Technical Notes, Volume 1 Number 3A

Choosing JBL Low Frequency Transducers

A. Introduction:

JBL's low frequency (LF) transducers fall into three major categories, based on their relative efficiencies. Those models in the lowest efficiency category exhibit high linearity and are primarily used as subwoofers and low frequency applications in studio monitors. The mid-efficiency models find their greatest application in general sound contracting work, and the highest efficiency models excel for LF horn applications as well as use with musical instruments.

The mid-efficiency models are further available in JBL's standard magnetic configuration as well as in the Vented Gap Cooling (VGC) configuration introduced in 1990. The VGC products provide advantages in heavy duty applications, where their superior power dissipation results in low dynamic compression.

It is the purpose of this Technical Note to explain to the professional user how LF transducers are chosen for specific jobs. We will also explain in detail the elements of construction and design of the transducers which optimize them for their particular jobs.

B. The Basic Matrix:

The primary JBL transducers are grouped into a three-way matrix, shown as follows:

Table I.

SENSITIVITY	MEDIUM	HIGH		MAXIMUM
EFFICIENCY:	0.5% - 3%	2% - 6%	2% - 6%	4% - 10%
LINEARITY:	HIGH	MEDIUM (STANDARD)	MEDIUM (VGC)	LIMITED
460 mm (18 in)	2245H	2240H	2241H	(E155-8)
380 mm (15 in)	2235H	2225H,J (E140-8)	2226H,J	2220H,J (E130-8)
300 mm (12 in)	(128H-1)	2202H	2206H	(E120-8)

Those models enclosed in parentheses are not in the normal 2200-series line-up, but they fit structurally into the matrix in the slots indicated. The model 128H-1 is used as the LF driver in the Model 4412 studio monitor system.

C. Sensitivity vs. Efficiency:

It is important to understand the difference between sensitivity and efficiency. The reference efficiency of a transducer is a function of its electro-mechanical parameters and is normally expressed as a percentage of the input power which is converted to acoustical power in the so-called piston band range of the transducer, over which its response is essentially omnidirectional.

Sensitivity is a measure of sound pressure output at some reference distance on-axis with a reference input signal. In normal industry practice, the reference distance is taken as one meter (3.3 ft.). The input signal may be one watt, or perhaps a stated rms voltage (2.83 V is common, in that it is the applied voltage which will produce a power of one watt in an 8 ohm load). It is important to note the frequency band over which the sensitivity measurement is made. Normally, it is stated over a fairly wide range, perhaps as high as 2.5 kHz; in such cases, on-axis directional effects will result in high sensitivity ratings.

D. Detailed Description of the Matrix:

In this section we will describe in detail the internal parts of a loudspeaker. For those who are not familiar with JBL LF transducer construction, we present in Figure 1A a labeled section view. Figure 1B shows the added detail of the VGC magnetic structure. The cone, voice coil, and frame details of the VGC products are the same as shown in Figure 1A.

1. MEDIUM-SENSITIVITY TRANSDUCERS:

a. Uses:

Primary use is as LF transducers in monitor systems as well as subwoofer designed for recording studios and and motion picture theaters. For these purposes, long travel at low frequencies is essential, as is low distortion. Smooth HF response is also a requirement for proper transition to mid- and high-frequency transducers in the 400 Hz to 1 kHz range.

b. Sensitivity and Power Handling:

Table II.

MODEL	RATED SENSITIVITY (1 W, 1 m)	CONTINUOUS PROGRAM POWER	REFERENCE EFFICIENCY
2245H	95 dB	600 Watts	2.1%
2235H	93 dB	300 Watts	1.3%
128H-1	91 dB	200 Watts	0.86%

c. Internal Design and Construction:

VOICE COIL: Flat copper wire (see Table VI), extended over-hanging winding for maximum linearity (see Figure 2A); 100 mm (4 in) voice coil diameter used in larger models; 75 mm (3 in) voice coil diameter used in 128H-1.

VOICE COIL FORMERS: Made of aluminum, Kapton polyimide plastic, or a composite for effective heat sinking and mechanical integrity (see Table VII).

SPIDER (Inner Suspension): All models use a special design which reduces dynamic offset and instability at high drive levels, resulting in unusually low distortion and "tight" transient character.

CONE: Straight-sided and ribbed for stability. Fairly large mass for optimum balance of efficiency, bass output, and low distortion, Aquaplas™ coating used on 2245 and 128H-1 to optimize stiffness and mass; mass ring on 2235 for desirable efficiency and bass balance.

SURROUND (Outer Suspension): Half-roll of polyurethane foam for high compliance and long travel (see Figure 3A).

DUST DOME: Made of similar felted material as cone for smoothest HF response.

2. HIGH-SENSITIVITY TRANSDUCERS:

a. Uses:

Primary use is in sound and music reinforcement, mounted in horn and direct radiator reflex-type enclosures. For these purposes, LF cone excursion has been limited and sensitivity increased, relative to the transducers of the medium sensitivity class, in order to get greater output in the 50 or 60 Hz range up to 800 Hz.

b. Sensitivity and Power Handling:

Table III.

MODEL	SENSITIVITY (1 W @ 1 m)	CONTINUOUS PROGRAM POWER	REFERENCE EFFICIENCY
2240H	98 dB	600 W	5%
2225H,J	97 dB	400 W	3.5%
E140-8	100 dB	400 W	4.9%
2202H	99 dB	300 W	6%
VGC PRODUCTS			
2241G,H	98 dB	1200 W	2.9%
2226G,H,J	97 dB	1200 W	3.3%
2206H,J	95 dB	1200 W	2.5%

c. Internal Design and Construction:

VOICE COILS: Flat copper or aluminum wire, 100 mm (4 in) in diameter. Slightly over-hung in the magnetic gap (see Figure 2A) for proper balance of sensitivity and linearity.

VOICE COIL FORMERS: Made of aluminum, Kapton polyimide plastic, or a combination, for effective heat resistance and sinking, and rigidity.

SPIDER (Inner Suspension): All models use a special design which reduces dynamic offset and instability at high drive levels, resulting in unusually low distortion and a "tight" transient character.

CONE: Straight-sided and ribbed for stability; however, total moving mass is less than in the case of medium efficiency transducers, without added damping compounds or mass rings.

SURROUND (Outer Suspension): Multiple half-roll (see Figure 3B) provides controlled travel. Stiffness is optimized by depth of rolls, weave of cloth, and damping treatment.

DUST DOME: Made of similar felted material as cone for smoothest HF response.

The E140 is similar to the 2225, but with an aluminum dome and less voice coil overhang for slightly more midrange efficiency, peaked high-frequency output, and a "punchy" sound character.

The E145 and 2234 are specialized transducers that combine high efficiency with high linearity. The E145 has a short copper coil moving in a very deep magnetic gap (Figure 2B) for maximum voice coil control and excursion linearity. This design also provides maximum low frequency output from a given enclosure size. The E145 can move as much air as a high efficiency 460 mm (18 in) transducer.

The 2234 is identical to the 2235 with the deletion of the mass ring. This raises the efficiency (mid-band sensitivity) for multiple woofer applications. The 2234 is used in the 4435 studio monitor.

