The Sixteenth International Congress on Sound and Vibration
Kraków, 5-9 July 2009

ACTIVE LOW-FREQUENCY MODAL NOISE CANCELLATION FOR ROOM ACOUSTICS: AN EXPERIMENTAL STUDY

Xavier Falourd, Hervé Lissek

Laboratoire d'Electromagnétisme et d'Acoustique, Ecole Polytechnique Fédérale de Lausanne, Station 11, CH-1015 Lausanne, Switzerland, e-mail: herve.lissek@epfl.ch

Pierre-Jean René

Acoustical Engineering and Research, rue de l'Ale, 25, CH-1003 Lausanne, Switzerland, e-mail: pjrene@a-e-r.ch

Low frequency background noise in rooms generated by numbers of human activities - traffic, railway, airport and industrial noise - creates major disturbances from loss of speech intelligibility to stress and fatigue. To overcome such situations classical solutions generally consist in deploying resonator-like absorbing materials to reduce both the acoustic level and the reverberation time. Unfortunately these traditional acoustic treatments are not efficient enough to attain A-weighted level specifications imposed by regulation laws. In the context of cancellation of low frequencies in rooms, an experiment was performed to qualify and quantify performances of a low-frequency noise cancellation active system. So as to minimize and increase performance in noise reduction, active solutions are actually studied to attain and fulfill high expectations in terms of integration with high efficiency in opposite to passive solutions. We propose an experiment based on active sources to counteract modal low frequency noise for quasi-stationary to permanent noise emission. We present some results using a step-by-step approach to understand the global behavior of the room excited in the frequency band of its first modes. Through coherent assumptions and observations we show the efficiency of low-power active system with a priori constraints affecting modal active control.

1. Introduction

The aim of this work is to analyze the global behavior a room in the frequency band of its first modes exciting by a loudspeaker to explore modal active control properties. For active control purposes, transitory sounds are particularly important; therefore the behavior of a sound field in a room excited by several parameterized sounds has to be studied in the time domain. The room response to the source activation has been modeled; this response consists of a free and a transitory state, both of which are qualified through coherent assumptions on room acoustics and loudspeakers parameters[1]. The principle of the Active Modal Control (AMC) is to decrease only first modal frequencies with a unique microphone-controller-loudspeaker system.

Engineers dealing with noise reduction in habitations close to transportation traffic or industrial facilities encounter several problems to decrease noise level in rooms at low frequencies. In the low frequency range, a room's acoustic response is driven by the modal behavior which is characterized by high levels at eigen-frequencies that can be very annoying inside rooms.

The aim of active modal control is to reduce the noise inside the rooms at these specific low frequencies by using the modal behavior itself. Several measurements have been performed near the Geneva Airport. Figure 1 illustrates the modal behavior in an office, located under the take off path of airplanes.

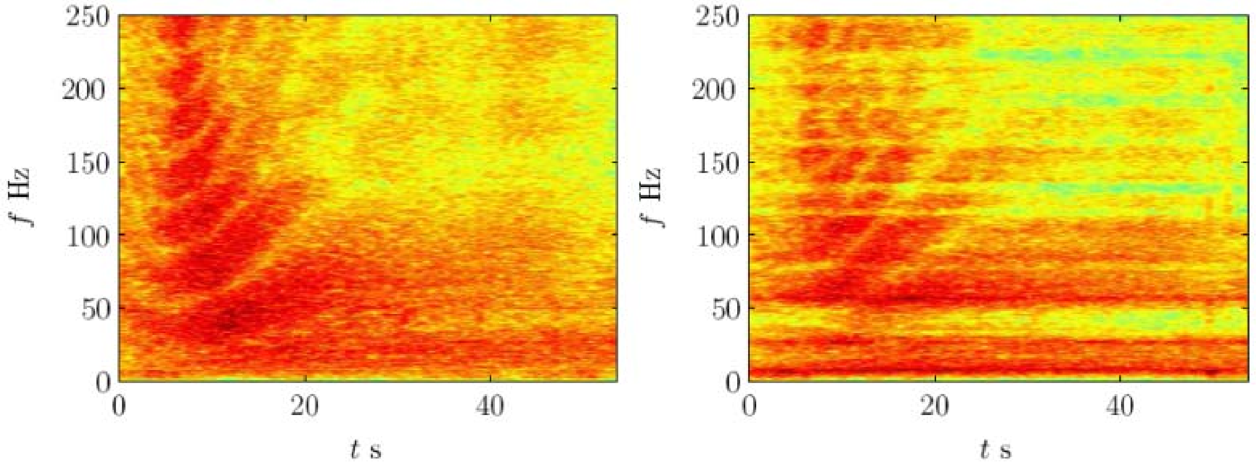

Figure 1 : Time frequency responses of the noise measured in a building during a taking off – left: outside in front of a window, right: inside the room.

