Digital Computation of Exchange rates for calculation of noise dosage in embedded systems.

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ABSTRACT

Varying noise legislations throughout the world use different techniques for noise dosimetry. One of areas they differ with each other is the use of exchange rates; for instance, the United States Occupational Safety and Health Administration (OSHA) requires the dose to be calculated with and exchange rate of 5 dB, whereas some previous regulations have used 4 dB and the majority of other international standards use 3 dB.

As such, workers in a multinational organization may be subject to multiple noise legislations simultaneously. This creates the need for modern personal noise dosimeters to be capable of compliance with multiple regulations in a single measurement, while still being portable and optimised for power and processing.

Modern Noise dosimeters come with multiple channels which may be set up with a different exchange rate among other settings like threshold values, criterion time, etc. These Channels usually share the same hardware resources however they may differ in how they actually process data in firmware.

This paper explores the effects of varying the integration interval to optimise the processing of exchange rates for noise dosimetry, and its effects on processing for low power, embedded systems. The results will be checked against the current dosimetry standards to evaluate their suitability.

Keywords: Exchange Rate, Noise Dosimetry
I-INCE Classification of Subjects Number(s): 78

1. INTRODUCTION

Modern personal sound exposure meters (PSEMs) or noise dosimeters have come a long way and improved significantly over the years, they need to be accurate, portable and capable of processing and storing significant amounts of data, often spanning over multiple work shifts. This means that PSEMs/noise dosimeters need to process data comparable to sound level meters but with the additional requirement for being portable enough to be easily wearable and capability to work over multiple shifts on a single charge. With these requirements, it is important to use the available resources efficiently.

These constraints usually manifest themselves as limited memory, low processor speeds and/or lower battery capacity in noise dosimeters. The firmware running in these processors need to be optimized for best performance to power ratio.

Sound exposure is calculated by measuring and accumulating sound pressure over a certain time. The exposure is the compared against a criterion level and criterion time, and the result is usually expressed as a percentage of the criterion time and duration. The criterion level applied for the criterion duration equals 100% exposure/dosage. [1], a threshold level may also be used and it corresponds to a level below which sound pressure level may be ignored in the accumulation of noise dosage.

As an example, a noise dosimeter configured to ISO standards i.e. exchange rate set to 3dB, no time weighting and threshold, with a criterion time of 8hours and criterion level to 85dB will produce a percentage dose equal to 270%. Compared to a dosimeter configured to OSHA HC standard with a criterion time of 8hours and criterion level of 90 dB, exchange rate set to 5 dB and slow time weighted data the percentage dose produced for the same input signal equals 73%. [4]

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Two of the main standards governing the acoustical performance and requirements from personnel sound exposure meters are IEC 61252:1993 (Electro acoustics-Specifications for personal sound exposure meters) and ANSI S1.25:2007 (Specification for Personal Noise Dosimeters) most modern PSEMs/Noise Dosimeters have to comply with the aforementioned standards.

A general overview of the workings of a noise dosimeter is shown in Figure 1, with the core functional blocks shown in Figure 2. [1]

