

REPORT ITU-R BS.2103-1

Short-term loudness metering

(Question ITU-R 2/6)

(2007-2008)

Foreword

This Report is in two parts. The first part discusses the need for different types of programme loudness meter for different contexts, discusses general psychoacoustic principles, specific psychoacoustic principles in the context of temporal loudness sensation, and discusses the incorporation of these principles into ballistic characteristics for short-term loudness meters. The second part of the Report deals with correlation of short-term meter characteristics with loudness listening tests. This correlation is examined for several possible equalization curves and for a range of ballistic rise and fall time constants.

The purpose of a short-term loudness meter in broadcasting is to give a short-term indication that reflects the likely contribution to long-term loudness, rather than short-term loudness per se. While these quantities are related, recent research has shown that they are not the same thing. The references used for performance assessment of each short-term meter variant are therefore listening test results on long-term loudness.

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Part 1

1 Introduction

Radiocommunication Study Group 6 has approved a number of new Recommendations for international standardization of loudness meters. This has occurred in response to a need by many member administrations for such an instrument or set of instruments. This need has arisen because of a number of recent developments in broadcasting.

2 Application specific loudness meters

Loudness meters are needed for several applications, including:

- For emission, as a quality-control check.
- To confirm that loudness is within acceptable limits.
- For production, as a level meter to replace the VU meter.

In quality control, a slow (many seconds) averaging meter is needed so that the average programme loudness can be read easily. A numerical readout is an advantage in these applications as it removes any need to interpret needle swings and perform any visual average estimation. A numerical readout also allows corrective gain to be easily determined.

In the production role, particularly if the loudness of complete programme mix is displayed by means of a single meter readout, it may be useful to have some indication of the perceived dynamic range as well as having an indicator fast enough to display individual loudnesses where these can be discriminated aurally. This gives rapid feedback to the programme maker on which to make decisions about individual levels in the mix or overall mix level. This can be particularly important in productions “on location”, where for various reasons, audio monitoring may not be optimal.

For these reasons, a moving-indicator with a short (less than one second) averaging time is needed in production for loudness monitoring. Such a meter could show instantaneous loudness or a slowed average of instantaneous loudness to simplify reading the instrument.

3 Human loudness perception

While loudness models for arbitrary sound types and for arbitrary sound levels are very complicated, ITU-R work has shown that for typical broadcast material and a limited range of loudness, a simplified model can give surprisingly good correlation with perceived average loudness over a 10-15 s interval. There is, so far, no evidence to show that this model cannot also indicate instantaneous loudness under the same constraints. In fact, it is essential to use the same model for instantaneous loudness assessment if results are to be obtained which are consistent with long-term average loudness measurements. The model is detailed in Recommendation ITU-R BS.1770.

The main concern in this Report is adapting this model to indicate instantaneous or short-term loudness.

Human sensory perception follows Stevens' Power Law [Stevens, 1957]. The general form of the law is:

$$\psi(I) = kI^a$$

where:

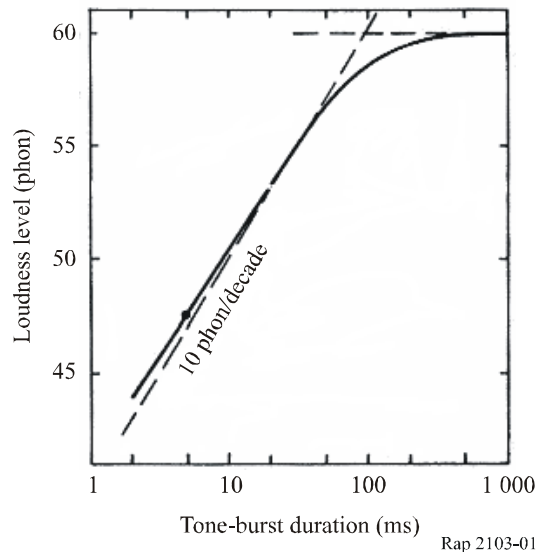
- I : magnitude of the physical stimulus
- ψ : psychophysical function capturing sensation (the subjective size of the stimulus)
- a : exponent that depends on the type of stimulation
- k : proportionality constant that depends on the type of stimulation and the units used.

