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ACTIVE ATTENUATORS: A HISTORICAL REVIEW AND SOME RECENT DEVELOPMENTS

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An early proposal for active attenuators is in a patent by Lueg filed in Germany in 1933 and in the USA in 1934 (1). His methods are similar to some which are current today. Proposals for obtaining phase opposition of the input wave form included the following: (a) for a single frequency by adjusting the distance between the microphone and the loudspeaker: (b) for a source in open space the phases are controlled by placing the microphone and loudspeaker at the same distance from the source: (c) for non-sinusoidal waves the noise was to be detected at the location of the loudspeaker, which was then driven in phase opposition.

These systems were not practical, largely because of problems of feedback, and there does not appear to have been further development for about twenty years when Olsen introduced his electronic sound absorber. Some of the proposals were similar to those of Lueg but Olsen was successful in developing hardware and does give laboratory results. In two papers in the mid-1950's (2, 3) he proposed localised noise reducers for occupants of vehicles, machine operators, machinery noise control, noise reducing headsets, duct noise reduction, etc.

Olsen did not publish development of his work outside the laboratory although some aspects were followed up by others:-

Transformer noise (4). Conover used a loudspeaker placed close to the transformer. Preliminary tests gave extremely promising results but field studies were disappointing. The method first filtered out the 120, 240 and 360 Hz harmonics of the 60 Hz power wave, phase shifted and amplitude controlled them appropriately before adding them into the power amplifier input. Field trials on a 15,000 kVA transformer with measurements at a distance gave attenuations of nearly 30 dB at 50 feet away to the front of the transformer, reducing to about 10 dB at 125 feet, but the results were less satisfactory at angles to the axis, there being an increase in sound level outside a beam of about 20° wide. Field tests continued to be disappointing and an attempt was made to include automatic adjustment of amplitude and phase of the auxiliary sound source, but this also failed because the feedback loop was unstable.

Noise reducing headsets (5, 6). Active ear defenders were under development in the mid 1950's and preliminary results on pure tones indicated an additional attenuation of 10 dB over 100-1200 Hz. However, the work does not seem to have progressed beyond the experimental stage.

The next major development occurred about 10 years later, in the mid-1960's, with the work of Jessel in Marseille (7). He introduced a new development to active attenuators in that his system absorbed the sound energy instead of taking it from one part of space to reappear elsewhere. In order to give absorption, it is necessary to have a complex attenuating source system which gives unidirectional radiation, unlike a monopole system which radiates uniformly. The simplest unidirectional radiator has a cardioid response pattern and Jessel obtained this with a dipole/monopole combination. Jessel and his co-workers have also made signigicant contributions to the theory of active attenuators, largely based on development of Huygen's Principle.

The effectiveness of cancellation between the primary noise P(p) and secondary noise P(s) from the attenuator system is estimated as follows, when the two noises are not in exact antiphase. Let $P(p)=A\cos\omega t$ and $P(s)=-B\cos(\omega t+\phi)$. Then it can be shown that the attenuation coefficient defined as:

$$\Delta = 10\log\left|\frac{P(p)}{P(p)+P(s)}\right|^2 \text{ is } \Delta = 10\log\left(1 - 2\frac{B}{A}\cos\phi + \frac{B^2}{A^2}\right)\text{dB}$$

The attenuation obtained depends on both the amplitude error and the phase error and 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. It is easiest to obtain the correct amplitude and phase condition at low frequencies (long wave length) and this is where active attenuators are most useful.

Basic types of active attenuators are as illustrated in Fig 1. In the conventional monopole a simple time delay arranges for the required phase opposition between the travelling waves and the cancelling input. There is feedback between the loudspeaker and the microphone and this gives problems. In the Chelsea monopole the simple time delay is replaced by a network which includes the feedback as part of the total system. In the Chelsea dipole, the microphone is placed centrally between the loudspeakers, fed in antiphase, and is therefore isolated from the radiation from the secondary sources. The Jessel tripole is arranged to give cardioid radiation so, ideally, isolating the microphone from the secondary sources. Similarly, the Swinbanks system uses time delays to produce cardioid radiation (8, 9). In its normal form the spacing is one quarter wavelength and the phase difference is 90°, corresponding with the requirements for cardioid radiation. With the exception of the Chelsea monopole, all these systems have frequency dependent characteristics, even for ideal loudspeakers. In general, the output varies as sin (kl), where $k = 2\pi/\lambda$ and l is the loudspeaker spacing. This limits the working region and brings in the need for electronic compensation of the frequency dependence if the working region is to be extended.

We feel that active attenuation of noise in ducts is in sight of solution. Ducts present the simplest problem as they are a one-dimensional system. However, active attenuation of wide band noise in open space, which is attracting increasing attention, is far more difficult. There has been some recent success in the control of transformer noise, modern variations of the work of Conover (10,11,12). The situation is eased for transformer noise because one is dealing with discrete frequencies and these present far fewer problems than does wideband noise. It is likely that the first application of active attenuation in three dimensions will be for transformer noise.