3. MAXIMUM SENSITIVITY TRANSDUCERS:

a. Uses:

Primarily in music reinforcement for driving LF horn systems. For these applications, the range of linear travel has been restricted in a trade-off for greater sensitivity in the 50 or 60 Hz range up to 1200 Hz.

b. Sensitivity and Power Handling:

Table IV.

MODEL	RATED SENSITIVITY (1 W, 1 m)	CONTINUOUS PROGRAM POWER	REFERENCE EFFICIENCY
E155-8	100 dB	600 Watts	4.9%
2220H,J	101 dB	200 Watts	8.7%
E130-8	105 dB	300 Watts	8.6%
E120-8	103 dB	300 Watts	8.6%

c. Internal Design and Construction:

VOICE COILS: Flat copper or aluminum wire, depending on transducer sensitivities. Voice coils either slightly underhang (2220) or overhang (E155) the top plate, or are of equal length (E120, E130) (see Figure 2C). Sensitivity is at a premium and is more important than linearity.

VOICE COIL FORMERS: Aluminum and Kapton polyimide plastic composite, for effective heat sinking and rigidity.

SPIDERS: Stiff, to keep resonance high.

CONE: "Curvilinear" on E120, E130, and 2220 and shown in Figure 4C. Curvilinear cones are thin and exhibit controlled high-frequency break-up for extended output. One piece cone/compliance construction provides increased top-end on E155, while straight sides and deep cone angle give rigidity.

SURROUND (Outer Suspension): Paper, integral with cone on E155. Multiple half-roll on E120, E130, and 2220.

DUST DOMES: Thin paper on 2220, aluminum on E120, E130, and E155 for extended HF response and minimum mass.

The E130 is similar to the 2220, but with an aluminum dome, and an aluminum voice coil equal in length to the magnetic gap, for maximum high-frequency output.

E. Comparative Frequency Response:

The three families of LF devices are normally mounted in different enclosure types; however, it is instructive to look at the frequency response of the three types mounted under similar conditions. Figure 5 shows the 2235, 2225, and 2220 mounted in a 280 liter (10 cubic foot) sealed enclosure. The curves were run in half space; that is, the enclosure front was flush with the large baffle surface.

At low frequencies, below about 60 Hz, all three drivers exhibit similar response. Above about 80 Hz, the three drivers diverge, and the 2235, the lowest sensitivity model of the three, levels off at a mid-band plateau of 93 dB. The 2225 continues to climb and does not level off until about 400 Hz at 97 dB. The 2220 levels off hardly at all, but we can see something of a plateau at about 101 dB in the 400 Hz range.

The mid-band levels of the three drivers are a result of their respective efficiencies, as is the reduction of the LF bandwidth of the curves.

Note the HF response of the three drivers. The 2235 begins to roll off at 1 kHz, and the slight peaks and dips in its roll-off characteristics are due to resonances in the polyurethane surround. Because of its lower mass, the 2225 reaches about 1600 Hz before it begins to roll off. It exhibits the smoothest roll-off characteristic of the group, due to its straight, ribbed cone and stiff, multiple half-roll surround. The 2220 exhibits the most extended response of the group, going out to 4 kHz before it rolls off sharply. This is due to break-up modes in its curvilinear cone.

Remember that each of the three transducer types is designed for a particular kind of enclosure and application, and that its sensitivity and bandwidth have been optimized for those applications.

F. Thiele/Small Parameters

While the high-frequency performance of a LF transducer is often unpredictable due to breakup modes and surround resonances, the precise nature of LF response can usually be accurately plotted beforehand through the use of the Thiele/Small parameters. All JBL ported enclosures have been designed using these parameters and, where possible, it is recommended that sound contractors use them. For the convenience of those who have need for designing special systems, we present here a tabulation of the Thiele/Small parameters for all JBL cone transducers which have been manufactured during the last two decades (see Table V). References which will be useful in Thiele/Small simulations are given at the end of this Technical Note (1,2).

Work done by D. B. Keele (3) has extended the usefulness of the Thiele/Small parameters to LF horn systems. Some details of this are shown in Figure 6, where both LF and HF roll-off frequencies have been related to specific Thiele/Small parameters. The high frequency mass roll-off of the driver in horn loaded use, f_{HM}, can be easily computed from the Thiele/Small parameters, and used as a strong indicator of how high in frequency a horn/driver system can be expected to produce power-flat output.

Field measurements of Thiele/Small parameters often show small variations in V_{as}, f_s, and Q_{ts}. These parameters are all affected by the stiffness of the cone surround and inner compliance, both of which may be influenced by temperature. In general, after a short period of use, the stiffness will settle into its target value. We hasten to point out that the stiffness variation will not cause actual response variations, inasmuch as the response, or low frequency alignment, of a loudspeaker system is dominated by enclosure volume, port tuning, and other parameters that are relatively constant.

G. Dynamic Compression in LF Transducers

An ideal loudspeaker should theoretically respond with the same frequency response with an input of 100 watts as with an input of 1 watt. There should only be 20 dB difference in level. In reality, considerable thermal and mechanical stresses are placed on a loudspeaker with high power inputs. Typically, they reduce its efficiency and alter its response. The change in performance from low to high power inputs is an important indicator of its behavior in many musical applications. Dynamic compression results from heating of the voice coil. It is the increase in resistance with heat that causes the signal compression.

Because of their large voice coils and heavy construction, JBL LF transducers have always exhibited relatively low dynamic compression, compared to competitive models with 2.5 inch diameter voice coils. However, JBL introduced the VGC products in an effort to reduce dynamic compression to even lower degrees and increase general power handling in the process. Figure 7 shows 1 watt and 100 watt superimposed compression curves for the JBL 2226H. The curves show compression on the order of 1.5 dB over the range from 100 Hz to about 2 kHz, with virtually no compression at lower frequencies.

H. Harmonic Distortion in LF Loudspeakers

1. MOTIONAL NON-LINEARITIES:

The voice coil length and top plate thickness can only indicate the potential excursion linearity of a loudspeaker (4). Unless the suspension elements are carefully matched to the motor structure, distortion and limited excursion will result. As the ends of the coil move outside the magnetic gap, at each position the motor strength is different from that observed when the voice coil is centered in its rest position. Under transient conditions the coil can actually jump forward, trying to move out of the gap. This is known as magnetic rectification, or DC offset, and it causes a high level of 2nd harmonic distortion to be generated as part of the transient signal. This effect is common to many long coil loudspeakers. By carefully choosing the stiffness characteristics of the outer suspension and spider, this offset can be eliminated and the linearity of the loudspeaker improved. JBL loudspeakers have inner suspensions which eliminate, or substantially reduce, DC offset. In some cases, this offset may be allowed to occur to a certain degree, to provide a desired musical effect. An example is the E140 bass instrument 380 mm (15 in) loudspeaker, where LF offset actually provides a "punchy" sound character.

Care must be taken that the suspension is not too stiff, or excursion will be limited. Also, if the suspension has a bias which prefers one direction of motion over the other, it can itself generate 2nd harmonic distortion as the voice coil tries to move against the bias. The E155 460 mm (18 in) bass instrument loudspeaker exhibits this suspension bias effect, giving it its distinctive low frequency sound character.

2. HARMONIC DISTORTION CHARACTERISTICS

The 2nd and 3rd harmonic distortion components generated by a loudspeaker, in combination with its fundamental output, create a complex "signature" which accurately defines a loudspeaker's sound and often enables us to identify it easily. Higher harmonics are also present, but their amplitudes are normally much lower than the 2nd and 3rd harmonic components.

