Guimarães - Portugal
acústica 2004

In situ absorption measurement of antinoise devices using pre-determined pulse waveforms

P. Cobo[a], A. Fernández[a] , R. Palacios[a], C. de la Colina[a], and M. Siguero[b]

[a] *Instituto de Acústica, CSIC. Serrano 144, 28006 Madrid (Spain), iacpc24@ia.cetef.csic.es*
[b] *Departamento de Comunicación Audivisual, Universidad Complutense de Madrid, Avenida Complutense s/n, 28040, Madrid*

ABSTRACT: Noise barriers can be characterized by using the Adrienne method which combines MLS signals with the subtraction technique. This paper deals with a method to shape the loudspeaker-microphone impulse response which utilizes inverse filtering techniques to design the waveform radiated by the loudspeaker according to some prescribed criterion. For instance, zero-phase cosine-magnitude waveforms provide minimum length within a given frequency band. Therefore, this technique allows approaching the microphone to the loudspeaker, and as a consequence, reduces the lowest reliable frequency of the absorption measurement.

1. INTRODUTION

The Adrienne method computes the normal incidence absorption coefficient of a barrier as [1-3]

$$\alpha(f) = 1 - \left(\frac{\tau_r}{\tau_d}\right)^2 \left|\frac{R(f)}{D(f)}\right|^2 \quad , \qquad (1)$$

where τ_d and τ_r are the travel times of the direct and reflected signals, respectively

$$\tau_d = \frac{d_a}{c} \qquad (2a)$$

$$\tau_r = \frac{d_a + 2d_m}{c} , \qquad (2b)$$

d(t) and *r(t)* are the direct and panel reflected events, *D(f)* and *R(f)* are the Fourier transform of *d(t)* and *r(t)*, respectively, and d_a and d_m in Eqs. (2) are the loudspeaker-microphone and microphone-barrier distances, respectively.
Keeping constant the loudspeaker-microphone distance, the next measurements can be carried out:

- The direct signal, when the barrier is absent.
- The direct+reflected signal, when the barrier is present.

As the distance loudspeaker-microphone is constant in both measures, the subtraction of the two previous traces will provide the signal reflected in the barrier [4]. In both measures, the direct and the reflected traces, will exist undesired events (diffraction on the edges of the sample, reflection loudspeaker-barrier-loudspeaker, etc.). For that reason, it will be necessary to separate in both measures the desired events from the undesired ones by means of an appropriate window. The length of the window determines the lowest reliable frequency of the method [5].
Sometimes may be of interest to work with signals shorter than the original loudspeaker-microphone impulse response. In this case we can use the arbitrary waveform synthesis, or parametric spectral shaping by inverse filtering [6-7]. This technique has been applied successfully to radiate minimum length pulses with underwater transducers for high resolution exploration of sea bottoms [8-9].

2. SPECTRAL SHAPING BY INVERSE FILTERING

Let *h(t)* be the impulse response of the loudspeaker-microphone system, and *H(f)* its Fourier transform. Let $Y_d(f)$ be the spectrum of the desired pulse that the loudspeaker might radiate. Then, it should be driven by a spectrum

$$X_d(f) = \frac{Y_d(f)}{H(f)} . \qquad (3)$$

To avoid instabilities at the notches of *H(f)*, a positive constant, *p*, must be added to the denominator (regularization). Thus

$$X_d(f) = Y_d(f)\frac{H^*(f)}{\left|H(f)\right|^2 + p^2} . \qquad (4)$$

The electrical signal which should drive the loudspeaker is

$$x_d(t) = \Im^{-1}\left\{ Y_d(f)\frac{H^*(f)}{\left|H(f)\right|^2 + p^2} \right\} , \qquad (5)$$

where $\Im^{-1}$ stands for inverse Fourier transform. Cosine-magnitude pulses have a magnitude spectrum given by [6]

$$\left|Y_d(f)\right| = \begin{cases} A\cos^g\left(\dfrac{\pi(f - f_0)}{B}\right) & f_1 \le f \le f_2 \\ 0 & f < f_1 ,\ f > f_2 \end{cases} , \qquad (6a)$$

with

$$\begin{aligned} f_0 &= \frac{f_2 + f_1}{2} \quad \text{, the central frequency} \\ B &= \left(f_2 - f_1\right) \quad , \quad \text{the bandwidth} \end{aligned} \quad . \tag{8b}$$

