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SOUND POWER OUTPUT OF LOUDSPEAKERS IN SMALL ROOMS

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1. INTRODUCTION

Audio Engineers have been aware of the dependence of the acoustic power output of a loudspeaker system sound source on its operating environment for some time now. The studies carried out by Allison [1,2] are the best known in the audio field; his work demonstrated both by theory and measurement the influence of the three room boundaries nearest to the sound source. The theoretical studies were mainly based on the earlier work of Waterhouse [3], who again only considered the three mutually perpendicular room boundaries nearest the source. In a more recent paper by Ballagh [4], this approximation is continued in a study of optimisation of the distance of the source from each of the three boundaries.

In this paper the author is chiefly concerned to point out the importance of considering all six room boundaries, i.e., the need to include the effect of the acoustics of the room enclosure. This requirement is nothing new to Acousticians, but Audio Engineers seem to be much less aware of the influence of room modes on the power output of the loudspeaker source.

2. INFLUENCE OF THE ROOM ENCLOSURE

The influence of room modes on the air load experienced by a vibrating diaphragm was noted as early as 1917 by Sabine [5]. He found that the amplitude of vibration of the diaphragm placed at a node of a standing wave was reduced when the position of the node was shifted by introducing damping into the room. When the diaphragm was forced to vibrate with the same amplitude as at first, he noted that the sound became "eight times louder".

The moving-coil direct-radiator loudspeaker drive units in common use today are different from the type used by Sabine in that they have a mechanical impedance which is generally very much greater than the air load. If we carried out Sabine's experiment with a modern loudspeaker we would observe very little change in vibration amplitude of the diaphragm, but of course we would observe a similar increase in sound level without the need to change the drive level. The virtual independence of the vibration amplitude on the air load reflects the very poor efficiency of modern loudspeaker systems, this being generally less than 1%. Fortunately this enables us to relate the acoustic power W radiated into the far field, given by [6]

$$W = R_r V^2 , \qquad (1)$$

directly to the resistive part R_r of the mechanical radiation load presented to the front (exposed) surface of the diaphragm because the rms value of the diaphragm velocity V is virtually independent of R_r.

Most of the well known texts on acoustics present some analysis of the radiat-

-ion resistance of a source placed within an enclosure, but graphical examples of the solution as a function of frequency are not given (to the author's limited knowledge). However, an example of this type was presented by Salava[7] for a rigid circular piston mounted in the wall of a rectangular room. Salava chose typical dimensions of a small listening room, and included the effect of boundary absorbtion equivalent to a reverberation time of 0.5 s. His calculations of the radiation resistance of the piston show narrow-band peaks centred on the frequencies of room resonance, where typically the power output increases by about 10 dB above the value for free-space loading of the piston.

3. MEASUREMENT OF POWER OUTPUT

The measurement of the acoustic power output of a loudspeaker sound source presents many technical difficulties, and such measurements are rarely carried out by loudspeaker engineers. Rough measurements are often taken by measuring the sound-pressure/frequency response at some points in the room using pink-noise excitation and third-octave frequency analysis. While this method is capable of demonstrating the influence of the near boundaries, as in the studies of Allison, the random nature of the excitation and the wide-band analysis prevent the influence of room modes on the power output being clearly seen.

In recent years the measurement of sound intensity using spaced pairs of matched microphones has proved to be a successful approach to the measurement of the sound power of noise sources, and the present author has developed his own measurement method based on similar lines, but particularly suited to loudspeaker systems. The technique, which was fully described in an earlier paper [8], makes use of two sensors attached to the central part of the loudspeaker diaphragm which measure the velocity of the diaphragm and the sound pressure on its surface.

For frequencies where the wavelength of sound in air is greater than the circumference of the driver diaphragm (i.e., for $ka < 1$ where $k = 2\pi f/c$, f is the frequency and c is the velocity of sound in air) the radiation load presented to the diaphragm is predominantly reactive, being due principally to the air mass in the immediate vicinity of the diaphragm. If the reactance of the mechanical radiation load is denoted by X_r, then the magnitude of the radiation impedance $|Z_r|$ is given by $(R_r^2 + X_r^2)^{\frac{1}{2}}$, and the phase angle ϕ of the radiation impedance is given by $\cos\phi = R_r/|Z_r|$. For low frequencies, where $ka < 1$ and the driver diaphragm vibrates uniformly, the pressure and velocity distributions on the diaphragm surface are essentially uniform [6], and thus via elimination of R_r in Equation 1 one can write

$$W = PV.\cos\phi.\pi a^2 , \qquad (2)$$

where P is the rms value of the sound pressure on the diaphragm surface. Sinusoidal motion of the diaphragm under steady-state conditions has been assumed here. Equation 2 can be compared to the power in an electrical load, $EI\cos\phi$, where $\cos\phi$ is described as the power factor.