Second harmonic distortion is caused by single-ended non-linearities, those preferring one direction of motion over the other. A non-linear bias in a suspension, improper centering of the rest position of the voice coil, and voice coil offsets will all cause 2nd harmonic generation. Flux modulation within the magnetic structure and simple cone break-up also generate 2nd harmonic distortion. In musical terms, the 2nd harmonic is the octave above the fundamental, and a consistently present 2nd harmonic, such as a flux modulation effect, adds a thick, muddy quality to the sound. Second harmonic effects which are a function of transient signals, such as DC offset or cone break-up, can be used to impart desirable sound characteristics to a loudspeaker's signature.

JBL's Symmetrical Field Geometry (SFG) magnetic structures significantly reduce flux modulation, as well as providing equal flux lines above and below the top plate. Through the action of SFG, both 2nd and 3rd harmonic distortion are greatly reduced.

Third harmonic distortion is caused by balanced non-linearities, those which are equally non-linear in both directions of motion. Third harmonic distortion rises with increasing frequency below 100 Hz as the voice coil motion exceeds the limits of the magnetic gap with increasing excursion. A suspension which restricts coil travel equally in both directions may cause this low frequency 3rd harmonic rise to occur sooner. Or, if it is precisely matched to the coil motion, it may actually improve coil linearity and reduce distortion.

High 3rd harmonic distortion in the mid-range band region can indicate magnetic gap magnetization effects or improper venting of the magnetic structure. The 3rd harmonic is the musical fifth above the octave, and it is generally not as tolerable to the ear as is 2nd harmonic distortion. It tends to add a harsh character to the sound. A square wave, for example, consists entirely of odd harmonics.

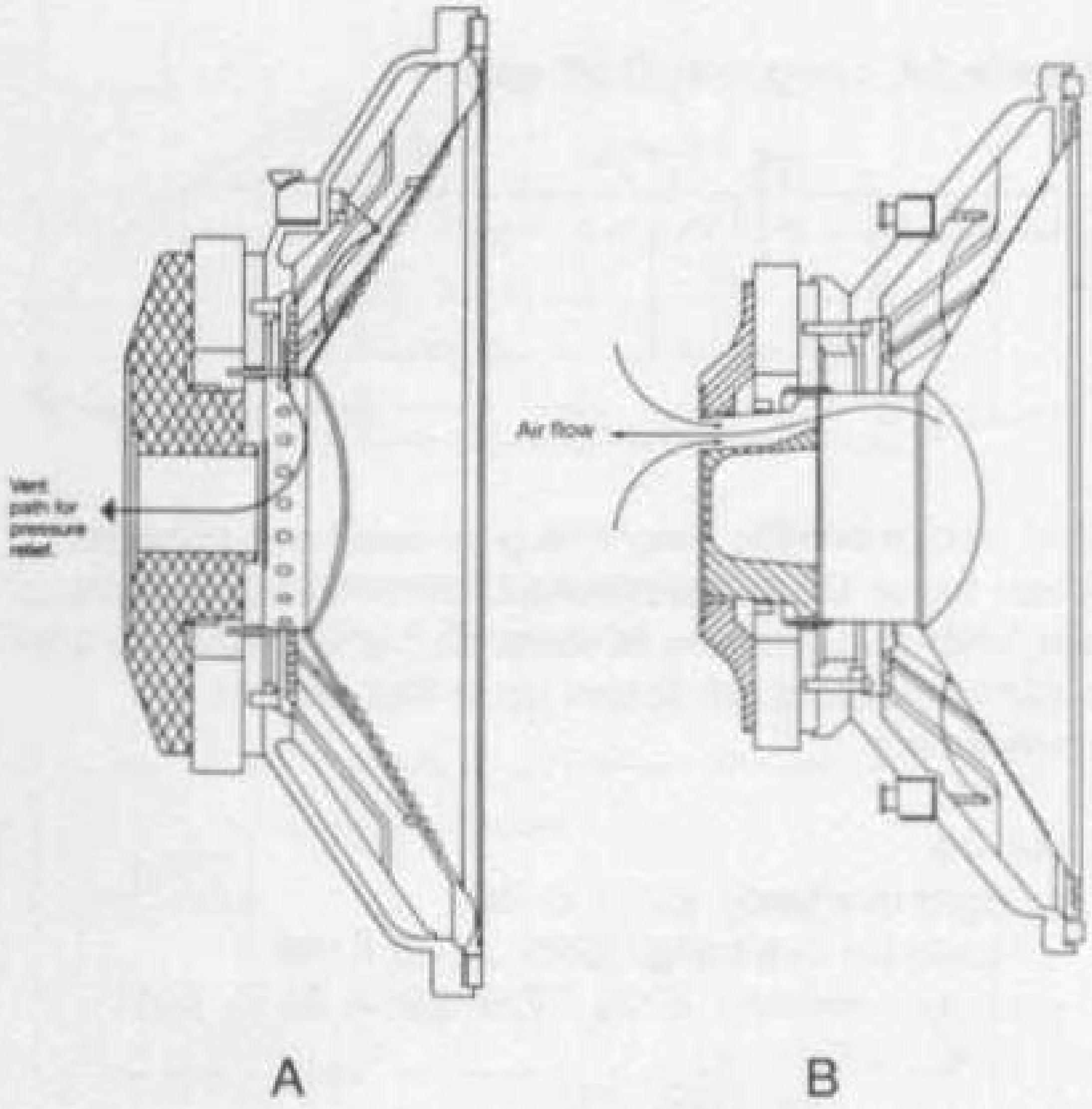
I. Sound Producers vs. Sound Reproducers

Another way of categorizing loudspeakers is to view them either as producers of sound or reproducers of sound. For the most part, JBL's E-Series loudspeakers are intended as producers of sound, while the 2200-Series products are reproducers of sound. As we have seen, there is a slight overlap of these functions in our basic matrix.

The following table summarizes the differences between the two types:

PRODUCERS	REPRODUCERS
E-SERIES	PRO-SERIES
RISING HF	FLAT RESPONSE
DYNAMIC NON-LINEARITIES	LINEAR
HF PEAKS	SMOOTH ROLL-OFF
FULL-RANGE USE	MF OR LF USE
SENSITIVITY:	SENSITIVITY:
500 - 2500 Hz, AVERAGED	100 - 500 Hz, AVERAGED
MODELS:	MODELS:
E110	2123
E120	2202, 2206
E130	2220
E140	2225, 2226
E145	2234
E155	2240, 2241

Figure 1. JBL Magnetic Structures. Standard ferrite (A); VGC (B).