For symmetric pulses around its centre, $\Psi_{X\,d}(f) = 0$ (zero-phase pulses). If pulses with the energy concentrated at its front are desired, the phase spectrum must be minimum (minimum-phase pulses). In the last case, the log-magnitude and phase spectra must be a Hilbert transform pair

$$\Psi_{X_d}(f) = \frac{-1}{\pi} \int_{-\infty}^{\infty} \frac{|X_d(\xi)|}{f - \xi} d\xi \,. \tag{9}$$

Let $m(t)$ be a MLS signal and $y_m(t)$ the pulse picked up by the microphone. Both are related by

$$m(t) \otimes y_m(t) = h(t)\,, \tag{10}$$

where $\otimes$ denotes circular correlation. Now, if the loudspeaker is driven with the signal $m(t)*x_d(t)$, where * denotes circular convolution, due to the system linearity, the signal $x_d(t)$ will invert the previously measured impulse response, $h(t)$, and as a consequence, the desired signal $y_d(t)$ will be radiated. In other words, to radiate the desired waveform, the loudspeaker must be driven with the convolution of the MLS, $m(t)$, with the inverse filter, $x_d(t)$.

3. EXPERIMENTAL SETUP

A Virtual Instrument (VI) was implemented for the in situ measurement of the absorption coefficient of noise barriers, $\alpha(f)$. The VI consist of an electroacoustic system, a NI DAQ PCI-6040E board, and a software package to process the measurements to obtain $\alpha(f)$. The electroacoustic system includes a RCF L10 loudspeaker within a wooden box of 44 litres, and a ½ " electret microphone, as well as the corresponding amplifiers. Both the loudspeaker and the microphone are kept at a fixed distance by four thin rods, Figure 1. Figure 2 shows the original impulse response and transfer function of the loudspeaker-microphone system.

Figure 3 shows the pulses radiated by the loudspeaker when their waveform is shaped to cosine-magnitude with parameters (g, f_1,f_2,p)=(0.5, 1 Hz, 6890 Hz, 0.5 %), and zero- and minimum-phase. Both shaped pulses are shorter than the original one, Figure 2a. While the zero-phase pulse is symmetrical with respect its maximum, the minimum-phase pulse has a better defined leading edge.

