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## Loudspeaker Damping

ALBERT PREISMAN\*

**Part 1. A discussion of theoretical considerations of loudspeaker characteristics, together with a practical method of determining the constants of the unit as a preliminary step in obtaining satisfactory performance.**

ONE OF THE CONSIDERATIONS in the design and application of loudspeakers is the adequate damping of their motion. Thus, owing to the masses and compliances involved, the sudden application or removal of current in the voice coil tends to produce a transient oscillation of a damped sinusoidal nature.

In particular, the sudden cessation of current in the voice coil may find the loudspeaker continuing to vibrate in the manner described, so that the sound "hangs over". Any one who has experienced this unpleasant effect will seek ways and means to eliminate it.

In the case of a horn type loudspeaker, the horn imposes in general sufficient mechanical loading to damp out such transient response of "hang-over", and also serves to limit the excursions of the voice coil so that it does not operate into the nonlinear portion of the air-gap magnetic field. The damping also serves to minimize nonlinear compliance of the suspension system by limiting the amplitude of oscillation.

However, if the horn design is limited by such considerations as maximum permissible mouth area and is operated at a frequency not too low to be transmitted by the horn taper yet low enough so that appreciable reflections occur at the mouth, then the horn may cease to act as a mechanical resistance, but instead become predominantly reactive, and thereupon cease to damp a resonance in the speaker unit occurring in this frequency range. In such an event other means of damping will be of value

to the designer or applications engineer.

In the case of the direct-radiator loudspeaker unit, the air load is small, and is mainly reactive at the lower frequencies. Hence mechanical damping of the unit is small in magnitude, and "hangover" effects may be particularly noticeable.

A reflexed cabinet may help to load the loudspeaker, or at any rate to produce a two-mesh mechanical network exhibiting two resonance peaks, neither of which is as high as that of the unit by itself or in a flat baffle. Nevertheless, the damping may still not be sufficient to produce "clean" low-frequency tones.

Hence, in general, it is advisable or at least desirable to provide sufficient damping of the direct-radiator type of unit by means of its electrical characteristics, so that whether it is operated into a horn, reflexed cabinet, or simply a flat baffle, it will be adequately damped.

An important point about electrical damping is that it represents high rather than low efficiency of operation, just as a horn does. On the other hand, were some material such as viscoloid employed to provide the required damping, the electrical input power would in part at least be converted into heat energy in the material instead of into acoustic energy, and thus represent a

decrease in efficiency. It will therefore be of interest to examine damping produced by the electrical characteristics of the system.

### Motional Impedance

When an alternating current flows in a voice coil, it reacts with the constant magnetic field to produce an alternating force which causes the voice coil to vibrate at the frequency of the current. In so doing, the voice coil cuts through the magnetic lines, and generates a counter electromotive force, c.e.m.f.

The action is exactly similar to that of the rotating armature of a d.c. motor—the armature generates a c.e.m.f. by its rotation in the magnetic field. Con-

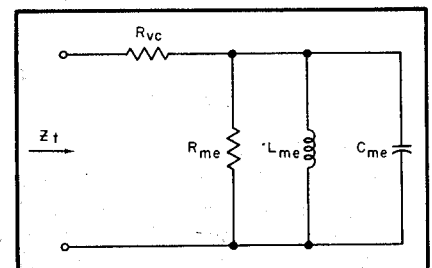


**Fig. 2. Mechanical characteristics of speaker as seen from voice-coil terminals.**

sider the case of the loudspeaker voice coil. The electrical c.e.m.f. which is generated, tends to oppose the flow of current in the coil, just as if its impedance had gone up. After all, one ohm of impedance simply means a one volt drop in the unit for a one-ampere current flowing through it; i.e., volts per ampere. In the case of the loudspeaker, the force, and hence motion and c.e.m.f., are proportional to the voice coil current, so that a ratio is involved which is an apparent impedance.

