# 'The upper limits...please stand by' – the measurement of airborne ultrasound

*By Ben Piper*

The measurement of Airborne Ultrasound (AUS) has been a rather niche field in the past, which is to be expected given that the vast majority of acoustic measurements are of sounds that we can hear or things which might affect those sounds. For the purpose of clarity AUS is defined for this article as all sound propagation in air above 17.2 kHz. This is the lower limit of the 1/3rd octave band centred at 20 kHz which is often the first 1/3rd octave band which is not specified in guidelines and legislation regarding noise exposure. There is a growing number of applications of AUS including haptic interfaces, pest deterrents and safety systems. AUS is also the by-product of a number of industrial processes such as ultrasonic cleaning and some types of welding. Further to this there is growing evidence that high levels of ultrasound, whether perceivable or not, can pose a health risk, although the risks are not yet fully understood. In order to make use of, control and understand the effects of AUS accurate measurements are required. In principle measuring AUS is no different from measuring audible sound and should be approached in the same way with consideration given to the measurement environment, the purpose of the measurement and every part of the measurement chain. However, most of the tools available for the measurement of sound are focussed in the audible range to cover the majority of applications.

As reverberation times are very short and air absorption is relatively high measurements of AUS can be considered to be either pressure or free-field. Measurements in a free-field are straightforward and the use of time gating techniques is very effective for isolating the direct sound from its environment, although this requires a repeatable sound. The challenge for free-field measurements comes when the source is unknown. As AUS has short wavelengths the variations in SPL over a small volume can be high. Strategies for scanning the soundfield and identifying an appropriate location to make a representative measurement are required. In both cases care must be taken with the alignment between the microphone and the source. As microphones become more directional at high frequency the impact of misalignment becomes larger. Sound sources also become more directional as frequency is increased which leads to significant wavefront curvature and the need for corrections. An effective approach to alignment is to make use of a pair of laser cross-line levels to ensure that the centre of the microphone is aligned with the centre of the source. In enclosed pressure fields the limitations are largely due to the geometry of the measurement space. Once length and radial modes are present it can be difficult to extract accurate measurements although if the geometry is simple models can be applied to correct for the lower order modes.

Microphone selection and calibration is critical for successful measurements of AUS. The size of the microphone contributes to its upper frequency limit. Table 1 shows common measurement microphone diameters with the range of upper frequency limits found in manufacturer's published data, upper limits specified in IEC-61094-4 and the range of sensitivities typically found. It should be noted that this data is taken from a review of several manufacturers and does not include every microphone on the market. Microphones designed to measure pressure extremes have been excluded.

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| Microphone diameter, mm (inches) | Range of upper frequency limits found in manufacturer's data, kHz | Highest frequency specified in IEC 61094-4, kHz | Range of nominal sensitivities, mV/Pa |
|---|---|---|---|
| 23.77 (1) | 8 - 18 | 16 | 47 - 50 |
| 13.2 (½) | 10 - 40 | 31.5 | 12.5 - 50 |
| 7 (¼) | 20 -100 | 50 | 0.9 - 4 |
| 3.5 (⅛) | 70 - 140 | n/a | 0.7 - 1 |

Table 1 - Collated data showing the typical range of upper frequency limits and sensitivities of measurement microphones and the highest frequency specified in IEC 61094-4 for each type.

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Smaller microphones are clearly more suited to high frequency measurement and this is not surprising as accurate measurements require uniform displacement of the microphone's diaphragm. The directivity of smaller microphones is also less and the effect of wavefront curvature will be smaller, meaning the impact of misalignment is reduced. The downsides to using smaller microphones are that the sensitivity and signal to noise ratio tend to be smaller.

Once a suitable microphone is selected consideration needs to be given to the calibration of the microphone. Most manufacturers give sensitivity data for their microphones for frequencies across the specified range of use. These are normally measured using electrostatic actuators and therefore the free-field response of the microphone is based on the use of models to derive the correction needed to the actuator data. Since 2013 Danish Fundamental Metrology (DFM) have been able to apply free-field reciprocity techniques to provide free-field calibrations up to 200 kHz and microphones calibrated using this method are used for research at Physikalisch-Technische Bundesanstalt (PTB). Whether calibrations of this high quality are required or the uncertainty based on the actuator and model method (1-2 dB at 100 kHz) is good enough depends on the purpose of the measurements in question.

When selecting data acquisition hardware for making measurements of AUS the main considerations should be sample rates and whether any filters or gain stages are applied to the incoming signal. The sample rate used should be at least 4 times the highest frequency of interest to give a reasonable degree of accuracy (of course a minimum of 2 times is required due to the Nyquist limit). If there are filters, which may be the case when using consumer grade sound cards, then their response needs to be measured and, if necessary, corrections should be applied to the resulting measurements.

For generated sound fields a broadband amplifier must be used covering at least the highest frequency of interest. Low end audio amplifiers normally have a high degree of attenuation per octave above 20 kHz and should be avoided. Finding a suitable sound source can also be tricky. In order to ensure the repeatability of the measurements, resonances in the source's frequency response need to be avoided and therefore a source with a high first resonance is required. There are a number of hi-fi tweeters on the market which use very stiff materials resulting in usable frequency ranges stretching up towards 100 kHz. The alternative is to use a measurement microphone as a source. The issue then becomes one of signal to noise ratio due to the small SPLs that microphones can generate when used in this way.

As research into both the effects and uses of AUS grows techniques to make accurate measurements are required for a number of different scenarios. Whilst measurements of AUS are in principle no different from measurements of audible sound care must be taken in selecting appropriate equipment and methodology. The free-field calibration infrastructure for measurements of AUS does exist but is currently limited to only two metrology institutes although as demand grows more services may become available.

## Further reading

- EMPIR EARS - Metrology for modern hearing assessment and protecting public health from emerging noise sources - http://www.ears-project.eu/empir/ears2.html
- Health Effects of Ultrasound in Air (HEFUA) -https://sites.google.com/site/hefua2/
- Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air? - Leighton, T.G. Proceedings of The Royal Society A: Mathematical Physical and Engineering Sciences, 1-68, doi:10.1098/rspa.2015.0624

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