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A LOUDSPEAKER SYSTEM WITH ACTIVE TRANSMISSION LINE LOADING

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1. INTRODUCTION

Loudspeaker enclosures, for domestic high fidelity systems, perform many important tasks. Amongst their acoustical functions, the aspects of most importance to the low frequency driver are

a) presentation of a defined acoustic backload and, in some designs,

b) coupling of back radiation from the driver to the listening space, supporting the low frequency response of the system.

Of the many low-frequency enclosure configurations possible, the "Transmission Line" system offers arguably the ideal solution to the two problems described above, aspiring to optimum acoustic backload with the potential for an excellent low frequency performance. This paper describes a modification to the "Transmission Line" cabinet, in which an active acoustic termination is added to the end of the line, improving both backloading on the primary L.F. driver and low frequency extension.

2. THE CONVENTIONAL TRANSMISSION LINE ENCLOSURE

2.1 Acoustic Backload

A direct radiating electrodynamic woofer experiences an air load on both sides of its cone under motion. The front load is dictated by the radiation impedance offered by the baffle/room whilst the backload is determined by the acoustics of the enclosure. Considering only low frequencies (< 200 Hz) this backload is usually either a compliance (in the case of an infinite baffle enclosure) or a second order sequence of compliance resistance and mass (below, at, and above resonance of a phase inverter enclosure).

Both infinite baffle and phase inverter enclosures are seen to offer reactive backloads to the low frequency driver. This is not intrinsically a problem, but the frequency dependence of the backload enormously complicates design. The alternative scenario of a frequency independent (ie. resistive) backload motivated the study of Labyrinth and, ultimately, Transmission Line enclosures [1].

In the acoustic Transmission Line enclosure the L.F. unit is backloaded by an acoustic waveguide, designed to offer an approximately anechoic impedance. In order to achieve an anechoic input impedance in a domestically compatible enclosure the line is of finite length (order 2m), and is folded. The introduction of absorbent material to this type of waveguide allows an input impedance to be achieved which is resistive down to very low frequency.

2.2 Frequency Response

In phase inverter enclosures the back radiation from the loudspeaker cone is inverted (by the phase response of a moving mass of air, or auxialiary cone, above resonance) such that the front and back radiation can be summed constructively in the listening space. This effect is used at low frequency to increase the source strength of the system and thereby support the bass response.

The transmission line loudspeaker can be constructed to exploit this principle by opening the end of the pipe to the listening space and designing the length such that a 180° phase shift occurs betwen port and primary cone velocity at a suitable frequency. Early designers [1] incorporated this technique and also understood that the effective length of their waveguide was modified by the propagation effects through the damping medium, an effect recently studied in [2].

A significant advantage of transmission line "delay" type phase inverters over conventional phase inverter cabinets is their driver to port phase response, which is approximately linear with frequency:

$$\Phi = 2\pi f \frac{d}{c}$$

where d = line length
c = speed of sound

Other phase inverters have a phase response which is frequency dependent, of form

$$\Phi = \mathrm{atn}\left[\frac{-\omega R}{K - \omega^2 m}\right]$$

where R = damping, m = mass, K = stiffness of the phase inverter

This phase response, having largest gardient $d\Phi/df$ at resonance, means that the supporting output from the port suddenly comes in phase with the main driver's output at the resonant frequency of the inverter. This accounts for the "boominess" sometimes attributed to phase inverter enclosures. The linear phase of the acoustic delay line in the ideal transmission line loudspeaker means that the contributions to forward radiation from the port is gradually introduced, permitting a smooth L.F. performance.

The ideal acoustic backloading on the main driver and potential for good bass performance has been exploited commercially, most notably by John Wright with IMF and, latterly, T.D.L. The recent appearance of new transmission line enclosures in the domestic high fidelity market suggests that an attempt to improve the performance of a transmission line loaded L.F. unit, such as described in this paper, may be of more than academic interest.

2.3 Problems with the Conventional Transmission Line

The naive description of the operation of a transmission line loaded loudspeakers given above assumes that sound propagating from the rear of the main driver

a) is not reflected from the open end of the line, and therefore,

b) is perfectly transmitted through the port, into the frontspace.

Both the backload presented to the main driver and the frequency response are compromised if the conditions above are violated.

Unfortunately, the inevitable change in acoustic impedance at the open port end of the duct does cause reflections at low frequency complicating the operation of a practical loudspeaker system. Further, the plug of air in the port moves as a lumped mass element, introducing a further phase term to the driver-port phase response, causing a departure from the simple linear phase characteristic. (This effect is usefully exploited in many systems as it enables a greater driver-port phase shift to be achieved with a shorter duct).