REFERENCES:

1. G. Margolis and R. Small, "Personal Calculator Programs for Appropriate Vented-box and Closed-Box Loudspeaker System Design," Jour. Audio Eng. Soc., Vol. 29, No. 8, (June 1981)

2. J. Young and G. Margolis, "A Personal Calculator Program for Low-Frequency Horn Design Using Thiele/Small Driver Parameters," Preprint 1443. 62nd Convention of the AES (March 1979)

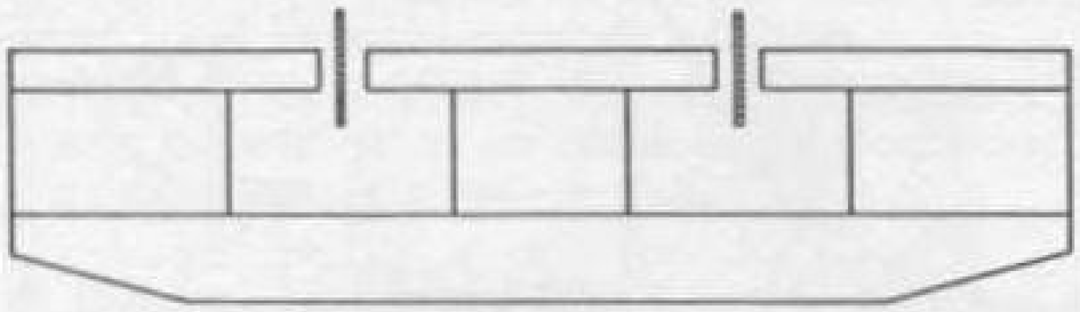
3. D. B. Keele, "Low-Frequency Horn Design Using Thiele/Small Driver Parameters," Preprint 1250. 57th Convention of the AES (May 1977)

4. M. R. Gander, "Loudspeaker Topology as an Indicator of Linear Excursion Capability," Jour. Audio Eng. Soc., Vol. 29, No. 11, (Jan, Feb 1981)

Figure 2. Three Voice Coil/Magnetic Gap Types

CROSS-SECTIONAL VIEWS OF LOUDSPEAKER MOTOR VOICE COIL AND MAGNET STRUCTURE

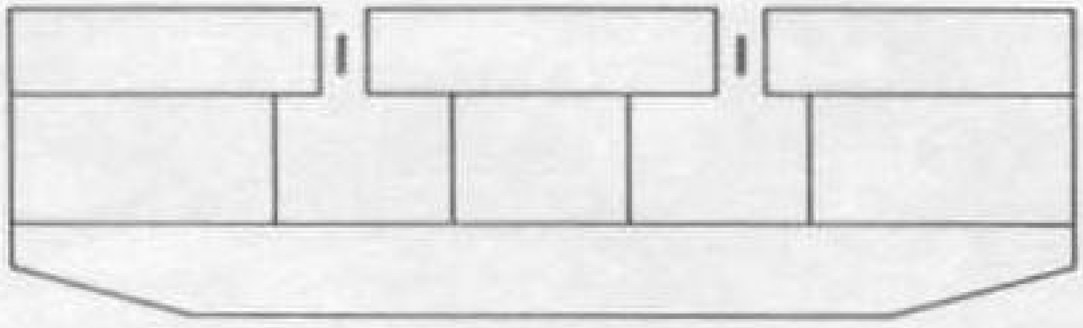
Figure 2A. Long coil/short gap



Coil moves outside magnetic gap, overhang provides linear travel. Requires precise choice of suspension elements to guarantee linearity. Both magnetic gap and voice coil depths are scaled up in 460 mm (18 in) transducers.

Used on:
  Slight overhang: 2202, E140
  Moderate overhang: 2225, 2240, E155
  Large overhang: 2206, 2226, 2234, 2235, 2241, 2245, 128H

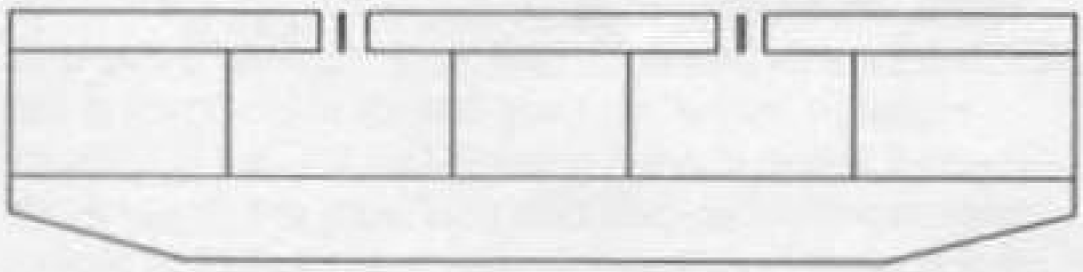
Figure 2B. Short coil/deep gap



Coil moves totally within gap for controlled response. Large heat sink, but expensive due to thick metal, large magnet required.

Used on:
  Slight gap overhang: 2220
  Very large overhang: E145

Figure 2C. Equal height coil and gap



Maximum efficiency: short, light coil completely within the maximum flux magnetic gap.
Minimal low frequency linearity, only what is provided by fringe flux.

Used on: E110, E120, E130

Figure 3. Different Types of Surrounds Compliances

Figure 3A. Half-roll of polyurethane foam

Low stiffness (high compliance) for long travel, but requires precise choice of centering spider for controlled linearity.

Used on: 2235, 2245, 128H, 2234

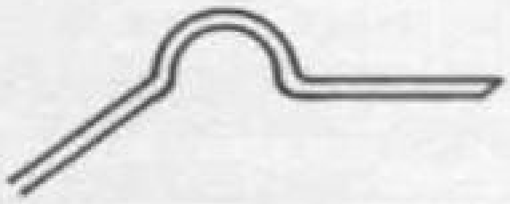


Figure 3B. Double half-roll cloth

Shapes of rolls can precisely "tune" stiffness characteristic

Used on: 2202, 2206, 2220, 2225, 2226, 2240, 2241, E120, E130, E140, E145

Figure 3C. Triple-roll treated cloth

Allows long excursion and is rugged.

Used on: 2206, 2226, 2241

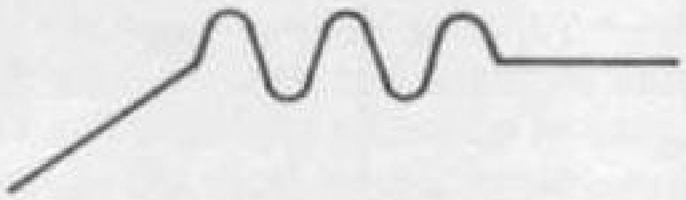


Figure 3D. Multiple-roll accordion pleat

Long travel, but prone to rim-resonance dip problems.

Used on: 2213 (4312 woofer)

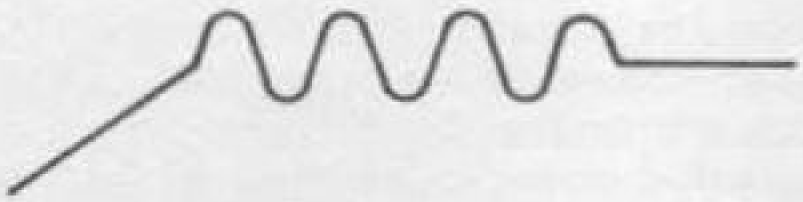


Figure 3E. One piece cone/compliance with treated edge

Stiff, non-linear suspension, provides HF resonance peak.

