inter-noise 83

THE ACOUSTICAL VIRTUAL EARTH AND ITS APPLICATION TO DUCTS WITH REFLECTING TERMINATIONS

M.C.J.Trinder (1) and P.A.Nelson (2)

(1) Dept.of Electrical Engr.Science, University of Essex, Wivenhoe Park, Colchester, CO4 3SQ
(2) Sound Attenuators Ltd., Eastgates, Colchester, CO1 2TW

INTRODUCTION

The principle of the "acoustical virtual earth" suggested by Olson and May (1) for the active control of sound, involves driving the instantaneous sound pressure at a microphone to zero by means of a loudspeaker in close proximity. Wheeler & Parramore (2) have applied the technique to the control of exhaust noise and Hong, Eghtesadi & Leventhall (3) have further demonstrated its applicability to the attenuation of duct-borne sound.

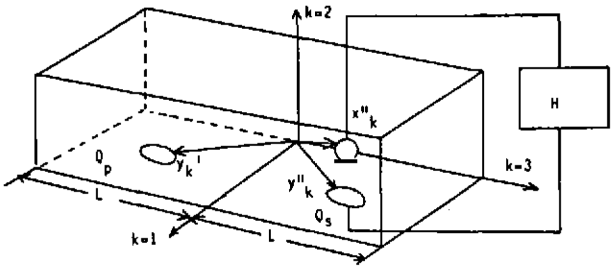
In this paper, an analysis of the technique is presented which shows the sensitivity of the system performance to microphone position and demonstrates that the cancelling loudspeaker acts as an open ended duct termination and reflects incident sound back upstream. In addition it is demonstrated that the technique is inherently effective in attenuating sound at the frequencies of longitudinal duct resonances. This makes the technique ideally suited to the active suppression of exhaust noise. Measurements of the acoustical response of a building ventilation system have also shown the presence of strong longitudinal modes and suggest that this could also be a potential area of application.

THEORY

A simple duct system with two loudspeakers is shown in Fig.1. Located at y_k' is a simple source having a volume velocity Fourier spectrum $Q_p(y_k')$ and situated at y_k'' a cancelling secondary source of strength $Q_s(y_k'')$. At a specific position x_k in the duct the acoustic pressure is the sum of the fields due to the two sources, thus

$$p(x_k) = Q_p(y_k')G(x_k|y_k') + Q_s(y_k'')G(x_k|y_k''), \qquad (1)$$

Fig.1



where $G(x_k|y_k)$ is the appropriate Green function relating pressure at a given position to a given source volume velocity. For the virtual earth system, the signal generated by microphone at x_k'' is fed back to the secondary loudspeaker via a transfer function H giving source strength

$$Q_s(y_k'')=H\,p(x_k''). \tag{2}$$

Combining (1) and (2) provides an expression for the pressure at the microphone;

$$p(x_k'')=Q_p(y_k')G(x_k''|y_k')(1/1-HG(x_k''|y_k'')). \tag{3}$$

For cancellation, the pressure at the microphone must be driven towards zero and this is achieved when the product $HG(x_k''|y_k'')$, the open loop transfer function, is large. The term $G(x_k''|y_k'')$ becomes large at the frequencies of the longitudinal resonances of the duct. Maximum reduction in level at the sensing microphone is thus produced at these frequencies.

MICROPHONE POSITION AND SYSTEM STABILITY

In order to minimise phase shift due to acoustic travel time it is necessary to position the microphone close to the secondary source loudspeaker. However, in the near field of the loudspeaker the microphone will not only sense the plane wave pressure, but also the evanescent modes. A detailed experimental and theoretical study of the loudspeaker near field in a rectangular duct has shown that the contribution from these non-propagating modes is minimised at a position near the duct axis. Also note that the feedback loop used becomes unstable above the cut-on frequency of the duct due to large phase shifts introduced by high order modes. A simple electronic filter is thus introduced in H to reduce the loop gain at higher frequencies.