When comparing the noise outside and inside the room, one can observe that the noise spectrum inside the room appears to be concentrated on modal frequencies, whereas the noise outside is strictly characteristic of the source. To reduce the annoyance in the room, the sound pressure level has to be reduced at these identified frequencies. If the modes of the room are excited with the broadband low frequency noise excitation of an air plane, it becomes obvious that the main energy concentrates on the eigen-frequencies in the room, and at the main annoying frequency, the noise level inside the room is higher than outside the building.

Passive materials and current building construction knowledge enable to avoid noise transmission in habitations at medium and high frequencies and the regulations based on the dBA scale can often be respected. Usual techniques of room acoustics and acoustic insulation reach their limits and cannot be improved due to cost and volume constraints. To reach our goal, active modal control seems one of the more effective solutions for quasi-stationary modal sound field cancellation[2].

2. Modal simulations of a reverberant room

In order to perform both computational and experimental assessment within the facilities of the Laboratory of Electromagnetics and Acoustics at EPFL (LEMA), we have chosen the reverberant chamber (figure 2) of about 200 m^3, the complex geometry of which does not allow the use of an analytical solution for the stationary waves description.

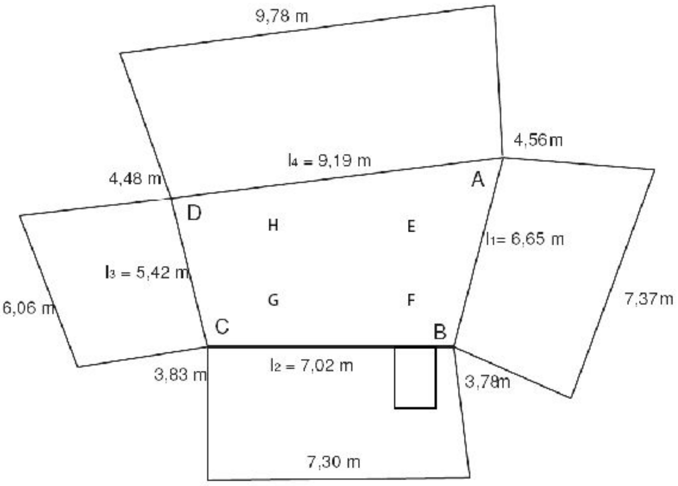

Figure 2 : Reverberant room dimensions and locations of microphones (A, B, C, D, E, F, G, H).

2.1 Numerical simulations

It has then been chosen to design a specific finite-element model of the reverberant chamber, with the help of Comsol Multiphysics® software. In order to assess the accuracy of the model, and verify the performances of the active modal control in rooms, six modes are modeled (fig. 3). Two eigen-modes are selected to verify the efficiency of Active Modal Control (26.7 Hz and 34.9 Hz).

