2.6 Ribbon loudspeakers[26,27]

The ideal radiator is one which (a) vibrates in phase over its whole surface, (b) has a mass comparable to the air load, and (c) has only resonances which are outside the working frequency band. In order to meet these requirements, the radiator must be subject to a mechanical force equal in amplitude and phase over the whole of its surface. There are only two commercial systems which meet this requirement, viz. the constant-charge electrostatic and the ribbon electromagnetic loudspeakers.

The ribbon loudspeaker consists of a light, flexible and essentially flat conductor suspended in a uniform magnetic field. It is supported at each end, and to reduce resonances in the transmitted band, is not stretched. To prevent sagging in the gap, it is transversely corrugated. This allows the compliance of the system and thus the resonant frequency (normally set at 100–150 Hz) to be controlled. The corrugations also considerably reduce the cross-resonances. At the end supports the ribbon is normally damped by a viscous elastomer, and the centre is supported by two blobs of a silicone gel. This not only keeps the ribbon securely in the centre of the pole-pieces and protects it from the inevitable shocks and bumps in transit, but also does not affect the performance. The dimensions of the ribbon determine its frequency range, sensitivity and power handling; it may be direct-radiating or horn-loaded.

Figure 2.82 shows the schematic of a basic ribbon transducer. A current flows

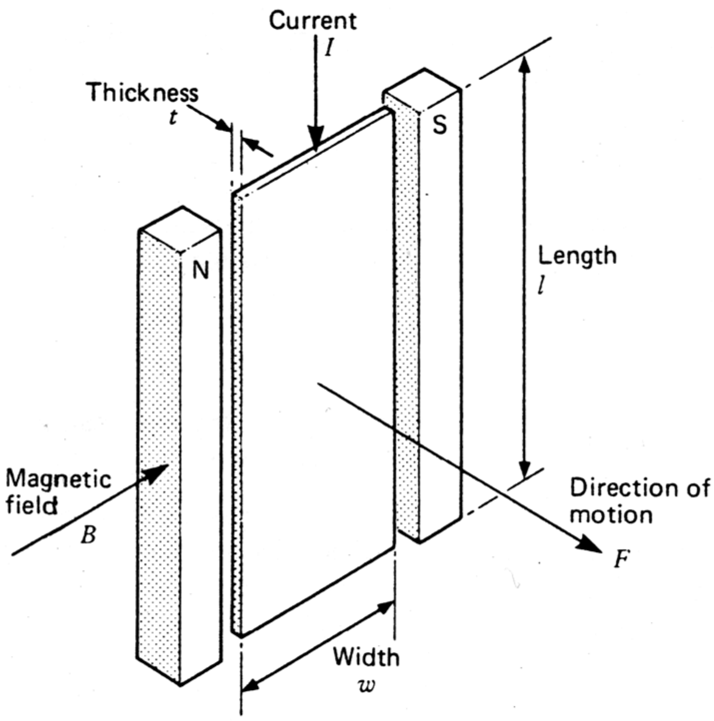

Figure 2.82. Basic dimensions of a ribbon in a magnetic field.

through the length of the ribbon, and its magnetic field interacts with the constant transverse magnetic field of strength B of the permanent magnet which is parallel to the plane of the ribbon. This generates a force F at right-angles to the plane of the ribbon, and results in its movement which will be communicated to the adjacent air. If the current is alternating, the ribbon movement will also be alternating, giving rise to radiation of a sound wave. When the current amplitude is constant, the force F_1 will be independent of frequency, but because of the mass inertia of the ribbon the high-frequency response will be reduced. Thus, for optimum high-frequency response the ribbon mass must be minimized.

