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A COMPARISON BETWEEN EXPONENTIAL AND LINEAR TIME-AVERAGING OF DIFFERENT NOISE ENVIRONMENTS

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SUMMARY

A comparison has been made between the statistical distributions of data sets acquired by sampling the conventional exponential time-averaged (RMS) sound level and the alternative short time-average sound level (Leq).

It has been shown, both theoretically and practically, that with one caveat, the techniques are interchangeable in their ability to capture and characterise the temporal variability of a noise climate, so long as care is taken to select appropriate sample rates. It has also been demonstrated that primary data processing with sampling rates of greater than 4 Hz, when combined with low-pass digital filtering, permits data interchange between short time-average and exponential time-average levels and vice-versa from the same input signal.

Due to the different averaging characteristics of each approach an individual sample level at a given time will possess different values when obtained through each acquisition process. This occurrence is material when considering maxima and minima as important control levels as is the case in many noise nuisance procedures. However, the adoption of shorter sampling intervals together with low-pass digital filtering permits these values to be accurately obtained.

With the exception of the characterisation of maxima and minima the statistical distribution of the temporal variability of different noise climates was found to be stable despite sample rate degradation to 0.25 Hz.

Thus there is a trade-off between capturing sufficient data to permit the accurate capture of maxima and minima, and sufficient data to characterise the temporal variability of the noise climate.

TIME AVERAGING

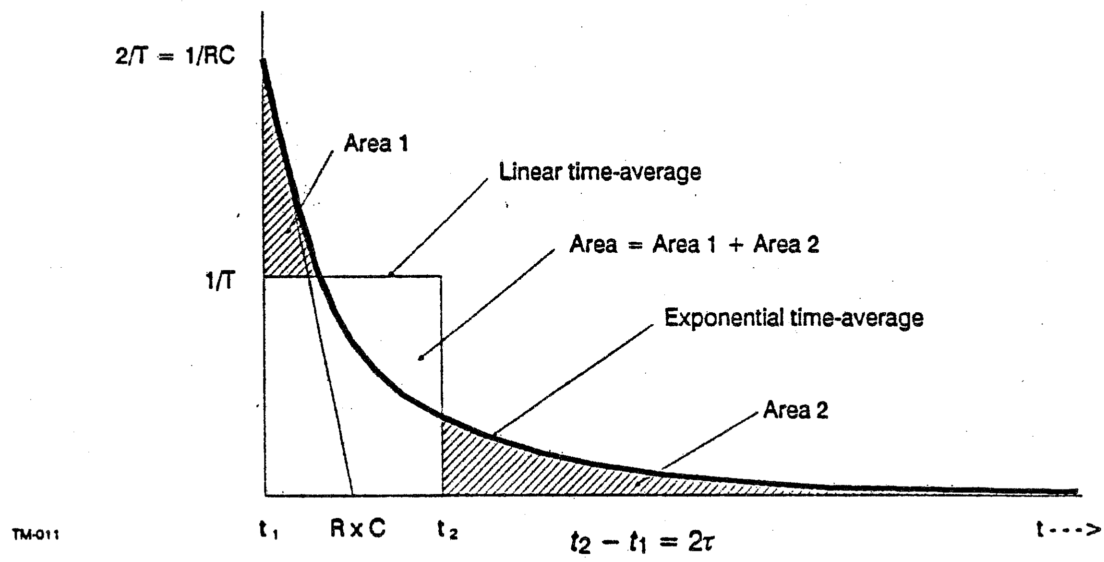
The purpose of any averaging technique is to reduce the volume of data needed to characterise the actual input signal without any significant loss of information about amplitude changes. In the case of averaging sound levels it is important not to lose any significant energy associated with level changes in order than this objective can be met.

The energy content of a sinusoidal signal has traditionally been characterised by the generation of a root-mean-square value (RMS) which is obtained through a running exponential time-average. Sound level meters have for 50 years been designed in this manner and the resulting continuous signal has been a close but imperfect analogue of the real-world continuous input.

In statistical distribution analysis this continuous signal is sampled at suitable intervals to generate a data set from which the familiar exceedance levels are calculated. There are however no standards to define the rate of sampling.

An alternative to exponential time-averaging is linear time-averaging whereby the energy content of a temporally variable signal is accumulated and time-averaged over the accumulation interval.

