Bandpass filters for the evaluation of short reverberation times

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Abstract: If short reverberation times e.g. of building elements are evaluated in a narrow frequency range (like one third octave bands), the result will be distorted by the applied bandpass filter. The influence of important parameters like the regression range of the reverberation time, the order of the filter and the number of eigenmodes in the passband of the filter is investigated. For different sets of parameters and a given limit of distortion the minimum permissible product BT of the bandwidth B and the reverberation time T is calculated.

MEASUREMENTS OF SHORT REVERBERATION TIMES

For the evaluation of reverberation times T different methods can be applied. Contrary to structural dynamics, where usually single eigenmodes are evaluated by modal or FFT analysis, in room acoustics reverberation times are calculated by integration of the impulse response in the time domain. Usually the system is exited with a broadband signal as is noise or an impulse. For an evaluation in frequency bands the impulse response is filtered in octave or one third octave bands. In case of impulse excitation the squared impulse response is integrated. The reverberation times (e.g. T_{10}, T_{30}) are calculated by linear regression of the decay curve. The same technique is applied in measurements of sound insulation and of loss factors of building elements (1). In the latter case reverberation times may be in an order of magnitude of 0.001 s. Apart from the desired effect of the band filter in the frequency domain, the filter causes a distortion of the impulse response depending on several parameters. In this paper the most important parameters for the error reduction of the reverberation time calculation are discussed.

INFLUENCE OF BANDPASS FILTERS

Jacobsen (2) found that the distortion caused by the bandpass filter is negligible if the product BT of the filter bandwith B and the reverberation time T of the system is less than 16 (4 in case of time-reversed filtering (3)). To investigate the quantitative influence of the bandpass filter for small values of T, an algorithm for modelling of impulse responses and calculation of reverberation times has been developed. The simulations base upon a model impulse response

$$h_{\text{model}} = \sum_{i=1}^{n} A_i \cos(2\pi(f_i t + \varphi_i)) \exp\left(\frac{-3\log(10)}{T_i} t\right), \qquad (1)$$

that represents an acoustic system with n eigenmodes (each with amplitude A_i, frequency f_i, phase φ_i and reverberation time T_i). The ratio $\Delta T = 10\log_{10}(T_{\text{filtered}} / T_{\text{model}})$ in dB of the reverberation time of the unfiltered impulse response T_{model} and the filtered impulse response T_{filtered} was calculated for different sets of parameters of the model impulse response, the applied bandpass filter and the calculation method. $|\Delta T|$ can be interpreted as classification limit for sound level meters similar to that given in IEC 651 (4).

Considering one eigenmode in the centre of the passband, a typical plot of ΔT vs BT for the regression ranges T_{10} to T_{30} is shown in figure 1 a). Figure 1 b) shows the plot of $|\Delta T|$ with a logarithmic scaled ordinate.

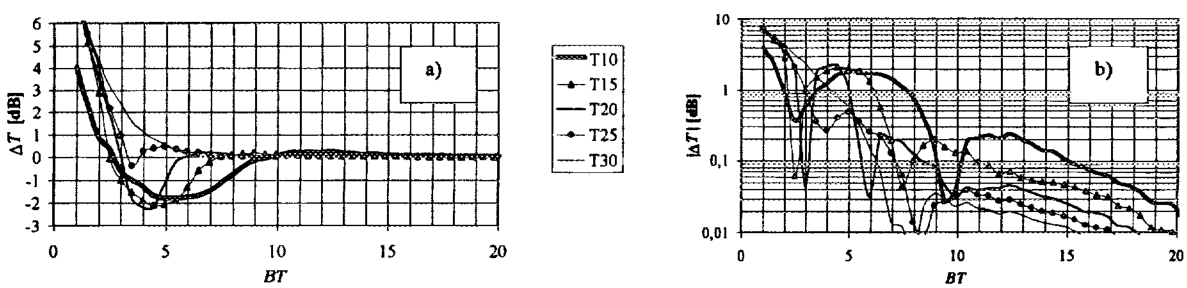

FIGURE 1. Error caused by a one third octave band filter (200 Hz centre frequency). a) linear, b) logarithmic scale.

Obviously, a more extended evaluation range of the regression (T_{30} instead of T_{10}) significantly reduces the error.

Other significant parameters that decrease the acceptable values of *BT* are a low order of the filter, a wide passband range (e.g octave instead of one third octave bands) and a minimum phase of the filter's impulse response if time-reversed filtering is used. The optimisation, however, is limited by the ranges given by the standard IEC 1260 (5).

In building acoustics, the mode density increases with frequency. Although a bandpass filter is applied, more than one mode can be present in the passband range. In this case the number and the position of the eigenmodes have an important influence on ΔT. An investigation of this realistic case was done by evaluation of model impulse responses consisting of a number of modes each with an individual amplitude, phase and frequency. To reduce the statistical error, the envelope of the 19 best out of 20 simulations were evaluated for each set of parameters. Figure 2 shows ΔT_{20} vs BT for an impulse response with 3 eigenmodes, filtered with a one third octave band filter with its centre frequency at 200 Hz.

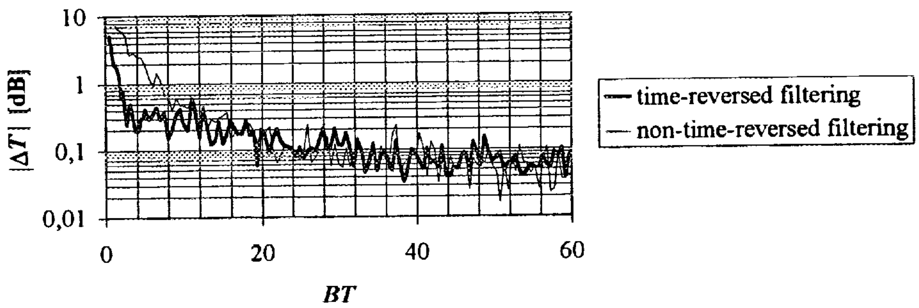

FIGURE 2. Influence of the filtering method and the number of eigenmodes inside the passband range.

The bold line shows ΔT_{20}, if a time-reversed filter is applied. The thin line represents the error, if the filter's impulse response is not reversed. With time-reversed filtering a smaller error occurs towards small values of *BT*. For high values of *BT* an increasing number of eigenmodes in the passband range causes a higher ΔT_{20} limit. If a fixed bandwidth is used, this limit cannot significantly be improved by modification of the filter structure.
If e.g. T_{20} shall be evaluated according to IEC 651 class 1 (error < 0.7 dB) with the set of parameters used above, the minimum acceptable *BT* is given to 7.5 for non-time-reversed filtering and 2.5, if reversed filtering is applied.

CONCLUSIONS

If only one mode is included in the passband range of the bandpass filter, a precise analysis of the reverberation times down to small values of *BT* is possible, if filters with minimum phase and time-reversed filtering are applied. If more than one mode is inside the passband of the filter, a filter-independent error must be taken into account. The error increases with the number of modes. It can be estimated by the simulations described above.

ACKNOWLEDGMENTS

The project was financially supported by the Physikalisch-Technische Bundesanstalt, Braunschweig, Germany. Some measurements were performed there by A. Meier, who gave helpful hints concerning the implementations.

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