The electromechanical force on the ribbon will be:

$$F_1 = BlI \text{ N} \tag{2.116}$$

and the velocity of the ribbon will be:

$$v = \frac{BlI}{Z_{\text{mT}}} \text{ m/s} \tag{2.117}$$

where I = current (A)
B = flux density (tesla)
l = length of ribbon (m)
Z_{mT} = total mechanical impedance (Ω)

The velocity of the ribbon will result in an opposing force due to the air-loading on both sides:

$$F_2 = 2AZ_{\text{u}}v$$

$$= 2AZ_{\text{u}}\frac{\text{d}x}{\text{d}t} \tag{2.118}$$

where A = area of ribbon (m^2)
Z_{u} = specific acoustic resistance (407 Ω)

The resultant of F_1 and F_2 will cause acceleration of the ribbon:

$$F_1 - F_2 = M\frac{d^2x}{dt^2} \tag{2.119}$$

where M = mass of ribbon (kg)

but the voltage developed across the ribbon due to its velocity is

$$V = Bl\frac{dx}{dt}\text{ V} \tag{2.120}$$

and

$$BlI - 2AZ_u\frac{dx}{dt} = pAt\frac{d^2x}{dt^2} \tag{2.121}$$

Thus

$$I = \frac{V}{R} + C\frac{dV}{dt} \tag{2.122}$$

from which the motional impedance can be derived:

$$R = \frac{B^2l}{2Z_uw}\ \Omega \tag{2.123}$$

$$C = \frac{pwt}{B^2l}\text{ F}$$

where p = density of ribbon material (kg/m^3)
w = width of ribbon (m)
t = thickness of ribbon (m)

The schematic is shown in Fig. 2.83(a).

In series with the motional impedance is the electrical resistance of the ribbon (see Fig. 2.83(b)):

$$R_1 = \frac{1\delta}{wt} \tag{2.124}$$

where δ = resistivity of ribbon material

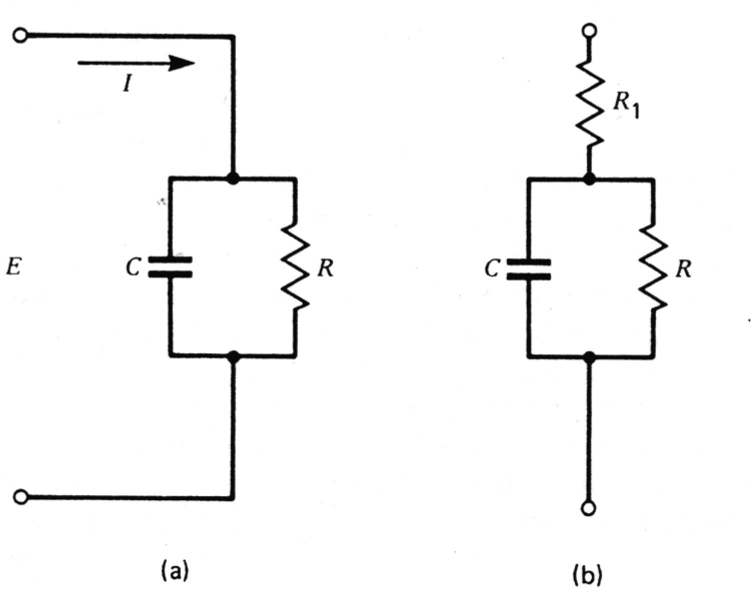

Figure 2.83. Motional impedance: (a) Equivalent circuit; (b) With addition of $R1$ d.c. resistance.

In order to obtain maximum efficiency, it is necessary to maximize R and reduce R_l to the limit. At frequencies where the shunt reactance of C can be neglected, the efficiency is

$$\varepsilon=\frac{R}{R+R_l} \tag{2.125}$$

but as frequency is increased the reactance of C will decrease, and when $XC=R$ the power available will have decreased by 3 dB; this will occur at:

$$\omega=\frac{R+R_l}{CRR_l}=\frac{1}{T} \tag{2.126}$$

where $\omega=2\pi f$, frequency (Hz)
T = time (seconds)

From the foregoing it will be seen that, in the interests of efficiency, the mass and resistance of the ribbon must be reduced as much as possible. It is convenient to introduce a 'factor of merit' given by the fraction ε/T, which should be as large as possible. From equations (2.125) and (2.126):

$$\frac{\varepsilon}{T}=\frac{1}{CR_l}=\frac{B^2}{p\delta} \tag{2.127}$$

This makes the problem look much simpler because all the ribbon dimensions have disappeared. It should be noted that p and δ separately are not important, but their product is.

