HORN LOADING REVISITED

by R.M. Harris, B.Sc.

Horn loudspeakers provide good low-frequency performance and high efficiency, but are impractical for many uses because they are very large. However, R.M. Harris describes a design that is suitable for use in an ordinary living room.

The weakest link in any hi-fi system is undoubtedly the acoustical transducer or loudspeaker. Sound recording technology is reaching new levels of precision and noise reduction with digital recording and compact discs. Amplifiers can be perfected to almost any degree, if the price is right, with hitherto unheard of purity in terms of harmonic distortion and intermodulation products. In other words, it is possible to reproduce sound faithfully from DC to RF, but only in terms of **electrical signals**. For, while electronic technology has passed from thermionic valves through discrete transistors to integrated circuits, the loudspeaker has hardly changed in its essentials since its invention in 1925*.

Since middle- and high-frequency propagation is characterized by small-amplitude sound waves, which eases most engineering problems, this article is confined to the problem of obtaining good, clean low-frequency sound reproduction.

Two physical principles account for most of the engineering difficulties at low frequencies. The first is that for a plane propagating sound wave the pressure, p, and particle velocity, u, are related in terms of the specific acoustic impedance of the medium (air):

$$p/u = Z_o \qquad [1]$$

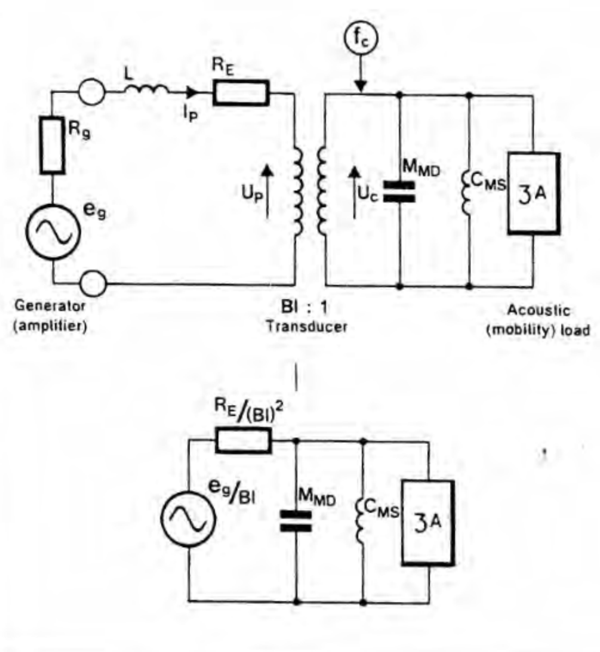
where

$$Z_o = \rho_o c \qquad [2]$$

in which ρ_o is the density of the medium and c is the velocity of sound in the medium.

At a point in space, the instantaneous particle displacement, y, of a sinusoidal sound wave of amplitude a and frequency f Hz, is given by

1



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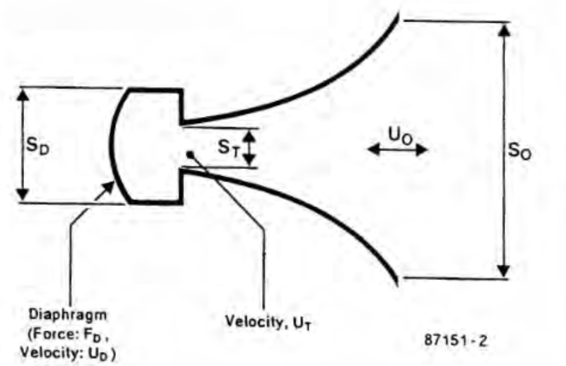

$$y = a \sin 2\pi f t \qquad [3]$$

and the instantaneous velocity is

$$u_t = dy/dt = 2\pi a f \cos 2\pi f t \qquad [4]$$

and the maximum velocity is

$$u = 2\pi f a \qquad [5]$$

For a given sound pressure level—SPL—of p, the amplitude is given by

$$a = u/2\pi f \qquad [6]$$

$$= Z_o p/2\pi f \qquad [7]$$

Both [6] and [7] simply state that the amplitude increases as the frequency decreases.

The second principle is that at low frequencies the wavelength in air is much larger than the dimensions of the sound source. This results in the radiation of spherical wave fronts from what is, in effect, a point source. The specific acoustic impedance, Z_s, is not the same for diverging waves, as given by the general formula

$$Z_s = \frac{p}{u} = \frac{\rho_o ckr}{\sqrt{1 + k^2 r^2}}\ 90° - \arctan kr \qquad [8]$$

where r is the radial distance from the point source, and $k = 2\pi/\lambda$.

When $kr >> 1$ ($r >> \lambda/2\pi$), the magnitude of Z_s approaches the value for a plane wave ($\rho_o c$) with u in phase with p. For $k2 = 1$, Z_s goes to zero and u tends to be in phase quadrature with p. The real part of Z_s (which is generally complex) falls to zero as r^2, which means that the mismatch between the transducer and the medium degrades in direct proportion to the square of the wavelength.

The corollary is that the speaker cone has to execute larger movements to maintain a constant SPL at lower frequencies if Z_s remains constant. If, however, Z_s (and in particular the real part of Z_s) falls at lower frequencies, the situation is exacerbated. So, all effects included, the cone amplitude needs to vary as λ^3 or as f^{-3}.

The foregoing general analysis clinches the central problem of designing for efficient bass reproduction. Large amplitudes are deprecated for moving-coil driver units: they introduce not only mechanical difficulties, but also distortion. It has been stated (Ref. 1) that any movement of the cone entails some distortion: the more it moves,