Electronic processing of the signals from the velocity and pressure sensors to implement Equation 2 is relatively simple for steady-state sinusoidal signals, although the computation of $\cos\phi$ must be done with care because ϕ is often quite near to 90° . Of the three variable terms in Equation 2, cos ϕ is by far the most dependent on the environment, being proportional to R_r . Figure 1 shows two examples of the power factor variation as a function of freq-uency determined from the sensor signals of the author's experimental system. In one case the loudspeaker system was placed in an anechoic chamber, while in the other case it was placed about 0.5 m out from the corner of a normal room. Increases in the power output of about 10 dB are indicated at frequencies of room resonance in accordance with the findings of Salava. The wide trough around 150 Hz is due to the destructive reflections from the near boundaries, as would be predicted by Allison's studies.

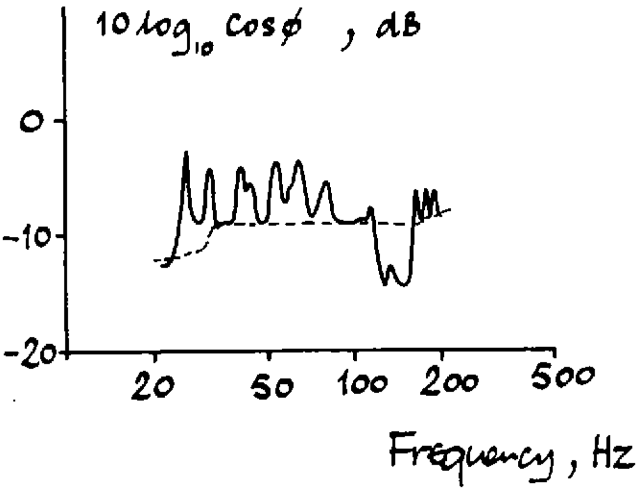

Figure 1 The power factor, expressed in dB, versus frequency of the radiation impedance load presented to the diaphragm of a moving-coil loudspeaker drive unit measured by means of velocity and pressure sensors fixed to the diaphragm. The broken curve is for the loudspeaker placed in an anechoic chamber, while the solid curve is for normal room loading.

4. TIME DEPENDENCE OF POWER OUTPUT

Under steady-state sinusoidal conditions the influence of room modes on the power output of the source is clearly of considerable importance, giving rise to variations at least as great as (but in addition to) those predicted by the simple near-boundary analysis. However, the room modes take some time to build up after the excitation is applied, and so we can expect the radiation resist-ance to be time dependent during this build-up period. When the excitation is first applied there will be a period when only reflections from the near boundaries fall back onto the source. During this period the studies of Waterhouse and Allison, etc., on the influence of the near boundaries should apply correctly. These simplified studies can thus be regarded as applying to the "early sound wave" comprising the direct sound wave from the source and the first reflections from the near boundaries.

When reflections from the distant boundaries reach the source the radiation resistance presented to the diaphragm will begin to increase at the frequencies of room resonance that are being excited by the source, but will also decrease at intermediate frequencies because here the reflections on average arrive out of phase with the source. If for argument's sake the power-output/frequency response during the propogation of the early sound wave is uniform, then as time goes on this uniform response is transformed into a highly irregular response with strong peaks at some of the frequencies of room resonance.

5. CONCLUSIONS

By using a novel measurement technique, the author has been able to demonstrate the important influence of room resonance on the power output of a loudspeaker sound source. For a proper theoretical analysis it is thus clearly necessary to consider the reflections from all six room boundaries, rather than only those from the three mutually perpendicular boundaries nearest the source. However, the simplified three-boundary analysis can still be usefully applied to the "early sound wave" comprising the direct wave from the source and the first reflections from the near boundaries.

6. REFERENCES

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