If the problems of reflection from the end of a finite length waveguide and ideal coupling between plane waves propagating in the pipe and radiated waves emerging from the port could be solved, the performance of a Transmission line loaded loudspeaker could be improved. Both of these problems can be addressed in parallel by an active termination, forming the port end of the duct, as is described below.

3. THE ACTIVE ACOUSTIC IMPEDANCE DEVICE

Recent advances in microelectronics and adaptive techniques in signal processing have seen the development of Active Control Techniques in acoustics and vibration [3]. Devices for the active cancellation of sound by "Anti-Noise" are well known, but other applications of active control techniques are still at early stages of development. Amongst these are systems which control the motion of a surface such that it presents a defined surface acoustic impedance to normally incident plane waves. Such a programmable acoustic impedance is under development at the Department of Applied Acoustics, University of Salford [4, 5].

A conventional low frequency driver can be instrumented with a pressure microphone and a means of measuring cone velocity* such that the surface acoustic impedance can be measured. The loudspeaker can be driven by a controlling voltage designed by a real time Digital Signal Processing computer to force the ratio of the pressure to cone velocity to some prespecified value [see Figure 1]. It is possible, for example, to require that the ratio of the pressure to the velocity should equal the characteristic impedance of the air adjacent to the cone, making the computer controlled loudspeaker act as an acoustic absorber. Such an absorber system has been constructed in the laboratory, built around a conventional 20 cm low frequency driver and is capable of operating as an ideal absorber with pressures in excess of 110 dB on its cone [5].

*Footnote accelerometers mounted on the loudspeaker cone or secondary voice coils are both used in the University of Salford system.

4. THE ACTIVELY TERMINATED TRANSMISSION LINE

If one of the active acoustic impedance devices is used at the port end of the line of an otherwise conventional transmission line loudspeaker the "Active Transmission Line" system depicted as Figure 2 results. The introduction of the controlled secondary driver is able to reduce the reflection coefficient of the "port" to values significantly below that of an open end (Figure 3 shows the reflection coefficient of an actively terminated duct with the active acoustic impedance device, built around a KEF B200, switched on and off). The low reflection coefficients possible at the port end of an actively terminated transmission line, in conjunction with the absorption offered by the damping material, allow a highly anechoic backload to be presented in the main driver unit.

As further evidence of the successful operation of the actively terminated transmission line it is possible to study the phase response between the velocity of the primary driver and the active termination. Such a phase response is presented as Figure 4 showing the phase with the computer control system on and off. When the termination is uncontrolled the mass of the secondary cone gives a large phase change in addition to that expected because of the spacing between the two drivers.

When the controller is switched on the phase difference is reduced and the phase becomes more linear with frequency. Also shown in Figure 4 is the phase change expected in a purely anechoic waveguide associated with a distance of 2.44m, the measured length of the prototype loudspeaker system. This is seen to be smaller than the phase change measured on the operating prototype loudspeaker, because the change in propagation speed associated with the absorbent material has not been accounted for [2]. If an appropriate value for the complex wavenumber associated with propagation through the long-fibre wool packing is used (giving a scaling of propagation speed of up to 1.8 times under 100 Hz [6]) then the measured data in Figure 4 is entirely consistent with expected behaviour.

5. CONCLUDING REMARKS

The performance of a transmission line loaded woofer in a domestic loudspeaker system is compromised by reflection from the end of the line. It has been demonstrated that this reflection can be minimised by installing a second computer controlled loudspeaker at the end of the waveguide, acting as an acoustic absorber. The introduction of such an active termination potentially improves the overall frequency response of the system as the port velocity and main driver velocity are related by a true "pure delay" linear phase relationship. The cost of incorporating an active absorber system in a transmission line enclosure is principally associated with the transducers; the signal processing requirement is small, particularly in the light of the increasing application of digital signal storage/ transmission and processing techniques in domestic audio systems.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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Figure 1 The Programmable Active Acoustic Impedance Device