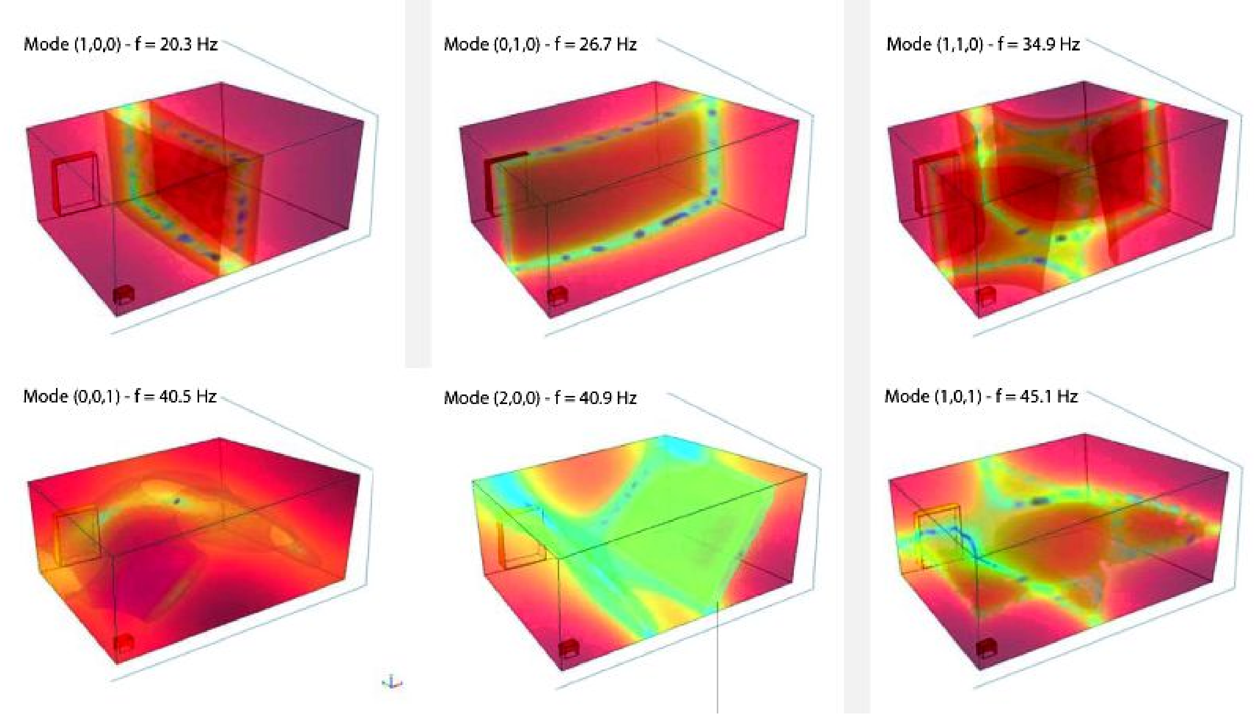

Figure 3: Spatial magnitude representation of the six first modes in the reverberant room,.

2.2 Modal Interference Principle

Following the simulations, the control is performed at specific eigen-frequencies with a primary source and a control source in two opposite corners of the room. It has been decided to use two different loudspeakers S1 and S2 located respectively at points A and B (fig. 2). It is expected to observe the modal interference diagram as presented on figure 4 to validate the feasibility of AMC.

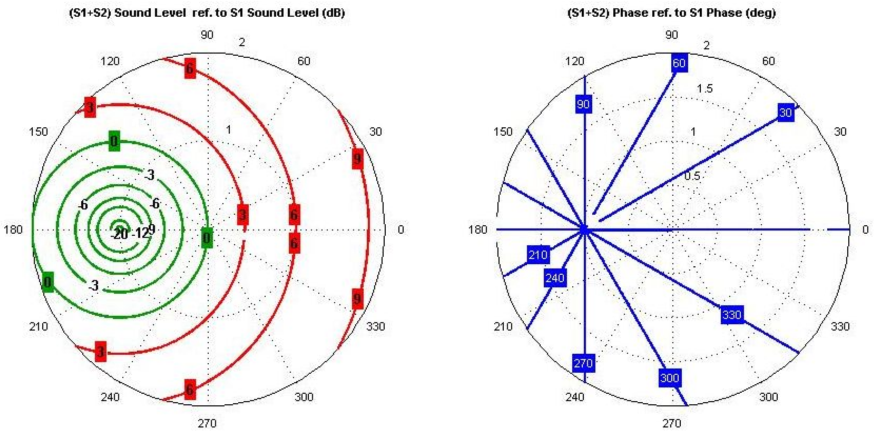

Figure 4: Polar diagrams of active control efficiency for a primary source S1 counteracted by a secondary source S2 at a given frequency f; in azimuth the phase difference and in radial axis the ratio of magnitude between S1 and S2– left: relative sound level diagram; right: relative phase diagram.

3. Modal measurements in the reverberant room

The following intends to demonstrate the performance of the AMC technique for the first eigen-modes of a room.