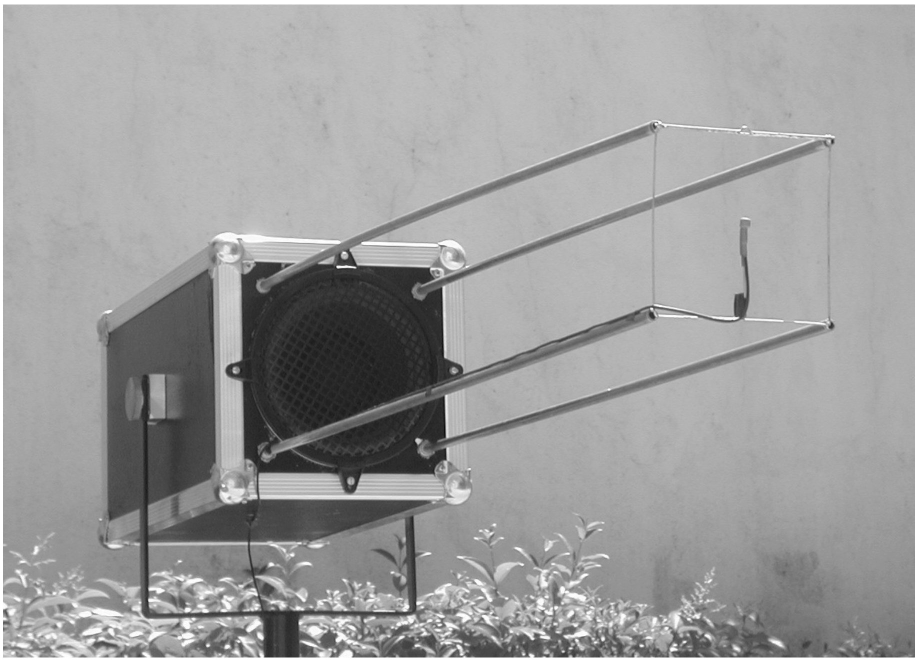

Figure 1 – The loudspeaker-microphone system

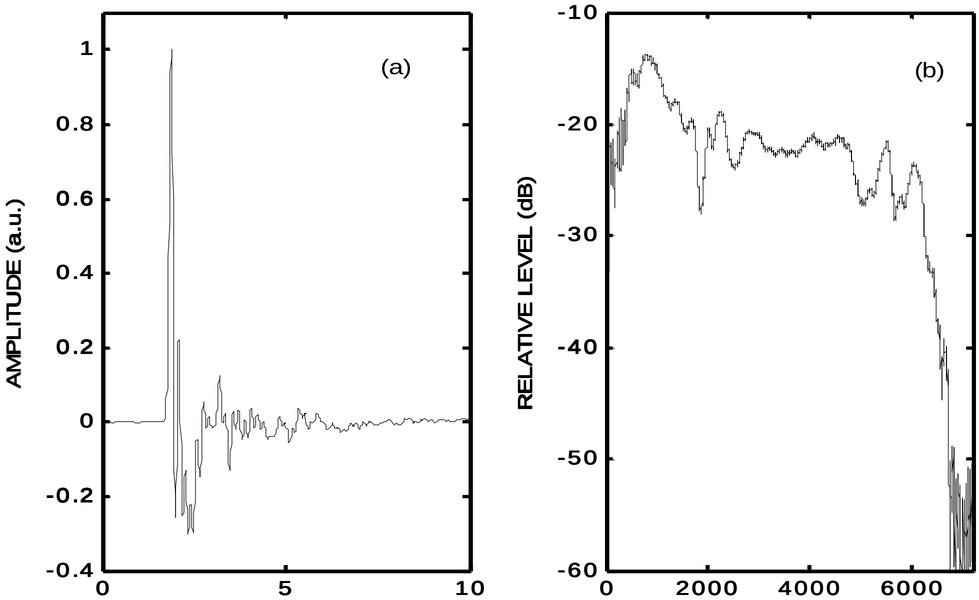

Figure 2 – The original impulse response (a) and the transfer function (b) of the loudspeaker-microphone system

