HORN-LOADED LOUDSPEAKERS

BY

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Abstract.—Direct radiation from a loudspeaker moving system is comparatively economical, but places a limit upon reproduction in the piston range. Components of a reproducing system should balance in quality for most effective results per dollar. Low-end performance depends to a great degree upon the enclosure, but is not improved markedly by increasing the enclosure size beyond a point. The transformer action of a horn achieves greater loading, high efficiency, lowered distortion, and smoother response. Useful boost of low-end output can be attained by proper horn-loading design, but space requirements have limited the application. A new back-loading horn enclosure of moderate size does not require a corner for efficient operation. Output is substantial at 30 cycles, and efficiency is four to six db above that of a conventional enclosure.

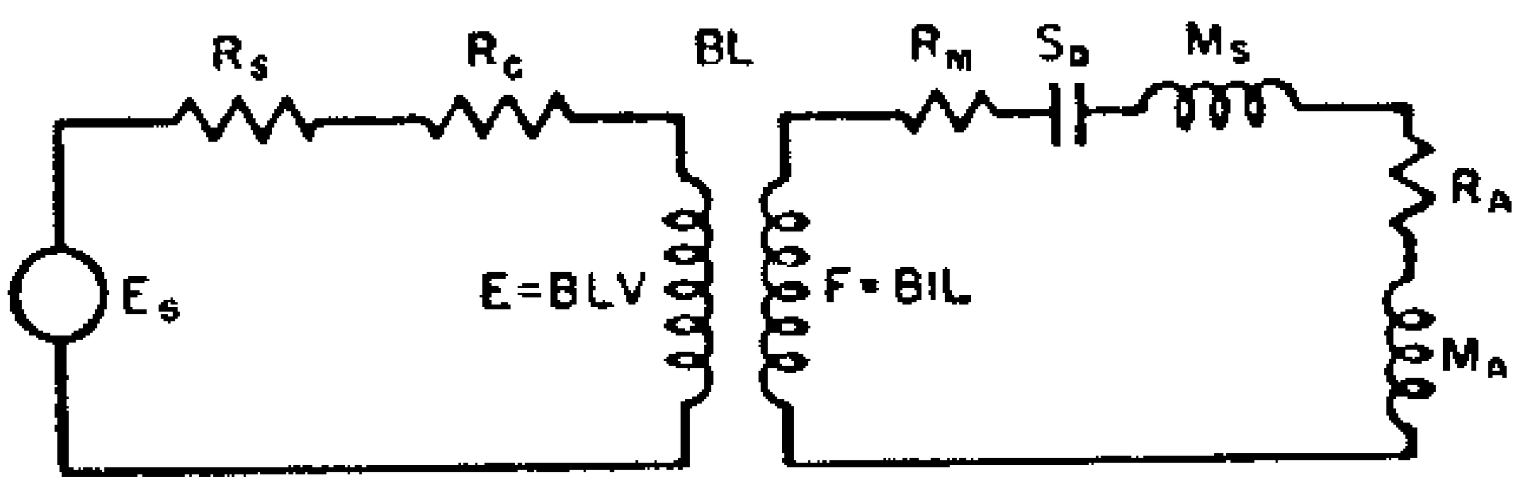
I. INTRODUCTION

There are two kinds of radiation means used to produce sound from a speaker. One is to couple the moving system to the air by the transformer-like action of a loading horn. The more common method is to couple the cone directly to the air, in the so-called direct radiator, or cone type unit. Most speakers used today are of the cone type. Cost is relatively low, ranging from a dollar or two at retail level for the smaller sizes to $50 or more for a 15-inch unit. Efficiency of the direct radiator is poor, being two to three per cent for smaller magnet sizes. Use of extremely large magnets can boost efficiency to about 10 per cent, but at a disproportionately high cost. It is cheaper to increase the electrical watts output of an amplifier source than to increase the speaker efficiency beyond a point where decibels must be balanced against cost. However, there are other considerations in favor of the higher efficiency units. Heavier magnetic structures can furnish improved damping and transient response.