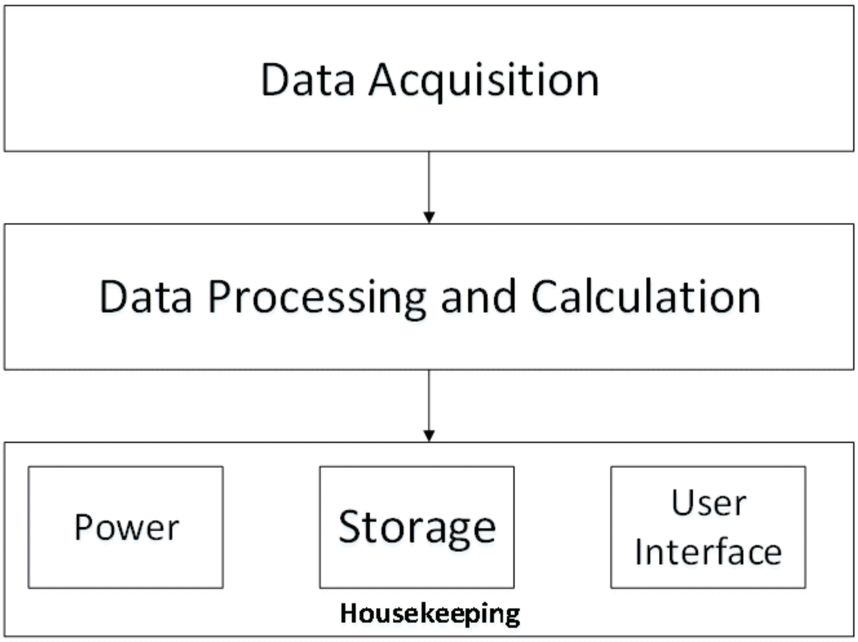

Figure 1 – General Overview of PSEM

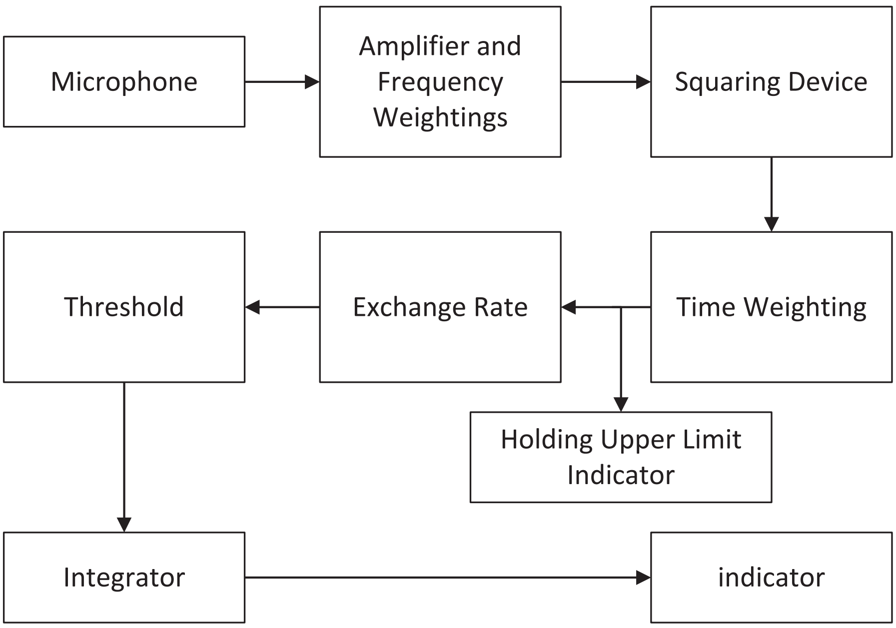

Figure 2 – Core Functional Blocks of a PSEM (ANSI 1.25)

1.1 Exchange Rates

The term exchange rate refers to the increase in noise level that corresponds to a doubling of the noise energy. An exchange rate of 3dB is commonly used in most international standards this means that no special exchange rate application or exponent circuit [1] is required for noise dosimetry. However, there are exceptions one of them being Occupational Safety and Health Administration (OSHA) in United States. According to OSHA, *"The OSHA standard uses a 5 dBA exchange rate. This means that when the noise level is increased by 5 dBA, the amount of time a person can be exposed to a certain noise level to receive the same dose is cut in half."* [3]

The ANSI S1.25 standard defines the criterion exposure, or dose, as follows:

$$D(Q) = 100 \underbrace{\left(\frac{T}{T_c}\right)}_{A} \underbrace{10^{[(L-L_c)/q]}}_{B} \quad (1)$$

Where:

- $D(Q)$ = Percentage criterion for exchange rate Q.
- T_c = Criterion duration
- T = Measurement duration
- L = Slow/Fast A-weighted sound level
- L_c = Criterion sound level
- Q = Exchange rate in decibels
- $q = 10$ for Q=3 dB, $4/\log 2$ for Q=4 dB and $5/\log 2$ for Q=5 dB

In equation (1), part A describes the effect of the measurement duration on the noise exposure, while part B relates to the effect of the noise level. According to the statement above from OSHA, halving the measurement duration (part A) and keeping the noise exposure $D(Q)$ constant means that part B must be doubled. Increasing L by Q decibels in equation (1) results in the doubling of $D(Q)$.