The two alternatives are illustrated graphically below :-



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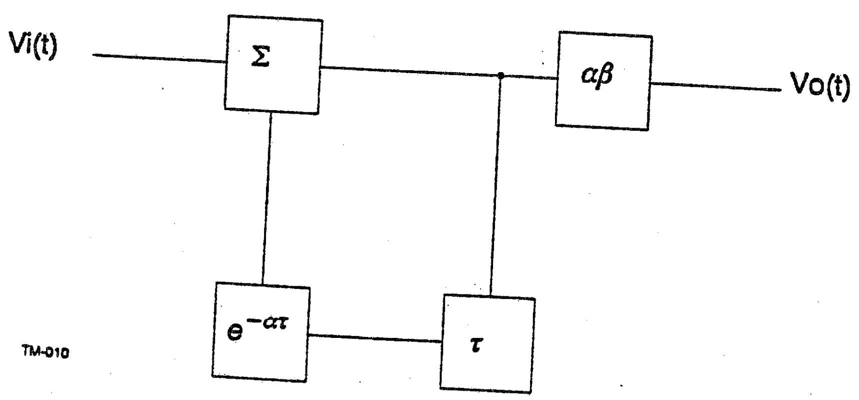
Whilst traditionally a continuous average over a long time interval is used to calculate the linear time-average level Leq, by choosing $(t_2 - t_1)$ to be a short interval then a discrete series of linear time-average levels can generate the data set to characterise the temporal variability of a noise climate. A linear time-average interval of $2 \times \tau$ will permit the linear average to accurately capture the energy content of the continuous signal. (Ref 1).

However, whilst a data-set so generated would adequately characterise the temporal variability of the input signal it would not permit the modelling of a continuous exponentially time-averaged signal to generate the accurate measurement of an RMS maximum or minimum level.

This short-coming can be overcome (Ref 2) with the use of a digital low-pass filter which has the following equivalent circuit :-



The filter characteristics and sample rate are related by the function

$$\alpha\beta = 1 - e^{-\alpha t}$$

where $\alpha = \frac{1}{\tau}$ and t = sample rate

For a range of sample rates we can calculate the filter characteristics as follows :-

t_s	$\alpha\beta$
0.01	0.0769
0.1	0.5507
0.125	0.6321
0.1875	0.7769
0.25	0.8647
0.5	0.9817
1.0	0.9997

Thus IEC-651 Fast time-weighting can for example be modelled by a 0.1875 sec linear average (3/2 x 0.125s) and a one-pole digital low-pass filter with the required characteristic, which was the case in a data acquisition system designed in 1979 (Ref 3). As the above table illustrates almost any sample-rate can be combined with a suitable low-pass digital filter characteristic so that it is feasible for instrument designers to primarily collect data as a linear-average or "dose" and then post-process it to obtain exponentially-weighted levels. Equally it is also true that continuous exponentially-weighted levels can be digitally sampled and the linear-averaged levels calculated from the samples.

In order to practically test the comparability of data sets obtained by the two alternative averaging techniques two different data acquisition systems were selected:

1/. CEL-393B Precision Computing Sound Level Meter uses primary data processing to generate an exponentially weighted time-average which is digitally sampled to generate linear time-average and statistical exceedance levels.

2/. CEL-493/238 Precision Sound Level Meter and Analyser which uses exponential-average primary processing but which allows the user to select between data storage of time histories as either sampled RMS levels or short-Leq levels.

A CEL-393B Precision Computing Sound Level Meter was used to perform in-situ calculation of L_{Aeq}, L_{AMAX}, L_{A10}, L_{A50} and L_{A90} and simultaneously to provide a wide dynamic range AC signal for tape recording.

Four different noise climates - Industrial Noise, Ambient Noise, Traffic Noise and Aircraft Noise - were analysed in this way and simultaneous tape recordings were obtained.

The recordings were then re-analysed in the laboratory to verify the tape recordings.

Each verified tape-recording was then re-analysed using a CEL-493/CEL-238 system which is a reprogrammable analysis and print system. This system choice permitted the selection of either Fast or Slow exponential time-weightings and additionally the ability to obtain linear time-average data-sets at any 0.5 second increment from 0.5 secs. Four linear time-average intervals were selected ; 0.5 s, 1.0 s, 2.0 s and 4.0 s and the ensuing data sets were downloaded from the CEL-238 to an IBM PC-AT via the RS-232C serial interface for disk archiving. The data files were subsequently imported into Lotus 1-2-3 where it was a simple task to analyse the linear time-average data sets into statistical distributions which could be compared with all the other analyses.

