantially. These devices exploit the extended range of audible frequencies across species and demographics of the human population to cause pain or discomfort, and therefore deter their target from the locality of the device. A report by The Children's Rights Alliance for England[2] found that 10% of children who completed the survey had been affected by a Mosquito device. There have also been reports of equipment such as lighting systems and data projectors (such as those found in the majority of secondary school classrooms) producing low-level VHF / US tones as a by-product of their operation.

Recent media reports[3] have picked up on the increase in VHF / US exposure and publicity surrounding the issue is gradually increasing.

It is conceivable that members of the public are exposed to VHF / US sound at work, during leisure time and at home and are unable to determine their exposure. Certain groups such as children in full-time education and the prison population may be unable to avoid exposure to VHF / US sound sources. With exposure to these frequencies so widespread, it important that dose-response relationships are well established for any potential ill-effects and that appropriate guidelines are in place to protect those exposed.

4 PAST RESEARCH AND CURRENTLY AVAILABLE GUIDELINES

Research evaluating human response to VHF / US exposure spanning the period from the 1960s to the modern day has been reviewed several times[4,5,6]. Many key studies tested relatively small numbers of young men who had been exposed to the predominantly industrial sources of ultrasound in use at the time; ultrasound exposure was accompanied by significant sound exposure in the audio frequency range and crucially, the level and duration of the exposure of subjects wasn't measured. This research is not nearly sufficient to establish dose-response relationships and in many cases it is not even possible to attribute subjective effects experienced to VHF / US sound exposure.

Nor does the research reflect the variability in sensitivity between different population demographics. This variability is understood to be significant, with a general trend of increased high frequency hearing acuity in young people and females. In recent audiology tests in the extended high-frequency range[7], 5% of the 5-19 age group tested had a hearing threshold at 20 kHz that was 60 dB more sensitive than the median for the 30-39 year age group.

The guidelines available to control VHF / US sound exposure are based on only six basic studies and outnumber these source studies by around 3:1[4]. Exposure conditions in the studies aren't sufficiently well described to determine whether the guidelines were breached. By being taken up by national bodies and re-published in a variety of places over a long period of time, the Damage Risk Criteria and Maximum Permissible Levels proposed in the 1960s have acquired a legitimacy that their authors never intended; the limitations and context of the initial results have been lost over time. The guidelines have been chosen in the VHF range to prevent subjective effects and in the US range above 20 kHz only pertain to the avoidance of hearing loss in the audio frequency range.

Where duration of exposure is taken into account there is an energy trading relationship i.e. halving of exposure time allows a 3 dB increase in permitted level. It is reasonable to assume that subjective effects may appear soon after the onset of exposure to VHF / US sound, so an increase in permitted level could potentially allow more severe effects in a larger proportion of the population. The nature of the industrial exposure that the guidelines were designed to protect against differs greatly from the increasingly prevalent incidental exposure in a number of ways. Industrial exposure to VHF / US sound was confined to working hours. Workers would have been aware of their exposure, which could be more easily mitigated by the use of appropriate hearing protection. These guidelines mostly refer to the maximum permissible sound pressure level in each third-octave band. They are based on studies of broadband exposure rather than VHF / US of a tonal nature as is frequently used in PAVA systems, for example.

Only one set of published guidelines considers public exposure[8]. These have been proposed on the basis of the same initial studies as an interim measure until more data becomes available. A maximum SPL of 100 dB is recommended with a maximum SPL of 70 dB in the 20 kHz 1/3 octave band.

5 CURRENT UK LEGISLATION

It is not currently required that emitters of VHF / US sound declare the location of sources or exposure levels. A review of environmental acoustic legislation pertinent to the use of a Mosquito high frequency sound deterrent[9] concludes that the only legislation that might affect the operation of such a device hangs on affected persons making a complaint of nuisance to the local authority. This is problematic because young people who might be more affected may not have the power to make a complaint, the local authority investigating the complaint may not hear the sound or be affected in the same way and may not have access to equipment capable of measuring VHF / US sound.

6 ONGOING RESEARCH

Interest in the effects of VHF / US sound exposure is beginning to build in the research community. A research project at The University of Southampton titled ‘Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air?’ is ongoing and has so far published a comprehensive summary[4] of the currently available knowledge and issues around the subject.

In 2015, the EARS project[10] reported back on research undertaken over three years into human perception of non-audible sound. New limit values have been proposed based upon both Lawton’s review[5] of previous guidelines and minimum hearing thresholds taken from previous literature and EARS project proceedings. Within the scope of the project, ‘a measuring system has been set up which ensures the traceability of airborne sound measurements in the ultrasonic range up to approx. 100 kHz’[11]. A follow-up project, EARS II[12], started in May 2016. The project aims to provide the knowledge base for future ultrasound policy and guidelines by experimentally determining loudness thresholds and the impact of ultrasound on multiple aspects of health, including the study of individuals with particular sensitivity to sound. Another of their aims is to develop instrumentation and measurement methods relating to ultrasound in both public and workplace environments.

