MONITORING DOMESTIC NOISE WITH INEXPENSIVE EQUIPMENT

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1. INTRODUCTION

Environmental Health (EH) Departments devote considerable resources to investigating domestic noise complaints. In 1989-90 Environmental Health Officers in England and Wales received 97,798 noise complaints, of which 61% were about domestic noise [1]. The object of investigating a complaint is to determine whether a statutory nuisance exists. In practice, this depends on the judgement of the Environmental Health Officer, which is usually informed by subjective listening and a broadband A-weighted sound pressure level (SPL) measurement. Though practice varies among EH Departments, it is common for more than one visit to a complainant to be made. In the case of domestic noise complaints, these visits usually have to be made outside office hours and thus entail significant overtime costs. In many cases, further action is not found to be justified after an initial visit, so some system of screening noise complaints is desirable.

A desire to reduce costs and implement a screening system has led to considerable interest in the use of unattended recording equipment. A recent paper [2] outlined the procedure of one EH Department, using a Sony digital audio tape (DAT) recorder and a Brüel and Kjær 2231 sound level meter. A possible problem when leaving such expensive recording equipment in complainants' homes, however, is the risk of theft or damage. The obvious question to ask, therefore, is whether a cheaper monitoring system might be used. Might it be possible to reduce the cost of the monitoring system, while achieving an accuracy sufficient for initial screening of complaints, at least? This paper presents evidence that this is indeed possible, by demonstrating the measurement errors introduced by an inexpensive tape recorder and microphone.

2. TAPE RECORDER

As an example of an inexpensive tape recorder, a Marantz SD-40 domestic hi-fi cassette deck was tested. This costs about £100 and is commonly available. Importantly, this machine accepts metal cassette tapes, and features Dolby B and C noise reduction and a tape counter. Its performance is compared with three instrumentation-quality tape recorders: a Nagra IV-SJ, a Uher 4200 Report IC, and an Aiwa HHB1 Pro DAT. The Uher machine is commonly used by EH Departments, and represents a baseline comparison point.

2.1 Frequency Response

The magnitude of the combined record/replay frequency response of each tape recorder was measured at discrete frequencies, using a sine wave generator, a frequency counter and a micro-voltmeter. All the measurements reported here were made at a signal level of 0 dB V.U. Manufacturers usually quote data for -20 dB V.U., which gives a better high-frequency roll-off. It was felt that, in this case, the frequency characteristics of the loudest sounds recorded are most likely to be of interest. 0 dB recording level, although the worst case, is therefore likely to be more representative.

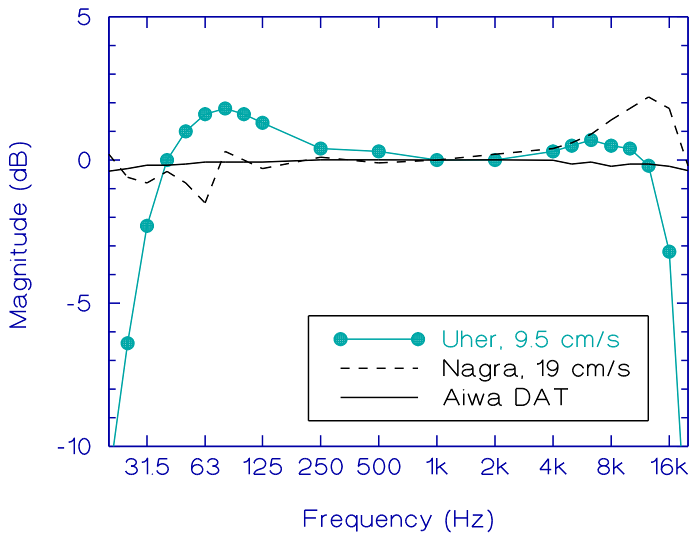

Figure 1: Record/replay frequency response of: Aiwa HHB1 Pro DAT, Nagra IV-SJ and Uher Report IC.