RESULTS

The measured results, together with computed standard deviations are shown below. Good agreement was obtained between in-situ and post-recording measurements, across both measurement systems and across all noise types. Somewhat surprisingly even when the time-history was characterized by 4 s linear-averages both the energy-content of the time history and its temporal variability were correctly obtained in comparison with sampled 0.125 s exponential-weighted levels. Across the metrics L_{Aeq}, L_{10}, L_{50}, L_{90} and all noise types the maximum standard deviation was 0.75 dB.

Considerably greater variability was obtained in the determination of the LAMAX resulting in standard deviations of 2 dB(A) for industrial noise and 4.27 dB(A) for traffic noise.

CONCLUSIONS

Even when the periodic averaging interval is extended to 4.0 sec both the overall time-average level Leq and the statistical distribution parameters L_{10}, L_{50} and L_{90} are correctly determined. However, at the distribution tails, differences between periodic linear time-average levels and exponentially time-averaged levels can be detected. All the linear time-average single value maxima tend to underestimate a sampled exponential time-average level when the $T = 2 \times \tau$ criterion is applied. This underestimate is capable of correction by the use of a digital low-pass filter and the choice of a suitable time-averaging interval.

REFERENCES

1. Randall R. B., Frequency Analysis, B&K Denmark.
2. Paularikas A.D., Seely S., Signals & Systems, PWS, Boston.
3. Overfield P., M.Sc Thesis (Unpublished), Hatfield Polytechnic 1979.

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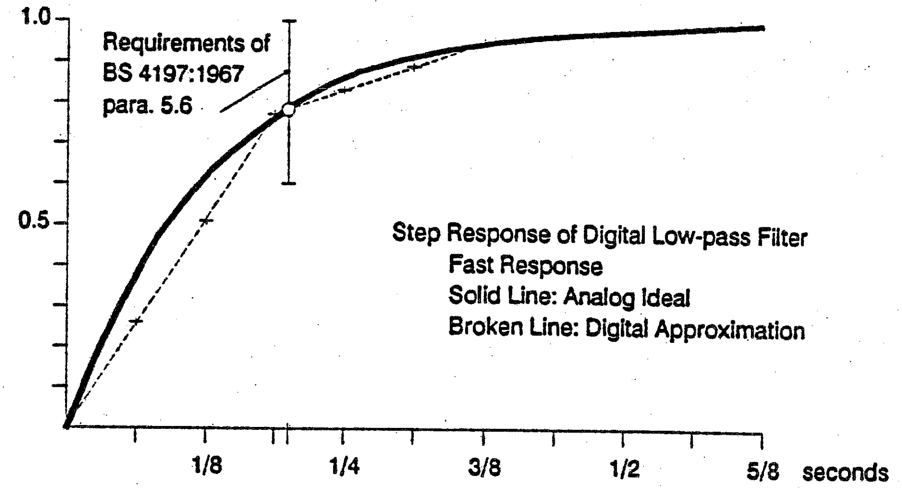
Reference 3



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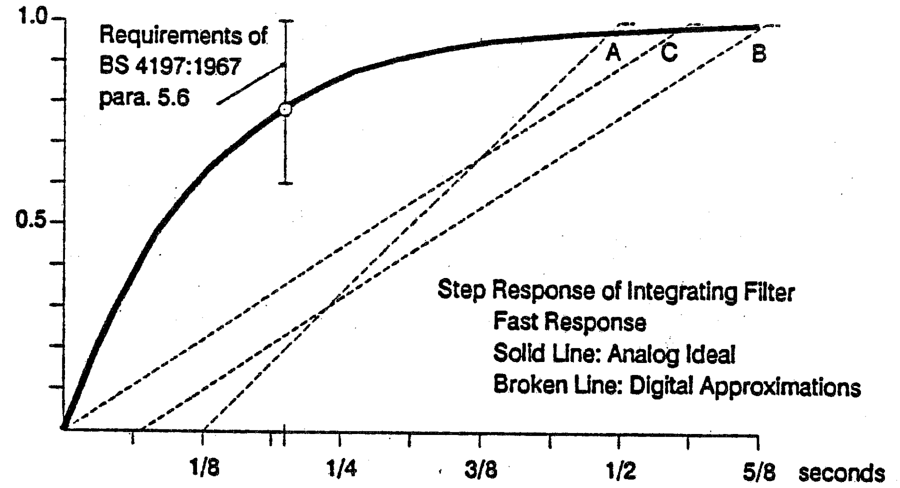