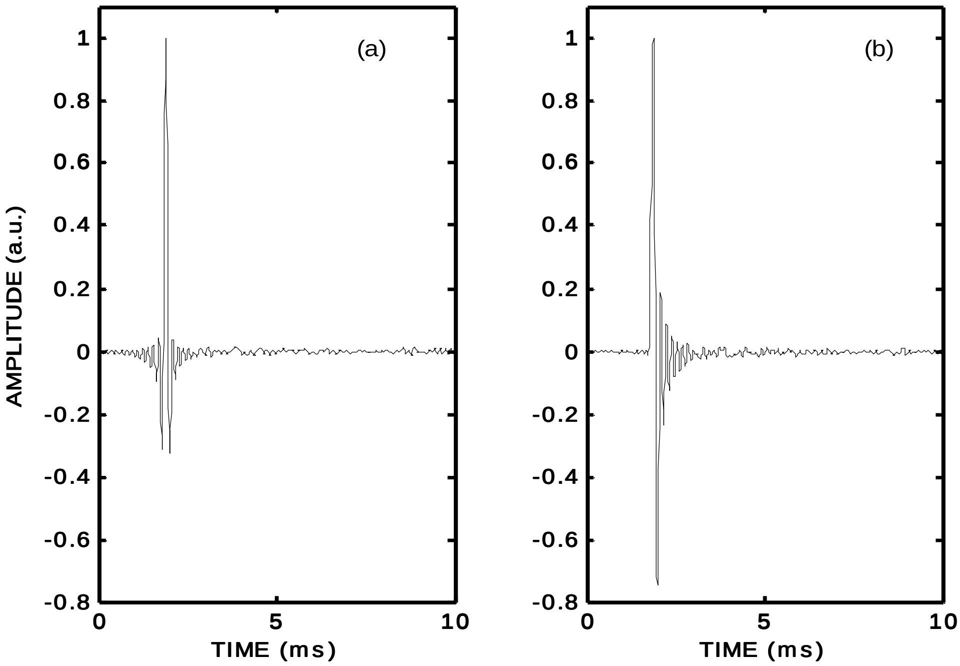

Figure 3 – Cosine-magnitude zero-pase (a) and minimum-phase (b) impulse responses of the loudspeaker-microphone system

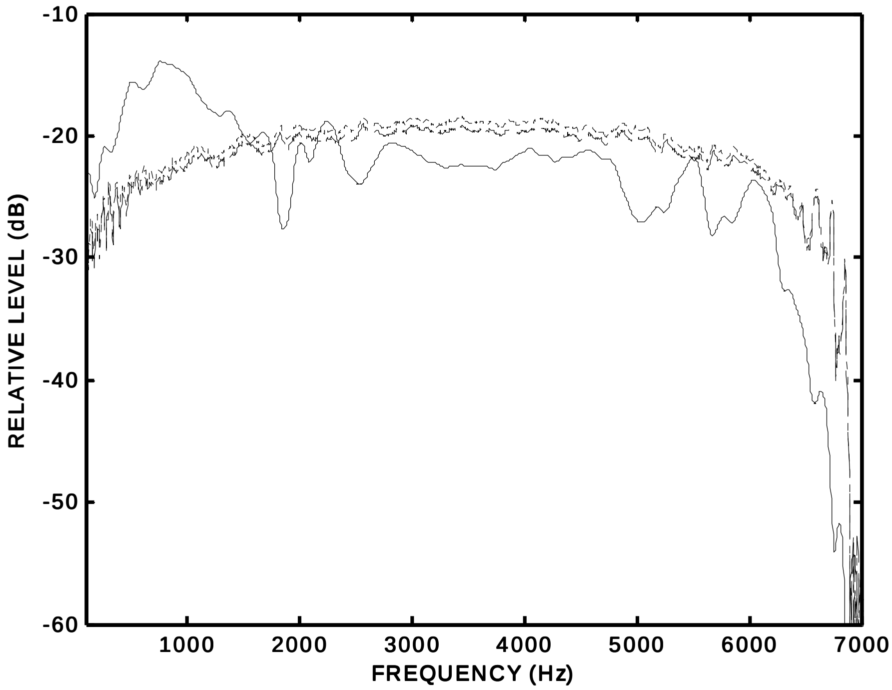

Figure 4 – Transfer functions of the loudspeaker-microphone system original (solid line), and shaped with cosine-magnitude zero-phase (dotted line) and minimum-phase (dashed line) filters

The effect of the inverse filtering is better seen in the frequency domain, Figure 4. Both filters equalize the frequency response of the loudspeaker into a cosine shape within its natural band.

4. RESULTS

The method explained above was applied to the absorption measurement of a rock wool panel of (2.4 × 2.4 × 0.05) m standing vertically at the anechoic room of the Acoustic Institute, Figure 5. In the lower part of Figure 5, a sketch of the reflected trace is drawn, showing the direct, panel reflected, edge diffracted, and loudspeaker reflected events, with travel times τ_d, τ_r, τ_b and τ_a, respectively.