For a constant exposure duration and an exchange rate of 3 dB, doubling the noise exposure means increasing the noise level L by 3 dB, which means doubling the acoustic energy E a person is exposed to as shown in equation (2):

$$L + 3 = 10\log(E) + 10\log(2) = 10\log(2E) \quad (2)$$

For a doubling of the energy to result in an increase of Q dB (Q=4 or 5 dB) in the noise level, a factor y must be applied to the energy:

$$10\log(2E.y) = 10\log(2) + 10\log(E) + 10\log(y)$$

The exchange rate Q can then be expressed as a function of y:

$$10\log(y) = Q - 10\log(2)$$

And finally:

$$y = 10^{\frac{Q-10\log(2)}{10}}$$

For example, using an exchange rate of 5 dB the factor y becomes:

$$y = 10^{\frac{5-10\log(2)}{10}} \approx 1.584$$

This means that for a same measurement duration, a person must be exposed to 1.584 times more acoustic energy to double its exposure at an exchange rate of 5 dB than it would if using an exchange rate of 3 dB.

2. Incorporation of Exchange Rates in Dosimetry

2.1 ANSI S1.25

ANSI S1.25 describes the principle of operation if a dosimeter in mathematical terms as:

$$D(Q) = (100/T_c)\int_0^T 10^{[(L-L_c)/q]}dt \quad (3)$$

This calculation has to be incorporated in calculating the noise dosage specifically in the order specified in Figure 2 after the time weighting and before the integration. Equation (3) involves exponent and division calculations and may have a significant impact on the processor depending on the rate at which they are carried out.

ANSI S1.25 specifies the various tests to verify the functionality of the exponent circuit (exchange rate) specifically in section 7.5 and section 7.7 section 7.5 details the testing procedure for the squaring, averaging and exponential circuits whereas section 7.7 para. 3 consists of a test to verify if the integration and exponent circuits are correctly placed within the noise dosimeter.

The paper will use these tests and their respective tolerances specified in ANSI S1.25 as a guideline to verify different simulations and noise dosage calculation scenarios discussed further on in this paper.

2.2 Processing Data for exchange rates

In an ideal scenario, the exponential averaging (time-weighting) and exchange rate application is carried out, immediately after the squaring as shown in Figure 2. The squaring is carried out for each sample coming in from the analogue to digital convertor, which is at the sampling rate depending on the frequency range specified.

This means that time weightings and exchange rate calculations are ideally carried out at sampling rate in resource constrained real-time systems this poses a considerable challenge. Generally Sound level meters and PSEMs may accumulate a number of samples before applying time-weighting and exchange rate calculations on incoming sound pressure samples.

The accumulation of samples reduces the number of instructions running at sampling frequency f_s to a more manageable rate:

$$Processing\ Rate = \frac{f_S}{Accumulation\ Interval}$$

Processing data are a lower rate means less loading for the processor carrying out calculations this usually means more sleep time and the ability to be clocked at lower frequency saving precious power and memory resources.

2.3 Simulations

In order to study the effects of changing the accumulation interval and its effects on the measured dose tests from ANSI S1.25 section 7.5 and section 7.7 were simulated in Matlab along with the functional blocks simulating the functionality of a noise dosimeter. The test signals were injected into the simulated noise dosimeter. The results were recorded and compared with the tolerances described in ANSI S1.25. All errors were computed against the ideal scenario where all the relevant calculations are carried out at sampling frequency.

