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MONOPOLE SYSTEMS FOR ACTIVE ATTENUATION OF NOISE IN DUCTS

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Monopole systems offer the simplest form of active attenuator for one dimension: especially for ducts in the plane wave region. 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 attenuation 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 causes difficulties in the operation of the attenuator, especially as the level at the microphone varies with frequency. The attenuator is based on interference, resulting in redistribution of energy without necessarily involving dissipation.

Consider the attenuator in more detail, taking into account the acoustical feedback from microphone to loudspeaker. In the conventional monopole, the electronic compensation is the simple time delay which is located between the microphone and loudspeaker (Fig 1). When the time delay is adjusted to equal the travel time of the noise from the microphone to the loudspeaker, and the loudspeaker energized in antiphase to the travelling noise wave, there is cancellation in the downstream direction, but the upstream wave adds to the noise at the microphone forming a feedback system (Fig 2).

The frequency and phase responses of this system are

$$|G(j\omega)| = \frac{1}{2\left|\sin\frac{\omega\tau}{2}\right|} \quad , \angle G(j\omega) = -\frac{\pi}{2}$$

where $\tau = 2\tau'$ and τ' is the time delay corresponding to the microphone-loudspeaker spacing $l/2$, ie $\tau' = l/2c = \lambda o/4c = 1/4fo$. In this $\lambda o = 2l$ is a wave length which is a characteristic of the system. $G(j\omega)$ is minimum when $f = fo$ and at this frequency the overall phase shift of the secondary source radiation in the downstream region is $-\pi$, cancelling the travelling wave. There is an instability at $f = 2fo$, and multiples, when $G(j\omega)$ is infinite. The microphone-loudspeaker spacing is seen to be an important factor in the operation of the attenuator, the greater the spacing the narrower the operating range. The conventional monopole has inherent limitations which prevent its adoption as a practical system.

There are several ways of overcoming the limitations. a) More complex, unidirectional sources may be used to reduce the feedback. b) Microphone isolation may be achieved by placing it centrally between the components of a dipole attenuator, as in the Chelsea Dipole. c) The feedback may be incorporated as part of the total system. d) The microphone-loudspeaker spacing may be reduced to increase the range of operation. Methods a) and b) have been discussed elsewhere (1-3). Methods c) and d) will be considered here.

c) The Chelsea Monopole. If, instead of applying a constant time delay after the microphone, we use a network with a suitable transfer function it is possible to include the acoustical feed-back path as part of the total system in order to give unit amplitude response and the phase shift which is required for cancellation over a band of frequencies. There is now no inherent limit on the band of operation. The system, which we refer to as the Chelsea Monopole, overcomes many of the difficulties of the conventional monopole, and is illustrated in Fig 3. The electrical network G_1 compensates the characteristic of the simple monopole to give the following response

$$G(j\omega) = 1 \quad , \quad \angle G(j\omega) = -\frac{\omega\tau}{2} = -\frac{kl}{2}$$

It is seen that the output of the system has a constant amplitude and a phase which is proportional to frequency, as is required for wideband active attenuation. Imperfections in the microphone and loudspeaker characteristics will, however, require further compensation, in order to reduce instabilities at higher frequencies.

d) The Tight-Coupled Monopole. As the microphone-loudspeaker spacing is decreased, Fig 2 tends to Fig 4 for zero spacing and the device is, ideally, stable at all frequencies. The physical system, which is shown in Fig 5, has been reduced to high-gain amplifier between microphone and loudspeaker. However, the frequency responses of the loudspeaker and the duct limit the gain, due to instabilities which may still occur at higher frequencies and this limits the amplifier gain. Improvement can be obtained by compensation of the loudspeaker and microphone characteristics. Fig 6 shows a typical monopole attenuator performance without loudspeaker/microphone compensation.

