# SUITABILITY OF LOW-FREQUENCY DRIVERS FOR HORN-LOADED LOUDSPEAKER SYSTEMS

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## ABSTRACT

The efficiency, bandwidth and power capacity of low-frequency horn-loaded loudspeaker systems are directly affected by the parameters of the driver used. Three new composite driver parameters, formed by simple combination of the basic parameters, give a direct indication of driver suitability for horn-loaded operation. These composite parameters also greatly simplify the selection of optimum horn constants and the calculation of system performance and ratings.

## 1. INTRODUCTION

Up until about 5 years ago, it was nearly impossible to obtain complete parameter information for the low-frequency moving-coil drivers available in the marketplace. As a result, the design of loudspeaker systems using these drivers was largely a matter of trial and error, often with disappointing results. Now, most manufacturers of loudspeaker drivers can supply a complete set of parameters so that performance of a driver in any enclosure can be predicted with reasonable accuracy. This approach is now routine in the design of direct-radiator loudspeaker systems.

Knowledge of fundamental driver parameters also permits prediction of the performance of the driver in a horn-loaded loudspeaker system. Some of the important relationships are presented in this paper. From these relationships it is shown that a few composite parameters can serve as a good guide to the performance possibilities of a driver.

## 2. HORNS AND DRIVERS

It is well known that the flare rate and mouth area of a horn (and hence the horn size) determine the lower cutoff frequency of a horn system. In practice this must always be so; otherwise the horn would be needlessly large and costly for the response achieved.

Almost all other performance factors of the horn loudspeaker system are determined by the driver and by the chosen ratio of driver diaphragm area to horn throat area.

We may isolate the influence of the driver on system performance by analysing a simplified system in which the horn is replaced by a rigid tube of infinite length having the same area as the horn throat. Such a system is illustrated in Fig. 1; it differs from the horn system only in that its low-frequency response is not limited by the horn. An impedance-type mechanical analogous circuit for this system is shown in Fig. 2. The symbols used in Figs. 1 and 2 are defined below.

$B$ Magnetic flux density in driver air gap.

$c$ Propagation velocity of sound in air, 345 m/s .

$C_{MB}$ Mechanical compliance of air in box behind driver, $= V_B/\rho_o c^2$

$C_{MC}$ Mechanical compliance of air between driver diaphragm and horn throat, $= V_C/\rho_o c^2$ .

$C_{MS}$ Mechanical compliance of driver suspension.

$e_g$ Voltage applied to driver terminals.

$f_g$ Mechanical force generator for analogous circuit, $= e_g Bl/R_E = e_g R_{ME}/Bl$ .

$l$ Length of voice-coil conductor in magnetic field.

$L_E$ Electrical inductance of driver voice coil.

$M_{MB}$ Mechanical air-load mass on rear of driver diaphragm.

$M_{MD}$ Mechanical mass of driver diaphragm and voice coil.

$R_E$ Dc resistance of driver voice coil.

$R_{MB}$ Mechanical resistance on rear of driver diaphragm.

$R_{MD}$ Mechanical resistance on front of driver diaphragm, $= (S_D/S_T)\rho_o c S_D$ .

$R_{ME}$ Mechanical resistance of driver motor, $= B^2 l^2/R_E$ .

$R_{MS}$ Mechanical resistance of driver suspension losses.

$S_D$ Effective projected surface area of driver diaphragm.

$S_T$ Area of horn throat or tube, always $\leq S_D$ .

$u_D$ Mechanical velocity of driver diaphragm.

$V_B$ Volume of air enclosed in box behind driver.

$V_C$ Volume of air between driver diaphragm and horn throat.

$\rho_o$ Density of air, 1.18 kg/m$^3$ .

For simplicity, the voice-coil inductance and diaphragm-throat coupling volume are ignored in this paper. The effects of these elements on the system high-frequency response are easily calculated in a practical case, but our purpose here is to establish the importance of the primary driver parameters such as motor strength, mass, compliance, excursion limit; and thermal power limit. The circuit of Fig. 2 thus simplifies to that of Fig. 3, where series elements of like type have been combined to give $R_{M2} = R_{MB}+R_{MS}$ , $C_{M2} = C_{MB}C_{MS}/(C_{MB}+C_{MS})$ , $M_{M2} = M_{MB}+M_{MD}$ .

## 3. HORN-SYSTEM EFFICIENCY

The efficiency of a horn system is the ratio of the power delivered to the throat to that taken from the driving source at the middle of the operating band. For midband operation, the circuit of Fig. 3 yields an efficiency $\eta_T$ given by

$$\eta_T = \frac{R_{ME}}{R_{ME}+R_{MD}+R_{M2}} \cdot \frac{R_{MD}}{R_{MD}+R_{M2}} \quad . \tag{1}$$

This expression has a maximum for $R_{MD}{}^2 = R_{M2}(R_{ME}+R_{M2})$ , but for most practical systems $R_{M2}$ is quite small and maximum efficiency results from using the lowest realizable value of $R_{MD}$; this occurs for $S_D/S_T = 1$ . The maximum attainable efficiency is than approximately

$$\eta_T(\max) = \frac{1}{1 + \frac{R_{MO}}{R_{ME}} + \frac{R_{M2}}{R_{MO}} + 2\frac{R_{M2}}{R_{ME}}} \quad , \tag{2}$$

where $R_{MO} = \rho_o c S_D$ is the value of $R_{MD}$ for $S_D/S_T = 1$ . Note that $R_{MO}$, which depends only on physical constants and the driver diaphragm area, is thus a fundamental parameter of the driver.

If $R_{M2}$ is negligible, the above equations reduce to

$$\eta_T = \frac{R_{ME}}{R_{ME}+R_{MD}} \tag{3}$$

and

$$\eta_T(\max) = \frac{R_{ME}}{R_{ME}+R_{MO}} \tag{4}$$

## 4. HIGH-FREQUENCY LIMIT

For the curcuit of Fig. 3, the power delivered to the throat falls by 3 dB at the frequency for which the reactance of the mass $M_{M2}$ equals the total circuit resistance. The upper half-power frequency $f_H$ is therefore given by

$$f_H = \frac{R_{ME}+R_{MD}+R_{M2}}{2\pi M_{M2}} \qquad (5)$$

Note that both this frequency and the system midband efficiency $\eta_T$ are functions of the value of $R_{MD}$ and hence of the diaphragm-throat coupling ratio $S_D/S_T$, because $R_{MD} = (S_D/S_T)R_{MO}$.

## 5. EFFICIENCY-BANDWIDTH PRODUCT

If we examine the behaviour of the system more closely, we find that the product of the system efficiency and the upper cutoff frequency is almost constant as $S_D/S_T$ is varied. From Eqs. 1 and 5, this product is

$$f_H \cdot \eta_T = \frac{R_{ME}}{2\pi M_{M2}} \cdot \frac{R_{MD}}{R_{MD}+R_{M2}} = \frac{f_S}{Q_{ES}} \cdot \frac{R_{MD}}{R_{MD}+R_{M2}} , \qquad (6)$$

where $f_S$ and $Q_{ES}$ are the common driver parameters given for this application by

$$f_S = \frac{1}{2\pi(M_{M2}C_{MS})^{\frac{1}{2}}} , \qquad (7)$$

$$Q_{ES} = 2\pi M_{M2}/R_{ME} . \qquad (8)$$

Eq. 6 exhibits a slight dependence on $R_{MD}$, but if $R_{M2}$