Loudspeaker Linear Parameter Definitions [1]

F_s

The frequency at which the combination of the moving mass and suspension compliance maximally reinforces cone motion. A more compliant suspension or a larger moving mass will cause a lower resonance frequency, and vice versa. Usually it is less efficient to produce output at frequencies below F_s, though motion below F_s can cause uncontrolled motion, mechanically endangering the driver. Woofers typically have an F_s in the range of 13–60 Hz. Midranges usually have an F_s in the range of 60–500 Hz and tweeters between 500 Hz and 4 kHz.

Q_{ts}

A unitless measurement, characterizing the combined electric and mechanical damping of the driver. In electronics, Q is the inverse of the damping ratio. The value of Q_{ts} is proportional to the energy stored, divided by the energy dissipated, and is defined at resonance (F_s). Most drivers have Q_{ts} values between 0.2 and 0.8.

Q_{ms}

A unitless measurement, characterizing the mechanical damping of the driver, that is, the losses in the suspension (surround and spider.) A typical value is around 3. High Q_{ms} indicates lower damping losses, and low Q_{ms} indicates higher. The main effect of Q_{ms} is on the impedance of the driver, with high Q_{ms} drivers displaying a higher impedance peak. One predictor for low Q_{ms} is a metallic voice coil former of a particular configuration. These act as eddy-current brakes and increase damping, reducing Q_{ms}. The same former, with an electrical break in the cylinder (so no conducting loop) avoids these losses.

Q_{es}

A unitless measurement, describing the electrical damping of the loudspeaker. As the coil of wire moves through the magnetic field, it generates a current which opposes the motion of the coil. This so-called "Back-EMF" decreases the total current through the coil near the resonance frequency, reducing cone movement and increasing impedance. In most drivers, Q_{es} is the dominant factor in the voice coil damping.

$B\ell$

Measured in tesla-metres (T·m). Technically this is $B \times \ell$ (vector cross product or $B\ell\sin\theta\hat{n}$), but the standard geometry of a circular coil in an annular voice coil gap gives $\sin(\theta) = 1$. $B\ell$ is also known as the 'force factor' because the force on the coil imposed by the magnet is $B\ell$ multiplied by the current through the coil. The higher the $B\ell$ value, the larger the force generated by a given current flowing through the voice coil. $B\ell$ has a very strong effect on Q_{es}.

V_{as}

Measured in litres (L), is a measure of the free air 'stiffness' of the suspension -- the driver must be mounted in free air. It represents the volume of air that has the same stiffness as the driver's suspension when acted on by a piston of the same area (S_d) as the cone. Larger values mean lower stiffness, and generally require larger enclosures. V_{as} varies with the square of the diameter.

M_{ms}

Measured in grams (g), this is the mass of the cone, coil and other moving parts of a driver, including the acoustic load imposed by the air in contact with the driver cone. M_{md} is the cone mass without the acoustic load, and the two should not be confused. Some simulation software calculates M_{ms} when M_{md} is entered.

R_{ms}

Units are not usually given for this parameter, but it is in mechanical 'ohms'. R_{ms} is a measurement of the losses, or damping, in a driver's suspension and moving system. It is the main factor in determining Q_{ms}. R_{ms} is influenced by suspension topology, materials, and by the voice coil former (bobbin) material.

C_{ms}

Measured in metres per Newton (m/N). Describes the compliance (ie, the inverse of stiffness) of the suspension. The more compliant a suspension system is, the lower its stiffness, so the higher the V_{as} will be.

R_e

Measured in ohms (Ω), this is the DC resistance of the voice coil. American EIA standard RS-299A specifies that DCR should be at least 80% of the rated driver impedance, so an 8-ohm rated driver will have a DC resistance of at least 6.4 ohms, and a 4-ohm unit should measure 3.2 ohms minimum. Advertised values are often approximate at best.

L_e

Measured in millihenries (mH), this is the inductance of the voice coil. The coil is an inductor in part due to losses in the pole piece, so the apparent inductance changes with frequency. Large L_e values limit the high frequency output of the driver and cause response changes near cutoff. Simple modeling software often neglects the effects of L_e , and so does not include its consequences. Building a copper cap into the magnet structure can reduce this effect.

S_d

Measured in square metres (m^2). The effective area of the cone or diaphragm. It varies with the conformation of the cone, and details of the surround. Generally accepted as the cone body diameter plus half the width of the annulus (surround). Wide roll surrounds can have significantly less S_d than conventional types.

