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DISTRIBUTED MODE LOUDSPEAKERS

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1. INTRODUCTION

Conventional loudspeakers operate pistonically, with the diaphragm moving as a rigid body. They have significant deficiencies such as directivity, diaphragm resonances, multiple diaphragms to cover a broad frequency range, coherent front and rear sound radiation etc. Recently New Transducers Pty Ltd (NXT) have patented and licensed worldwide a new form of loudspeaker known as a Distributed Mode Loudspeaker (DML) to overcome many of these deficiencies. This paper will cover the history of distributed mode loudspeakers, the theory behind their operation, and a comparison of their performance relative to conventional loudspeakers.

2. CONVENTIONAL LOUDSPEAKERS

Loudspeakers are commonly of pistonic form having either a cone-shaped diaphragm or a planar diaphragm. Much of the teaching in pistonic loudspeaker theory has involved the suppression of unwanted diaphragm resonances in an attempt to create a true piston. The theory of pistonic radiation is explained in practically every text book written on the subject of acoustics. A cone is acoustically equivalent to a piston. A planar diaphragm may be driven as a rigid plate, i.e. pistonically (in a similar fashion to a cone), or as a flexible membrane driven (electrostatically or electrodynamically) in phase over its whole surface.

Olson[1] describes in detail the structure and operation of cone-type loudspeakers with circumferential corrugations introduced into commonly used felted paper cones to increase radial rigidity to control the bending properties of the diaphragm, thereby improving its performance. In the context of ribbon loudspeakers, Borwick[2] explains that the thin flat conductor (which is also the diaphragm) has transverse corrugations, which increase in bending stiffness to allow the resonant frequency to be controlled and to reduce cross-resonances.

The sound power (dB re 1pW) radiated from a vibrating piston is dependent on the area of the piston, S, the velocity of the piston, U, and the radiation impedance, R, as per equation (1) below (ρc is the characteristic impedance):

$$L_w = 10\log U^2 + 10\log S + 10\log R + 10\log(\rho c / 2.10^{-12}) \qquad (1)$$

The radiation resistance is dependent on the size of the piston relative to the wavelength of sound radiated, as shown on Figure 1.

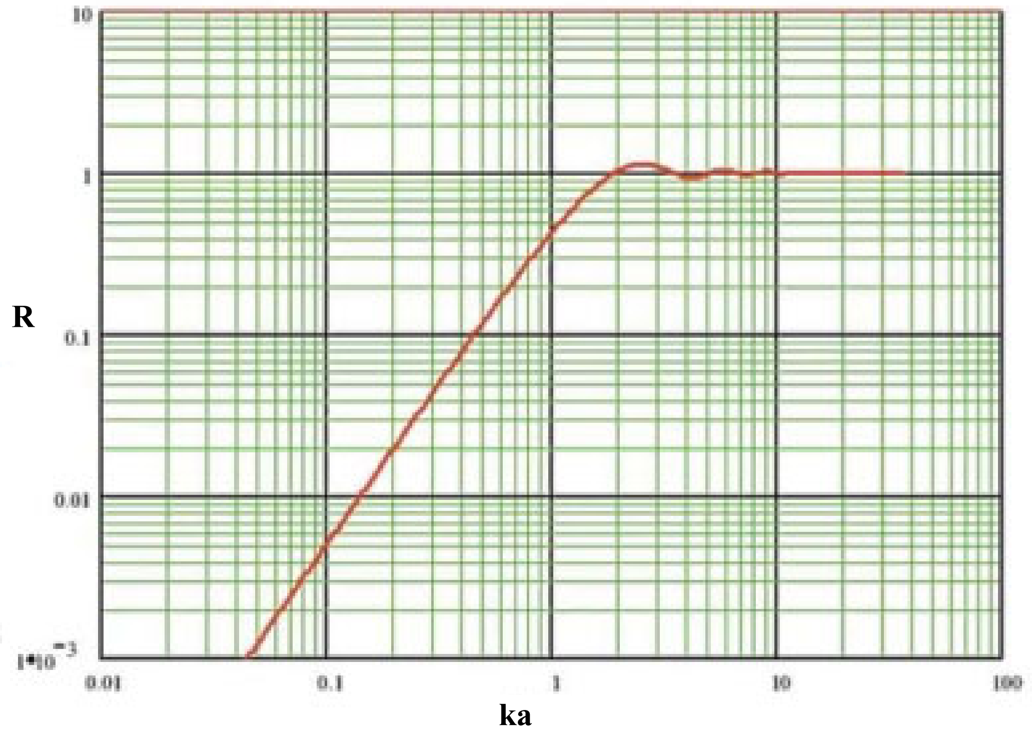

Figure 1: Radiation resistance, R (normalised to ρc) versus wavenumber, k (normalised to the piston radius, a), for a piston mounted in an infinite baffle.