The frequency responses of the three instrumentation recorders are shown in Figure 1; they have been normalised to 0 dB at 1 kHz. Clearly, the DAT recorder is in a different league from the others. A conservative estimate of the uncertainty in the measurement is ± 0.14 dB — only below 50 and above 5000 Hz does the response of the DAT fall outside this margin. The position of the low- and high-frequency roll-off for the Nagra and the Uher can be changed by changing the tape speed. A speed below the maximum possible has been selected here for both machines, to give a good low-frequency response. This is because most domestic noise complaints are about sound which has passed through a wall, ceiling or floor, so that high-frequency components will tend to be attenuated.

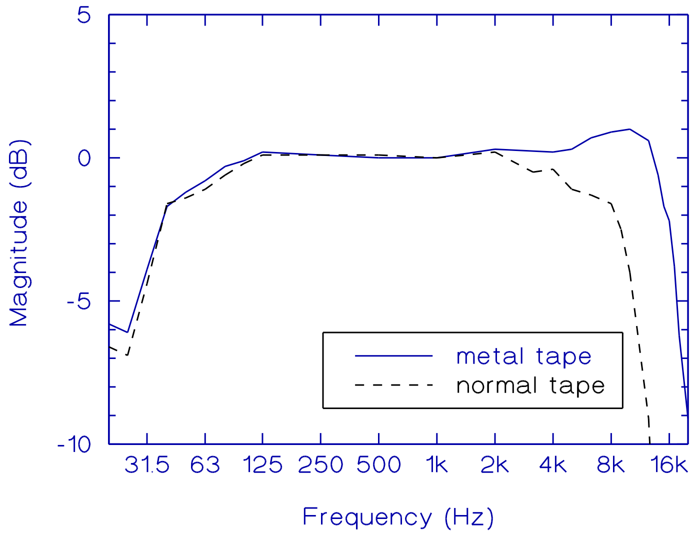

Figure 2: Record/replay frequency response of Marantz cassette deck (no noise reduction).

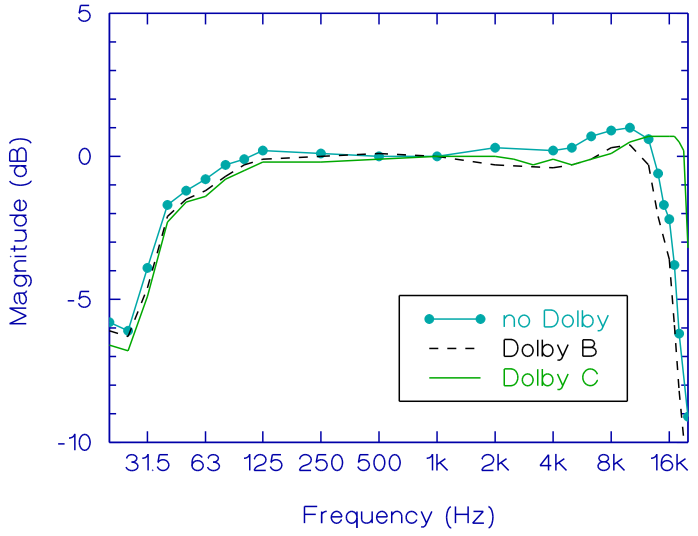

Figure 3: Record/replay frequency response of Marantz cassette deck (metal tape).

The measured frequency response of the Marantz depends on the type of tape cassette and noise reduction used. From Figure 2 it is clear that paying double the price of normal tape for metal tape cassettes is worth it for the gain in high-frequency performance. (The manufacturer's recommended tapes, TDK AD90 (normal) and TDK MA90 (metal), were used.) In Figure 3, using Dolby B noise reduction slightly worsens the high-frequency roll-off. Dolby C significantly extends it, however, and provides a very sharp cut-off at 20 kHz, with little pass-band ripple. The response of the Marantz with metal tape and Dolby C, in Figure 3, compares well with that of the Uher, in Figure 1.