Examination of the early "dynamic" speakers shows little fundamental difference in their basic construction from the cone speaker of today. Magnetic materials and circuits are considerably improved, yielding much greater efficiency and response smoothness in today's product. Cone and spider materials are better, and with the materials available the moving systems have run the gamut of variation based upon weight and contour. But the modern speaker looks very much like the first "dynamic" speakers, with similar response balance and fundamental resonance.

It should not be inferred from this that the design or operation of a moving system is simple.

The operation can be predicted quite well over a relatively narrow band called the piston range, in which the cone moves as one piece. Design equations necessarily refer to operation in this range. The piston range of practically all speakers covers four to four and one-half octaves. Below resonance, response falls off rapidly, and above the piston range the cone no longer moves as a unit. As the frequency is increased beyond the top limit of the piston range, the cone goes into a variety of radial and circumferential modes of vibration which makes scientific prediction and analysis very difficult. Here, speaker design becomes an art, based to a great degree upon empirical work.



DIRECT RADIATOR EQUIVALENT CIRCUIT IN INFINITE BAFFLE

R_S = SOURCE IMPEDANCE
R_C = VOICE COIL RESISTANCE
BL = FORCE FACTOR
R_M = MECHANICAL RESISTANCE
S_D = SUSPENSION STIFFNESS
M_S = DYNAMIC MASS OF SPEAKER
R_A = RADIATION RESISTANCE
M_A = RADIATION MASS

Fig. 1—Direct radiator equivalent circuit.

Figure 1 shows the equivalent circuit of a direct radiator in an infinite baffle. Radiation resistance at low frequency for a typical 15-inch high efficiency speaker is measured in hundreds of ohms, while the mechanical resistance losses in the same speaker are measured in thousands of ohms. So regardless of the amount of magnet used, theoretical efficiency at resonance is limited. However, the higher the product of flux density and voice coil wire length, the more favorable the ratio between reflected radiation resistance and voice coil resistance.

A practical result of the change of cone operation to various modes is to allow considerable extension of the response. Current practice in advertising in the industry is to claim for single motor speakers another three to four octaves response beyond the four to four and one-half in the piston range. Much of this response extension, especially where elements such as double cones or aluminum domes are used, is accompanied by a choppy sound pressure on the speaker axis, and the presence of strong sound pressure lobes at various angles from the axis. Regardless of the method used for extension beyond the piston range, the total radiation output begins dropping at a point far below the high frequency cutoff of the speaker. In the case of 10-inch and 12-inch sizes, this point usually occurs at 5000 to 6000 cycles.

Changeover from piston to modal operation at the higher frequencies is accompanied usually by effects which tend to reduce the value of range extension. The resulting generation of spurious sounds, called breakups or birdies, in sine wave operation gets the most attention, as this phenomenon is easily noticed and measured. Actually these sounds rarely are troublesome in actual operation of the speaker, and are noticeable only upon sustained application of a single note at the particular frequencies of occurrence. More serious for the most critical applications are the response roughness, transient, harmonic, and intermodulation distortion resulting. An analysis of existing commercial designs indicates that at the present stage of the art, the best compromise between extreme top-frequency limit and other important factors is to design around conventional domes, cones, and suspensions. Multi-channel systems, of course, are widely used to hold the operating range of speakers more nearly within the piston-range octaves.

II. DRIVING AMPLIFIER DAMPING

Beside these considerations, the quality of a speaker depends upon its size and upon the magnetic energy available. For frequencies in the piston range, the larger the cone the less the excursion which is necessary for a given amount of output, the less the distortion arising from non-linearities in the moving system. Greater magnetic energy makes greater damping possible. Damping also depends upon the internal impedance of the driving amplifier. The current trend in amplifiers is to aim at an internal impedance which is a fraction of the rated output impedance of the amplifier.