The accumulation interval in this paper is varied from 0.078 ms to 100 ms, or at a rate varying from 12800 Hz to 10 Hz the effects of varying this interval specifically for exchange rates in light of tests defined in ANSI S1.25 are shown in section 2.3. The sampling frequency is 25600 Hz.

2.3.1 **ANSI S1.25 Section 7.5**

The simulated signals are shown in Figure 3. The injected signal consists of short duration tone bursts at 4 kHz superimposed over a low-level continuous 4 kHz sinusoidal signal.

Figure 3 shows the injected signal for a tone burst duration of T_b, ANSI S1.25 recommends tone burst durations of 1ms, 10 ms, 100 ms and 1 second. The results obtained are shown in Figure 4a and Figure 4b the test was repeated for both slow and fast weighted. [1]

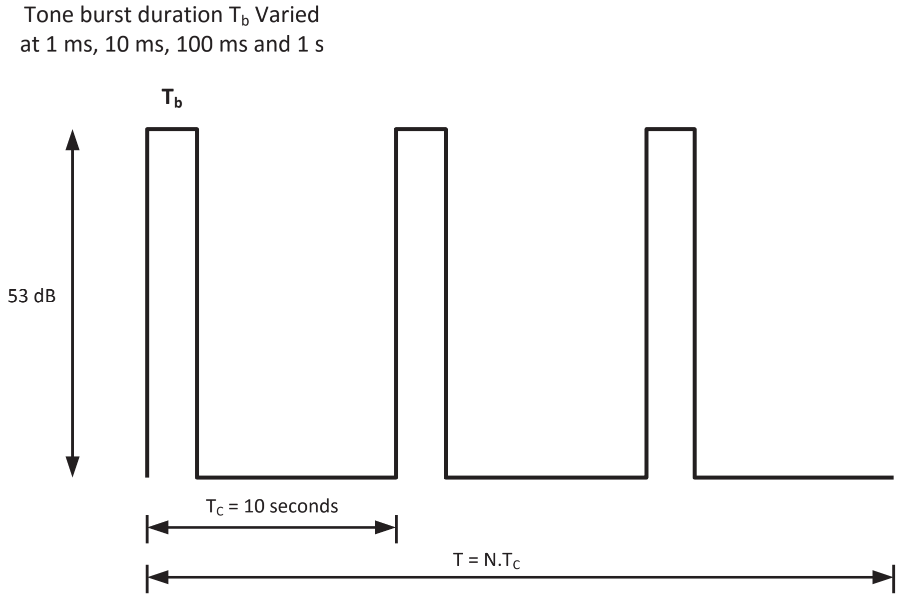

Figure 3 Injected Tone burst signal

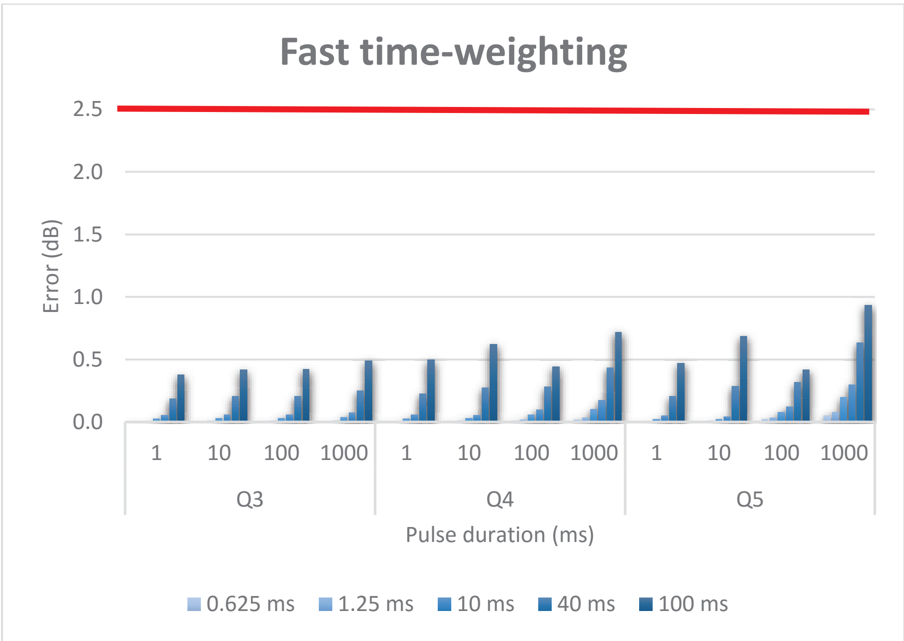

Figure 4a Error for tone burst response for Fast time weighted data.

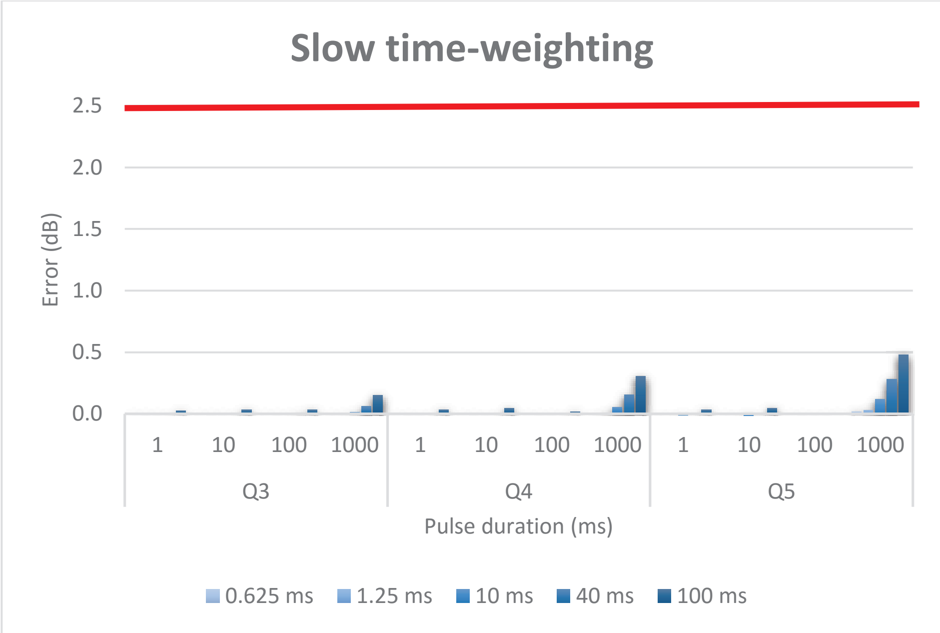

Figure 4b Error for tone burst response for Slow time weighted data.

The results in Figure 4a and Figure 4b show that the error is directly proportional to the accumulation interval. The effect on the error is greater for fast time weighted data compared to slow time-weighted data, this is understandable as the accumulation interval approaches the time constant the error increases. The accumulation before time weighting and exchange rate calculations essentially acts as a low pass filter before the time weighting filter, this removes out any high frequency content or pressure fluctuations from the incoming signal resulting in the increased error.

The maximum error noted is for an accumulation interval of 100 ms is 0.93 dB for an exchange rate of 5 dB and fast time weighted data.

This error is still within the tolerance of ±2.5 dB specified in ANSI S1.25 section 7.5 Table 4a and 4b. [1]

2.3.2 ANSI S1.25 Section 7.7

The relevant test in section 7.7 uses a reference level L_{ref} at 1 kHz for a reference duration of T and measuring the indicating dose this serves as the reference dosage (D_{ref}), the test then injects a signal of duration $2T$ with the level equivalent to reference level for a duration of $\frac{T}{10}$ and a level of $L_{ref} - 20$ dB for the reminder of the time period.