Equation (2.127) shows that only two quantities are a prerequisite for good design: flux density and ribbon material. B must be as high as is practical; it must be remembered that the efficiency is proportional to B^2, so even a small improvement is worthwhile. Table 2.5 gives details of available materials:

Table 2.5 Comparison of possible ribbon materials

Material	p ($\times 10^3$ kg/m^3)	δ ($\times 10^{-8}$ Ω/m)	$p\delta$ ($\times 10^5$)	*Sensitivity (dB)*
Al	2.7	2.67	7.21	0
Be	1.8	4.2	7.56	−0.4
Cu	8.96	1.6	14.34	−6.0
Ag	10.4	1.59	16.54	−7.2

Thus aluminium is slightly ahead of beryllium in the efficiency stakes and is considerably cheaper to produce and much easier to fabricate.

The ribbon dimensions are determined by the radiating surface area, which in turn is controlled by the frequency range. It should be noted that the provision of a horn can increase the lower frequency range by at least two octaves, thus reducing the diaphragm area proportionately. Having determined the area, the length and width must be decided, and this introduces a conflict of interests: to obtain a high flux density, the gap width must be as small as possible (the length of the magnet is directly proportional to flux density and gap width). This means a narrow ribbon. It is also a fact of life that as the gap with is increased the ratio of leakage flux to working flux also increases. The gap efficiency is:

$$\varepsilon_g=\frac{T}{3.5W+T} \tag{2.128}$$

where T = thickness (i.e. pole thickness)
W = gap width

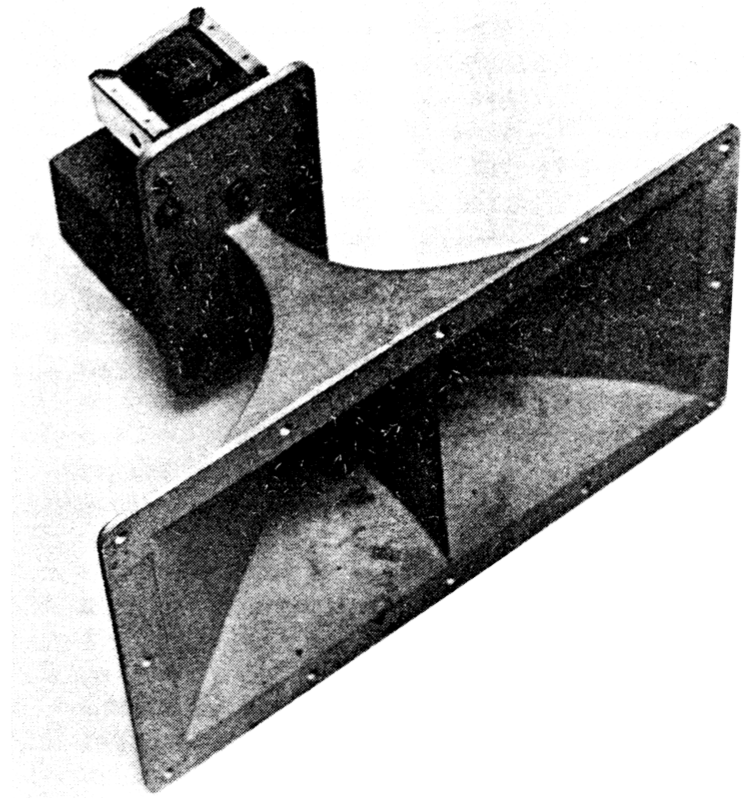

Figure 2.84. The Decca/Kelly 'London' ribbon loudspeaker.

Thus for a 10 mm gap width and pole thickness of 1 mm (which are normal dimensions for commercial ribbon loudspeakers) the gap efficiency is 2.78%, i.e. 97.2% of the available magnetic flux is wasted as 'leakage'.