2.2 Signal-to-Noise Ratio

The record/replay signal-to-noise ratio was measured using broadband pink noise, from 20 Hz to 20 kHz. Because A-weighted SPL is the most common measurement for domestic noise complaints, a broadband A-weighted signal-to-noise ratio is presented in Table 1. The tape recorders are ranked according to this figure.

Tape machine	Tape	Noise reduction	Speed (cm/s)	S/N (dB(A))
Aiwa HHB1 Pro	Sony PDP-30	none	0.815	71
Marantz	TDK MA90	Dolby C	2.38	62
Marantz	TDK SA90	Dolby C	2.38	62
Nagra IV-SJ	Maxell XLI 35-90B	none	38	60
Marantz	TDK AD90	Dolby C	2.38	59
Marantz	TDK MA90	Dolby B	2.38	56
Marantz	TDK SA90	Dolby B	2.38	55
Uher Report IC	Maxell XLI 35-90B	none	19	54
Nagra IV-SJ	Maxell XLI 35-90B	none	19	53
Uher Report IC	Maxell XLI 35-90B	none	10	52
Marantz	TDK AD90	Dolby B	2.38	52
Marantz	TDK SA90	none	2.38	48
Marantz	TDK MA90	none	2.38	47
Marantz	TDK AD90	none	2.38	43

Table 1: Broadband A-weighted signal-to-noise ratio of four tape recorders.

The best performer is again the DAT. Its figure of 71 dB(A) is below the manufacturer's specification, however, and contamination from electrical noise during the measurement cannot be ruled out. In any case, a signal-to-noise ratio of 71 dB(A) is quite possibly over-specified for domestic noise measurements.

At 62 dB(A), the Marantz with a metal tape and Dolby C is 9 dB(A) noisier than the DAT, but it is ahead of both the Nagra and the Uher. Tape type has some effect on the performance of the cassette deck here, but it is the noise reduction system that makes the biggest difference. Dolby C concentrates its improvements to the signal-to-noise ratio into a spectrum shape like that of the A-weighting curve, and this moves the Marantz (with metal tape) from near the bottom of the table to second place.

On the grounds of signal-to-noise ratio and frequency response, then, one can say that if the Uher is adequate, then so is the Marantz with a metal tape and Dolby C.

3. MICROPHONE

When selecting an example microphone for this project, low cost, a flat frequency response, omnidirectionality and no requirement for a power supply were the main criteria. The main compromise was a trade-off between the first two requirements. A Beyer Dynamic M101(NC) moving-coil microphone was chosen, at a cost of about £150.

3.1 Calibration

An obvious problem in substituting for a standard instrumentation microphone is calibration. Because the response of a substitute microphone to a standard calibrator is not known in advance, a way of comparing it to a calibrated system, such as a sound level meter (SLM), is needed. An old Dawe 1417A falling-ball calibrator was used to compare levels recorded by the Beyer Dynamic - Marantz system to those measured by a Brüel and Kjær 2231 SLM.

The A-weighted level from the calibrator was measured at a specific position with the 2231. The Beyer Dynamic microphone was then placed in the same position and the calibration noise recorded. The difference between the level of the playback and the 2231 reading was then the calibration correction.

Measurement system	σ_{n-1} (dB(A))
4230 - 2231 - Uher	0.07
Inexpensive system	0.20

Table 2: Calibration standard deviation for different measurement systems.

The repeatability of this procedure was compared to that of the more usual one using a Brüel and Kjær 4230 calibrator, a 2231 SLM, and a Uher tape recorder. Each calibration procedure was followed ten times and the standard deviation of each series of calibration levels appears in Table 2. While the complete procedure for the inexpensive system has a larger random error than the other system, it is an acceptable size. To a 95% confidence limit, one can expect the calibration to introduce a random error of ± 0.4 dB(A).

