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## INR as an Estimator for the Decay Range of Room Acoustic Impulse Responses

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### ABSTRACT

A room acoustic impulse response can be used to derive the reverberation time and other parameters. For this a certain minimum energy decay range or effective signal-to-noise ratio is required, which relates to the difference between the initial signal level and the noise level. An impulse response parameter called INR is presented as an estimator for the decay range and shown to be a useful qualifier in practical measurements.

### 1. INTRODUCTION

The definition of the reverberation time presumes that the (backward integrated) RMS value of a room acoustic impulse response follows a straight line when plotted on a dB scale. The reverberation time is then calculated from the slope of the regression line over the largest useful range of this plot. This regression range is directly related to the decay range, which in turn is limited due to measurement noise, as depicted in figures 1 and 2.

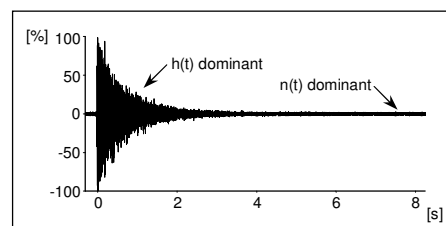


Figure 1: Measured impulse response  $p(t)$ , including actual system response  $h(t)$  and noise  $n(t)$ .

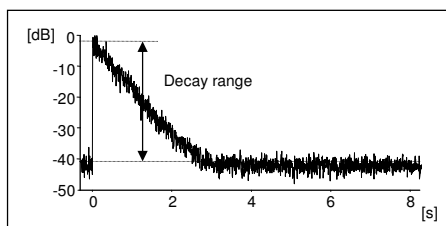


Figure 2: ETC plot: logarithm of lowpass filtered version of  $p^2(t)$ .

The ISO 3382 standard prescribes a decay range of 35 dB for the measurement of  $T_{20}$  (regression range -5...-25 dB) and of 45 dB for the measurement of  $T_{30}$  (regression range -5...-35 dB). The ISO 18233 standard uses the effective signal-to-noise ratio instead. Although the terms ‘decay range’ and ‘effective signal-to-noise ratio’ are conceptually clear, no definition is given. Hereafter a parameter to denote the decay range is defined, called INR or Impulse response to Noise Ratio, introduced by Acoustics Engineering in 1998 [6].

## 2. DEFINITION

The INR is defined as:

$$INR = L_{IR} - L_N \quad [dB] \quad (1)$$

where  $L_{IR}$  is the maximum RMS level in dB of  $p(t)$  and  $L_N$  is the noise level in dB. To define  $L_{IR}$ , the backward integration method by Schroeder [1] is as useful as it has already proven to be for the accurate determination of the slope. Indeed, the maximum of the Schroeder plot in figure 3 is easy to find, but its exact relation with  $L_{IR}$  is not obvious.

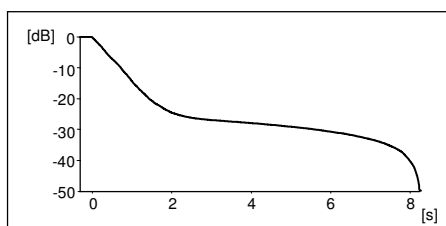


Figure 3: Schroeder plot of  $p(t)$  (without noise compensation).

Although there is no simple relation that is valid for all impulse responses, a good approximation can be made under the above-mentioned assumption that the RMS

value of a room acoustic impulse response is essentially exponential with a decay rate of  $60/T_{60}$  dB/s:

$$h(t) = h_0 \cdot U(t - t_d) \cdot C(t - t_d) \cdot 10^{-\frac{3(t-t_d)}{T_{60}}} \quad (2)$$

where  $h_0$  is the maximum impulse response value,  $t_d$  is the time for the direct sound to travel from source to receiver,  $U(t)$  is the unit step function (0 if  $t < 0$ , 1 if  $t \geq 0$ ),  $C(t)$  is any carrier signal with unit RMS value, and  $T_{60}$  is the reverberation time. The maximum RMS level is:

$$L_{IR} = 10 \cdot \log(h_0^2) \quad [dB] \quad (3)$$

Integrating  $h(t)$  backwards according to Schroeder results in:

$$S(t) = 10 \cdot \log \left[ \int_t^\infty h^2(t) \right] \quad [dB] \quad (4)$$

and

$$S(0) = 10 \cdot \log \left[ \frac{T_{60}}{6 \ln 10} \cdot h_0^2 \right] \quad [dB] \quad (5)$$

Therefore, starting from an exponential impulse response and substituting (5) into (3), we obtain:

$$L_{IR} = S(0) + 10 \cdot \log \left[ \frac{6 \ln 10}{T_{60}} \right] \quad [dB] \quad (6)$$

In words:  $L_{IR}$  is defined as the level of the total impulse response energy normalized to the decay time  $T_{60}$ .

