Time reversal imaging of noise sources inside a reverberant room

Guillemette Ribay[1], Cedric Roux, Julien De Rosny[1], Mathias Fink[2]
[1] *Laboratoire Ondes et Acoustique, F-75005 Paris, France*
[2] *Laboratoire Ondes et Acoustique, F-75005 Paris, France, Email : mathias.fink@loa.espci.fr*

Introduction

The purpose of our work is to image audible random noise sources in a reverberation room. To this end, we apply the Time Reversal Process. Thanks to it, the multiples echoes in the cavity become advantageous. Basically, in a first step, a source emits a random noise; at the same time, the pressure amplitude $p_i(t)$ is recorded at each point i from a set of N points, called the Time Reversal Mirror. In a second step, the time reversed signals pi(θ-t) are emitted at each point i ; at the same time, the pressure amplitude is measured around the initial source. A spatial focusing of the acoustic energy is observed at the initial source position.

I Numerical simulations

A numerical code called Acel was used. Developped by Michaël Tanter, it is based on the finite elements method. We simulated a 2D reverberant cavity whose dimensions ($5*3m^2$) are close to the ones of the reverberation room used in our experiments. We chose two zones, one where the sound speed is 340m/s, and the other one, simulating the walls, with a sound speed of 1020m/s. Thus the impedance mismatch allows important wave reflections at the interface. The boundary conditions of the simulation mesh are totally absorbing.

After time-reversal of a point-like random source, the energy (i.e., time-integrated squared field) distribution is peaked around the initial source (see Fig. 1).

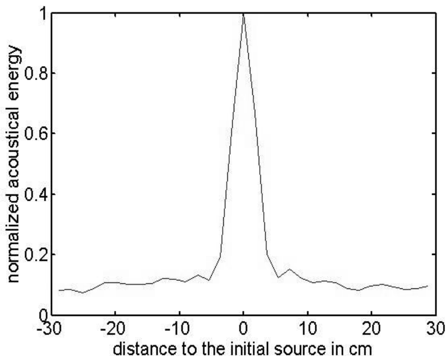

Figure 1: Normalized acoustical energy I(x) versus abscissa x

We define then a signal to noise ratio equal to the maximum of I(x) divided by the mean value of I(x) outside the focal spot. The SNR with respect to the number N of elements of the Time Reversal Mirror is plotted in Fig.2.

Moreover, we studied the focal spot width (width corresponding to the half maximum value of I(x)). On Fig. 3, we observe that the dependence of I(x) on the central wavelength of the emitted noise (knowing that the bandwidth of this noise was constant and equal to 500 Hz) is linear. The resolution limit is reached : the focal spot width is about half a wavelength.

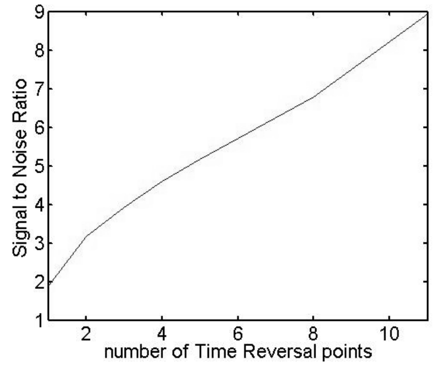

Figure 2: SNR versus the number of Time Reversal elements

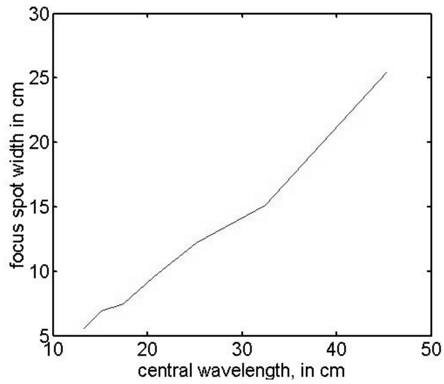

Figure 3: Focus spot width with respect to the central wavelength

Finally, we studied the influence of the central wavelength on the SNR (figure 4).

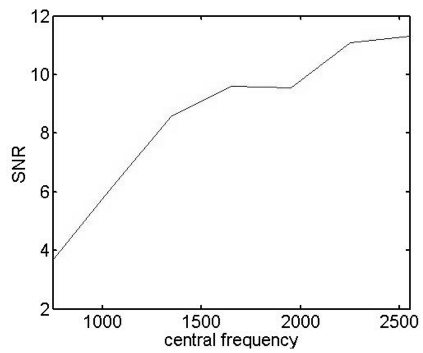

Figure 4: SNR versus the central frequency of the emitted noise

The SNR grows with respect to the central frequency because as long as the wavelength is larger than the distance between two Time Reversal elements, these elements record and re-emit correlated signals.