The Journal of the Acoustical Society of America is currently accepting manuscripts on a wide range of topics related to ultrasound for a Special Issue on “Ultrasound in Air”, with a deadline for submission of 20 July 2017. It is hoped that this new focus on the topic of ultrasound will encourage more research into the effect of ultrasound on humans, more measurements to quantify public exposure and the development of measurement methods and standards covering the ultrasonic frequency range.

7 MEASURING VHF / US SOUND

Measurement of VHF / US sound is fraught with difficulties. Standards for the measurement of VHF / US sound are under development, however currently available guidance does not cover this frequency range. Under IEC 61672-1[13], the allowances for variation in measured level increase to (+3.0, - ∞) dB in the 20 kHz third-octave band, meaning that the top class of available sound level meter can under-read by any amount in that frequency band and still comply with the standard.
Three measurement systems tested by Apex are detailed in Table 1. Microphones and sound level meters comply with IEC 61672-1.

Equipment used	**Measurement system**		
	1	**2**	**3**
Microphone	Norsonic type 1209	NTi Audio MC230	NTi Audio MC230
Preamplifier	Norsonic type 12584	NTi Audio MA220	NTi Audio MA220
Data acquisition system	Norsonic Precision Sound Analyser Nor140	NTi Audio XL2-TA	M-Audio MobilePre sound card with ARTA software
Calibrator	Norsonic type 1251	NTi Audio Larson Davis CAL200	NTi Audio Larson Davis CAL200

Table 1: Measurement systems tested by Apex

Pure tones were generated at 16 kHz and 20 kHz in turn and played through a speaker. With the microphone at normal incidence at a distance of approximately 15 cm from the centre of the speaker the Z-weighted sound pressure levels were measured in the third-octave bands with these centre frequencies, as well as the narrowband value determined from an FFT spectrum where possible. This informal test of the three systems showed discrepancies in the measured third-octave band level that may nonetheless comply with the Class 1 tolerances, as shown in Table 2. Spectra derived using system 3 to measure a calibrator tone and 20 kHz tone played through a speaker are shown in Figure 1 and Figure 2, respectively.

Measurement system	**Sound pressure level / dB**		
	16 kHz third-octave band	**20 kHz third-octave band**	**Narrowband value centred on 20 kHz**
1	79	60	[a]
2	75	54	[a]
3	75	[b]	55

[a] Sound level meters unable to generate an FFT spectrum at these frequencies
[b] ARTA virtual sound level meter does not measure in third-octaves above the 16 kHz band

Table 2: Comparison of sound pressure levels measured using three measurement systems

