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ACTIVE ATTENUATORS FOR NOISE

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The concept of active attenuators for noise is not new, a patent having been taken out over 40 years ago (1). Attempts to produce practical systems (2)-(5), have not yet led to commercial results. However, recent developments in electronic techniques, feedback and control theory, and the formal theoretical basis for active attenuators make the practical possibilities now look better.

The basic principle of active attenuators, as developed by Jessel and his co-workers (6) (7) is as follows. Consider a domain Ω enclosed by a surrounding surface Σ. The primary source produces a pressure P^p at point Q in the domain. According to Huygen's principle, the primary source can be replaced by a number of secondary sources situated on the surrounding surface Σ so that the pressure P^s at Q due to the secondary sources is identical with that which was produced by the primary source. If now the primary source and secondary sources are operating together, the resultant at Q is the sum of the two. If the phases of the secondary sources are reversed, the pressure at Q is reduced to zero.

It is necessary to determine the effectiveness of the cancellation at Q when the primary and secondary source radiations do not balance exactly.
Let $P^p = A \cos \omega t$ and $P^s = - B \cos (\omega t + \delta\varphi)$. Then it can be shown that the attenuation is:

$$\Delta = 10 \log \left(1 - 2 \frac{B}{A} \cos \delta\varphi + \frac{B^2}{A^2} \right) \text{ dB}$$

The attenuation depends on both the amplitude error and the phase error. If the attenuation is to be at least 15 or 20 dB an amplitude error of about 10% is permissible with a phase error of about 0.1 radians. However, if the amplitudes and phases are carefully controlled, very high attenuations are potentially available.

Several configurations of active attenuator are possible. The simplest method uses a monopole secondary source. Consider the application to attenuation in ducts. The noise from the primary source is detected by a microphone and the signal delayed to allow for the travel time from microphone to secondary source. The secondary source is then energized in antiphase to the travelling wave. Assume that, with the secondary source off, the sound level along the duct is uniform. When the monopole secondary source is switched on it radiates both upstream and downstream, producing a reduced level downstream and a standing wave upstream, towards the primary source. The secondary source is equivalent to a partially reflecting plane (or to an impedance change) in the duct. The standing wave can cause difficulties in the operation of the attenuator, especially because the level at the microphone varies with frequency and this must be compensated for in the drive to the secondary source.

The standing wave which is produced by the monopole attenuator is caused by the upstream component of its propagation. If the monopole could be replaced by a higher order source, which gives unidirectional propagation downstream, the standing wave would be eliminated. The duct level then remains constant up to the location of the secondary source and is reduced downstream of the secondary source.

There are a number of ways in which a unidirectional secondary source can be realized but the main developments are due to Jessel (6) and Swinbanks (8). Jessel uses a monopole-dipole combination to give unidirectional propagation. Swinbanks' system employs two sources. Both systems give a cardioid radiation pattern. Practical arrangements of the two types of unidirectional propagating attenuators are shown in Fig. 1. In the Jessel system, the phase shifters operate partially as time delays and also provide the requisite relative phase differences between the components of the array. In the Swinbanks system, pure time delays may be used. The long delay allows for the travel time between microphone and array, whilst the source delay gives the required time delay between the sources. The Swinbanks system has been developed by Poole and Leventhall (9), (10) at Chelsea College.

The monopole attenuator is equivalent to an impedance change in the duct and therefore causes redistribution of energy in the system without necessarily involving dissipation of energy. However, the multipole source systems result in a steady level in the duct up to the attenuator position, followed by a considerably reduced level downstream of the attenuator. This means that the downstream acoustic energy has disappeared and it must therefore have been converted to some other form within the attenuator system.

Other methods of active attenuation have been developed at Chelsea College (11) (12). The Chelsea Dipole system employs two spaced sources energized in antiphase and with the microphone situated between them. The radiation from the two secondary sources cancels at the microphone, which ideally responds only to the travelling wave in the duct. The Chelsea monopole system overcomes the difficulties caused in the conventional monopole by the upstream component of its propagation, by including this within the total feedback system and applying a simple compensating circuit. The configurations of the Chelsea Dipole and Monopole Systems are shown in Fig. 2 and typical performances of early versions in Fig. 3.