3.2 Frequency Response

The Beyer Dynamic microphone was compared to a Brüel and Kjær 4155 half-inch condenser microphone. This was done by measuring the impulse response of a loudspeaker in an anechoic chamber with the 4155 at a fixed position. The 4155 was then replaced by the Beyer Dynamic and the measurement repeated. Both impulse responses were Fourier Transformed, and the resulting frequency response from the Beyer Dynamic measurement divided by that from the 4155 measurement. This removed the influence of the loudspeaker, amplifier, etc., to leave the frequency response of the Beyer Dynamic relative to the 4155. This response is shown in Figure 4. Clearly, the response of the microphone will contribute more error than that of the cassette deck. The low-frequency roll-off of the microphone is at a higher frequency than that of the Marantz, and the high-frequency deviations are larger. How large an effect this will have on a typical domestic noise measurement is estimated in the following section.

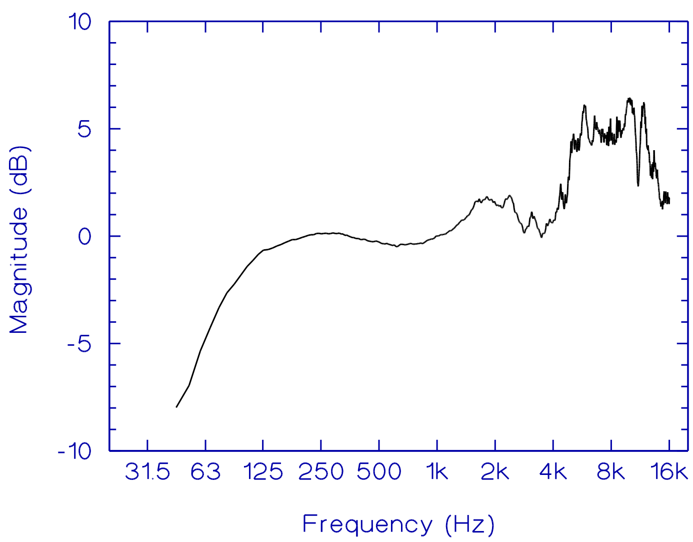

Figure 4: Free-field frequency response of Beyer Dynamic M101(NC) microphone, relative to Brüel and Kjær 4155 microphone.

4. TYPICAL MEASUREMENT ERRORS

To examine the effect of the frequency response of the measurement system, four common domestic noises are considered. Typical octave spectra were obtained from the literature for: car traffic [3], amplified rock music [4], male speech [5] and impact noise (the ISO impact transmission reference curve [6]). The data for the first three noises is for the sound as it would be measured external to the dwelling, of course. To obtain representative interior spectra, the sound reduction of the building was modelled by subtracting the ISO airborne sound reduction index reference curve [7] from the traffic, music and speech data. Assuming that the reverberation time of the receiving room has a flat frequency characteristic, this leads to typical spectra for the four noises shown in Figure 5. The curves have been normalised to 0 dB at 1 kHz.

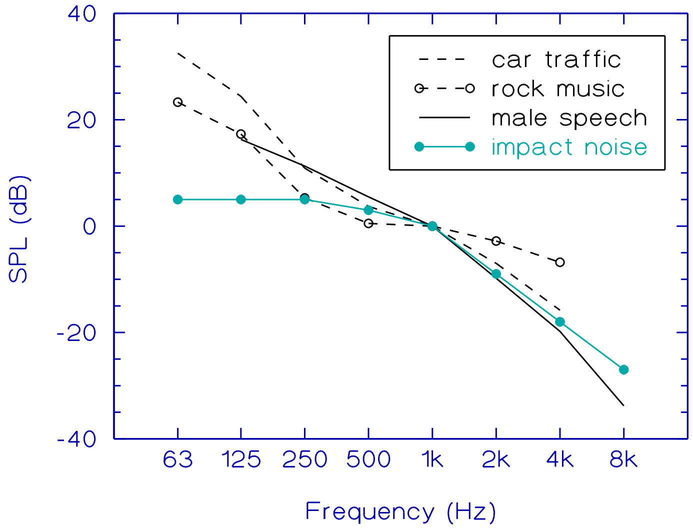

Figure 5: Calculated typical interior domestic noise spectra.

