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NOISE CONTROL IN RESONANT SOUNDFIELDS USING ACTIVE ABSORBERS

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INTRODUCTION

The resonant behaviour associated with the normal modes of an enclosed soundfield offers a mechanism by which high sound pressures can be generated. The dimensions of small built spaces and the interiors of passenger vehicles are such that the normal modes at the lower end of the audible frequency range are rather widely spaced; the modal overlap is small. These isolated acoustic modes dominate the low frequency acoustics of the spaces and can give the soundfield a boomy subjective quality. Reducing the low frequency sound pressure levels in enclosed soundfields often amounts to an attempt to suppress these low frequency modes.

The quality factor of the resonance associated with a normal mode of an enclosed soundfield is dictated by a measure of the damping experienced by air moving in that mode. Unfortunately, it is difficult to arrange for the efficient dissipation of energy from low frequency modes of an enclosed soundfield such that low frequency resonances often have high quality factors, allowing a small well-coupled source to generate high levels of acoustic potential in the enclosure.

Active techniques for controlling sound and vibration [1] offer a commercially viable strategy for the control of the low frequency modes of an enclosed sound field. It is the purpose of this paper to describe the active control of the low frequency acoustics of enclosed fields using active acoustic absorbers. These are devices which have programmable surface acoustic impedance. Although they are small and entirely self-contained, they can exert useful global control over the low frequency modes of an enclosed space.

THE ACTIVE ACOUSTIC ABSORBER

The active absorber [2] is built around a conventional low frequency electrodynamic loudspeaker, which is instrumented with an accelerometer and a pressure microphone. The accelerometer is mounted on the loudspeaker's diaphragm and the pressure microphone is positioned close to the diaphragm. The source strength of the loudspeaker, Q_s, is adjusted by a control system. The control system seeks to drive the (frequency domain) ratio of the pressure detected by the microphone to the source strength Q_s to a pre-specified value. The active absorber can be configured to perform various control tasks by specifying an appropriate surface acoustic impedance. A summary of the impedances associated with various control tasks is presented in [3].

If a space is excited by a simple primary noise source at location P of strength Q_P then the acoustic field due to both the primary noise source and a controlling "absorber" at S is described by:

$$p(x) = Q_P.Z_{P,x} + Q_S.Z_{S,x}$$

where $Z_{y,x}$ denotes the acoustic transfer impedance between y and x. The absorber will only be capable of exerting useful control over the field caused by the primary if Q_s is correlated with Q_p:

$$Q_S(\omega) = H.Q_P(\omega)$$

The feedforward controller H determines the surface impedance at the absorber:

$$\frac{p_S}{Q_S} = Z_S + H^{-1}.Z_{P,S}$$

in which Z_S is the radiation impedance of the absorber (measured when the primary source is off) [3].

It is simple to define appropriate control filters, H, and their associated impedances at the absorber for various local control actions, such as cancelling the total pressure at a point x_0 in the enclosed field. This generally requires a microphone at the control point x_0. To establish control over the extent of the enclosed soundfield, global control, generally requires that the field be more completely instrumented. Control at a number of points will generally imply a number of pressure microphones in the field.

An attraction of the active absorber described above is that it is self-contained; it is therefore of interest to consider if global control strategies can be achieved which do not require microphones remote from the absorber.

Global control of enclosed soundfields using the absorber
The controller which gives optimal control of the total low frequency acoustic potential over the enclosure, H_{opt}, is [3]:

$$H_{opt}(\omega) = \frac{-\int_V Z_{p,x} Z^*_{s,x}\, dV}{\int_V |Z_{s,x}|^2 dV}$$

such that the active absorber should offer surface impedance of :

$$\frac{P_S}{Q_S} = Z_S - \frac{\int_V |Z_{s,x}|^2\, dV}{\int_V Z_{p,x} Z^*_{s,x}\, dV}.Z_{p,s}$$

Notice that, although detailed knowledge of the fields caused by both primary and secondary sources is required to calculate the volume integrals, the optimal solutions above could be calculated off-line, with no requirement for an array of microphones in the field. Although such a system is possible, it would be somewhat impractical; two simpler approaches are considered below.

Global control in the context of a single dominant mode. When the low frequency acoustics of an enclosed field are dominated by a single mode, the optimal cancellers above can be dramatically simplified [1]. The (general) transfer impedance $Z_{y,x}$ can be expanded into a modal description:

$$Z_{y,x}(\omega) = \sum_{n=0}^{\infty} A_n \psi_n(y) \psi_n(x)$$

in which A_n and ψ_n are the frequency and spatially dependant separable factors of the n'th mode, respectively. If only the j'th mode is significant then the optimal controller H_{opt} is simply:

$$H_{opt}(\omega) = \frac{-\psi_j(p)}{\psi_j(s)}$$

and the absorber impedance which gives optimal control in this application is:

$$\frac{p_S}{Q_S} = A_j \psi^2(S) - \frac{A_j \psi^2(S)}{A_j \psi(S) \psi(P)}.A_j \psi(P) \psi(S) = 0$$

This is reiteration of a known result; suppressing a dominant mode is achieved by driving the pressure at any point to zero. This is achieved by the zero impedance at the "absorber" location.

A practical controller. A practical control strategy for suppressing the low frequency modes of enclosed soundfields has been identified. As active acoustic absorber has been found to give useful performance when the absorbing source has surface impedance equal to the negative conjugate of the radiation load it would experience in free-field [4],[5],[3]:

$$\frac{p_S}{Q_S} = -Z_S^*|_{FF}$$

In this configuration, the absorber requires no knowledge of the field in the room and can be configured (and calibrated) by measuring its own radiation load and applying gating techniques to approximate the free-field radiation load.

