PART XVIII *Design Factors Affecting Direct-radiator Loudspeaker Performance*

A loudspeaker generally is designed to provide an efficient transfer of electric power into acoustic power and to effect this transfer uniformly over as wide a frequency range as possible. To accomplish this, the voice coil, diaphragm, and amplifier must be properly chosen. The choice of the elements and their effect on efficiency, directivity, and transient response are discussed here.

7.10. Voice-coil Design. Inspection of Fig. 7.6 reveals that region *C* is a very important part of the response curve, because the average effi-

ciency is governed by it. From Eq. (7.19), which is valid for this region, if the indicated approximations hold, we see that the maximum power available efficiency at a given frequency is proportional to

$$\text{PAE} \propto \frac{l^2 R_g}{[(R_g + R_E)(M_{MD} + 2M_{M1})]^2} \tag{7.22}$$

Now, the resistance R_E can be expressed in terms of the mass of the voice-coil winding M_{MC} by writing

$$R_E = \frac{\kappa l}{\pi a_w^2} \tag{7.23}$$

where κ = resistivity of voice-coil conductor in units of ohm-meters. The value of κ for different materials is given in Table 7.1.
a_w = radius of wire in meters.
l = length of voice-coil winding in meters.

Also,

$$M_{MC} = \pi a_w^2 l \rho_w \tag{7.24}$$

where ρ_w = density of the voice-coil wire in kilograms per cubic meter (see Table 7.1). Combining (7.23) and (7.24), we get

$$R_E = \frac{\kappa l^2 \rho_w}{M_{MC}} \tag{7.25}$$

Substituting (7.24) in (7.22) yields

$$\text{PAE} \propto \frac{l^2 R_g}{\left[\left(R_g + \frac{\kappa l^2 \rho_w}{M_{MC}}\right)(M_{MC} + M'_{MD} + 2M_{M1})\right]^2} \tag{7.26}$$

where $M'_{MD} = M_{MD} - M_{MC}$.

Differentiation of this equation with respect to M_{MC} and equating the result to zero gives the value of M_{MC} necessary for maximum power output from a generator of impedance R_g provided we assume that the coil length is already predetermined. Hence, M_{MC} for maximum PAE is found from

$$M_{MC}^2 = \frac{\kappa l^2 \rho_w}{R_g}(M'_{MD} + 2M_{M1}) \tag{7.27}$$

Further, substituting (7.25) in (7.27), we get

$$M_{MC} = \frac{R_E}{R_g}(M'_{MD} + 2M_{M1}) \tag{7.28}$$

As an alternate possibility, we assume that the resistance of the coil, R_E, is to be constant. Allow M_{MC} and l to vary. Then determine M_{MC} for maximum PAE.

TABLE 7.1. Resistivity and Density of Various Metals

Metal element	Resistivity, ohm-m	Density, kg/m³
Aluminum	0.0283×10^{-6}	2.70×10^{3}
Antimony	0.417	6.6
Bismuth	1.190	9.8
Cadmium	0.075	8.7
Calcium	0.046	1.54
Carbon	8.0	2.25
Cesium	0.22	1.9
Chromium	0.026	6.92
Cobalt	0.097	8.71
Copper	0.0172	8.7
Gold	0.0244	19.3
Iridium	0.061	22.4
Iron	0.1	7.9
Lead	0.220	11.0
Lithium	0.094	0.534
Magnesium	0.046	1.74
Manganese	0.050	7.42
Mercury	0.958	13.5
Molybdenum	0.057	10.2
Nickel	0.078	8.8
Platinum	0.10	21.4
Potassium	0.071	0.87
Silver	0.0163	10.5
Sodium	0.046	0.97
Tin	0.115	7.3
Titanium	0.032	4.5
Tungsten	0.055	19.0
Zinc	0.059	7.1

From Eq. (7.25), we have

$$l^2 = \frac{R_E M_{MC}}{\kappa \rho_\omega} \tag{7.29}$$

Putting this in (7.22) yields

$$\text{PAE} \propto \frac{R_E R_g M_{MC}}{(R_g + R_E)^2 (M_{MC} + M'_{MD} + 2M_{M1})^2} \tag{7.30}$$

where, as above, $M'_{MD} = M_{MD} - M_{MC}$. Maximizing, we get

$$M_{MC} = M'_{MD} + 2M_{M1} \tag{7.31}$$

Finally, let us assume that M_{MC} of Eq. (7.30) is a constant and that we wish to let R_E and l vary. Then determine R_E for maximum PAE. Maximizing Eq. (7.30), we get

$$R_E = R_g \tag{7.32}$$

Hence, for the optimum value of power available efficiency, we see

from Eqs. (7.28), (7.31), and (7.32), that $R_E = R_g$ and

$$M_{MC} = M'_{MD} + 2M_{M1}.$$

It is not usual, however, that the voice coil should be this massive, for the reason that a large voice coil demands a correspondingly large magnet structure.

Values of voice-coil resistances and masses for typical American loudspeakers are given in Table 8.1 of the next chapter.

TABLE 8.1. Typical Values of l, R_E, and M_{MC} for Various Advertised Diameters of Loudspeakers

Advertised diam, in.	Nominal impedance, ohms	l, m	R_E, ohms	M_{MC}, mass of voice coil, g
4–5	3.2	2.7	3.0	0.35–0.4
6–8	3.2	3.4	3.0	0.5 –0.7
10–12	3.2	4.4	3.0	1.0 –1.5
12	8.0	8.0	7.0	3
15–16	16.0	...	...	12