Used on: E155

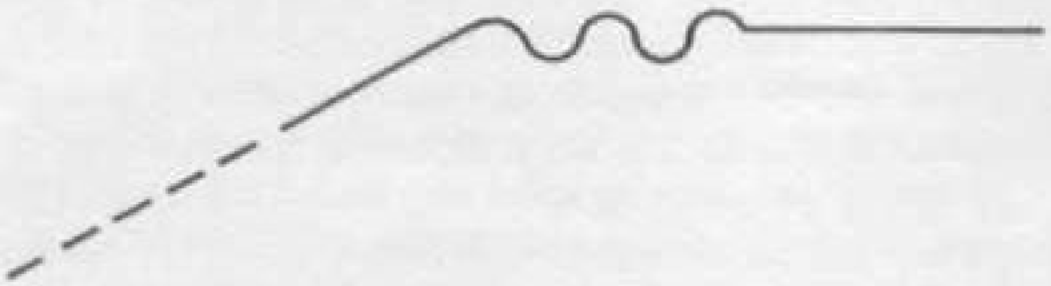


Figure 4. Different Cone Shapes

Figure 4A. Straight-sided cone with reinforcing ribs

Attempts to simulate theoretical piston action.

Used on: 2225, 2226, 2235, 2240, 2241, 2245, 128H,
2234, E140, 2206

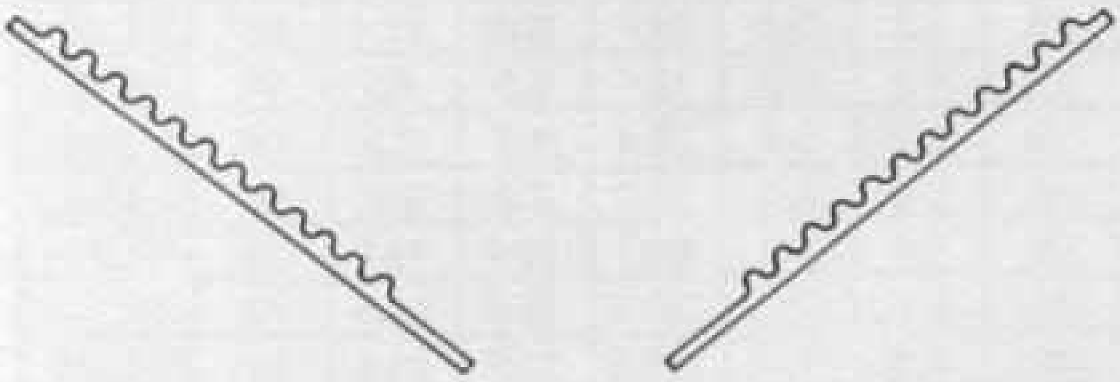


Figure 4B. Straight-sided smooth cone with deep cone angle

Uses deep cone angle to maintain rigidity.

Used on: E145, E155

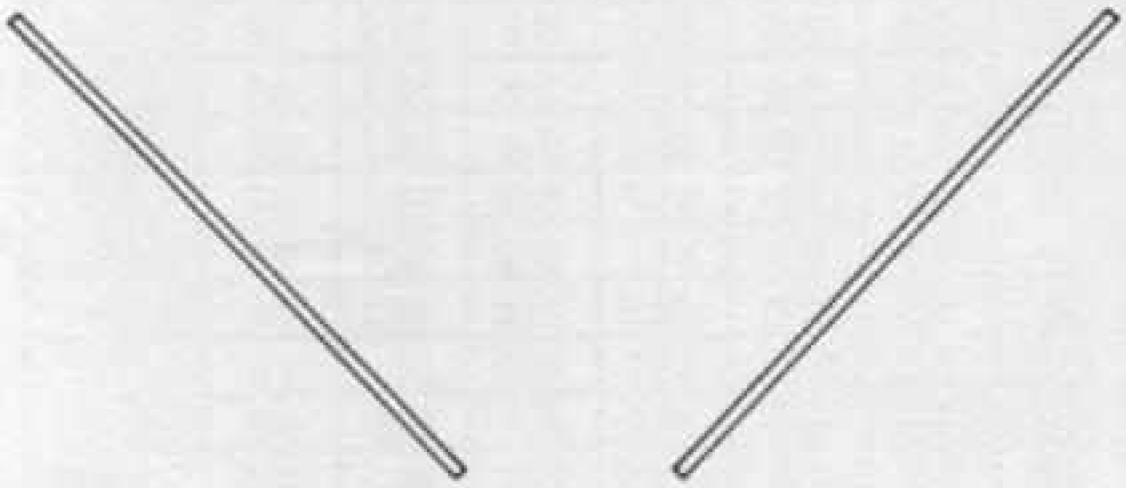


Figure 4C. Curvilinear cone

Cone flexing at mid-points provides greater high frequency output.

Used on: 2220, E110, E120, E130

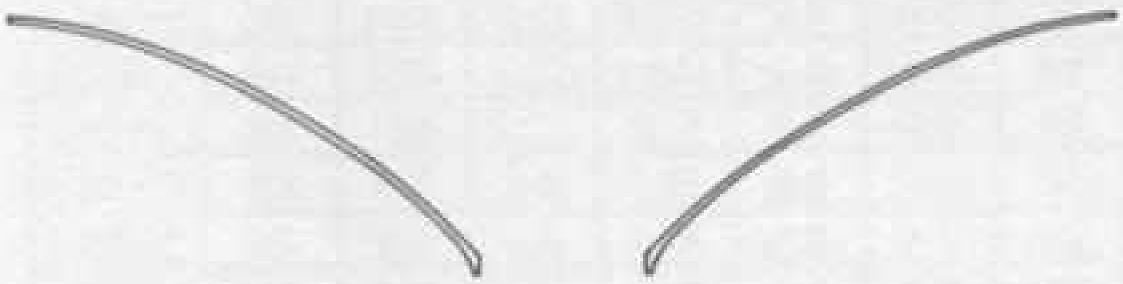


Figure 5. Relative Responses of JBL Models 2220 (Top Curve). 2225 (Middle Curve) and 2235 (Bottom Curve)

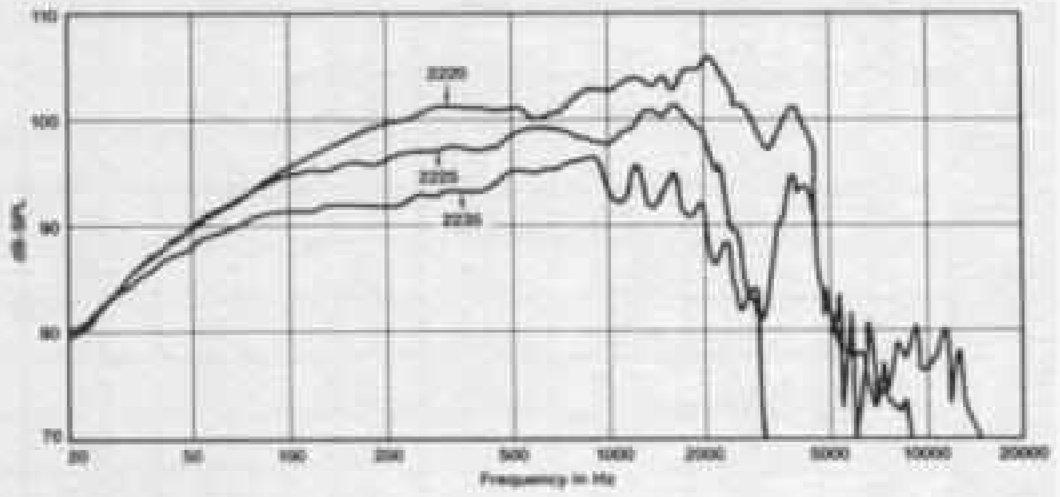
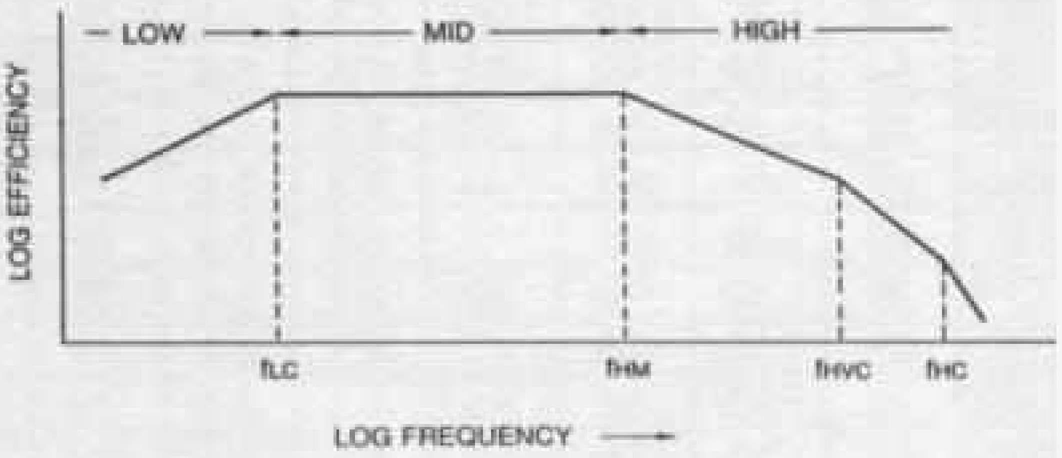


