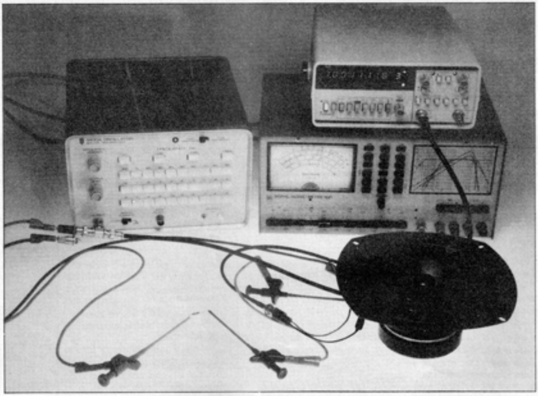
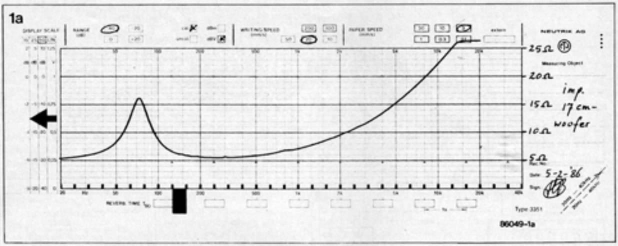
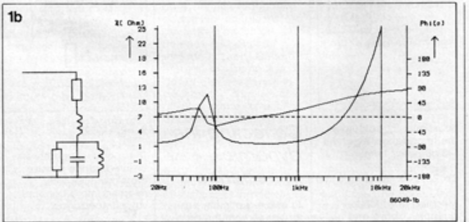
LOUDSPEAKER IMPEDANCE CORRECTION

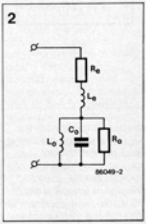


A loudspeaker presents a complex load to the output amplifier and the cross-over network. This load can be measured and any deviation from the nominal impedance corrected. In this manner a multi-way loudspeaker system with a passive cross-over network can be made to function optimally.

A loudspeaker looks a simple enough device: a frame, a coil, a magnet, and a cone of paper or of man-made fibre. Put it in a box and you have a sound reproducer. If only it were as simple as that. . . *Designing a closed loudspeaker box (Elektor India, March 1986)* explained the fundamentals of calculating the dimensions of a closed box on the basis of the characteristics of the drive unit used. That thus dealt with the acoustics of the system. The present article takes a closer look at the electrical aspects. Before reading any further, note that if the cross-over network is of the active







type, the loudspeaker impedance is of no particular importance. With a passive filter, however, it is a prime factor.

Dynamic impedance

A drive unit may be represented by an electrical circuit containing resistance, capacitance, and inductance. Its impedance may, therefore, be inductive, capacitive, or resistive, depending on the frequency of operation. Moreover, the impedance is affected, to some extent, by the type and dimensions of the enclosure in which the drive unit is housed. Figure 1 shows the dynamic impedance of a 17 cm bass unit measured over the frequency range of 20 Hz to 20 kHz. This curve is characterized by the peak around 75 Hz and the slowly rising impedance with frequency. The peak is caused by the resonance frequency of the equivalent circuit, while the rising with frequency results from the self inductance of the voice coil. As the cross-over network has been designed for operation into a constant-value ohmic load, the performance of the system will be adversely affected by this varying impedance.

Equivalent circuit

A (simplified) equivalent circuit of a typical drive unit is shown in Fig. 2. The voice coil has a resistance, R_e, which determines the minimum impedance of the drive unit. From the curve in Fig. 1 it is clear that for the drive unit used here $R_e = 5.5$ ohms. The inductance of the voice coil is represented by L_e. The parallel circuit L_0-C_0-R_0 causes exactly the same peak as the drive unit proper. Note that it is in series with the series combination of R_e and L_e.