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RESULTS APPENDIX

Mean And Standard Deviation

dB(A) Parameter	AIRPORT Mean	AIRPORT SD	AMBIENT Mean	AMBIENT SD	INDUSTRIAL Mean	INDUSTRIAL SD	TRAFFIC Mean	TRAFFIC SD
L_{max}	92.3	0.30	66.4	0.57	88.6	2.00	86.5	4.27
L_{10}	82.0	0.20	61.4	0.19	75.5	0.41	79.6	0.10
L_{50}	63.6	0.36	54.2	0.46	67.5	0.75	79.0	0.05
L_{90}	54.7	0.20	51.8	0.55	57.0	0.58	78.6	0.05
L_{eq}	79.3	0.05	57.6	0.00	72.7	0.41	79.4	0.19

Airport Noise

DATA TYPE	CEL-238/393		CEL-238/493					
dB(A) Parameter	RMS Fast	RMS Slow	RMS Fast	RMS Slow	0.5s L_{eq}	1.0s L_{eq}	2.0s L_{eq}	4.0s L_{eq}
L_{max}	92.7	92.1	92.7	92.1	92.4	92.4	92.1	91.9
L_{10}	81.5	82.0	82.0	82.0	82.0	82.0	82.0	82.2
L_{50}	63.0	63.5	63.5	63.5	63.6	63.6	63.4	64.3
L_{90}	54.5	54.5	54.5	54.5	54.9	54.9	54.6	54.9
L_{eq}	79.2	79.3	79.3	79.3	79.3	79.3	79.3	79.4

Ambient Noise

DATA TYPE	CEL-238/393		CEL-238/493					
dB(A) Parameter	RMS Fast	RMS Slow	RMS Fast	RMS Slow	0.5s L_{eq}	1.0s L_{eq}	2.0s L_{eq}	4.0s L_{eq}
L_{max}	67.4	66.7	66.9	66.0	66.4	66.1	66.0	65.7
L_{10}	61.5	61.5	61.5	61.0	61.5	61.3	61.3	61.2
L_{50}	53.5	53.5	54.0	54.5	54.3	54.3	54.3	54.8
L_{90}	51.0	51.0	51.5	52.0	52.0	52.0	52.3	52.4
L_{eq}	57.6	57.6	57.6	57.6	57.6	57.6	57.6	57.6

Industrial Noise

DATA TYPE	CEL-238/393		CEL-238/493					
dB(A) Parameter	RMS Fast	RMS Slow	RMS Fast	RMS Slow	0.5s L_{eq}	1.0s L_{eq}	2.0s L_{eq}	4.0s L_{eq}
L_{max}	92.3	86.3	91.9	85.7	89.2	82.4	81.7	82.4
L_{10}	79.5	79.5	79.5	79.5	79.6	79.7	79.7	79.7
L_{50}	79.0	79.0	79.0	79.0	79.1	79.1	79.1	79.0
L_{90}	78.5	78.5	78.5	78.5	78.6	78.6	78.6	78.6
L_{eq}	79.7	79.6	79.3	79.3	79.3	79.2	79.2	79.2

Traffic Noise

DATA TYPE	CEL-238/393		CEL-238/493					
dB(A) Parameter	RMS Fast	RMS Slow	RMS Fast	RMS Slow	0.5s L_{eq}	1.0s L_{eq}	2.0s L_{eq}	4.0s L_{eq}
L_{max}	91.4	89.2	90.0	87.7	89.6	88.2	87.7	84.7
L_{10}	75.5	76.0	75.0	75.0	75.3	75.3	75.5	76.1
L_{50}	67.0	68.5	66.5	68.0	66.8	67.0	68.0	68.2
L_{90}	57.0	57.5	56.5	57.5	56.4	56.6	56.7	58.0
L_{eq}	73.4	73.4	72.5	72.5	72.6	72.5	72.5	72.5