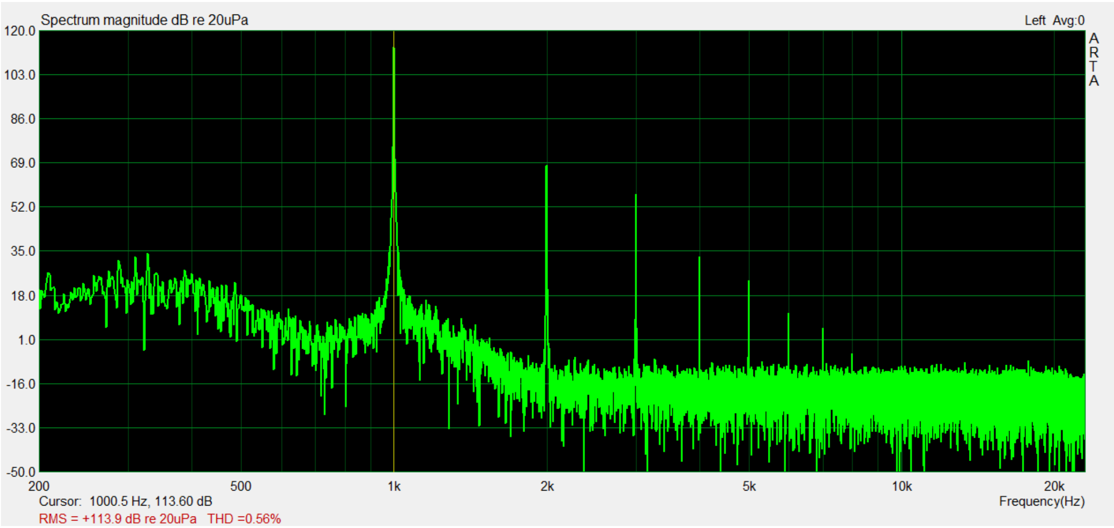

Figure 1: Output from measurement system 3 measuring a calibrator tone

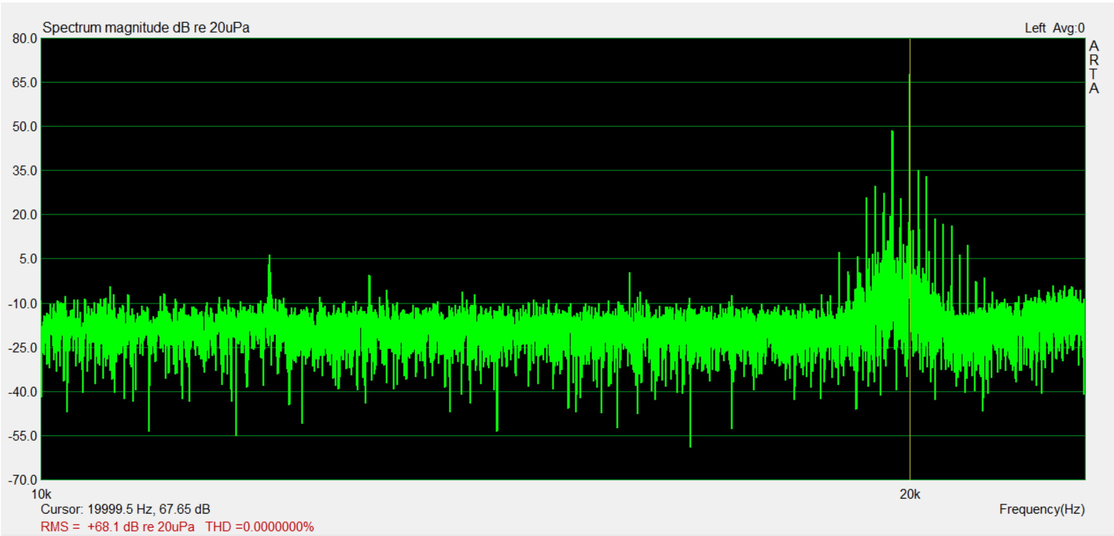

Figure 2: Output from measurement system 3 measuring a 20 kHz tone

Greater directionality due to the short wavelengths at high frequency can greatly change the levels measured with a small change in microphone angle. Directivity patterns for the microphone capsule used in measurement system 3 are given in the product literature only up to 12.5 kHz. Measurements of a 20 kHz tone made using system 3 with the microphone positioned at a range of angles to the source between 0 and 90 degrees had a range of 6 dB, as shown in Table 3.

Approximate angle of incidence / degrees	**Sound pressure level / dB Narrowband value centred on 20 kHz**
0	53
45	47
90	50

Table 3: Comparison of sound pressure levels measured at different angles of incidence to the source

8 VHF SOUND FROM PROJECTORS IN SCHOOLS

Apex chose to investigate claims that data projectors commonly used in school classrooms and elsewhere can inadvertently emit VHF tones from the projector cooling fan. In the absence of appropriate standards directing the measurement of VHF sound and in the interest of a consistent approach, advice on an appropriate measurement method was sought from researchers at the Institute of Sound and Vibration Research, University of Southampton. Their recommendation was to take Z-weighted measurements in third-octave bands at typical head-height observer positions to allow comparison with existing exposure guidelines, alongside a continuous spectrum to identify the frequency of tones.

Measurements were taken around four Epson interactive projectors using measurement system 3 described in Table 1. An initial procedure was followed to determine the presence of any significant VHF sound content. Using ARTA to display a 'live' FFT spectrum of the measurements, the microphone was moved around the projector at approximately head height to search for VHF tones, with particular attention paid to the areas around the ventilation grilles where the amplitude of sound emissions could be expected to be greatest. No significant frequency content above 10 kHz was detected from any of the four machines tested.

The projectors tested had been installed over the past 10 years, and all had the same manufacturer. Anecdotal accounts have implicated particular brands of projector in producing VHF tones and it is possible that different models are more problematic. It is also possible that projectors in a worse state of repair are more likely to emit tones. Further measurements may be taken to investigate these conjectures.

9 CONCLUSIONS

In the light of the changes in VHF / US sound exposure patterns it is clear that the current level of regulation and knowledge of the subjective effects of VHF / US sound are insufficient. Media reports are beginning to raise public awareness of the issues at hand and there have been numerous calls for further work to classify the location and output of VHF / US emitting devices, research into the link between VHF / US exposure and subjective effects with regard to children and other sensitive individuals and an eventual move towards establishing dose-response relationships.
Attempts by Apex to measure VHF sound emissions reveal the barriers to measuring a sound pressure level reliably but ultimately, no VHF content was discovered to be emitted by the school equipment tested.

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