Now it is possible to combine the measured frequency responses of the various measurement systems with the interior noise spectra to find the expected measurement errors for each combination of measurement system and noise. Figure 6 shows an example: the expected measured spectra from the Uher and the (Marantz + Beyer Dynamic) system are plotted with the error-free noise spectrum for rock music. Note that the response of the 4155 microphone is assumed not to introduce significant errors — this will bias the comparison slightly against the (Marantz + Beyer Dynamic). The combined effect of the low-frequency roll-offs of the Marantz and the Beyer Dynamic microphone can be clearly seen.

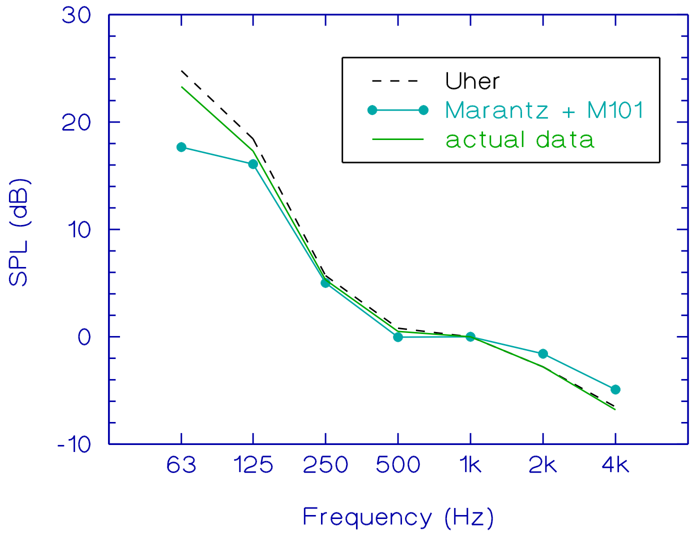

Figure 6: Rock music spectrum indoors, expected actual and calculated for two measurement systems.

dB(A)	traffic (cars)	male speech	rock music	impact noise	average
Marantz	-1.7	-0.4	-0.4	-0.2	0.7
Uher	1.0	0.4	0.6	0.2	0.6
Aiwa	0.0	0.0	0.0	0.0	0.0
Nagra	-0.2	0.0	0.0	0.0	0.1

Table 3: Calculated broadband A-weighted measurement errors introduced by four measurement systems into the SPL of four interior domestic noises.

The effect of the measurement system errors on the most important parameter, broadband A-weighted SPL, is shown in Table 3. The difference between the expected measured signal and the error-free signal has been expressed as an A-weighted sum, for each combination of measurement system and noise. The errors introduced by the Aiwa and the Nagra are insignificant. The errors introduced by the (Marantz + Beyer Dynamic) system are of the same order as those caused by the Uher. The cheaper system is better than the Uher with rock music, as faithful with speech and impact noise, and worse with traffic noise. The size of these errors, in combination with the random error on calibration, is small enough for the system to be used for screening, at least. A conservative estimate for the error is:

	± 0.7 dB(A) (for the frequency response)
+	± 0.4 dB(A) (for the calibration)
=	± 1.1 dB(A).

The low-frequency roll-off of the Beyer Dynamic microphone is the most significant cause of error.

5. CONCLUSION

The performance of an inexpensive system for monitoring domestic noise has been investigated. The system was based on a Marantz cassette deck and a Beyer Dynamic microphone, bought "off the shelf" with a total cost of about £250. It was compared to three more costly instrumentation systems. It was found that the inexpensive system introduced measurement errors close to those introduced by a system based on a Uher tape recorder. A pessimistic estimate for the total broadband error is ± 1.1 dB(A). This makes the system viable for initial screening measurements of domestic noise, at least. The frequency response and signal-to-noise ratio of the cassette deck were optimised by using a metal tape and Dolby C noise reduction. The performance of the system could be improved by using a microphone with a better low-frequency response.

6. REFERENCES

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