This law is a consequence of the fact that biological processes, and perception in particular, can usually be modelled by first-order differential equations. These models generally apply to both the magnitude of sensation and to the onset and disappearance of the sensation. In other words, they generally apply in both amplitude and time.

In terms of temporal models of sensation, this means that sensations do not suddenly appear and disappear, but rather the sensation becomes gradually apparent when the stimulus is presented and the sensation gradually disappears after the stimulus is removed. This is illustrated by Zwicker's data on temporal loudness effects for a 2 kHz toneburst stimulus (see Fig. 1) which indicate the relative loudness of a toneburst as a function of its duration. This can also be interpreted as the onset of loudness perception at the start of a continuous tone.

FIGURE 1

Zwicker's data on temporal loudness sensation



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4 Review of proposed ballistic types

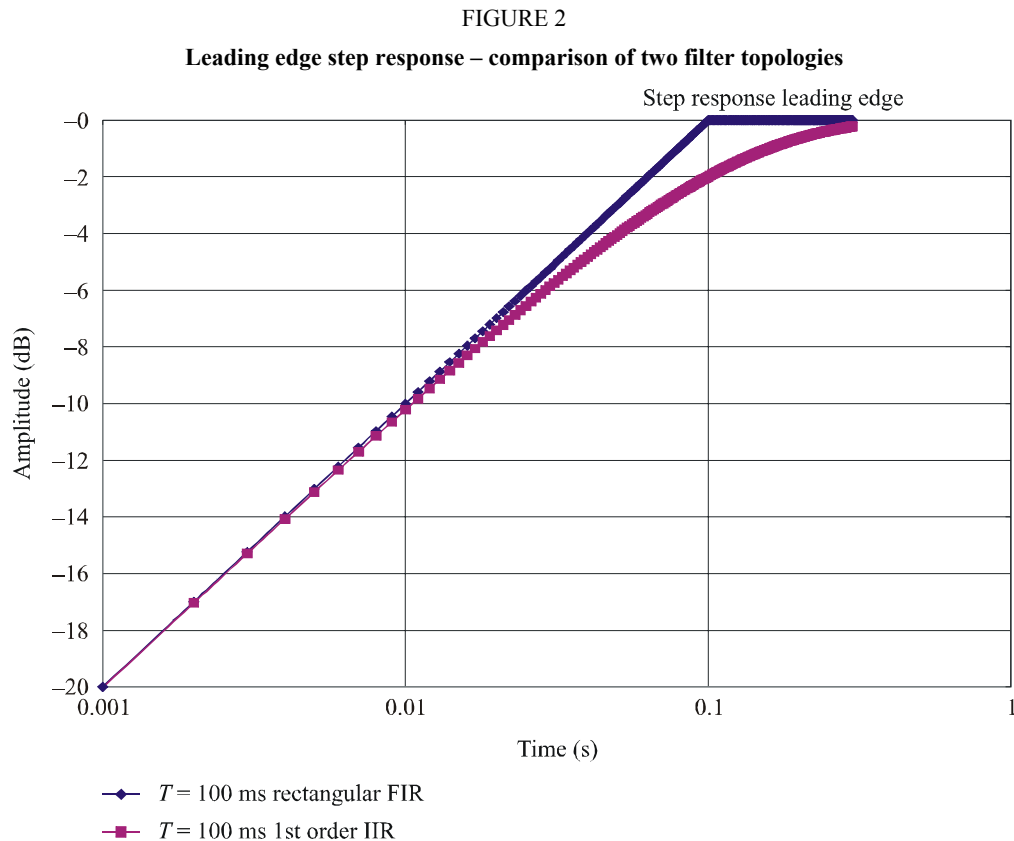
First order differential equations have solutions for impulse and step stimuli which are simple exponential functions.

Modelling temporal loudness perception can therefore be done with first-order analogue filters which have simple exponential rise and fall characteristics for such stimuli.

This type of filtering can be replicated in the digital domain using a first-order IIR topology or an FIR topology, although the IIR topology is far more computationally efficient. The FIR equivalent has an exponentially falling set of sample weights, corresponding to the impulse response of the first order analogue filter.