For instance, in some of the more expensive amplifiers intended to drive 16-ohm speakers the rated internal impedance is a small fraction of an ohm. This excellent regulation is better than required for critical damping of high quality speakers. The d-c resistance of a 16-ohm speaker voice coil is about eight to twelve ohms. The point of diminishing returns from the standpoint of damping would seem to be reached when the amplifier internal impedance is brought down to as low as one-third to one-fifth that of the voice coil resistance. In the case of the 16-ohm system two to four ohms, or roughly one to two db regulation, appears satisfactory. For a balance in damping qualities as well as response, the present state of the art dictates that considerably more money must be spent for the speaker than for the amplifier, if the quality of all the elements of the listening system is to be in line.

In one respect, an amplifier of extremely good regulation punishes the speaker performance. A highly efficient speaker, that is, one with high magnetic energy, has an impedance rise in the region of fundamental resonance which can be as high as 10 to 15 times the rated speaker impedance. This condition reduces the amount of power that can be drawn from the amplifier at resonance, especially where the amplifier approaches the constant voltage or perfect regulation condition. The effect may be that of less bass response than if an amplifier of poor regulation is used. As damping is highly desirable from the standpoint of transient performance, response smoothness, and efficiency, what can be done to achieve a boost in low frequency output of a good speaker on a good amplifier?

III. BASS OUTPUT INCREASE

Adjustable bass-boost in the amplifier is usually desirable to compensate for listening levels lower than the level of original program, and for bass deficiency in some program material. There are ways to increase the speaker efficiency, too.

At low frequencies the speaker is no better than the enclosure used with it. A properly tuned bass-reflex enclosure delivers more low-frequency output at lower distortion than can be obtained from open-backed or closed-box type cabinets. Over about one octave, movement of the cone is less, while the port radiates most of the power. The reduced cone movement lowers distortion generated by non-linearities in the moving system and magnetic field. Increasing the enclosure size beyond a point gains little in practical performance. In the case of a 15-inch speaker, this point is eight to nine cubic feet.

A tuned pipe, or column, enclosure can add large thumps at resonant frequencies of multiples of one-quarter wave. The problem with this type enclosure is loss of level where the enclosure is not resonant. Absorption damping is required to reduce roughening effects of resonances of higher order than the fundamental.

A good method of increasing low-frequency output is to mount a number of speakers in a large enclosure. This does not mean that two speakers of cone area equal to one larger speaker cone will be superior to the larger one, however. Area is what counts. Resonance of the speakers must be low enough for the intended purpose, as operation will not be improved below their resonant frequency. The size of the enclosure should be greater than that used for a single speaker.