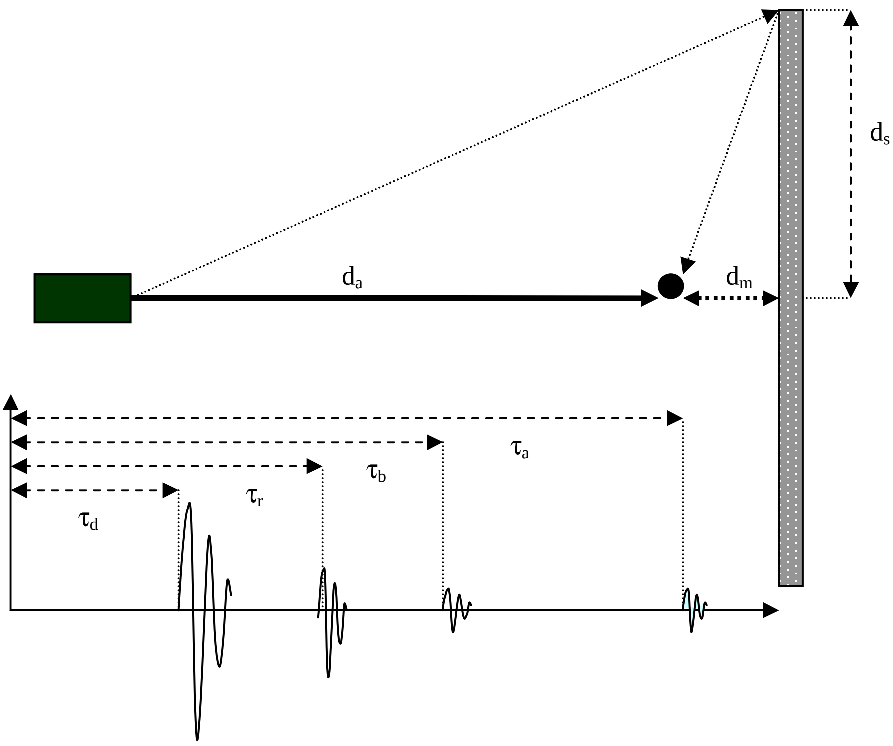

Figure 5 – Experimental setup for the absorption coefficient measurement of a rock wool panel in the anechoic room of the Acoustic Institute

For d_a=2 m, d_m=15 cm, y d_s=1.2 m, the corresponding travel times are τ_d=5.88 ms, τ_r=6.76 ms, τ_b=10.8 ms, and τ_a=18.53 ms. Therefore, the direct and reflected events should overlap unless the loudspeaker-microphone impulse response were shorter than 0.88 ms. This criterion is fulfilled for both the cosine-magnitude zero- and minimum-phase pulses, but not for the original one.
Figure 6 shows the absorption coefficient of the rock wool panel measured by the Adrienne method with parametric shaping of the loudspeaker-microphone transfer function into cosine-

magnitude and zero- and minimum phases. The direct and panel reflected events were picked up from the corresponding traces by a 5.3 ms Adrienne window, which limits the lowest reliable frequency to 212 Hz.