It has been suggested in discussions on loudness metering that the long-term loudness algorithm, which uses FIR filtering with rectangular weighting, could be adapted to model instantaneous loudness perception by simply shortening the time window over which it is applied. This would provide a poor model of loudness perception, as illustrated in Figs. 2 and 3.

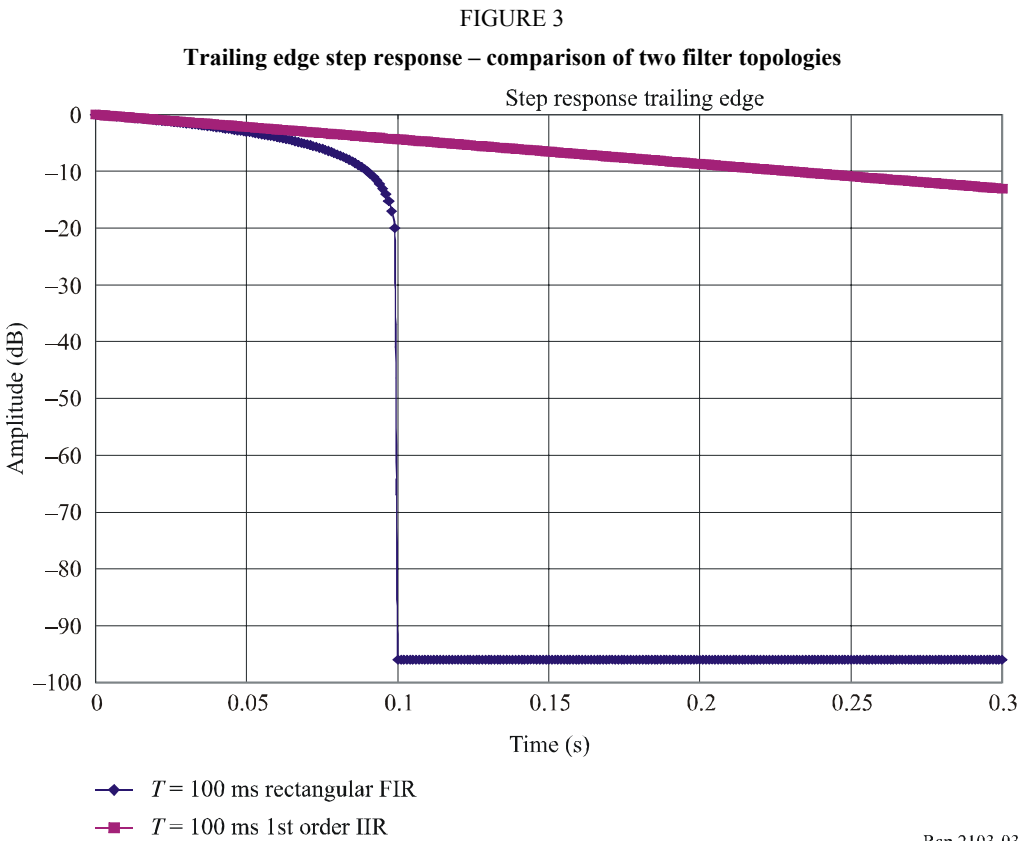
Figure 2 shows the leading-edge step response of an FIR filter with rectangular weighting and a time window of 100 ms (the best fit for Zwicker's data), compared with a first-order IIR filter with the same time constant. The IIR filter performance follows Zwicker's data within 0.1 dB, while the rectangular FIR filter has a worst-case 2 dB error at 0.1 s. The agreement between the two is otherwise good in the early and late phases.



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Figure 3 shows a similar comparison for a step response at the trailing edge. Here the disagreement is more marked. While the IIR filter falls off gradually and continuously, the rectangular FIR filter falls gradually at first and then drops precipitously at $T = 100$ ms. This FIR filter is unlikely to be a good model of perception. It gives a very discontinuous representation which does not occur in actual sensation. In other words, it is “jumpy” or “jerky”.