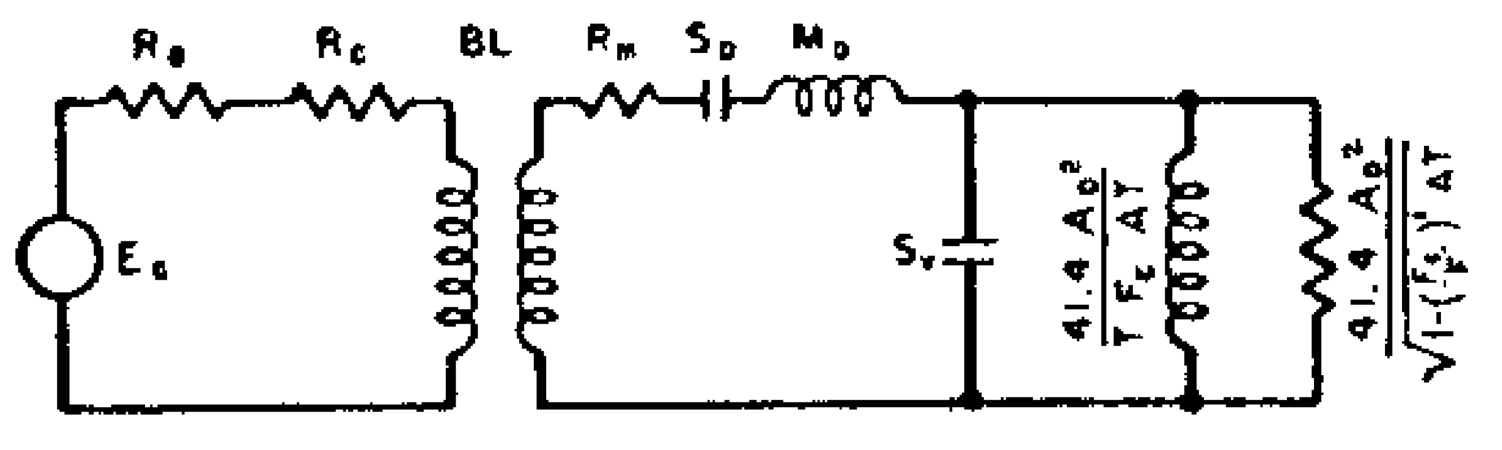


Fig. 2—Horn speaker equivalent circuit.