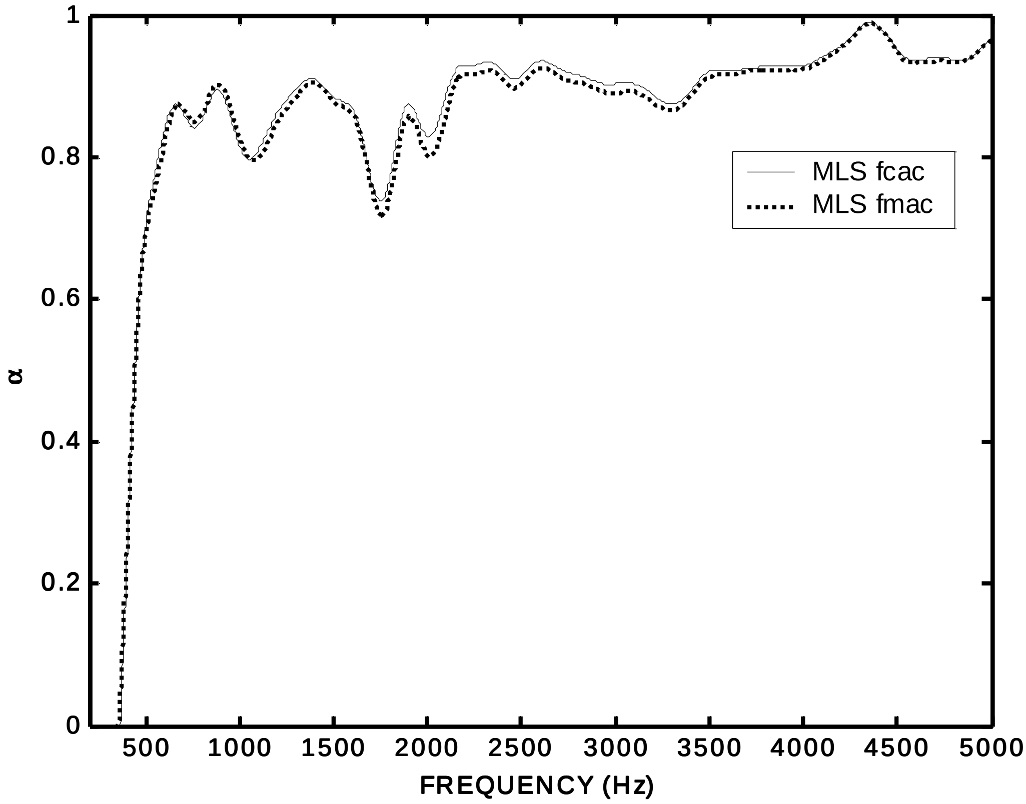

Figure 6 – Absorption coefficient of the 5 cm thick rock wool panel measured in the anechoic room with a MLS signal shaped with cosine-amplitude and zero- and minimum-phases

The measured absorption coefficient is not consistent below 350 Hz. This is likely due to diffraction in other edges of the experimental rig which were not taken into account in the calculation; for instance, the wooden frame which supports vertically the panel.

5. CONCLUSION

A new method is proposed to shorten the impulse response of the electroacoustic system used to measure the absorption coefficient of a noise barrier by the Adrienne method. The method applies inverse filtering to shape the transfer function in a prescribed way. Zero-phase cosine-magnitude shaping provides the shortest impulse response within a preset frequency band. Minimum-phase cosine-magnitude pulses, on the other hand, have a better defined leading edge. Electroacoustic systems with shorter impulse responses allow setting the microphone closer to the barrier, this in turn moving away the edge diffraction and affording a lowest reliable frequency of the method.

ACKNOWLEDGEMENT

This research has been supported by the Spanish Ministry of Science and Technology, under Grant. Nº. DPI2001-1613-C02-01.

REFERENCES

[1] Garai, M., 1993. “Measurement of the sound-absorption coefficient in situ: The reflection method using periodic pseudorandom Sequences of Maximum Length”. Applied Acoustics, 39, 119-139.
[2] Clairbois, J.P., Beaumont, J., Garai, M., and Shupp, G., 1998. “A new in-situ method for the acoustic performance of road traffic noise reducing devices”. Proceedings ICA 98, Seattle (USA), 471-472.
[3] Morgan, P.A. and Watts, G.R., 2003. “A novel approach to the acoustic characterisation of porous road surfaces”. Applied Acoustics, 64, 1171-1186.
[4] Mommertz, E., 1995. “Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique”. Applied Acoustics, 46, 251-263.
[5] Cobo, P., 1998. “Some calculations concerning the Adrienne setup and the lowest reliable frequency”. Technical Report ADR5-3, Project MAT1-CT94049, EC Measurement and Testing Programme.
[6] Cobo, P., 1995. "Application of shaping deconvolution to the generation of arbitrary acoustic pulses with conventional sonar transducers". Journal of Sound and Vibration, 188, 131-144.
[7] Mommertz, E. and Müller, S., 1995. “Measuring impulse responses with digitally pre-emphasized pseudorandom noise derived from Maximum-Length Sequences”. Applied Acoustics, 44, 195-214.
[8] Cobo, P., 1994. "Signal processing techniques to increase the vertical resolution of sea bottom echograms". In Current Topics in Acoustical Research, Council of Scientific Research, India, p.1-12.
[9] Cobo, P., Ranz, C., y Cervera, M., 2002. “Increasing the vertical resolution of conventional subbottom profilers by parametric equalization”. Geophysical Prospecting, 50, 139-150.