Non-exponential reverberation and its effect on sound perception

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Any acoustic signal in a room extinguishes progressively with time. The effect is called reverberation. It is caused by the sound attenuation, by multiple reflections from the walls and from different objects in the room and by other relaxation processes. The reverberation may affect significantly the intelligibility of speech and music [1].

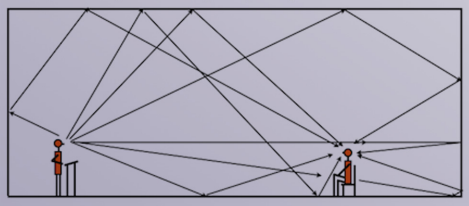


Fig. 1) The reverberation. Schema of multiple reflections from the walls.

The sound produced by an instantaneous burst, mathematically a Dirac delta function, is called impulse response $g_{imp}(t)$ for the given locations of the sound source and of the receiver.

The effect of any signal $s(t)$ issued from the same source is given by the convolution of the signal with the impulse response function

$$(g_{imp} * s)(t) = \int_{-\infty}^{\infty} g_{imp}(t-\tau)s(\tau)d\tau \qquad (1)$$

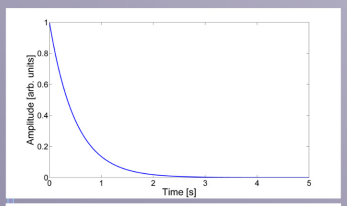
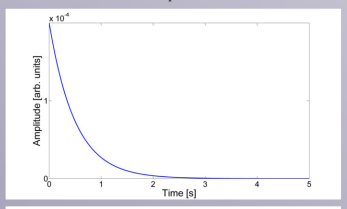
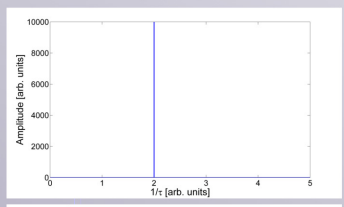
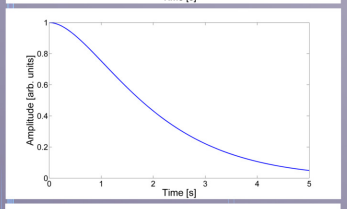
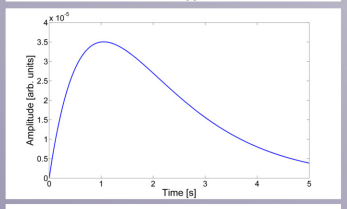
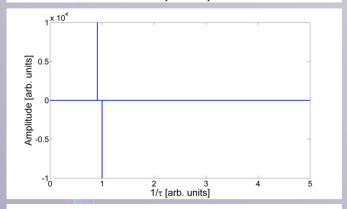
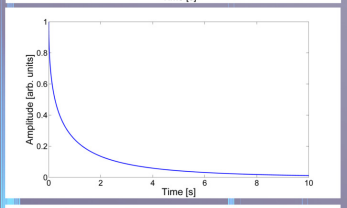
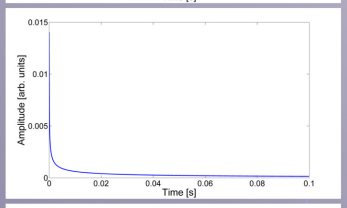
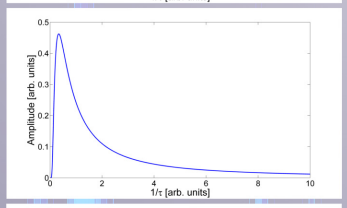
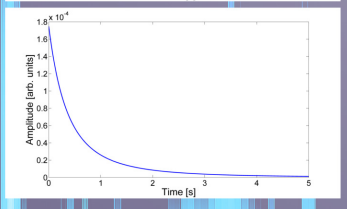
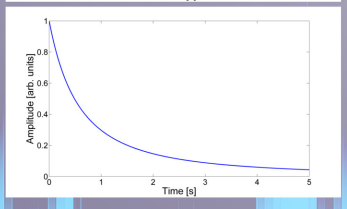
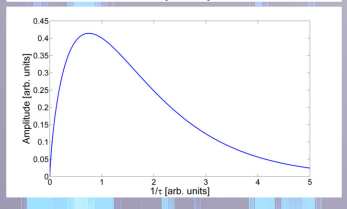
A number of models has been proposed to describe the relaxation in systems where the equilibrium state is attained by multiple processes characterized by different time scales. The relaxation then is described by the relaxation function $f_{relax}(t)$ such that

$$g_{imp}(t) = -\frac{df_{relax}(t)}{dt} \qquad (2)$$

Given the distribution of the relaxation times the relaxation function reads

$$f_{relax}(t) = \int_{0}^{\infty} \rho(\tau)\exp(-t/\tau)d\tau \qquad (3)$$

Table 1) Examples of known relaxation functions, the corresponding distributions of relaxation times impulse responses.

	Relaxation function $f_{realx}(t)$	Impulse response $g_{imp}(t)$	Distribution of relaxation times $\rho(1/\tau)$
Debye			
Overdamped harmonic oscillator			
Stretched exponent			
Power law			

How to distinguish a non-exponential relaxation resulting from a linear combination of purely exponential relaxation processes from that resulting from a one-scale but nonlinear process?

One manifestation is higher harmonics generation!!!

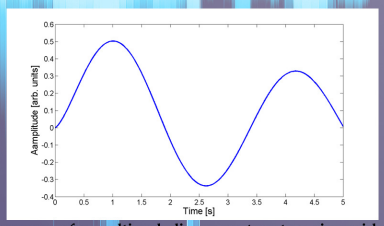


Fig. 2) Response of a multiscale linear system to a sinusoidal signal

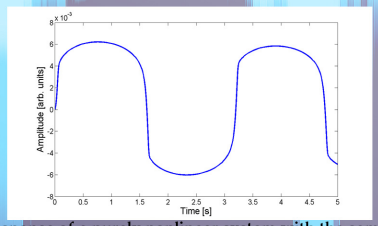


Fig. 3) Response of a purely nonlinear system with the same relaxation function to the same signal

Similar effects are expected in other condensed matter systems.

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[2] see e.g. M. N. Berberan-Santos, E. N. Bodunov, B. Valeur, Chemical Physics 315 (2005), 171.
[3] P. Zieliński, Physica B: Condensed Matter 316 (2002) 603.

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