The force applied to a diaphragm can be considered to be constant with frequency, hence the diaphragm undergoes constant acceleration meaning the velocity decreases by 6dB per octave with increasing frequency. However the radiation resistance increases at 6dB per octave as shown on Figure 1. Hence the sound power radiated is constant until the wavelength of sound is comparable to the diaphragm diameter, from this frequency the sound power radiated drops and becomes directional.

It is thus well known that single cones have practical limitations in providing a uniform response over a wide frequency range. For this reason ports and damping are introduced to cabinet enclosures to improve the low frequency performance, while multiple cones driven by a single or multiple voice coils have been used to improve the high frequency response. Such arrangements are discussed by Olson[1].

Whilst the force applied to a diaphragm can be considered to be constant with frequency, conventional loudspeakers are effectively a mass (being the diaphragm) on a spring (being the flexible surround fixing the diaphragm to the baffle) with therefore a resonant frequency dependent on the mass and spring stiffness. A uniform low frequency response is therefore harmed by this resonance, and while the mechanical impedance is a minimum at this frequency, the electrical impedance is a maximum (Marion and Hornyak[3]) effecting the amplifier power requirements.

3. DISTRIBUTED MODE LOUDSPEAKERS

Sound radiation from structures is a natural property. The advent of musical instruments is a good example. Any structure, including a flat-panel diaphragm, may be excited or set into motion to radiate sound either pistonically or by using *bending wave* motion. When a planar diaphragm operates in bending, its behaviour and sound radiation is different to a piston.

The sound power (dB re 1pW) radiated by bending waves in a panel is given by equation (2) below, with $<u^2>$ the average surface velocity, S, the surface area and, σ, the radiation efficiency.

$$L_w = 10\log < u^2 > + 10\log S + 10\log\sigma + 10\log(\rho c / 10^{-12}) \qquad (2)$$

The radiation efficiency is dependent on the resonant response of the panel, which depends on the following properties:

- aspect ratio;
- boundary conditions (ie. Clamped, free in translation or rotation);
- bending stiffness (and variation per axis)
- surface mass
- damping

Note that the radiation efficiency peaks at the coincidence frequency, as shown on Figure 2 below, which is the frequency at which the wavelength of bending waves in the panel coincides with an acoustic wavelength. The coincidence frequency is dependent on the bending stiffness and mass of the panel.

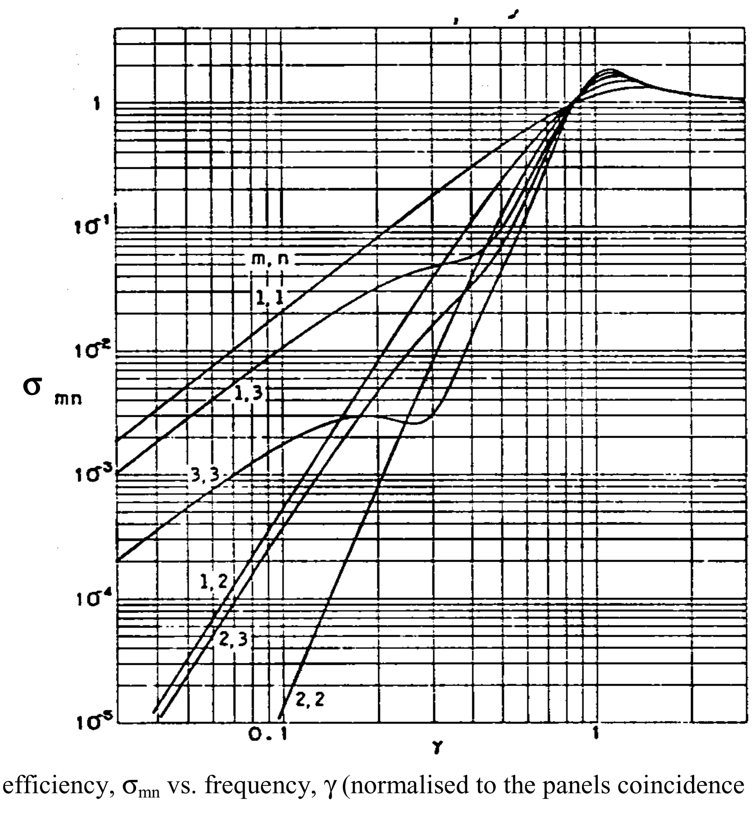

Figure 2: Radiation efficiency, σ_{mn} vs. frequency, γ (normalised to the panels coincidence frequency) per mode.