EXPERIMENTAL RESULTS

The global low frequency control of enclosed soundfields using self-contained systems designed to offer programmable surface impedance is illustrated below.

Controlling room modes. Figure 1 shows the pressure response at an arbitrary point in a small reverberant room. The room is excited by a constant velocity source on one wall. An active absorber was mounted on the opposite wall and configured to offer surface impedance equal to the negative conjugate of its free-field radiation load. The absorber is seen to effectively control the first two non-zero modes of the space. Its position was such that it could not couple into the third mode sufficiently well to control it.

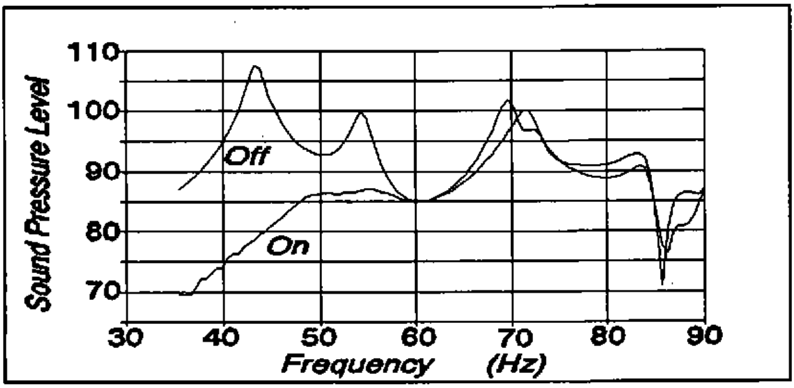

Figure 1 Pressure response at a point in a small reverberant room, with and without active absorption

Controlling modes in an aircraft cabin. Figure 2 shows attenuation in the pressure field at the rear of a medium haul aircraft caused by a single absorber. The aircraft cabin exhibited an acoustic mode at 110 Hz which could be strongly excited by the aircraft's engines during certain normal flight envelopes. The absorber is seen to offer useful attenuations over a wide area of the cabin.

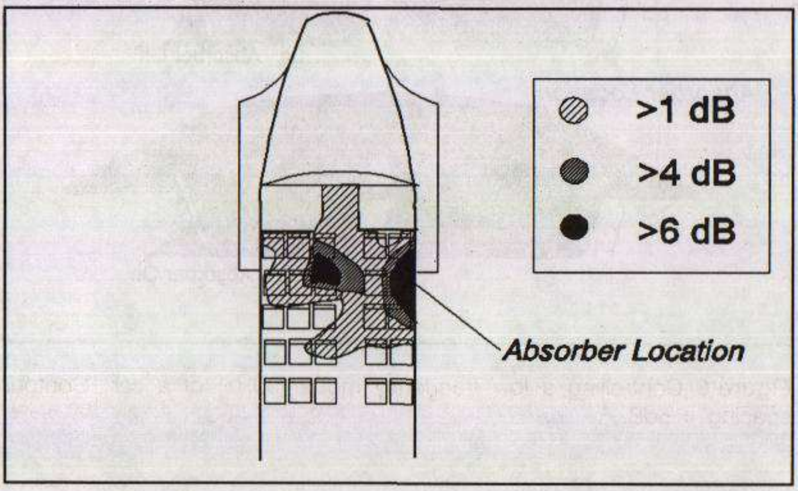

Figure 2 Attenuation of the low frequency noise in an aircraft cabin

Controlling modes in a passenger car. Figure 3a shows a mode of a medium sized car at approximately 90 Hz. A single absorbing loudspeaker, mounted in a position frequently used for low frequency sources in the in car entertainment system (and potentially integrated in that system) is able to suppress the spatial variation in the pressure associated with that mode (Figure 3b).

CONCLUSIONS

It has been shown that self contained acoustic absorbers can be configured so as to exert useful global control over the acoustics of enclosed soundfields at frequencies of low modal overlap. If detailed knowledge of the acoustics of the space and the coupling of all sources is available, the absorber can be configured to give optimal cancellation of the enclosed field. In those situation where a single mode is dominant and the residues of other modes can be ignored, the absorber can "short circuit" a mode by asserting an impedance zero at almost any point in the room. A more practical configuration for an absorber has been suggested, which was shown to offer useful performance in a variety of applications.

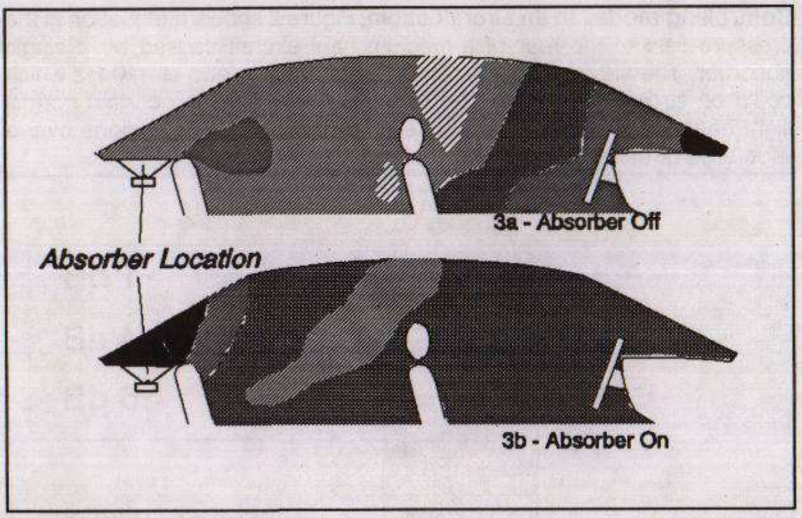

Figure 3 Controlling a low frequency mode (90Hz) of a car. Contour spacing = 5dB.

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