

therefore remains constant. On the other hand, the acoustic impedance is defined as the pressure divided by the flow (=velocity times cross-sectional area). So, in the exponential horn, acoustic impedance varies inversely as the cross-sectional area. The horn transforms a small flow at high pressure in the throat to a large flow at low pressure in the mouth. Conventionally, the horn is driven by a diaphragm (e.g., the cone of a loudspeaker) of larger cross-sectional area,  $S_D$ , than that of the throat,  $S_T$ , as shown in Fig. 2. The force,  $F_D$ , acting on the diaphragm is related to the pressure,  $p_T$ , in the throat by:

$$F_D = S_D p_T \quad (10)$$

Also,

$$u_D = u_T S_T / S_D \quad (11)$$

where  $u_D$  is the velocity of the diaphragm and  $u_T$  is the particle velocity in the throat.

The mechanical impedance,  $Z_M$ , is defined as force per unit velocity. So, for the diaphragm,

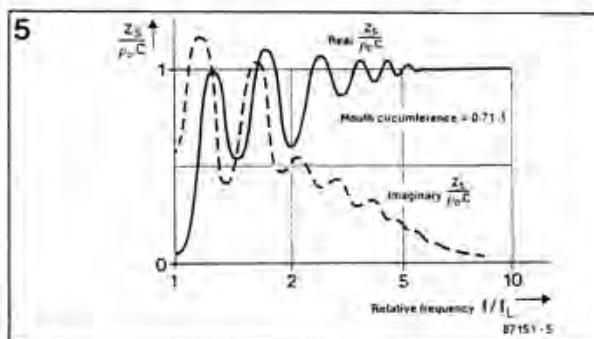
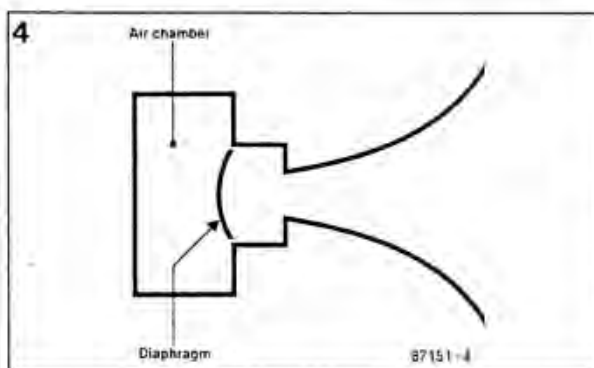
$$\begin{aligned} Z_M &= F_D / u_D \\ &= (S_D^2 p_T) / (S_T u_T) \\ &= (S_D^2 / S_T) (p_T / u_T) \end{aligned} \quad (12)$$

where  $p_T$  and  $u_T$  are the pressure and velocity respectively in the mouth of the horn. For a horn of sufficient dimensions, the coupling to the outside world becomes 100% and the specific acoustic impedance at the throat approaches  $\rho_0 c$ . Strictly, this is true only for an infinite horn, but for practical purposes a horn of which the circumference of its mouth equals the wavelength of the lowest frequency to be propagated is adequate. Under these conditions, the mechanical impedance becomes

$$Z_M \approx \rho_0 c (S_D^2 / S_T) \quad (13)$$

To equal this value of  $Z_M$ , an infinite baffle design would require a cone diameter of  $\lambda/\pi$ , where  $\lambda$  is the wavelength. At 40 Hz,  $\lambda = 8.28$  m, resulting in an impractical cone of more than 2.5 m in diameter.

The most serious restriction relating to low-frequency applications of horns is the cut-off



frequency,  $f_L$ , below which sound will not propagate. If the cross-sectional area of the horn varies with the distance,  $x$ , along the horn as

$$S_x = S_T \exp(mx) \quad (14)$$

the parameter  $m$ , expressed in  $m^{-1}$ , is called the **flare constant**. The low-frequency cut-off is given by

$$f_L = mc / 4\pi \quad (15)$$

For instance, if  $m = 0.3646 m^{-1}$ ,  $f_L = 40$  Hz.

For an infinite exponential horn, the real part of the throat impedance falls abruptly to zero at the cut-off frequency—see Fig. 3. The imaginary (reactive) part rises to a maximum at  $f_L$  and then falls asymptotically to zero. Above  $f_L$  it resembles a mirror image of normal capacitive reactance, which is the reason that it is often called negative capacitance reac-