References

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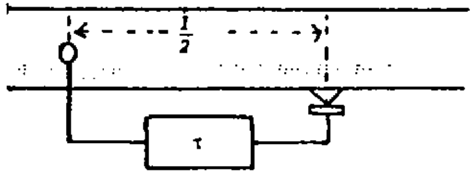

Fig 1
Conventional Monopole

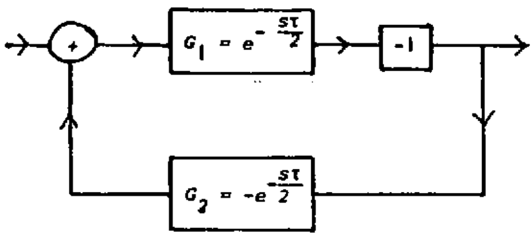

Fig 2
Conventional Monopole as a feedback system

$$G(j\omega) = \frac{1}{2|\sin\frac{\omega\tau}{2}|}, \quad \angle G(j\omega) = -\frac{\pi}{2}$$

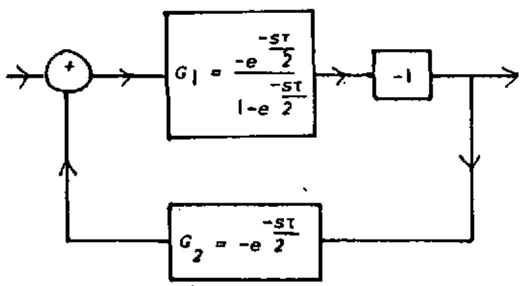

Fig 3
Chelsea Monopole as feedback system

$$|G(j\omega)| = \quad, \quad \angle G(j\omega) = -\frac{\omega\tau}{2}$$

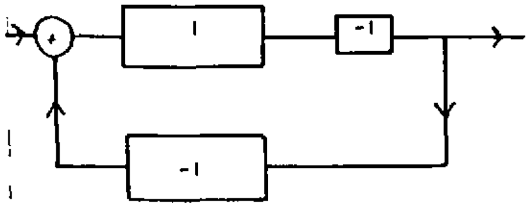

Fig 4
Tight coupled monopole as a feedback system

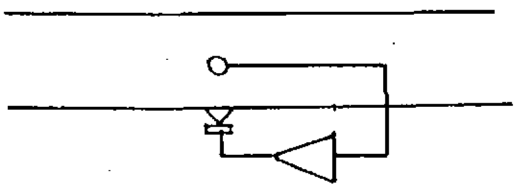

Fig 5
Tight coupled monopole

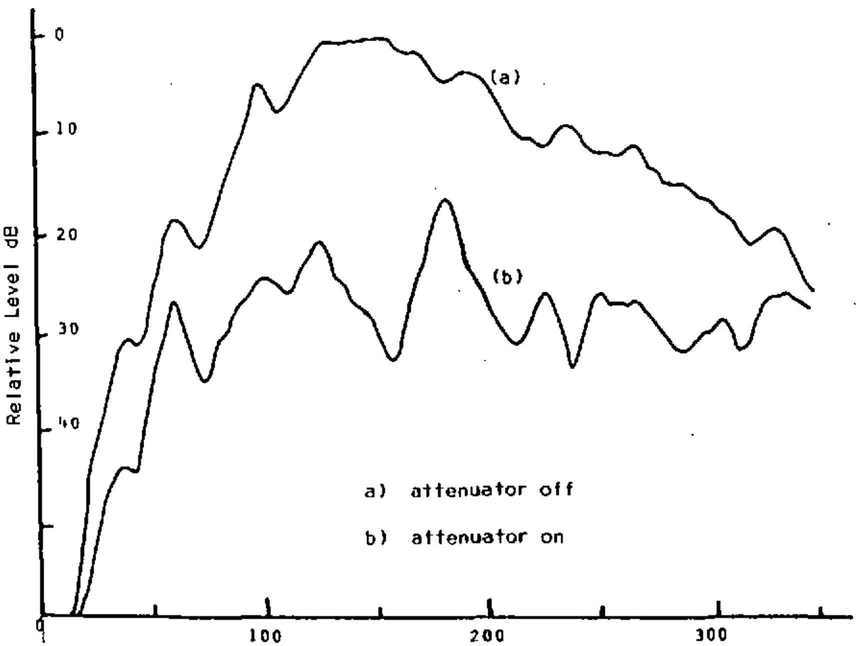

Fig 6 Attenuator performance