3.1 Experimental validation for two modes

In order to assess the accuracy of the model, and verify the performances of the active modal control in rooms, it has been decided to validate the interference model through a complete scanning of amplitude ratio and phase difference of the secondary source S2 and the primary source S1. For the purpose of the present paper, we have only focused the study on the mode (0,1,0) at 26.7 Hz and mode (1,1,0) at 34.9 Hz. Figure 5 shows the result of two measurements at location C to figure out the modal interference behavior of the room excited by two competitive loudspeakers located on points A and B.

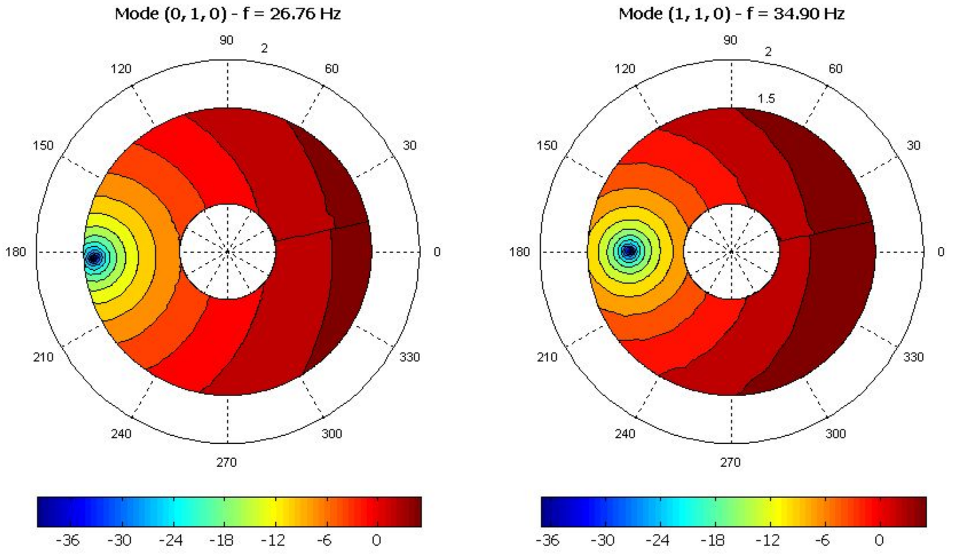

Figure 5 : Experimental polar diagrams of sound level reduction at location C for two modes – left: scan of mode (0,1,0); right: scan of mode (1,1,0). Scans are realized with amplitude ratios within [0.5-1.5] interval and for whole phase rotations between S1 and S2.

The observed differences in amplitude and phase between experiment and simulation are due to differences of the frequency response and the phase response of the two sources S1 and S2. Hence, it is remarkable that the interference model is fully matched for both modes. Abatements of ~40 dB have been reached for the two eigen-frequencies at location C.

As it is illustrated on figure 3, spatial magnitude content of each mode is fully defined by the geometry of the room. Then, giving the quality factor of a mode one is able to define the decrease time of the eigen-frequency at every location of interest.

3.2 Spatial and temporal analysis of active modal control

For this purpose, we focused the measurements on the mode (1,1,0) at 34.9 Hz because of its four quarters distribution. Four microphones are located in the corners A, B, C and D at one meter high; four microphones are located on the floor on locations E, F, G and H. Two different measurements are compared:

A. The primary source S1 is switched on. Once a stationary sound level obtained, S1 is switched off so as to measure the free regime of the reverberant room at this specific eigen-frequency.
B. The primary source is activated. Once a stationary sound level obtained the secondary source S2 is switched on so as to counteract the primary sound level imposed by S1. The sound level decreases since magnitude and phase of S2 were tuned to be optimal for minimizing sound level on microphone D.

Figure 6 and figure 7 illustrate measurements of sound levels and relative phases at 34.9 Hz. Calculations are done using Hilbert transform after a band pass filtering around the eigen-frequency. One should observe some significant differences between the free-regime and the active modal control regime. Major observations are resumed in two following parts.

3.2.1 Measurements on corners: locations A, B, C and D

Stationary Regime (sound level imposed by S1):

- Sound pressure levels (dB): $L_B = L_D = 96$ dB, $L_A = L_B - 3$ dB, $L_C = L_B + 3$ dB
- Relative Phase (degrees): $\Phi_B = \Phi_D$, $\Phi_C = \Phi_B - 180$, $\Phi_A = \Phi_B - 165$.