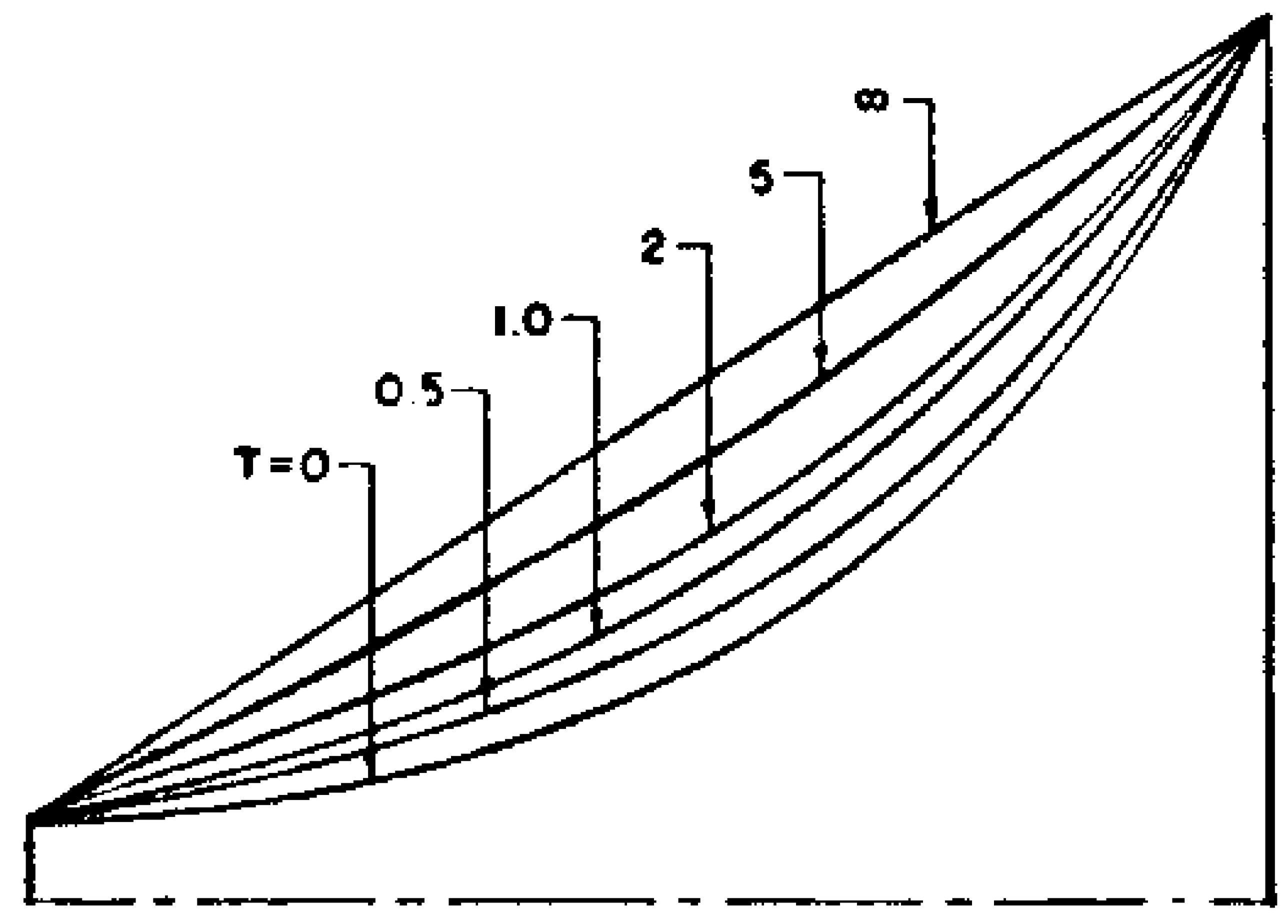


Fig. 3—Hypex horn flares.

The most effective way to boost the output of the speaker is to load the cone with a horn. The horn acts like a transformer to give the speaker a higher radiation-resistance load. Figure 2 shows the equivalent circuit of a horn-loaded speaker. Here, the ratio of radiation resistance to mechanical losses can be more favorable than in the case of a direct radiator. At low frequency, the loading on a 15-inch speaker cone can be measured in tens of thousands of ohms, instead of hundreds of ohms when an infinite baffle is used. Resulting advantages of high efficiency, low distortion, and high power handling capacity come from the decreased cone movement.

Horn-type units of the medium-frequency type long have been used commercially for public address work, both with straight and folded horns. More recently, middle- and high-frequency horns have given a boost to the high-fidelity audio industry. These units radiate into what is essentially free space, and in this case a minimum mouth size is required to prevent reflections which roughen response, and to attain necessary output. Radiating members in horn driver units usually are called diaphragms instead of cones; these are mostly of phenolic composition, with natural or synthetic cloth base. This type diaphragm is more rugged than metal, and has a greater resistance to emission of spurious sounds during operation.

The fundamental parameters of a horn are the throat size, mouth size, and flare. These parameters determine the frequency band over which the horn is effective. While the exponential flare is widely used, an advantage in operation near cut-off can be obtained with hyperbolic flares shaped from a formula trade-marked Hypex. Figure 3 shows the shapes of various Hypex flares possible. The parameter T determines the flare shape.

For some time horn loading has been used in conjunction with conventional direct radiator speakers as drivers for theater and outdoor use, for low frequency reproduction. The same design elements apply to horns for low frequencies as for medium and high frequencies, except that two factors are smaller problems in actual performance. Spatial distribution is no longer a problem at low frequencies, and configuration of the mouth and the flare are of less consequence. Mouth size compared to wavelength of the sound can be less than in higher frequency units radiating into space. The reason is that the floor, walls, and other large surfaces close to the mouth effectively act to create mirror images of the radiating surface, thus raising the radiation resistance and increasing efficiency. For free-space radiation a satisfactory rough figure of mouth diameter in inches for circular horns is the quantity 4000 divided by the lowest frequency to be reproduced. Placement of a horn close to another surface which acts as an additional baffling surface can reduce the mouth area requirement to approximately one-half.

Recently there has been interest in adapting horn loading for use in the home, where space usually is at a premium. Space can be saved by use of a corner of a room as one section of a folded horn. The other section or sections are then built into an enclosure for the speaker. Currently there are three main types of corner horns.