Hence, when a loudspeaker voice coil

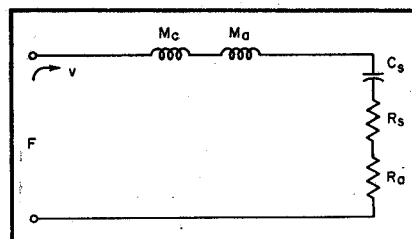


**Fig. 1. Equivalent circuit of loudspeaker unit at low frequencies.**

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is permitted to vibrate, its impedance apparently goes up. The increase in impedance owing to its motion is known as the MOTIONAL IMPEDANCE, and it is measured in ohms just as the electrical impedance of the voice coil is measured in ohms.

Several characteristics of the motion impedance can be readily analyzed qualitatively. In the first place, the lower the mechanical impedance, the more readily does the voice coil vibrate, and the higher is the induced e.m.f. for a given current flowing through it; i.e., the higher is its motional impedance.

A second point to note is that the greater the magnetic flux density, the greater is the induced e.m.f., and the higher is the motional impedance of the voice coil. Finally, we note that if the total length of voice-coil wire is increased, there is more conductor cutting the magnetic field, and hence more e.m.f. induced. Therefore the motion

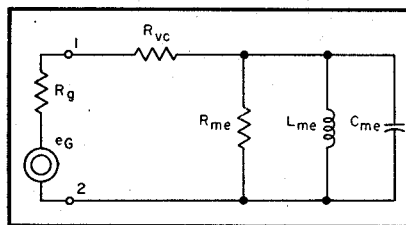


Fig. 3. Circuit of Fig. 2 with addition of generator.

impedance increases if the length of voice coil wire is increased.

The actual quantitative relations are as follows:

$$Z_{me} = \frac{(Bl)^2 \times 10^{-9}}{Z_m} \quad (1)$$

where  $Z_{me}$  is the motional impedance in electrical ohms;  $B$  is the magnetic flux density in gauss;  $l$  = length of voice coil conductor in cm., and  $Z_m$  is the mechanical impedance in mechanical ohms (dynes/cm/sec.).

#### Loudspeaker Low-Frequency Resonance

The mechanical impedance  $Z_m$  of the loudspeaker unit varies considerably over the frequency range. However, at the lowest audio frequencies it is of greatest importance, particularly with regard to "hangover" effects, and hence will be analyzed at this point.

At the lowest audio frequencies, the loudspeaker unit acts mechanically as a simple series resonant circuit. This is illustrated in Fig. 1. The masses involved are those of the cone,  $M_o$ , and the air set in motion by the cone  $M_a$ . The latter is a function of frequency but can be assumed fairly constant over

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a narrow frequency range involving the resonant frequency of the unit.

The compliance  $C_s$  represents that of the suspension, both of the rim of the cone and of the center spider. It is apt to be nonlinear, particularly for large excursions, but is reasonably constant for moderate and small amplitudes of vibration.

The resistive factors are that of the suspension  $R_s$ , and that of the air set in motion by the cone,  $R_a$ . The latter is particularly variable with frequency, but is usually very small at the low frequency at which resonance occurs, particularly if the speaker unit is tested by itself, or at most in a flat baffle. Values for several sizes of cones are given by Olson.<sup>1</sup>

From Fig. 1, it is apparent that

$$Z_m = (R_s + R_a) + j\omega(M_o + M_a) + 1/j\omega C_s \quad (2)$$

Substituting this in Eq. (1), we obtain

$$Z_{me} = \frac{(Bl)^2 \times 10^{-9}}{(R_s + R_a) + j\omega(M_o + M_a) + 1/j\omega C_s} \quad (3)$$

If we divide the numerator and denominator of the right side of Eq. (3) by  $(Bl)^2 \times 10^{-9}$  we obtain

$$Z_{me} = \frac{1}{\frac{(R_s + R_a)}{(Bl)^2 \times 10^{-9}} + j\omega \frac{(M_o + M_a)}{(Bl)^2 \times 10^{-9}} + \frac{1}{j\omega C_s (Bl)^2 \times 10^{-9}}} \quad (4)$$

Let

$$\begin{aligned} (R_s + R_a) / (Bl)^2 \times 10^{-9} &= G_{me} = 1/R_{me} \\ (M_o + M_a) / (Bl)^2 \times 10^{-9} &= C_{me} \\ \text{and } C_s (Bl)^2 \times 10^{-9} &= L_{me} \end{aligned} \quad (5)$$

where

$R_{me}$  is the motional resistance corresponding to the mechanical damping  $R_s$  and  $R_a$ ,  
 $C_{me}$  is the motional capacitance corresponding to  $M_o$  and  $M_a$ , and  
 $L_{me}$  is the motional inductance corresponding to  $C_s$ .