SYSTEM PERFORMANCE

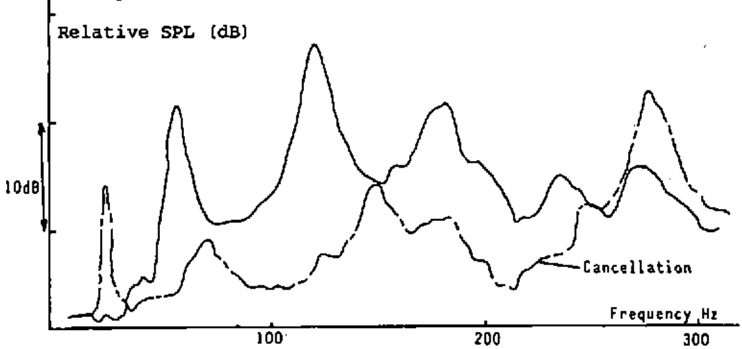
In Fig.2 the attenuation performance of an acoustical virtual earth system is shown for an open ended duct 2.5m long having a cut-on frequency of 750Hz. The results show a narrow band analysis of the SPL produced downstream of the secondary source when the primary source is excited with white noise. The system is clearly most effective at the frequencies of the longitudinal resonances of the duct. Note also that a shift in frequency of the longitudinal resonances is produced as the cancelling loudspeaker behaves as the effective duct termination. This effect can be deduced from the expression derived by Doak (4) for the Green function for a simple source in an open ended duct of length 2L. Thus, for plane waves only

$$x_3>y_3,\ G_0(x_3|y_3)=i\rho_0 c_0 \sin k(L+y_3)\sin k(L-x_3)/A\sin 2kL, \tag{4}$$

where the duct resonant frequencies are given by $\sin kL=0$. By combining (2) and (4) and setting the pressure to zero at y_3'' it can be shown that the sound pressure downstream of the secondary source also becomes zero. For the condition $y_3'<x_3<y_3''$ it can be shown that the sound field upstream of the secondary source is given by

$$G_0(x_3|y_3)=i\rho_0 c_0 \sin k(L+y_3')\sin k(y_3''-x_3)/A\sin k(L+y_3''). \tag{5}$$

Fig.2

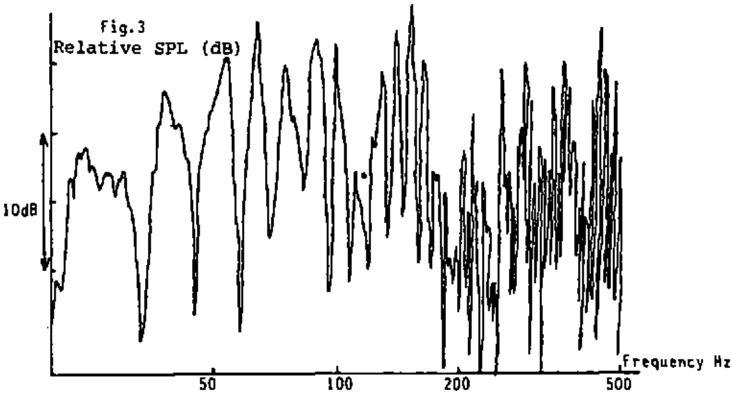


This is the sound field produced by a simple source in a duct length $L+y_3''$, demonstrating that for ideal operation of the cancelling system the effective duct length has been reduced by the distance between the secondary source and the duct end.

ACOUSTIC RESPONSE

In equation (3) it has been shown that the system performance is intrinsically dependent upon $G(x_k''|y_k'')$ and demonstrates that cancellation is maximised at the frequencies of the longitudinal resonances of the duct. The applicability of the virtual earth technique to attenuating low frequencies in a practical ventilation system is clearly influenced by the presence of these modes. Note that these may be damped by any dissipative attenuator already present in the system to attenuate middle and high frequencies. Measurements made of the acoustical response of a ventilation duct used to service a multistorey building are shown in Fig.3. It is seen that strong resonances are present in this case and the duct system may therefore respond to the application of the virtual earth technique.

Fig.3



REFERENCES

{1} H.F.Olson and E.G.May, "Electronic Sound Absorber", J.A.S.A., Vol.25, No.6, (1953).

{2} P.D.Wheeler and T.S.Parramore, "Active Silencing of a Transportable Generator Set", Proc.Inst.of Acoustics, (1981).

{3} W.K.W.Hong, Kh.Eghtesadi and H.G.Leventhall, "The Tandem Tight-coupled Active Noise Attenuator in a Duct", Acoustics Letters, Vol.6, No.2, (1982).

{4} P.E.Doak, "Excitation, Transmission and Radiation of Sound from Source Distributions in Hard-walled Ducts of Finite Length (II)", J.S.V., 31, (2) (1973).