There was work in France a few years ago on the control of traffic noise passing through a window, by using active attenuation, but this was only partially successful and was discontinued (13). The system involved a number of sources outside the window fed from a microphone via various conditioning units. It was felt that the technical difficulties of transducer directivity, phase and amplitude response were too great to be overcome in the three-dimensional situation. There is continuing interest in active attenuators in the Soviet Union as shown by publications in their Acoustics journals. Much of the work is theoretical, although some results on duct systems have been published.

Considering general applications of active attenuators in noise control, early uses are likely to be for duct silencers and transformer noise. The problem of machinery noise control is a difficult one as are all active attenuator applications in three dimensions. One area in which active attenuators have been successful is in the control of repetitive noise from engines. Here one is assisted by the repetitive nature of the noise, which simplifies the problem as one has the memory of the previous cycle to assist attenuation of the present cycle. An area in which active attenuators would be useful is that of gas turbine silencing. Conventional gas turbine silencers are large and expensive and are less effective at lower frequencies, which is the region in which active attenuators are most useful. However, there are considerable difficulties to be overcome before active attenuators can be used in this way.

There is the elusive problem of active attenuation over a useful enclosed volume. This is the ultimate aim of all active attenuator enthusiasts but it is possible that solutions will be only for limited conditions, due to the difficulty of reconstituting a wave form in three dimensions.

I am convinced that active attenuators will have a role to play in noise control in the 1980's and they could be applied now to fairly simple situations. I do not think that they are ever going to become the almost magical way of producing silence which some propagandists imply and many others hope, but it is well worth keeping a realistic eye on areas in which they could be useful.

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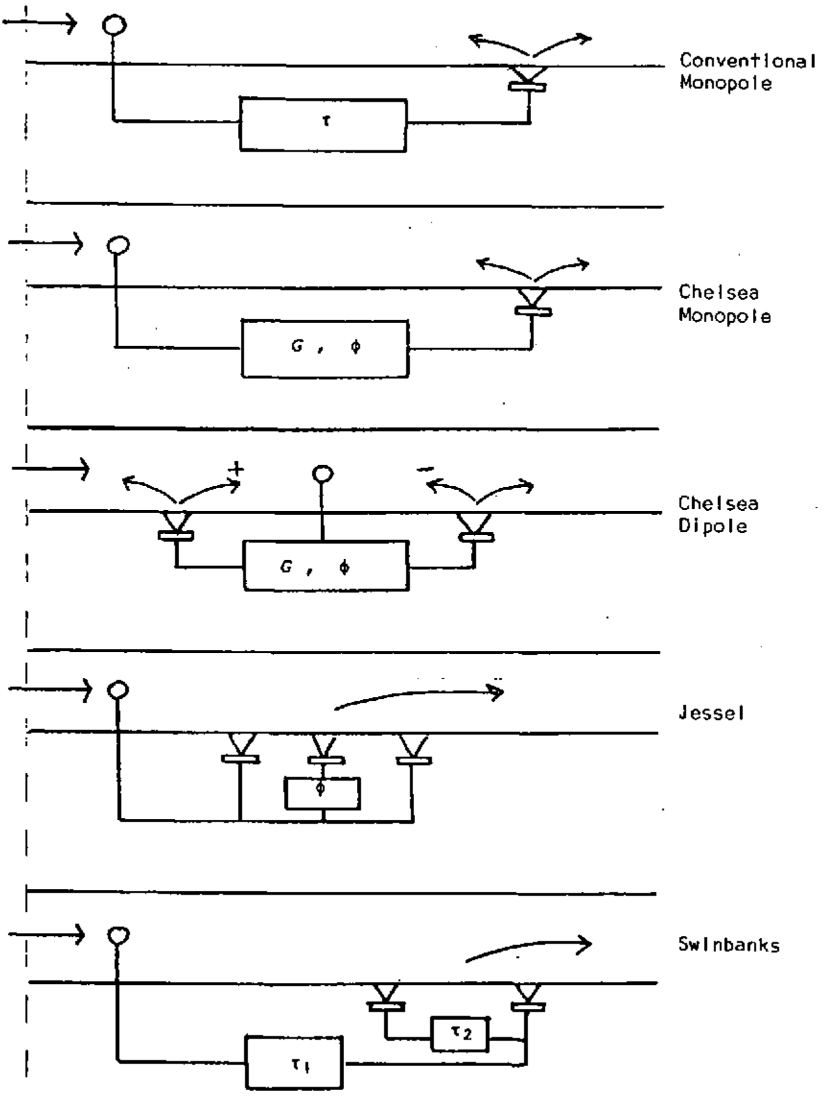

Fig 1 Active attenuators