The same signal is then repeated so the total duration is $2T$, and the indicated dosage measured to be D_{signal} the standard then specifies the range between which the ratio (D_{signal}/D_{ref}) falls and the values are shown in Table 1:

Table 1

Exchange Rate	Ratio D_{signal}/D_{ref}	Tolerance
3	$0.19 - 0.25$	$\pm 14\%$
4	$0.23 - 0.28$	$\pm 10\%$
5	$0.29 - 0.34$	$\pm 8\%$

The allowed tolerance figures is the percentage difference between the tolerance limits and the mid value of the ratios.

The simulated signal is shown in Figure 5.

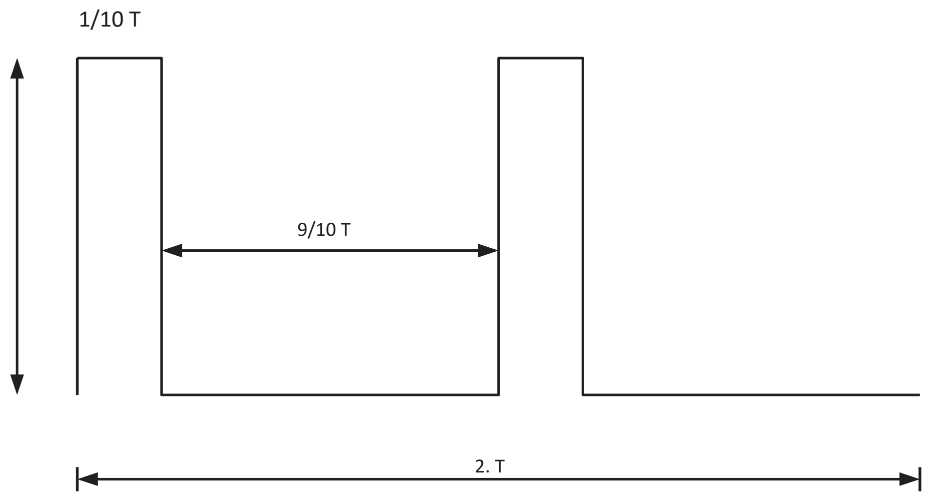

Figure 5 Injected Signal for the test described in ANSI S1.25 section 7.7 para. 3

The results obtained are shown in Figure 6a for slow time weighted data and 6b for fast time-weighted data.

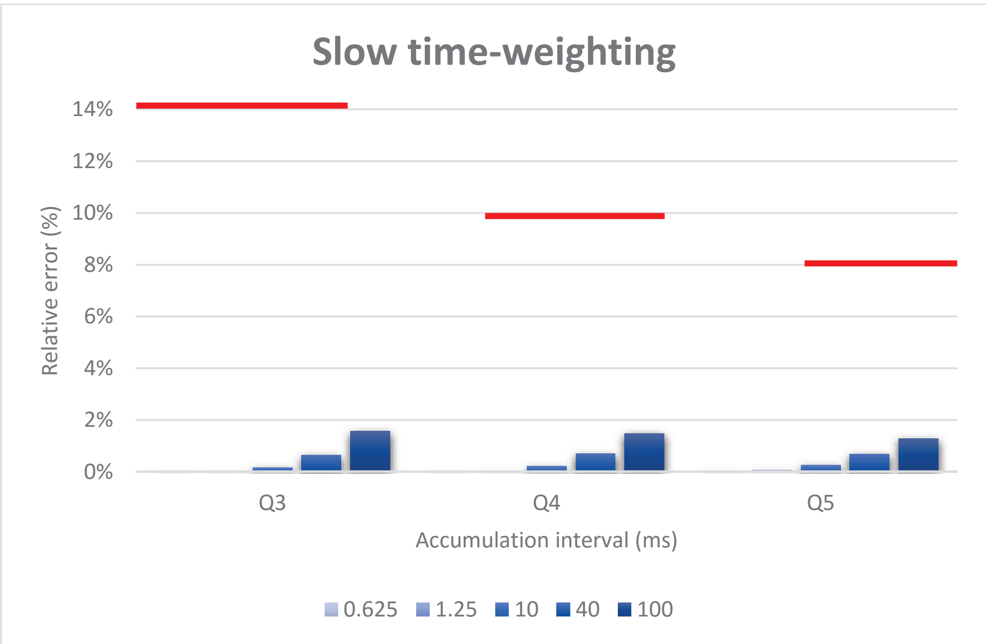

Figure 6a Relative difference in ratios expressed as a percentage for slow time-weighted data.