Having decided the length and width of the ribbon, the thickness t must be determined: again there is a conflict of requirements as (a) the mass (and hence t) must be minimal to meet the high-frequency response specification, and (b) the ribbon must have sufficient cross-sectional area to carry the current without overheating at the specified maximum power of the loudspeaker. In practical terms, (b) is decided first and the resultant mass and upper frequency cut-off point determine the gap flux density B. As an example, the Decca/Kelly 'London' Ribbon Loudspeaker (see Fig. 2.84) has the following parameters: the ribbon dimensions are 55 mm length, 8.5 mm width and 0.01 mm thickness; mass is 4.65 mg; d.c. resistance is 0.02 Ω; gap flux density is 0.85 tesla. The sensitivity is +92 dB SPL over a frequency range of 1–30 kHz, and the power-handling capacity is 25 W. Because the resistance of the ribbon is 0.02 Ω, it requires a matching transformer with a turns ratio of 20:1 to match a nominal 8 Ω power amplifier.

In an effort to reduce some of the intransigencies mentioned above, printed-circuit techniques can be used to produce a flat diaphragm with substantially a 'current sheet' effect over the diaphragm area, at the same time reducing the magnet gap to manageable proportions. Figure 2.85 shows the diaphragm schematic. It consists of a polyimide base 12 μm thick with a 10-turn rectangular aluminium voice coil etched onto it. The effective length is 0.5 m and its mass is 40 mg. The resistance is 8 Ω and the total effective mass of the diaphragm assembly is 48 mg. This is two orders of magnitude greater than the basic ribbon, but it is still less than 1/20th that of a soft dome tweeter. It will be seen that there is a gap between the 'turns'. This can be eliminated (and thus more nearly approximate a current sheet) by filling the gap with an additional coil mounted on the underside. Figure 2.86 shows a cross-section of this coil.

Using this configuration of a rectangular voice coil complicates the magnet system somewhat, but it is not really so difficult. Figure 2.87 shows the layout of the magnet

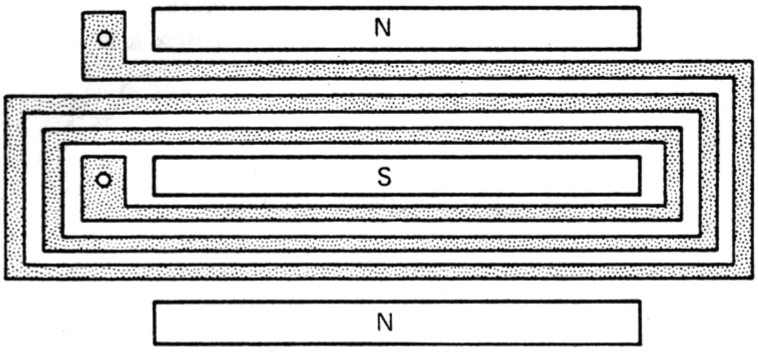

Figure 2.85. Schematic of the printed circuit diaphragm.

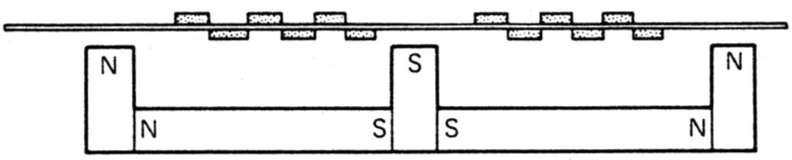

Figure 2.86. Double-sided diaphragm.

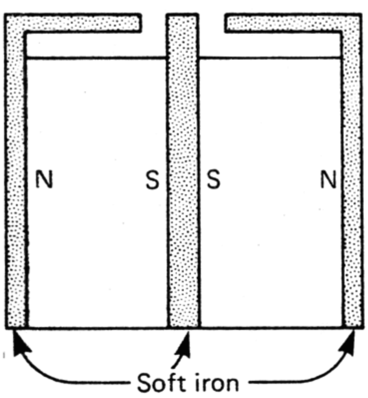

Figure 2.87. Layout of the magnet assembly.

system. The magnets are anisotropic ferrite blocks, the gap width is 4.0 mm and the top plate is 2.0 mm; the centre pole is 4.0 mm, and the flux density is 0.55 tesla. The gap efficiency is $12\frac{1}{2}\%$ – not very good, but infinitely better than the 10 mm gap of the original ribbon. Even more important is the cost, which is only 1/20th the price of a cast columnar magnet. Sensitivity is +93 dB SPL, and the claimed frequency response is flat from 2–40 kHz.