The future for active attenuators is very bright. Enough is now known to enable us to produce a working system for use in a ventilation duct, in order to control the lower frequency noise. The application of active attenuators to more difficult areas such as gas turbine installations is further away. The problems of temperature, gas velocity and the effects of the environment on the transducers have to be solved first. Important applications could also be in the control of noise from machinery and in three dimensional space. There has been some successful work on sources containing discrete components, e.g. transformer noise (13) but the general application to broadband sources presents difficulties due to the complicated nature of the sound fields. In particular the sound field at a point remote from the detection microphone does not necessarily relate directly to that at the microphone. This problem does not arise in the one dimensional duct system.

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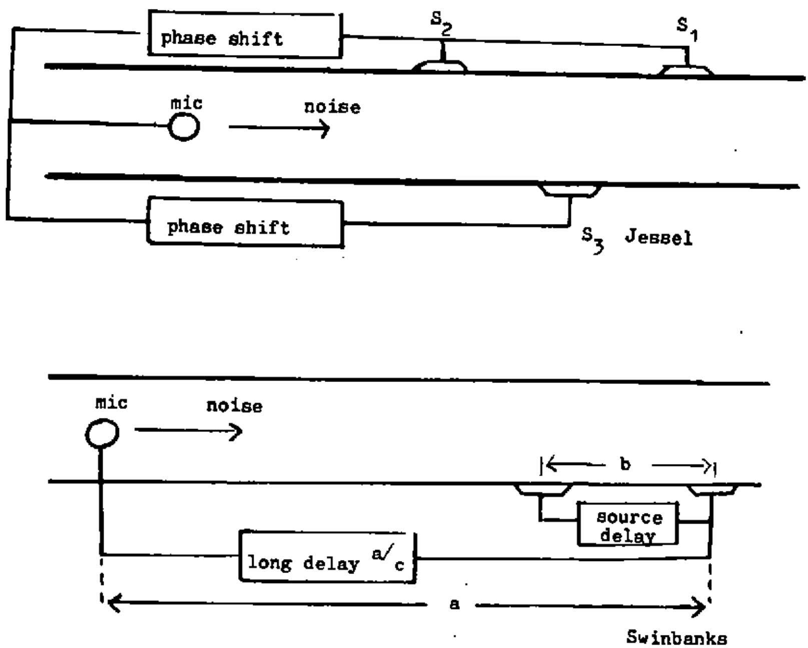

Fig. 1. Jessel and Swinbanks Attenuators

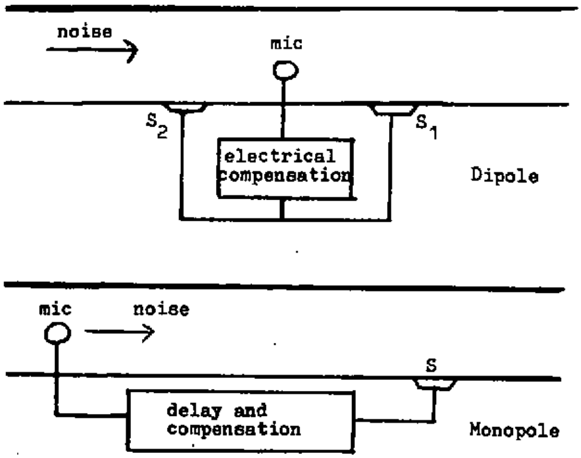

Fig. 2. Chelsea Dipole and Monopole Systems

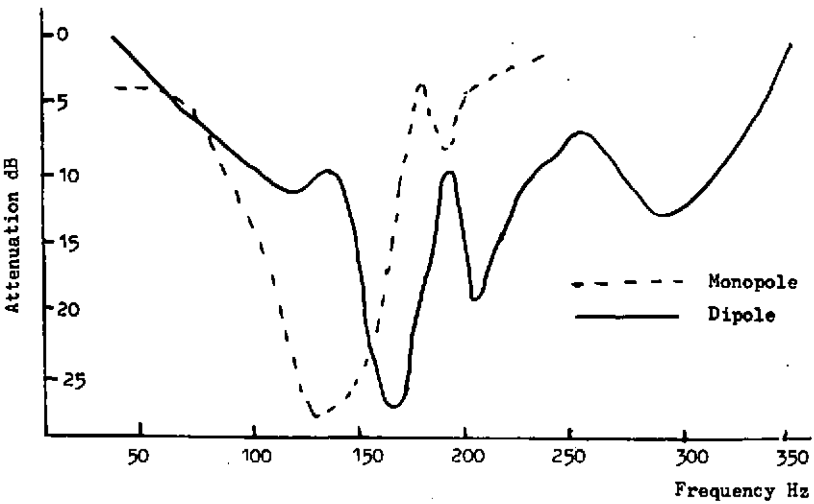

Fig. 3. Performance of Chelsea Systems