# Active absorption systems: Study and implementation of an adaptive control procedure.

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## Introduction

Since its appearance the active noise control has been focused mainly in overcome problems of noise using as control criterion the sound pressure minimization since this is one of the simplest approaches. But in recent years new methodologies have arisen to improve the solutions in this as well as in other acoustic areas. In a quick bibliographic review it is possible to find several of these approaches where new control criteria are used, such as energy density [1], acoustic intensity [2], impedance [3], radiated-absorbed power [4] and others [5]. The method presented in this paper combines the principles of sound intensity measurements developed by Fahy [6] and the development of an active absorber cell by Nishimura [7] to carry out a study about active absorption system and its implementation using a feedback control. The final aim of this work is to develop an efficient active absorber for low frequencies using the minimization of a sound wave propagating in a particular direction as a control criterion.

## Theory

Considering a one-dimensional waveguide and a standing wave inside, it is possible to decompose the sound field in an incident ($p_i$) and a reflected ($p_r$) part, each of them propagating in opposite directions. Making use of the well known equations from the techniques to calculate the sound intensity [6], it is possible to obtain the pressure and the particle velocity in the middle point of two closely separated microphones as

$$p(t) = \frac{p_1(t) + p_2(t)}{2} \qquad \text{[Pa]} \qquad (1)$$

and

$$u_x(t) = \frac{1}{\rho_0} \int_{-\infty}^{t} \frac{p_1(\tau) - p_2(\tau)}{d} \, d\tau \qquad \text{[m/s]} \qquad (2)$$

where ($p_1, p_2$) are the pressures coming from the microphones separated by a distance $d$ and $\rho_0$ is the air density.

In general, the incident and the reflected parts of the sound field can be expressed as

$$p_i = p_{i_0} \, e^{j(\omega t - kx)} \qquad \text{[Pa]} \qquad (3)$$

$$p_r = p_{r_0} \, e^{j(\omega t + kx)} \qquad \text{[Pa]} \qquad (4)$$

where $\omega$ is the angular frequency and $k$ is the wave number. Now the particle velocity can be calculated for each of these components as

$$u_i = \frac{j}{\omega \rho_0} \frac{dp_i}{dx} = \frac{1}{\rho_0 c} \, p_i \qquad \text{[m/s]} \qquad (5)$$

$$u_r = \frac{j}{\omega \rho_0} \frac{dp_r}{dx} = \frac{-1}{\rho_0 c} \, p_r \qquad \text{[m/s]} \qquad (6)$$

Thus, the total particle velocity $u$ at some point will be the superposition of both components as

$$u = u_i + u_r = \frac{1}{\rho_o c}(p_i - p_r) \qquad \text{[m/s]} \qquad (7)$$

Likewise, the total pressure $p$ at some point will be the superpositions of the individual pressures as

$$p = p_i + p_r \qquad \text{[Pa]} \qquad (8)$$

Now combining eq. (7) and (8), the incident and the reflected parts of the total sound field can be calculated as

$$p_i = \frac{1}{2} \, (p + \rho_0 \, c \, u) \qquad \text{[Pa]} \qquad (9)$$

$$p_r = \frac{1}{2} \, (p - \rho_0 \, c \, u) \qquad \text{[Pa]} \qquad (10)$$

By this mean it is possible to decompose the sound field in $p_i$ and $p_r$ using $p_1$ and $p_2$, first calculating (1), then using numerical integration to compute (2) and later combine those equations into (9) and (10). Equations (1) and (2) are valid provided that a matched microphone pair is used. All the procedure described above is denominated from now on as wave separation (WS).

This decomposition in two parts of the total sound field makes possible to create an automatic procedure able to minimize $p_r$ and therefore realize the active absorption.

## Implementation

The controller will consist in the mixture of a FX-NLMS adaptive algorithm [9] and the WS procedure described in the latter section. A feedback implementation was chosen since it is more advisable for real applications. A block diagram can be seen in Figure (1).

There, $\mathbf{w}$ represents the filter coefficients responsible to generate the controlling signal $y$ fed into the secondary source, $\widehat{\mathbf{c}}$ is the estimation of the secondary path, or internal model [8], and $r_0$ is the desired reflection coefficient of the controller. To obtain full absorption $r_0$ must be set to a small value, close or equal to 0.