$X_{\max}$

Specified in millimeters (mm). In the simplest form, subtract the height of the voice coil winding from the height of the magnetic gap, take the absolute value and divide by 2. This technique was suggested by JBL's Mark Gander in a 1981 AES paper, as an indicator of a loudspeaker motor's linear range. Although easily determined, it neglects non-linearities and limitations introduced by the suspension. Subsequently, a combined mechanical/acoustical measure was suggested, in which a driver is progressively driven to high levels at low frequencies, with $X_{\max}$ determined at 10% THD. This method better represents actual driver performance, but is harder and more time-consuming to determine.

V_d

Specified in litres (L). The volume displaced by the cone, equal to the cone area (S_d) multiplied by $X_{\max}$. Any particular value may be achieved in any of several ways. For instance, by having a small cone with a large $X_{\max}$, or a large cone with a small $X_{\max}$. Comparing V_d values will give an indication of the maximum output of a driver at low frequencies. High $X_{\max}$, small cone diameter drivers are likely to be inefficient, since much of the voice coil winding will be outside the magnetic gap at any one time and will therefore contribute little or nothing to cone motion. Likewise, large cone diameter high $X_{\max}$ drivers are likely to be more efficient as they will not need, and so may not have, long voice coils.

η_0

Specified in percent (%). Comparing drivers by their reference efficiency is more useful than using 'sensitivity' since manufacturer sensitivity figures are too often overly optimistic.

Loudspeaker Parameter Measurement Worksheet

- Measure DCR across terminals to find R_e
- Measure resistance of source resistor R_s
- Measure the full impedance curve of the loudspeaker and identify:
  - The resonant frequency F_s
  - The frequency range where the loudspeaker is linear
- Set the frequency generator to a small voltage and to some frequency in the linear section and measure:
  - The voltage output of the amplifier across the speaker V_s
  - Calculate $I_s = V_s / (R_e + R_s)$
- Set the frequency generator to F_s and verify that the voltage across R_s is at a minimum.
  - Record the voltage across R_s as V_m
  - Record the frequency at which this occurs as a more exact F_s
- Calculate the following values
  - $I_m = V_m / R_s$
  - $R_m = (V_s - V_m) / I_m$
  - $r_0 = I_s / I_m$
  - $I_r = \sqrt{I_m I_s}$
  - $V_r = I_r R_s$
- Find the frequency on both sides of F_s at which the voltage across the resistor is V_r
  - F_+
  - F_-
- Verify that $F_s = \sqrt{F_+ F_-}$, if it does then continue, else you messed up.
- Then Q_{es} , Q_{ms} , and Q_{ts} can be calculated as follows
  - $Q_{ms} = \dfrac{F_s \sqrt{r_0}}{(F_+ - F_-)}$
  - $Q_{es} = \left(\dfrac{Q_{ms}}{r_0 - 1}\right)\left(\dfrac{R_e}{R_s + R_e}\right)$
  - $Q_{ts} = Q_{ms} \dfrac{Q_{es}}{(Q_{ms} + Q_{es})}$

- Method for measuring V_{as}
  - Choose a closed box with volume cubic of the nominal speaker diameter.
  - Calculate the total volume of loudspeaker and box as mounted V_b
  - Find the resonant frequency of the loudspeaker-box combination F_b
  - $V_{as} = V_b \left(\left(\dfrac{F_b}{F_s} \right)^2 - 1 \right)$
  - More accurate results should be found by measuring Q_{es} again with the box attached, Q_b .
  - $V_{as} = V_b \left(\dfrac{F_b Q_b}{F_s Q_{es}} - 1 \right)$

- Additional electrical and mechanical analogs [2]
  - $C_{mes} = \dfrac{M_{ms}}{B^2\ell^2}$
  - $F_s = \left(2\pi\sqrt{C_{ms}M_{ms}}\right)^{-1}$
  - $R_{es} = \dfrac{B^2\ell^2}{R_{ms}}$
  - $L_{ces} = B^2\ell^2 C_{ms}$
  - $Q_{es} = 2\pi R_e C_{mes} = \dfrac{2\pi F_s M_{ms} R_e}{B^2\ell^2}$
  - $Q_{ms} = 2\pi R_{es} C_{mes} = \dfrac{2\pi F_s M_{ms}}{R_{ms}}$
  - $V_{as} = \dfrac{\rho_0 c^2 {S_d}^2 L_{ces}}{B^2\ell^2} = \rho_0 c^2 {S_d}^2 C_{ms}$
  - $\eta_0 = \dfrac{4\pi^2 F_s^3 V_{as}}{c^3 Q_{es}}$

References

[1] Great simple definitions provided by http://en.wikipedia.org/wiki/Thiele/Small
[2] W. Leach, R. Schafer, T. Barnwell, "Time-Domain Measurement of Loudspeaker Driver Parameters," IEEE Trans. on ASSP, vol. 27, no. 6, pp. 734-739.