In short, we shall assume that the mechanical resistance appears as an electrical conductance  $G_{me} = 1/R_{me}$ ; the mechanical compliance appears as an electrical inductance; and the mechanical mass appears as an electrical capaci-

tance. The latter transformation has been known for a long time in the power field; years ago oscillating synchronous motors were used in Europe as electrical capacitors, since a relatively small armature mass appeared as a surprisingly large electrical capacitance.

If we substitute Eq. (5) in Eq. (4), we obtain:

$$Z_{me} = \frac{1}{(1/R_{me}) + j\omega C_{me} + (1/j\omega L_{me})} \quad (6)$$

The quantities on the right side represent a resistance, capacitance, and inductance in parallel. Since the parallel impedance is equal to the reciprocal of the sum of the reciprocals of the individual impedances.

Hence we finally arrive at the conclusion that the mechanical characteristics of the loudspeaker at the lower frequencies appear at the electrical terminals of the voice coil as shown in Fig. 2. Here  $R_{vo}$  represents the electrical resistance of the voice coil; the electrical (clamped) inductance of the voice coil can be disregarded at the lower audio frequencies.

The mechanical characteristics of the speaker appear as a parallel resonant circuit shunted by a certain amount of resistance; these constitute the motional impedance  $Z_{me}$  of the speaker, and the

<sup>1</sup>H. F. Olson, "Elements of Acoustical Engineering," p. 126. D. Van Nostrand Co., New York.

total electrical impedance  $Z_t$  is  $Z_{me}$  plus  $R_{vc}$ .

We can now analyze the behavior of the speaker from its electrical motional impedance characteristics. Thus, just as *Fig. 1* indicated a certain frequency of resonance, so does *Fig. 2* indicate this fact. Since the two circuits are equivalent, they must have the same resonant frequency. This can be readily shown. Thus, from Eq. (5)

$$\begin{aligned} L_{me} C_{me} &= C_s (Bl)^2 \times 10^{-9} \frac{(M_o + M_a)}{(Bl)^2 \times 10^{-9}} \\ &= (M_o + M_a) C_s \end{aligned} \quad (7)$$

that is, the electrical  $LC$  product equals the mechanical  $MC$  product; either therefore represents the same resonant frequency.

It will be of interest to compare the behavior of the electrical circuit of *Fig. 2*. For example, at the resonant frequency of the loudspeaker, namely

$$f_r = \frac{1}{2\pi(M_o + M_a)C_s} = \frac{1}{2\pi L_{me} C_{me}} \quad (8)$$

the mechanical current or velocity  $v$  is a maximum, and is in phase with the force  $F$ , *Fig. 1*.

This in turn means that the electrical c.e.m.f. will be a maximum and in phase opposition with the force  $F$ , which in turn is in phase with the current in the voice coil. Hence this c.e.m.f. will produce an in-phase or *resistive* reaction: the generator will view the voice coil as having increased in impedance, and that this increased impedance is resistive in nature.

Now refer to *Fig. 2*. At the frequency of resonance,  $L_{me}$  and  $C_{me}$  act as an open circuit shunting  $R_{me}$ , so that the electrical impedance is

$$Z_t = R_{vc} + R_{me} \quad (9)$$

and is a maximum. Furthermore, if the mechanical resistance  $(R_s + R_a)$  is small,  $v$  will be a maximum, as will also be the c.e.m.f., whereupon the electrical source will see a *high* resistive impedance  $R_{me}$ . This checks the inverse relation between  $R_{me}$  and  $(R_s + R_a)$  given in Eq. (5); when  $(R_s + R_a)$  is small,  $R_{me}$  appears large since  $(R_s + R_a)$  appears in the denominator of the expression for  $R_{me}$  in Eq. (5).

*To be concluded in the April issue.*