Impedance calculations

A dynamic impedance characteristic, such as that in Fig. 1, can be determined with the simple set-up of Fig. 3. If the resistance R is large compared with the nominal loud-

Fig. 1. The impedance curve of a typical loudspeaker unit in (a) was measured under controlled conditions. Subsequently, an equivalent circuit was calculated and built: the impedance curve of this is shown in (b). The resemblance between the two characteristics is striking.

Fig. 2. The equivalent electrical circuit of a loudspeaker looks anything but a resistance.

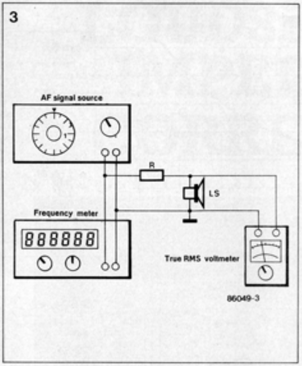
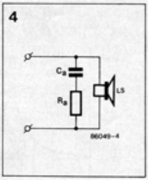
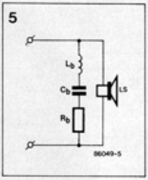


Fig. 3. Typical set-up for measuring loudspeaker impedance over a range of frequencies.

Fig. 4. An RC network across the loudspeaker compensates for the rise in impedance with frequency.

Fig. 5. The resonance peak of a loudspeaker may be negated with a suitable LCR network across the unit.





speaker impedance, the AF signal source functions as a perfect current source. If, for instance, R=3k3, and the output of the signal source is set at 3.3 V r.m.s., the current through the loudspeaker coil is 1 mA. Each millivolt drop across the loudspeaker, therefore, represents 1 ohm. It is clear that the true RMS voltmeter should be a sensitive type. The impedance presented by the loudspeaker can now be measured over a range of frequencies, and the curve plotted from the values measured. It is, of course, essential that the drive unit is housed in its normal enclosure to ensure that the true impedances are measured.
The voice coil resistance, R_e, may be measured with an accurate ohmmeter, or with the set-up of Fig. 3. The latter is not too accurate, but it will do. In this case, the minimum impedance over the frequency range is ascertained.
Next, ascertain the impedance, Z_0, at the resonant frequency, f_0. The true impedance, Z, is

$$Z = Z_0 - R_e \quad (1)$$

Subsequently, calculate the impedance, Z_3, at the −3 dB points from

$$Z_3 = R_0 + Z\sqrt{2} \quad (2)$$

Measure at which frequencies above and below f_0, f_a and f_b respectively, the impedance has the value Z_3.
The bandwidth, BW, of the resonance peak is calculated from

$$BW = f_a - f_b \quad (3)$$

Values of the equivalent circuit components can now be calculated from the following.

$$L_0 = BWZ/2\pi f_0 \quad (4)$$

$$C_0 = 1/2\pi BWZ \quad (5)$$

$$R_0 = Z \quad (6)$$

For bass speakers, measure at which frequency, f_x, the impedance is equal to $2R_e$. Then,

$$L_e = \sqrt{3}R_e/2\pi f_x \quad (7)$$

For middle and high frequency speakers, measure at which frequency, f_r, the impedance is equal to $\sqrt{2}R_e$. Then,

$$L_e = R_e/2\pi f_r \quad (8)$$

Correcting the dynamic impedance

To ensure optimum performance from the passive network and loudspeaker, the impedance presented to the filter by the loudspeaker should remain constant over the frequency range of the system. This is readily effected by an RC combination across the drive unit as shown in Fig. 4, where

$$R_a = R_e \quad (9)$$

$$C_a = L_e/R_e^2 \quad (10)$$

Note that the minimum impedance of the loudspeaker remains equal to R_e.
Correcting the resonance peak is normally not necessary, because it usually lies well outside the pass band of the cross-over network. None the less, where it is felt necessary, it can be done with the aid of the circuit in Fig. 5. Here,

$$L_b = L_0 R/R_0 \quad (11)$$

$$C_b = C_0 R_0/R_b \quad (12)$$

$$R_b = R_e + R_e^2/R_0 \quad (13)$$

These correcting networks ensure that the passive cross-over filter is terminated into a constant-value impedance.

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