Free Regime (S1 switched off):

- Sound pressure levels (dB): $L_B = L_D = 96$ dB, $L_A = L_B - 3$ dB, $L_C = L_B + 3$ dB
- Relative Phase (degrees): $\Phi_B = \Phi_D$, $\Phi_A = \Phi_C = \Phi_B - 180$.

AMC Regime (S1 and S2 switched on)

- Sound levels differ from the previous free regime measurements. AMC tuned to be optimal for minimization at location D present the same decreasing curve as for the free regime. Hence it is not the case for microphones in A, B and C where sound levels decrease with some particular characteristics. On location B, the decrease is asymptotic; on contrary on locations A and C curves present some local minima before an asymptotic increase of the sound level. Regarding the relative phase curves one can observe the monotonic behavior of phase for locations B and D and the phase shift for location C and D.

3.2.2 Measurements in quarters: locations E, F, G and H

There are some similarities with the measurements in corners. On location E, sound level attain the background noise, no phase measurement is then possible. One should observe the different time where sound levels attain a local minima for microphones F, G and H.

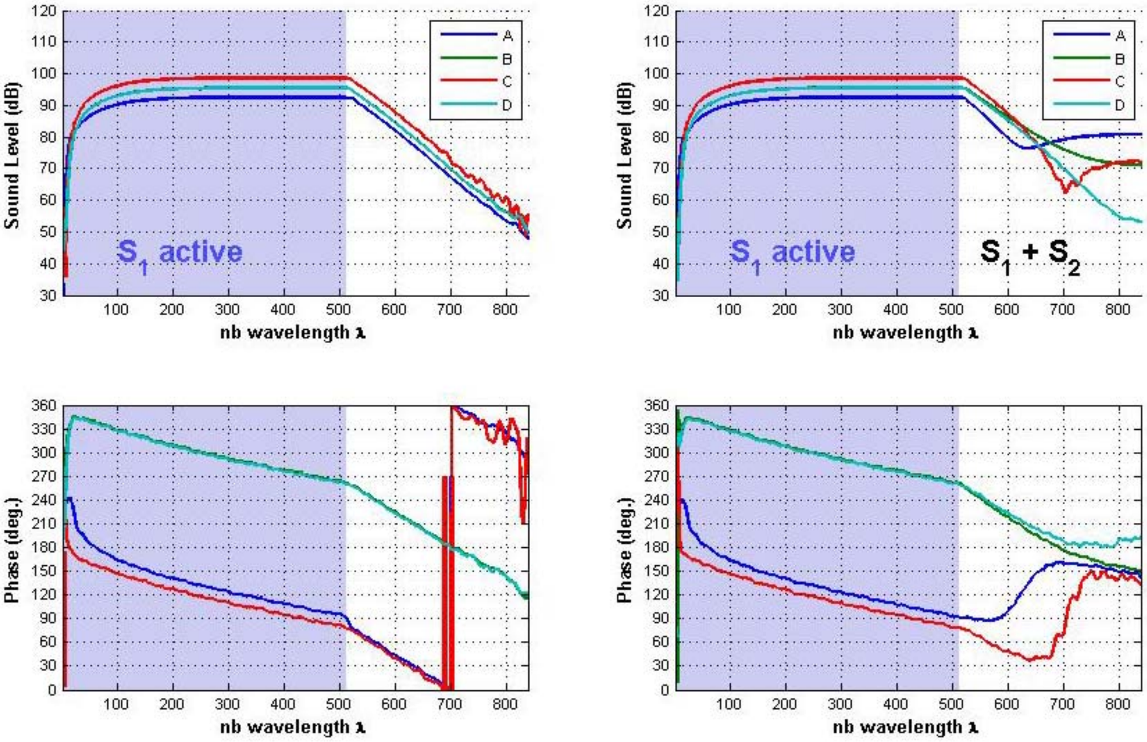

Figure 6: Direct comparison of the free regime versus the active modal control with sound levels (upper charts) and phase curves (lower charts) - in blue: period from transient to stationary of 500 wavelength at 34.9 Hz of the primary source S1; white zones : left, free regime (S1 is switched off); right, active modal control (S1 counteracted by S2).