The radiation efficiency differs dependent on the order of each mode, as shown on Figure 2 above. For low modal orders, radiation is from the panel edge, with a mode of order (1,1) similar to a piston as per comparison with Figure 1, and even-even modes dipole/quadrupole in type and therefore inefficient radiators. The relative phases of resonant modes is also important, particularly for low order modes as modes can combine either constructively or destructively modifying the radiation efficiency of the combined mode. Hence the placement and type (eg. Force or moment, constrained or unconstrained) of actuator used to excite resonant modes requires careful consideration.

In contrast to conventional loudspeakers, it can be shown (Cremer et al[4]) that the driving point impedance is independent of frequency, and dependent only on the mass and stiffness of the panel.

4. HISTORY

Initial attempts to create flat panel loudspeakers focused on exciting the panel above the coincidence frequency, however this requires a light-weight and very stiff panel, which proved impractical to excite.

Britain's Defence Evaluation and Research Agency (DERA) stumbled across the technology when attempting to quieten noise within helicopter interiors. They sought a research partner with loudspeaker experience to commercialise the product. Mission loudspeakers undertook the task, which proved so successful that New Transducers Ltd[6] (NXT) was spun-off as an independent company. Rather than operate above a panels coincidence frequency, NXT attempted to provide a uniform response below coincidence. This has the advantage that sound radiation is diffuse below coincidence (above coincidence sound radiation will be optimal at particular angles at which the acoustic wavelength coincides with the bending wavelength in the panel).

Others to explore this technology include Noise Cancellation Technologies, Slab, and Sound Advance, many of whom have joined with NXT to further develop the technology.

5. PERFORMANCE COMPARISON

From the above discussion of the theory behind conventional and distributed mode loudspeakers, the performance characteristics of each are summarised below:

- Conventional loudspeakers are increasingly directional with increasing frequency. Distributed mode loud speakers are highly diffuse.

- Conventional loudspeakers require multiple drivers to span a broad frequency range and to avoid directivity effects. Subject to the size of loudspeaker, DML's may require the addition of a low frequency driver (below 250Hz).

- Conventional loudspeakers have a “cross-over” frequency (the frequency at which sound radiation is interchanged between drivers) in the frequency range at which the ear is most sensitive. (typically 2kHz). If required, the cross-over frequency for DML’s is in the range where the ear is least sensitive.

- Due to the pistonic nature of sound radiation from conventional loudspeakers, sound radiation from the front and near is highly correlated requiring enclosure. Except at very low frequencies, DML’s do not suffer from this.

- Significant effort is required to reduce any resonant response for the diaphragm or enclosure of conventional loudspeakers. DML’s enhance and control (not eliminate) resonant response and do not require enclosure.

- The reactive nature of the conventional means of supporting a diaphragm significantly effects the low frequency response and power requirements. In contrast DML’s have a purely resistive driving point impedance, that is independent of frequency.

- The frequency response of DML’s is at least as uniform as conventional loudspeakers, subject to panel selection, exciter type and location.

- The diffuse nature of sound radiation from DML’s , means:

    - There is less interaction with the room response.

    - The acoustic feedback margin is improved, by avoiding strong spectral reflections back into open microphones.

    - “hot spots” are reduced in conventional ceiling mounted public address systems.

- The high coil displacements required for low frequency sound radiation from conventional diaphragms contrast with the small displacements required of a conventional and electrodynamic actuator when used to excite resonance in a DML. That is DML’s are at least if not more linear (or have less distortion) than conventional loudspeakers.

- The sensitivity and efficiency of DML’s is comparable with conventional loudspeakers, with the stiffness and mass of the panel used in DML’s the only impediment. More power output from the DML’s is possible by simply increasing the size of the panel (which also increases the frequency range as the resonant frequencies are lowered).

6. APPLICATIONS

The low profile, cost effective nature of distributed mode loudspeakers presents many possible applications, such as (NXT Technology Review[5]):

- Hi-Fi and Home Cinema
- Public Address System
- Multimedia
- Telecommunications
- Television
- Automotive
- Aircraft
- Advertising

7. CONCLUSIONS

This paper has highlighted the theory behind DML technology that since conception has spurned a new loudspeaker market with products superior to conventional loudspeaker technology.

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