The pyramid type has symmetrical radiation areas from the enclosure leading onto the floor and each wall of the corner. The asymmetrical type has symmetrical radiation areas from the enclosure onto the walls only. Another type of corner horn is something like a bass reflex enclosure with the ports horn-loaded to some extent by the corner. There are various versions of these as to size, and there is considerable difference in operation between large and small-size corner horns. The large horns have more output and smoother response.

In the types of corner horns available on the market commercially, to our knowledge there are none of optimum size which will allow for the front radiation required for the higher frequencies by a unitary, coaxial, or triaxial speaker. Additional to this, it seems that most people just do not have a corner available for installation of a corner horn. Of a local group of high-fidelity enthusiasts numbering about thirty, we are told that only one of the group has a corner in which to place a corner horn. For these reasons, it was decided at Jensen to develop a non-commercial back-loading enclosure in which the front of the speaker could radiate in normal fashion. The main criterion was to be performance, although size admittedly is important.

IV. BACK-LOADED HORN ENCLOSURE

After investigation and construction of a number of types of back-loading enclosures, it was found that the one of Fig. 4 gave the performance wanted. It consists of a Hypex horn of T equal to 0.7, mouth area of 1260 square inches, and a sound path length of 62 inches. Theoretical cut-off is 40 cycles, with good contribution at 30 cycles. The heavy air-mass loading of the high efficiency 15-inch direct radiator used with it reduces the resonant frequency of the speaker to 25 cycles. In an infinite baffle, the same speaker has a resonance of 45 cycles. This direct-radiator driver has an infinite-baffle efficiency of about 10 per cent, so the four to six db gain shown in Fig. 5 indicates that with this enclosure, an efficiency of 30 per cent to 50 per cent is attained.

The enclosure has a sound chamber such as is used in higher frequency horns. This serves the purpose of shunting out radiation from the rear of the cone above about 300 cycles, where cone front radiation takes over. The total volume is about 27 cubic feet, with outside measurements of 63-inch height, 24¾-inch depth and 37½-inch width. The sides, top, and bottom can be cut from standard four-foot by eight-foot sheets without wastage. Three-quarter-inch wood is found to be sufficiently heavy to prevent excessive vibration of the sections. Beside the interbracing effect of joining the various section of the enclosure, one brace is used between the sound chamber shelf and the back. Construction is not too difficult for the home-woodshop worker, and material cost for medium-grade plywood should be about $45 to $50. In quantities of ten or more, we are told that this unit could be produced for about 200 dollars each. At the present time it is not planned to commercialize the enclosure, instead to leave it up to those who want to construct for their own use.

Construction must be carefully done so that air leaks are avoided. High sound pressures are developed; so all cracks should be tightly sealed to confine air movement