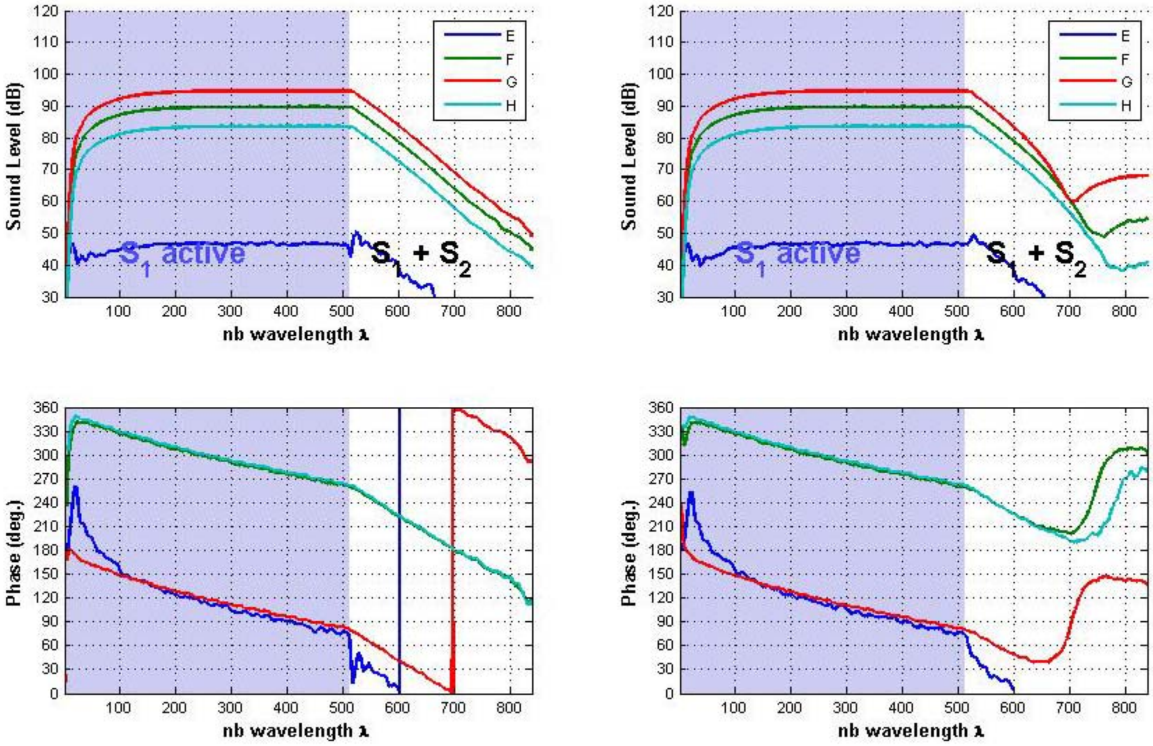

Figure 7: Direct comparison of the free regime versus the active modal control with sound levels (upper charts) and phase curves (lower charts) - in blue: period from transient to stationary of 500 wavelength at 34.9 Hz of the primary source S1; white zones : left, free regime (S1 is switched off); right, active modal control (S1 counteracted by S2).

4. Conclusions

A full description of the reverberant room state under controlled sound fields is described giving some recommendations to integrate an active system to counteract stationary to quasi-stationary sound field. Based on the analysis of sound levels, reverberation time and modal content of the sound field, some measurements illustrate the need to explore in the spatial and in the time domain the efficiency of active modal control. It is established that quality factor of each mode will have an impact on the design of an AMC controller.

Modal control is very efficient and easy to implement solution to reduce low frequency noise in rooms. The time behavior of eigen-modes can be a problem when controlling a non stationary source. Some strategies to counteract quasi-stationary to impulsive source have to be engaged.

Further experimental and numerical validations should be performed with less impedant walls, such as those of actual habitations, and with real low-frequency noise sources.

REFERENCES

[1] P.-J. René, *Contributions aux études sur le couplage électroacoustique dans les espaces clos en vue du contrôle actif*, PhD Thesis, 2006, Ecole Polytechnique Fédérale de Lausanne.

[2] F-E Aballéa, Hervé Lissek, P-J René. Assessment of different low frequency soundproofing systems for room acoustics, *Inter-Noise 2008*, Shanghai, China