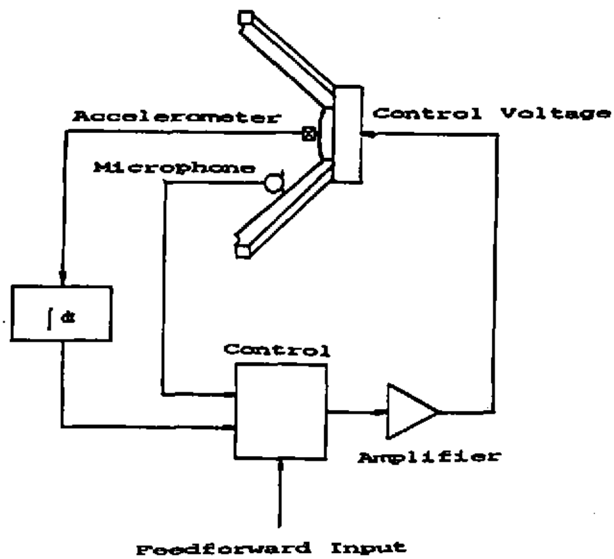

Figure 2 The Active Transmission Line Loudspeaker

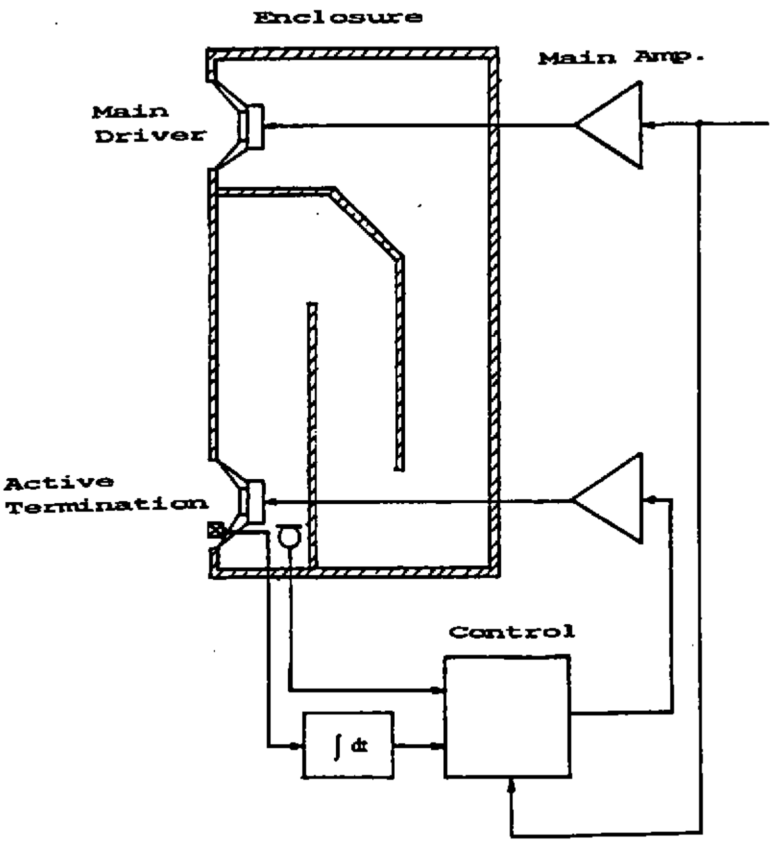

Figure 3 Reflection Coefficient of the Active Termination

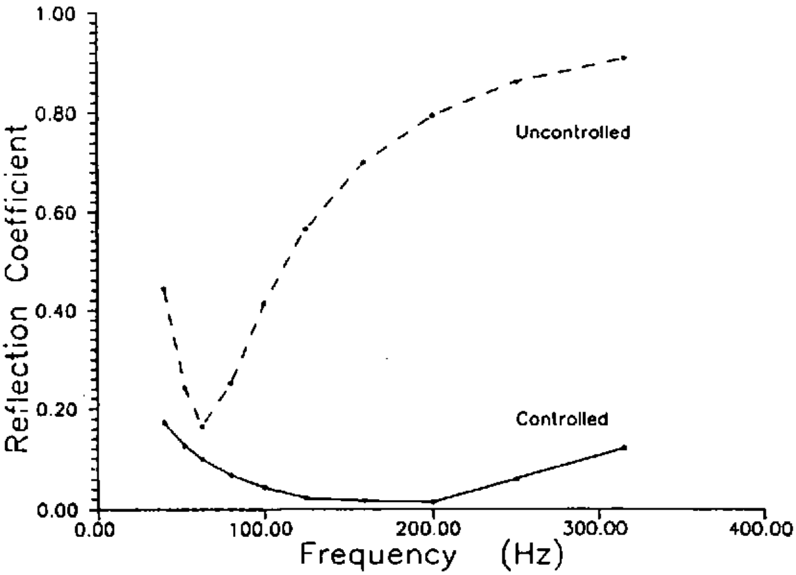

Figure 4 Main Cone Velocity to Secondary Cone Velocity Phase Response