Practically, the INR can be obtained as follows:

1. Determine  $L_N$  from the tail of  $p(t)$ , defined as the part of  $p(t)$  where the energy level of  $p(t)$  is essentially constant in time.
2. Determine the Schroeder curve  $S(t)$  in the usual way, with or without noise compensation.
3. Estimate  $T_{60}$  from the initial decay of the Schroeder curve.
4. Calculate  $L_{IR}$  according to equation (6)
5. Calculate INR according to equation (1)

### 3. EVALUATION

#### 3.1. INR of practical impulse responses

Over the last 10 years the INR has been calculated for many impulse responses, measured in various sound fields. In general, these impulse responses can be roughly divided into three types, based on the overall envelope shape: ‘normal’, with a ‘high-initial-peak’ and with a ‘slow-attack’. The ETC (Energy Time Curve) and Schroeder plots of such impulse responses are shown with the corresponding calculated INR values in figures 4 through 6.

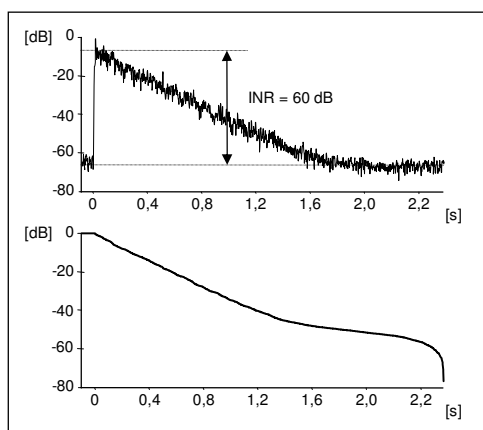


Figure 4: ETC and Schroeder plot of an impulse response measured in a diffuse sound field (‘normal’).

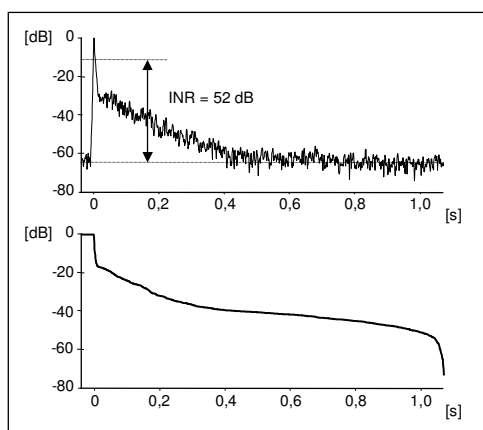


Figure 5: ETC and Schroeder plot of an impulse response in front of a loudspeaker (‘high-initial-peak’).

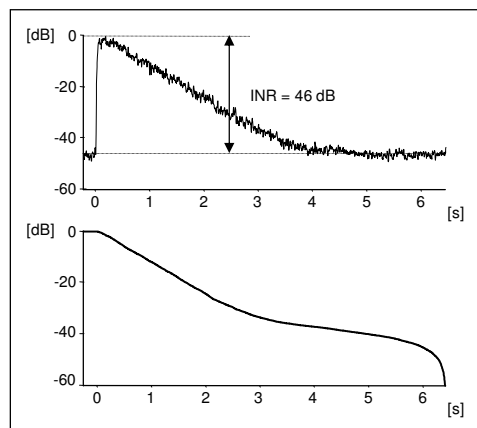


Figure 6: ETC and Schroeder plot of an impulse response measured in the receiving room in a sound insulation measurement setup (‘slow-attack’).

As could be expected, the INR of the ‘normal’ impulse response can be estimated quite easily by visual inspection of the ETC plot. The INR of the ‘high-initial-peak’ impulse response is clearly affected by the direct sound peak and much more difficult to determine unambiguously from the ETC plot. The INR of the ‘slow-attack’ impulse response just exceeds the peak RMS to noise level ratio.

#### 3.2. INR as impulse response qualifier

Whether an acoustical parameter can be derived accurately from an impulse response largely depends on the INR. In this way the INR serves as a quality parameter for impulse response measurements. Table 1 shows the minimum INR for some parameters. Most practical INR values range from 35 to 60 dB.

Parameter	Symbol	INR
Speech Transmission Index [2][4]	STI [-]	> 15
Level [5]	$L_x$ [dB]	> 30
Reverberation Time $3T_{(-5,-25)}$ [3]	$T_{20}$ [s]	> 35
Reverberation Time $2T_{(-5,-35)}$ [3]	$T_{30}$ [s]	> 45

Table 1. Some acoustical parameters with minimum INR value for accurate measurements.

#### 4. CONCLUSIONS

1. The INR is an impulse response qualifier that is closely related to the decay range as mentioned in the ISO 3382 and ISO 18233 standards.
2. Its definition, based on the RMS and Schroeder curves, makes the INR easy to calculate and useful for practical acoustical impulse responses.

#### 5. REFERENCES

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