Figure 6. Use of Thiele/Small Parameters in Determining LF Horn Response



$$f_{LC} = Q_{TS}\, f_S/2$$

$$f_{HM} = \frac{2\, f_S}{Q_{TS}}$$

$$f_{HVC} = \frac{R_E}{\pi\, L_E}$$

$$f_{HC} = 2\, Q_{TS}\, f_S \left(\frac{V_{AS}}{V_{FC}}\right)$$

Figure 7. Dynamic Compression in LF Transducers (2226H)

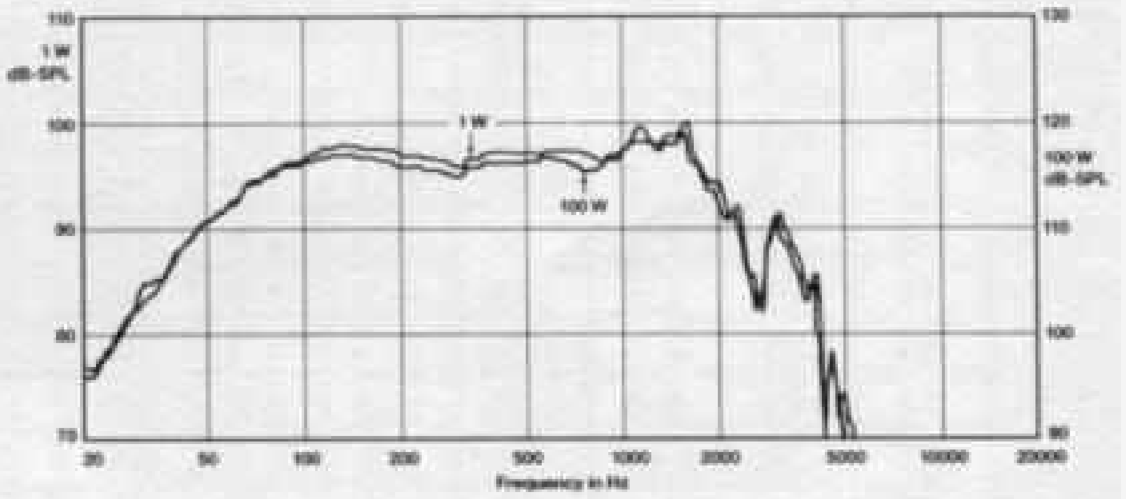


Table V.
Thiele/Small Parameters of JBL Drivers

MODEL	fs	Qts	Qms	Qes	Vas	Eff	Pe	Xmax	VD	Re	Le	SD	Dia	Bl	Mms	flux
112A	40	.21	4.0	.22	1.2	.90	60	.11	3	5.8	0.3	28.3	6.0	12.0	22	0.95
116A	28	.46	5.0	.51	2.6	.30	50	.19	5	5.2	0.6	28.3	6.0	6.7	25	0.85
122A	17	.23	7.0	0.24	12.0	.67	50	.27	22	5.7	1.5	81.7	10.2	16.0	100	1.08
123A	25	.49	8.5	.52	8.3	.68	50	.31	23	4.4	0.6	75.4	9.8	8.9	85	1.00
124A	16	.14	6.0	.14	14.1	1.1	100	.20	16	6.3	1.4	81.7	10.2	21.0	100	1.20
125A	25	.43	7.5	.46	8.3	.77	50	.19	14	5.2	0.7	75.4	9.8	7.5	32	0.85
127A	25	.43	7.5	.46	8.3	.77	50	.19	14	5.2	0.7	75.4	9.8	7.5	32	0.85
127H	25	.43	7.5	.46	8.4	.77	50	.19	9	6.6	0.7	49.0	7.9	7.5	33	1.07
128H	20	.24	7.0	.25	9.9	.86	100	.31	25	5.7	0.6	81.7	10.2	16.0	90	1.07
130A	37	.18	4.0	.19	10.5	7.7	100	.08	11	5.7	0.8	138.9	13.3	22.5	70	1.10
136A	16	.21	5.5	.22	26.0	1.4	100	.20	27	6.3	1.4	136.8	13.2	21.0	151	1.20
2105H	200	.53	3.0	.65	.035	1.2	25	.06	1	6.1	0.3	9.6	3.5	6.6	3.5	1.35
2108	40	.17	4.5	.18	1.3	1.2	75	.06	2	5.8	0.5	28.3	6.0	13.0	20	1.02
2110	60	.31	3.5	.34	1.2	2.1	25	.10	3	6.0	0.3	33.2	6.5	6.8	11	0.85
2115A	55	.48	4.0	.54	1.2	1.0	30	.22	6	5.5	0.3	28.3	6.0	6.8	11	0.85
2118H	85	.35	2.4	.40	0.5	2.1	100	.12	4	5.5	0.6	33.2	6.5	11.0	17	1.05
2118J	85	.35	2.4	.40	0.5	2.1	100	.12	4	10.3	0.9	33.2	6.5	15.0	17	1.05
2120	65	.36	4.0	.40	1.6	3.0	75	.06	3	6.0	0.4	49.0	7.9	10.3	17	1.02
2121	35	.19	5.5	.20	3.9	2.7	75	.06	3	6.8	0.9	49.0	7.9	12.7	25	1.00
2121H	35	.16	5.5	.17	3.9	2.7	75	.06	3	6.0	0.8	49.0	7.9	13.7	26	1.02
2122H	40	.23	1.9	.26	2.3	2.4	100	.12	6	5.8	0.6	50.3	8.0	13.2	28	1.02
2123H	85	.32	2.5	.37	0.7	3.5	250	.10	5	4.2	0.4	49.0	7.9	13.0	25	1.07
2123J	85	.32	2.5	.37	0.7	3.5	250	.10	5	8.7	0.8	49.0	7.9	18.7	25	1.07
2125	45	.45	4.5	.50	4.8	2.5	50	.10	8	6.0	0.5	81.7	10.2	12.4	45	1.00
2130	50	.20	4.0	.21	4.3	6.9	100	.06	5	6.3	0.6	81.7	10.2	18.0	35	1.20
2135	40	.25	4.0	.27	10.5	6.7	125	.06	8	6.3	0.6	138.6	13.2	18.0	60	1.20
2142H	72	.75	4.2	.92	1.6	1.82	100	.25	20	5.2	0.85	81.7	10.2			
2145A	30	.51	12.0	.53	5.5	.76	50	.14	10	5.0	0.4	67.9	9.3	9.4	50	1.00
2150	55	.64	5.0	.73	3.5	2.2	50	.10	12	5.5	1.0	116.9	12.2	22.3	105	1.20
2152H	85	.39	3.3	.44	1.3	5.1	150	0.1	8	4.5	0.5	81.7	10.2			
2155H	53	.47	4.47	.53	5.8	4.4	150	0.1	14	4.2	0.48	138.9	13.3			
2202A	50	.17	3.5	.18	3.1	5.5	100	.12	10	5.5	1.0	81.7	10.2	22.0	50	1.20
2202H	50	.16	3.5	.18	3.1	6.0	150	.14	11	5.5	1.1	81.7	10.2	22.5	50	1.20
2202J	50	.16	4.3	.18	3.1	6.0	150	.14	11	11.0	1.8	81.7	10.2	27.8	50	1.20
2203A	16	.14	6.0	.14	14.1	1.1	100	.20	16	6.3	1.4	81.7	10.2	21.0	100	1.20
2203H	16	.14	6.0	.14	14.1	1.1	100	.20	16	6.3	1.4	81.7	10.2	21.0	100	1.20
2204H	45	.35	1.7	.44	3.1	1.8	350	.27	22	6.2	0.7	83.3	10.3	15.0	57	1.20
2204J	45	.35	1.7	.44	3.1	1.8	350	.27	22	12.4	1.6	83.3	10.3	25.5	57	1.20
2205A	30	.21	5.0	.22	10.5	3.5	150	.10	14	5.5	1.3	138.9	13.3	22.3	105	1.20
2205H	30	.21	5.0	.22	10.5	3.5	150	.10	14	5.5	1.3	138.9	13.3	22.3	105	1.20
2206H	52	.32	4.45	.34	2.2	2.5	600	.30	25	5.3	1.5	84.9	10.4	18.1	65	
2213	25	.49	8.5	.52	8.3	.68	50	.31	23	4.4	0.6	75.4	9.8	8.9	85	1.00
2213H	25	.49	8.5	.52	8.3	.68	75	.31	23	4.4	0.6	75.4	9.8	8.9	85	1.00
2214H	23	.24	10.5	.25	7.9	1.1	200	.26	21	5.6	1.3	81.7	10.2	16.0	90	1.07
2215H	20	.21	5.5	.22	26.0	2.6	100	.16	22	5.7	1.0	138.9	13.3	22.0	97	0.90
2215A	20	.21	5.5	.22	26.0	2.6	100	.16	22	8.8	2.2	136.8	13.2	22.0	97	0.90
2220A	37	.18	4.0	.19	10.5	7.7	100	.08	11	5.7	0.8	138.9	13.3	22.5	70	1.10
2220H	37	.17	5.0	.18	10.5	8.7	200	.12	17	5.7	1.0	138.9	13.3	22.5	70	1.15
2220J	37	.17	5.0	.18	10.5	8.7	200	.12	17	13.2	2.0	138.9	13.3	34.0	70	1.15
2225H	40	.28	2.5	.31	6.0	3.5	200	.20	28	6.3	1.1	138.9	13.3	23.0	105	1.20
MODEL	fs	Qts	Qms	Qes	Vas	Eff	Pe	Xmax	VD	Re	Le	SD	Dia	Bl	Mms	flux