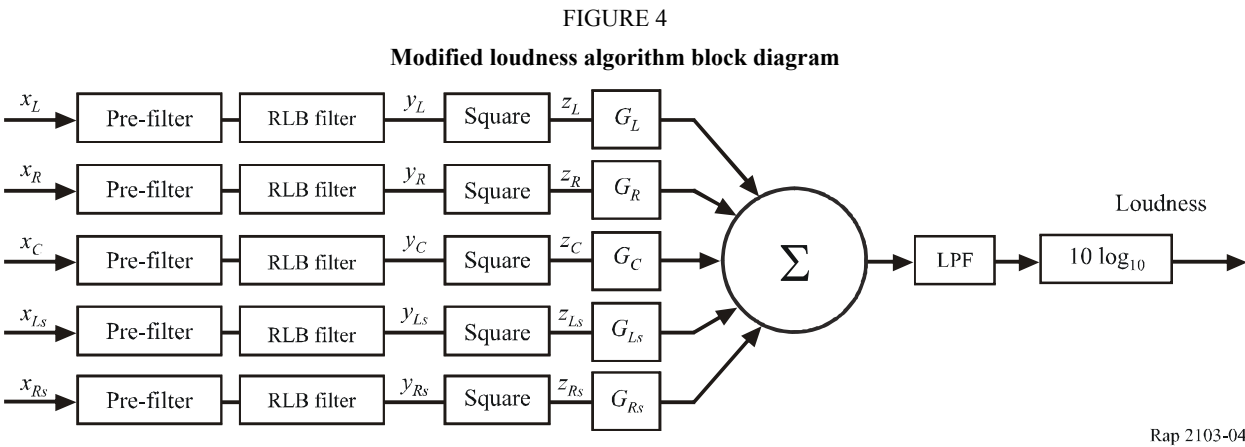
Since human perception generally follows Stevens’ Power Law, and this law represents the behaviour of biological systems which can generally be modelled by first-order differential equations, and since first-order IIR filters model such equations well, and since rectangular-weighted FIR filters do not model such equations well, we should use a first-order IIR filter in any loudness meter that attempts to model instantaneous loudness perception.



5 Implementation – theory

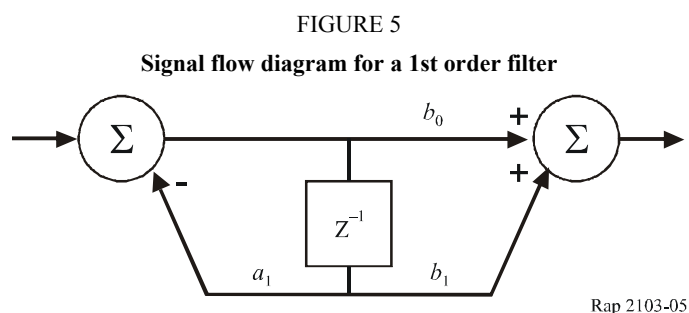
5.1 Algorithm topology

For consistency with the long-term loudness meter, the implementation of the short-term loudness meter followed the block diagram in Fig. 4.



5.2 Output filter topology

The low-pass filter stage at the output was functionally equivalent to the first order IIR topology shown in Fig. 5.



5.3 Time constant for instantaneous and fast response

The time constant of the filter should be a minimum of $T = 100$ ms to avoid exaggeration in the modelling of perceived instantaneous loudness. $T = 100$ ms will indicate the perceived dynamic range of the programme. A longer time constant could be used, at the discretion of the operator, to indicate the average loudness with reduced meter swing.

Operational trials in Japan have shown a longer time constant to be preferred over the 100 ms time constant for short-term loudness measurement and indication. It is the view of Japanese experts that a ballistic that changes faster than the commonly used VU meter is not desirable for short-term loudness measurement and indication.

5.4 Audio block decimation

Decimation by averaging blocks of samples may be used to reduce the computation load on the output filter. The decimated sample rate is arbitrary but should be significantly higher than 10 sample/s. Tables 1 and 2 give examples of filter coefficients for a decimated sample rate of 320 samples/s.

TABLE 1

Filter coefficients for first order low-pass filter, $T = 100$ ms

Sample rate	320/s	Gain	6.465674116e + 01
—	—	b_0	1
a_1	-0.9690674172	b_1	1

TABLE 2

Filter coefficients for first order low-pass filter, $T = 400$ ms

Sample rate	320/s	Gain	2.556465999e + 02
—	—	b_0	1
a_1	-0.9921767002	b_1	1