II Experiments in a reverberation room

We worked in a 5*3*3 m^3 reverberation room, whose reverberation time T_{60} is 3 seconds (corresponding to the room including the experimental setup). Thanks to an electronic device, whose sampling frequency is 20kHz, connected to loudspeakers, random signals are emitted with a frequency band ranging from 300 to 2000 Hz. Our device allows the pressure measurement (during the second step) along one axis. The noise emission and time reversed signals must last more than the reverberation time of the room in order to reach a stationary regime. As expected, we observed a half-wavelength focusing like in the simulations. Besides we noted a linear evolution of the SNR versus the number of couples {microphone/loudspeaker} used for Time Reversal.

In order to evaluate the resolution capacities, two sources emit the same noise (correlated sources) or two different noises (uncorrelated sources). The corresponding focusing are plotted in Fig. 5. Obviously the resolution is better when the emitted noises are uncorrelated.

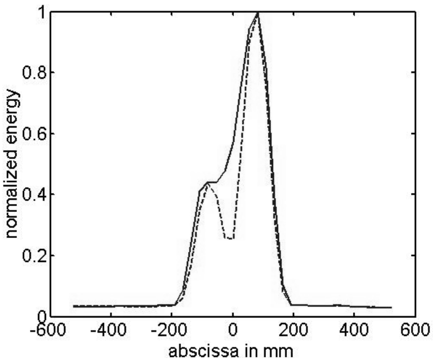

Figure 5: Normalized energy after time reversal of two random sources that are uncorrelated (dashed line) and correlated (solid line).

As obtained in the simulations, the focal spot enlarges as the wavelength increases (figure 6).

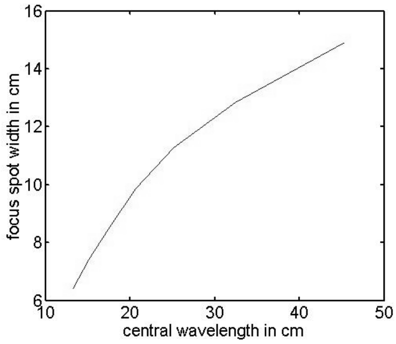

Figure 6: focal spot width versus the central wavelength

Finally, on figure 7 is presented the SNR versus the central frequency of the emitted noise: at low frequencies, the curve looks like the one observed in simulation.

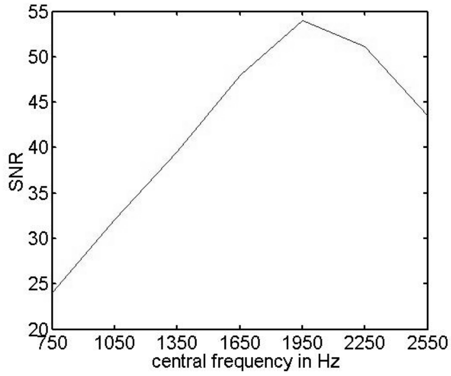

Figure 7: SNR versus the central frequency of the emitted noise.

III **Discussion**

Previous works performed on pulsed Time Reversal ([1] and [2]) and the existence of a straightforward relationship between Time Reversal of a pulse and noise lead to compute the SNR of a Time Reversed random source

SNR= N, when $\tau << \tau_H$,

SNR= $N * \frac{\tau_H}{\tau}$ when $\tau_H << \tau$

Where τ_H is the Heisenberg Time of the room, that is the inverse of the modal density, and τ is the reverberation time. In our experiments, τ is small compared with τ_H ; that is why we observe a linear dependency of the SNR with respect to N.

Conclusion

We have proved the efficiency of the Time Reversal Method to build the image of random noise sources in a reverberant room. The potential use of the Method could be for example noise imaging of engines.
One still have to develop a more sophisticated theory in order to describe more precisely our experimental results. Moreover, many experiments have to be performed to test the robustness of the method to fluctuations of room parameters (such as temperature, reverberation time, etc…)

References

[1] C. Draeger, "Ondes élastiques et réversibilité", Phd thesis, University of Paris 11 (1997)

[2] J. De Rosny, "Milieux réverbérants et réversibilité", Phd thesis, University of Paris 6 (2000)