Table V.
Thiele/Small Parameters of JBL Drivers

MODEL	fs	Qts	Qms	Qes	Vas	Eff	Pe	Xmax	VD	Re	Le	SD	Dia	Bl	Mms	flux
2225J	40	.28	2.5	.31	6.0	3.5	200	.20	28	12.9	2.2	138.9	13.3	34.0	105	1.20
2226G	40	.31	5.0	.33	6.2	3.3	600	.30	41	2.5	0.92	136.8	13.2	13.5	98	
2226H	40	.31	5.0	.33	6.2	3.3	600	.30	41	5.0	1.75	136.8	13.2	19.2	98	
2226J	40	.31	5.0	.33	6.2	3.3	600	.30	41	10.0	3.5	136.8	13.2	27.1	98	
2231A	16	.21	5.5	.22	26.0	1.4	100	.20	27	6.3	1.4	136.8	13.2	21.0	151	1.20
2231H	16	.21	5.5	.22	26.0	1.4	100	.20	27	6.3	1.4	136.8	13.2	21.0	151	1.20
2234H	23	.22	2.0	.25	16.2	2.1	150	.33	46	6.0	1.2	138.9	13.3	20.5	105	1.20
2235H	20	.25	2.5	.28	16.2	1.3	150	.33	46	6.0	1.2	138.9	13.3	20.5	155	1.20
2240G	30	.25	2.5	.25	17.0	5.0	300	.22	44	2.5	0.7	201.1	16.0	17.1	164	1.22
2240H	30	.23	2.2	.25	17.0	5.0	300	.22	44	6.0	1.4	201.1	16.0	25.0	164	1.22
2241G	35	.40	5.7	.43	11.0	2.9	600	.30	57	2.5	0.86	191.1	15.6	13.6	145	
2241H	35	.40	5.7	.43	11.0	2.9	600	.30	57	5.0	1.75	191.1	15.6	19.2	145	
2245H	20	.27	2.2	.27	29.0	2.1	300	.38	76	5.8	1.4	201.1	16.0	21.0	185	1.22
D123	45	.45	4.5	.50	4.8	2.5	50	.10	8	6.0	0.5	81.7	10.2	12.4	45	1.00
D130	40	.25	4.0	.27	10.5	6.7	75	.03	4	6.3	0.6	139	13.3	18.0	60	1.20
D131	50	.18	8.5	.18	4.5	8.4	75	.03	2	6.3	0.5	81.7	10.2	18.0	35	1.20
D208	60	.31	3.5	.34	1.2	2.1	25	.10	3	6.0	0.3	33.2	6.5	6.8	11	0.85
E110	65	.36	4.0	.40	1.6	3.0	75	.10	5	6.0	0.4	49.0	7.9	12.1	21	1.03
E120	60	.17	1.8	.19	2.8	8.6	150	.12	10	6.3	0.4	81.7	10.2	21.7	36	1.35
E130	40	.19	1.8	.21	10.5	8.6	150	.10	14	6.3	0.4	138.9	13.3	21.1	60	1.35
E140	32	.17	5.0	.19	10.5	4.9	200	.14	19	5.5	1.1	138.9	13.3	24.1	94	1.35
E145	35	.25	6.0	.26	9.7	4.3	150	.28	39	5.7	1.6	138.9	13.3	16.1	55	0.97
E155-4	30	.20	2.2	.22	15.0	4.9	300	.20	35	2.5	0.7	176.7	15.0	17.1	125	1.22
E155-8	30	.20	2.2	.22	15.0	4.9	300	.20	35	6.0	1.4	176.7	15.0	25.0	125	1.22
G125-8	65	.32	5.5	.34	2.5	5.5	200	.10	8	5.2	0.5	81.7	10.2	13.7	37	0.98
G135-8	45	.36	5.5	.38	8.3	5.5	200	.10	14	5.2	0.5	138.9	13.3	13.7	60	0.98
G135-A	45	.48	6.6	.51	7.7	3.8	200	.24	33	6.0	0.75	138.9	13.3	15.8	60	0.98
K110	65	.36	4.0	.40	1.6	3.0	75	.06	3	6.0	0.4	49.0	7.9	10.3	17	1.02
K120	50	.20	4.0	.21	4.3	6.9	100	.06	5	6.3	0.6	81.7	10.2	18.0	35	1.20
K130	40	.25	4.0	.27	10.5	6.7	125	.03	4	6.3	0.6	138.9	13.3	18.0	60	1.20
K140	30	.21	5.0	.22	10.5	3.5	150	.20	28	5.5	1.3	138.9	13.3	22.3	105	1.20
K145	35	.29	6.0	.30	8.6	3.4	150	.20	25	8.8	2.2	122.7	12.5	21.7	75	0.90
K151	30	.27	6.0	.28	12.9	3.4	150	.10	17	6.0	2.0	165.1	14.5	22.0	125	1.20
LE5-10	250	1.0	3.0	1.6	.026	.69	25	.06	1	6.0	.05	9.6	3.5	4.3	3	1.30
LE8T	45	.49	4.0	.55	1.2	0.5	25	.18	5	5.5	0.3	28.3	6.0	6.2	16	0.85
LE8TH	45	.56	4.0	.65	1.2	0.5	25	.22	6	5.5	0.3	28.3	6.0	6.2	16	0.85
LE10A	30	.41	6.0	.44	3.6	0.6	75	.24	12	4.4	0.6	49.0	7.9	8.1	35	1.02
LE10H	33	.37	6.9	.39	2.7	0.7	75	.24	12	4.8	0.6	49.0	7.9	9.7	40	1.02
LE111A	25	.17	6.0	.18	3.6	0.87	75	.24	12	5.7	1.5	49.0	7.9	16.0	50	1.08
LE12C	30	.51	12.0	.53	5.5	0.76	50	.14	10	5.0	0.4	67.9	9.3	9.4	50	1.00
LE14A	28	.32	6.5	.34	5.2	0.95	100	.20	20	6.3	1.4	102.1	11.4	21.5	140	1.20
LE14H	26	.27	2.3	.30	5.2	0.89	150	.33	34	5.9	1.3	102.1	11.4	22.0	139	1.25
LE15A	20	.21	5.5	.22	26.0	2.6	100	.16	22	8.8	2.2	136.8	13.2	22.0	97	0.90
MI-10	75	.33	1.8	.41	1.3	3.5	150	.12	6	5.6	0.6	52.8	8.2			
MI-12	65	.46	2.2	.58	2.7	3.5	150	.12	10	5.6	0.6	84.9	10.4			
MI-15	55	.62	2.8	.79	6.0	3.5	150	.12	17	5.6	0.6	138.9	13.3			