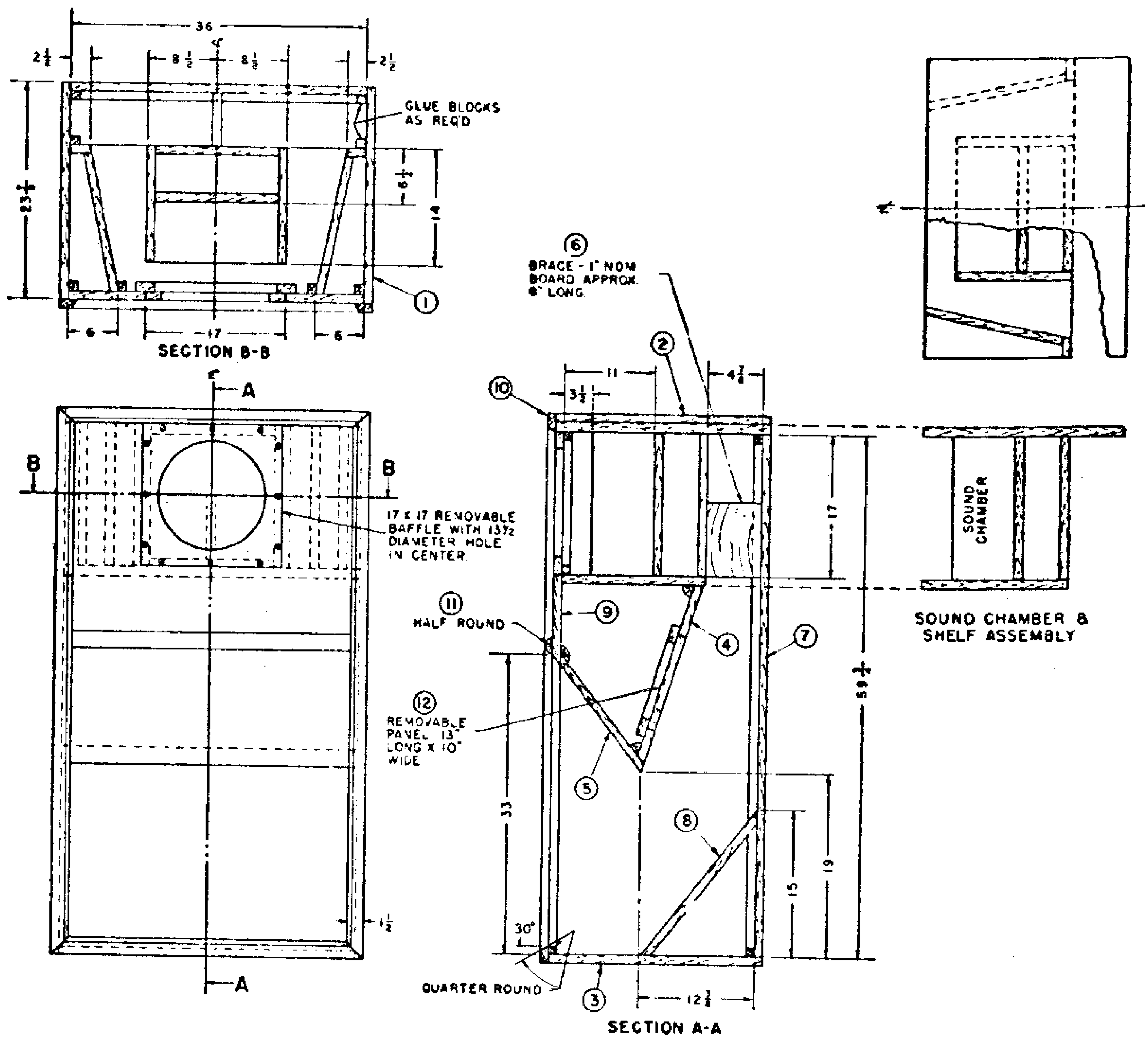


Fig. 4—Back-loaded horn enclosure.

to the proper path. Joints should be well made, so that the interbracing effect of joining the sections can be obtained. Assembly is most easily done in a specific sequence of operations. It would be difficult to build the shell and then install the sound chamber, separtors and baffles. The best way to make the structure is to construct the sound chamber-shelf assembly, and then add the sides (*1*), top (*2*), bottom (*3*), cavity