## Results

The performance of the system was evaluated using pure tones and band-passed noise signals, and the parameter chosen to evaluate was the absorption coefficient $\alpha$. As mentioned at the beginning, it is only of our interest

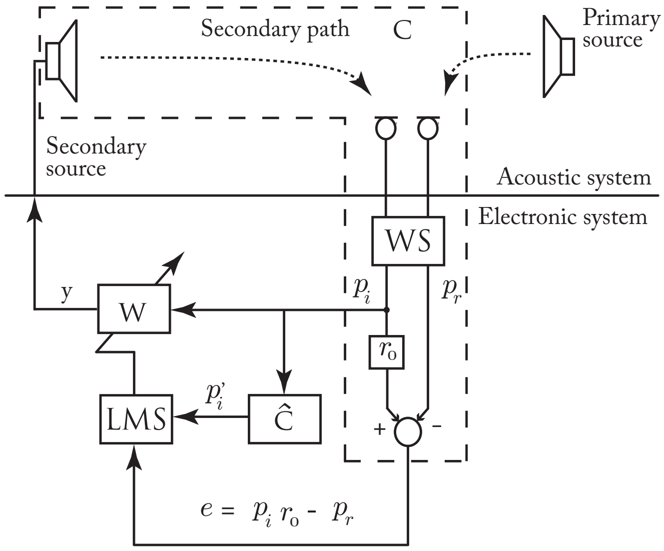



**Figure 1:** Block diagram of the feedback active absorption system.

to absorb sound at lower frequencies, therefore the excitation range was selected between 100-1000 Hz. As a first evaluation case a Kundt's tube was used and $\alpha$ was measured. Table (1) shows the values of $\alpha$ obtained using discrete pure tones as excitation signal under two conditions to compare, system turned on and off.

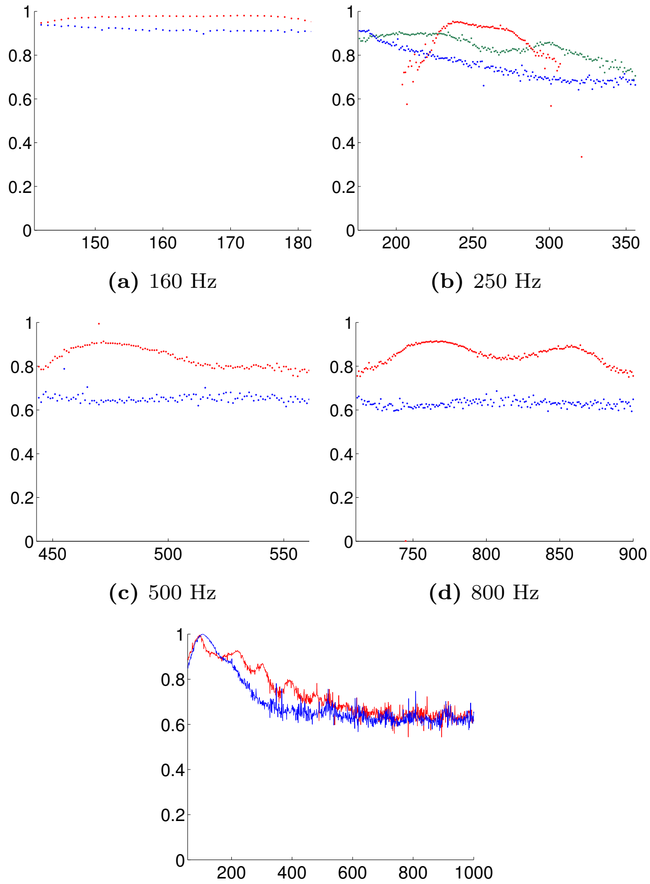
| $f$ [Hz] | Absorption coefficient $\alpha$ | |
|---|---|---|
| | System off | System on |
| 100 | 0.9990 | 0.9993 |
| 200 | 0.8665 | 0.9994 |
| 300 | 0.6867 | 0.9994 |
| 400 | 0.6626 | 0.9994 |
| 500 | 0.6430 | 0.9995 |
| 600 | 0.6285 | 0.9995 |
| 700 | 0.6039 | 0.9996 |
| 800 | 0.6347 | 0.9996 |
| 900 | 0.6104 | 0.9997 |
| 1000 | 0.6290 | 0.9997 |

**Table 1:** Absorption coefficient obtained with the active system on and off using pure tones as excitation signal inside a Kundt's tube.

The high values of $\alpha$ in the condition of the system being off, are explained due to the passive absorption of the secondary loudspeaker produced by the movement of the membrane.

Now instead of pure tones, third octave band-passed noise was fed through the primary source to observe the behavior of the controller. Figure (2) shows the absorption coefficient curves obtained, a few selected bands are plotted 160, 250, 500 and 800 Hz. An extra case is shown in Figure (2.b) where also a signal of 1/1 octave band was used to excite the system and compare the result to a wider band excitation. The last plot, i.e Figure (2.e) shows the behavior of the system using the full range of interest as excitation signal, 100-1000 Hz.