MI-15A	40	.42	4.0	.47	9.6	3.5	150	.14	19	5.6	0.9	138.9	13.3			
M121-8	60	.245	4.0	.25	2.5	6.0	300	.18	15	5.2	0.63	81.7	10.2	17.5	39	
M151-8	45	.25	4.8	.27	7.0	6.5	300	.20	27	4.8	0.72	136.8	13.2	18.8	70	
MODEL	fs	Qts	Qms	Qes	Vas	Eff	Pe	Xmax	VD	Re	Le	SD	Dia	Bl	Mms	flux

Table V.

Thiele/Small Low Frequency Driver Parameters and Definitions

NOTE: The Parameters marked with an (*) asterisk are the minimum set required for a complete low frequency system design.

SMALL SIGNAL

PARAMETER	DESCRIPTION	UNITS
*f_S	Resonance frequency of driver in free-air	hertz
*Q_{ts}	Total of driver at "fs" including driver loss mechanism	dimensionless
*Eff	Reference efficiency h_o (half-space acoustic load)	%
*V_{as}	Volume of air having same acoustic compliance as driver suspension	cubic feet
Q_{es}	Q of driver as "f_S"considering electromagnetic damping only	dimensionless
Q_{ms}	Q of driver at "f_S"considering mechanical loss mechanism only (non-electromagnetic)	dimensionless
L_e	Voice coil inductance	mH

LARGE SIGNAL

PARAMETER	DESCRIPTION	UNITS
*P_e(Max)	Thermally-limited maximum electrical input power	watts
X_{max}	Peak linear displacement of driver diaphragm (0 to peak)	inches
S_D	Effective projected surface area of driver diaphragm	square inches
*V_D	Peak displacement volume of driver diaphragm (0 to peak)	cubic inches
*R_E	dc resistance of driver voice coil	ohms

MISC. DATA

PARAMETER	DESCRIPTION	UNITS
Dia	Piston diameter	inches
Bl	Bl Product	N/A (Newtons/ampere)
M_{ms}	Effective moving mass	grams
flux	Flux density	tesla

Table VI. Voice Coil Wire

<table>
<tr><th>Material</th><th>Characteristics</th><th>Used On</th></tr>
<tr><td>Aluminum</td><td>Fragile – Difficult to solder
Light – Highest efficiency
High resistance – Lower inductance increases high frequency output</td><td>Cone transducers for maximum efficiency and high frequency output (Sensitivity)
Horn compression drivers</td></tr>
<tr><td>Copper</td><td>Rugged – Highest power handling
Heavy – Additional mass reduces effects.
Low resistance – More turns increases "Bl" factor (Motor strength)</td><td>Low frequency transducers for ruggedness, resistance to thermal compression effects.</td></tr>
<tr><td colspan="3">Ribbon wire voice coils use flat milled wire for greater wire density within the available magnetic gap space, hence greater efficiency.</td></tr>
</table>

Table VII. Voice Coil Form Materials

<table>
<tr><td colspan="3">Support tube, bobbin, supports voice coil within magnetic gap and connects coil to cone. Must maintain concentricity (roundness) and strength and at high temperatures and forces.</td></tr>
<tr><th>Name</th><th>Type</th><th>Characteristics</th></tr>
<tr><td>Kraft paper
Bond paper</td><td>Wood pulp
Rag, cloth</td><td>Low power designs
Light, but fragile</td></tr>
<tr><td>Nomex (DuPont™)</td><td>High temperature nylon paper (Polyimide)</td><td>Temperature resistance; good adhesion properties for bonding (gluing)</td></tr>
<tr><td>Kapton (DuPont™)</td><td>Plastic film (Polyimide)</td><td>Insulator. Higher temperature than Nomex, high stiffness, difficult to glue.</td></tr>
<tr><td>Aluminum</td><td>Thin foil film.
Various thicknesses</td><td>Stiff, rigid, conducts heat for additional voice coil sinking. Can act as shorted turn on moving assembly, creating eddy currents which add damping to reduce bass, high end.</td></tr>
</table>