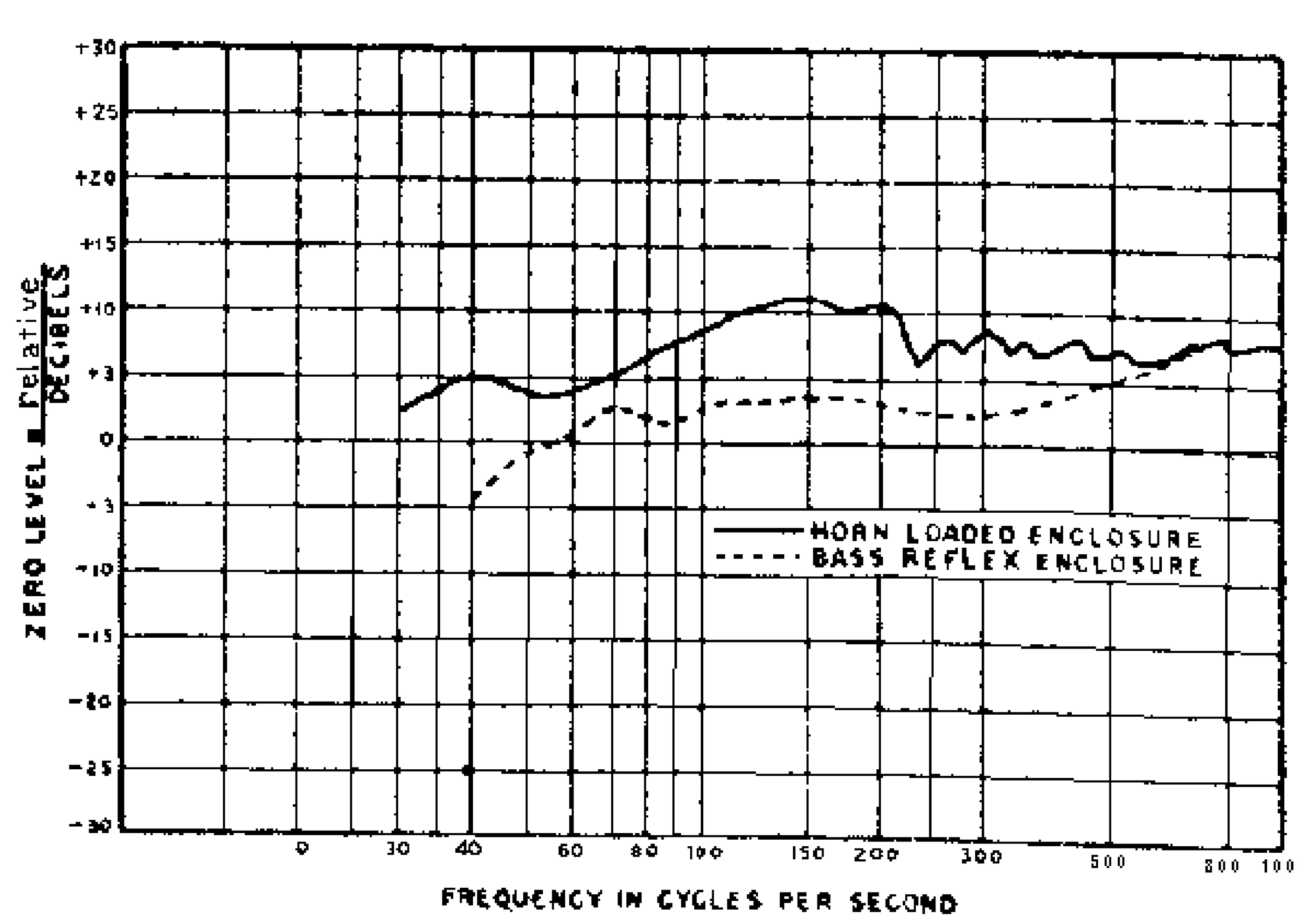


Fig. 5—Total radiation, bass reflex, and back-loaded horn enclosures.

back (*4*), cavity baffle (*5*), brace (*6*), back (*7*), bottom baffle (*8*), front panel (*9*), and then the trim (*10* and *11*), in that order.

Variations of this design can be used if the air path dimensions are not changed much, and if the structure is not weakened by thinning down the wood or reducing the bracing. Vibration of a panel section of the enclosure is a sign of power being lost, and can be detected by touching the section during high level operation from a program material source. There is space available in the center of the enclosure to mount networks, amplifiers, and other apparatus. Speaker controls can be mounted on the front panel.

Placement is not critical. Operation is slightly better in an upright position than when placed on a side, but either mounting method is satisfactory. Corner operation is satisfactory, but not necessary.