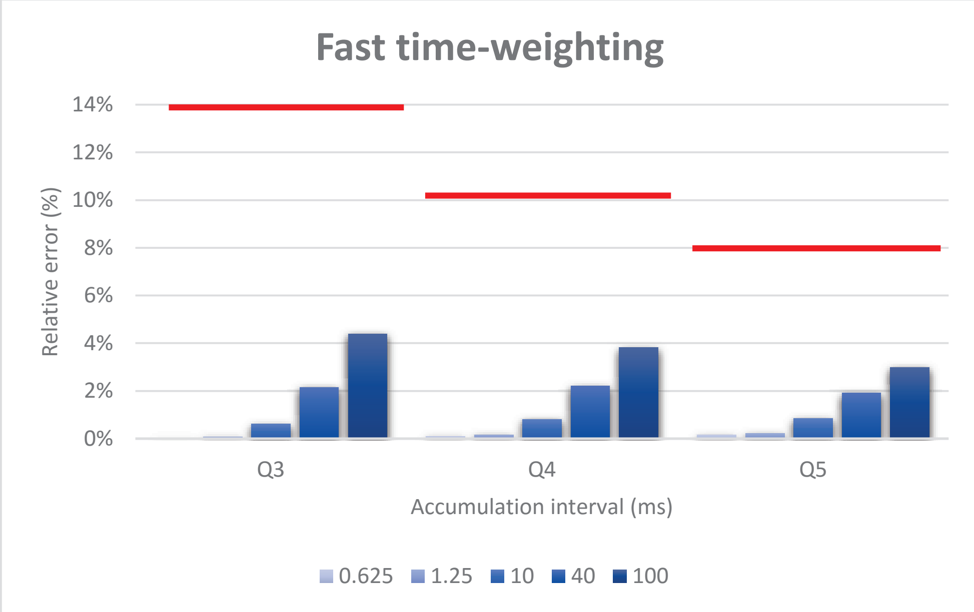

Figure 6b Relative difference in ratios expressed as a percentage for fast time weighted data.

The data presented in figures 6a and 6b generally follow a trend similar to that seen in the results from section 2.3.1, which is to say that the percentage error is directly proportional to the accumulation interval, and that the error is most significant in fast time weighted data. However, the percentage error here is greatest for the exchange rate of 3 dB and least for 5 dB.

Compared to the percentage error allowed in ANSI S.125 section 7.7 para 5, even with the biggest accumulation interval of 100 ms the error is well within the tolerance.

3. Discussion and conclusions

The results of the experiment show that varying the accumulation interval certainly introduces an error in the computed exposure compared to the ideal values obtained by carrying out all the processing at the sampling rate. However the differences are well within the tolerances defined in ANSI S1.25 for their respective tests. The scope of this paper only covers the tests related to exchange rate defined in ANS1 S1.25 section 7.5 and ANSI S1.25 section 7.7 para 3. The effects of varying the accumulation interval on other acoustic parameters specified in the standards may still need to be evaluated.

The instructions involved in processing the exchange rate and time weightings are constant on for each calculation on a given processor. Using the results obtained from this paper, we may conclude that the frequency of the exchange rate and time weighting computations may be reduced significantly from sampling frequency f_s to a much lower rate, noticeably reducing the load on the processor, while still being compliant with the relevant standards.

As an example, using $f_s = 25600$ Hz the calculations may be carried out 256 times less often (accumulation interval of 10 ms) while negligible effects on computed exposure.

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