The latter presented case is useful to illustrate the general behavior of the active controller and to give the



**(a)** 160 Hz **(b)** 250 Hz **(c)** 500 Hz **(d)** 800 Hz **(e)** Wide band

**Figure 2:** Absorption coefficient curves measured using third octave band filtered noise as excitation signal except in (b) where also 1/1 octave was used. Blue: system off, Red: System on, using a third octave band filtered signal, Orange: System on, using 1/1 octave band filtered signal.

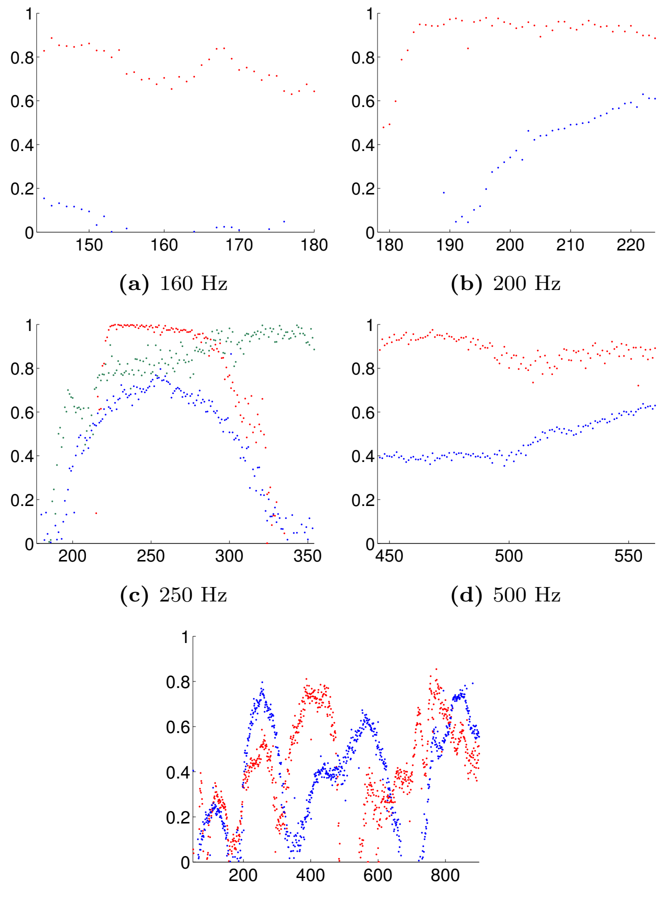
basic understandings of the mechanism of absorption but it possesses limited applicability due to its one-dimensional nature. Hence, a second case of evaluation was implemented to bring the system closer to a real working conditions. Thus, now the secondary source was mounted in the surface of a large panel and the primary source in front, and both elements inside the anechoic chamber. By this means it could be possible to visualize the performance of the system under sound propagation in three dimensions. As in the first case, the same excitation signals were used and the absorption coefficient was measured. Table (2) shows the values of $\alpha$ obtained using discrete pure tones as excitation signal under two conditions to compare, system turned on and off. Repeating also the measurements of the first case, i.e. using band-passed noise as excitation signals, absorption coefficient curves were obtained as shown in Figure (3). In all these cases, third octave filtered noise was used, and in addition, Figure (3.c) shows a curve using 1/1 octave band noise as excitation signal.

## Conclusion

The system showed a acceptable performance under pure tone excitation signals, achieving absorption coefficients

| $f$ [Hz] | Absorption coefficient $\alpha$ | |
|---|---|---|
| | System off | System on |
| 100 | 0.94952 | 0.99972 |
| 200 | 0.87513 | 0.99992 |
| 300 | 0.55602 | 0.99997 |
| 400 | 0 | 0.99998 |
| 500 | 0 | 0.99998 |
| 600 | 0.10163 | 0.99998 |
| 700 | 0.31450 | 0.99997 |
| 800 | 0.28528 | 0.99995 |
| 900 | 0.35285 | 0.99991 |
| 1000 | 0.72080 | 0.99986 |

**Table 2:** Absorption coefficient obtained with the active system on and off using pure tones as excitation signal inside the anechoic chamber.



(a) 160 Hz (b) 200 Hz

(c) 250 Hz (d) 500 Hz

(e) Wide band

**Figure 3:** Absorption coefficient curves measured using third octave band filtered noise except in (c) where also 1/1 octave was used. Blue: system off, Red: System on, using a third octave band filtered signal, Orange: System on, using 1/1 octave band filtered signal.

of almost $\alpha \approx 1$. This performance tends to reduce when a broadband excitation signal is used and as the bandwidth of the signal increases the performance reduces further. Since the derivation of the mathematical model was made considering only a one-dimensional propagation field, the extrapolation of the controller to a three-dimensional sound field did not produce a substantial effect in the absorption of the reflected sound waves. Of course, this was expected and is mainly due to the fact that only one secondary source was used. Therefore a further study becomes necessary to assess the effect of the absorption when the number of secondary sources is increased.

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