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A Ton-and-a-Quarter of Sound . . . . page 19

COVER STORY

Ton-and-a-Quarter of Sound

Each system of this stereo pair weighs over 1200 pounds—totalling about a ton-and-a-quarter. The weight results from the use of concrete as the horn material in order to eliminate spurious radiation from the horn itself.

WALTER WYSOCZANSKI*

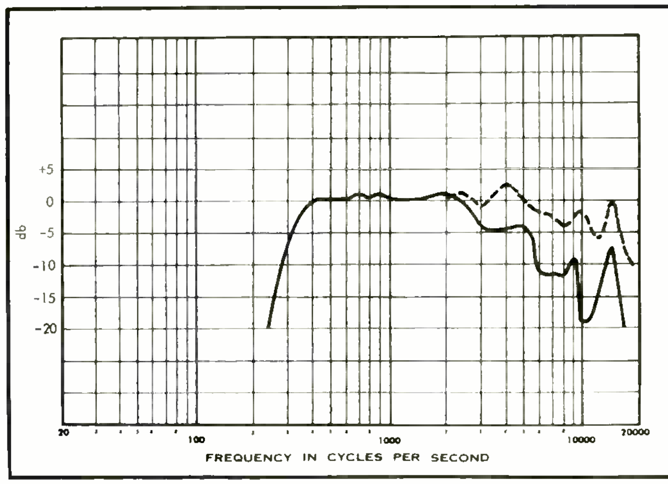
A PROPERLY DESIGNED HORN speaker system is capable of exceptionally fine sound reproduction. However, in most cases the design is compromised in several ways, thereby yielding results considerably inferior to that which is possible. The design described in this article is intended for home use, however the usual compromises involving space and weight (and time and effort), have been somewhat relaxed in order to more closely approach ideal performance. The results of following such an approach have indeed been gratifying.

The design of this horn system was not a sudden conception, but was the outcome of many experiences, experiments, and considerations involving several different horns and drivers. Some of the important conclusions leading to the final system will be related. Sufficient information is presented to enable an experienced concrete worker to duplicate it.

Generally, the finest examples of sound reproducing systems are still found in motion picture theaters. Thus it seemed that the desired objectives could be achieved by starting from this source, with its wealth of engineering experience. Also, the necessary components are available.

The typical motion picture theater uses a two-way horn system with the crossover at 500 cps. The low-frequency channel uses two 15-inch drivers on a horn with taper cutoff frequencies from about 50 to 110 cps and the range below this cutoff usually being supplemented by bass reflex loading. The high-frequency channel has one or more drivers coupled to multi-cellular horns. For larger theaters, or auditoriums, these basic systems are used in stacked or multiple arrays for greater power and wider distribution. The basic system unit is designed to deliver high-level sound, at low distortion, to volumes very much larger than the typical large living room. An immediate advantage of using theater components in the living room is the extremely low distortion for the loudest-listening levels. A common characteristic of transducers such as speakers is that the distortion generated has an inverse relation to the amplitude of motion of the diaphragm.

Fig. 1. Axial frequency response using Altec Lansing 288B driver with 30210 coupler and with 1005 multicellular horn (——) or without the horn (----). Measurement made one foot from horn mouth with Sony C-37 microphone.



From acoustics literature it was determined that certain rules should be followed for the best results: The system should have but two channels (one crossover point). The problem of effectively integrating two channels is difficult enough; for three or more it is extremely difficult. Therefore, a two-channel system was decided upon, divided at the most typical crossover frequency of 500 cps and with a bandwidth (half-power points) of 40 to 16,000 cps. This bandwidth may seem narrow, but systems (any kind) that actually can cover it with high quality are extremely rare.

It was also deemed important that all the voice coils, or all the diaphragms, lie in a common plane close to each other—the next best situation to the impossible requirement that they occupy the same space! This provides for smoothest crossover and a minimum of transient distortion due to different sound path lengths.

Both the horn axes should be straight in order to avoid the many difficulties introduced by bends in the horn.

The High-Frequency Horn

Tests were begun using an Altec 288B with an Altec model 1005 multicellular horn for the high frequencies. At first, listening tests showed discouraging performance in the upper frequency ranges.

The response from 400 to 2500 cps was perfect (*Fig.* 1). However, the need for considerable improvement above 2500 cps was quite clear. Close inspection of the driver (the diaphragm voice coil assembly is readily removable and replaceable) led to the conclusion that it should be capable of good response to at least 12,000 cps. This made the horn suspect. Fortunately a quick and simple test was possible: The driver is joined to the horn by a flared 6-in. long coupling (Altec 30210) whose area on one end is sufficient to act as the mouth of a horn, when used alone, for good loading to a little below 2500 cps. The 1005 multicellular structure was removed leaving the 288B with 30210 coupler, and another response curve, starting at 2000 cps, was run. The same reference level was used, and this time the upper response proved to be acceptable up to about 16,000 cps. Thus it was concluded that the multicellular structure was somehow interfering with the full capabilities of this excellent driver, yet only multicellular horns were available for it. A different and better type of horn would have to be constructed.

A horn with good polar distribution was sought. It should have a distribution equal to or better than that produced by a multicellular type. Study and comparison of the polar patterns for different horn types showed that a horn having two straight sides and a

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curved mouth (also known as a sectoral horn) should give excellent results. Altec Lansing manufactures a smaller version of the 288B, the 802D, which has curved-mouth horns available for it (models 511B and 811B). An Altec 802D-511B combination was obtained and it was soon confirmed from listening to it, and comparing with several horns, that this type of horn has the most ideal polar pattern for the objectives at hand. The sectoral horn did not interfere with the high-frequency performance of the drivers as did the multicellular type. It was also noted during the various tests that certain coloration was introduced due to the horn material according to whether it was of wood, aluminum, or Fiberglas.

The Altec 288B driver produces, essentially, a plane wave pressure front at its 1.4-in. diameter output opening. The problem is to properly couple this high-pressure source into the listening volume. This involves expanding and reshaping the wave front.

The expansion can be made to follow any of several mathematical shapes. The two most efficient and useful for this problem are the hyperbolic and exponential flares. There are two important characteristics for deciding which flare type to use. The hyperbolic flare has superior loading (flatter frequency response) near cutoff, while the exponential flare introduces less second harmonic distortion. In the initial volume, or throat, of a horn the pressures remain quite high, so much so that the air behaves in a much more non-linear fashion than it does when driven at lower pressures. For sinusoidal pressures, this non-linearity can be detected as second harmonic distortion. This distortion is proportional to the sound intensity at the throat; that is, for a given acoustical output, the horn with a larger throat cross-sectional area will introduce less distortion. The Altec 288 is a good choice in this respect since it couples to a larger throat than most drivers designed for a similar frequency range. The faster the expansion of the horn, the faster the intensity is reduced, and therefore the smaller the distortion. A faster expansion means a higher horn cutoff frequency. For the same cutoff frequency, the exponential horn expands faster than the hyperbolic and therefore will introduce less distortion. And for a given intensity, the distortion increases directly with frequency. But, fortunately, the peak intensity content of typical program material above 1000 cps falls off at about the same rate, thereby mitigating this effect. The exponential flare was chosen mainly because of its lower distortion, while still retaining good response near its cutoff.

The cutoff frequency of 250 cps was selected to provide good loading for the driver for about an octave below the crossover frequency.

The next parameter to be determined would be the horn length. This also fixes the mouth area. But the length also affects the polar pattern. The polar pattern is closely related to the shape of the wave front being radiated at the horn mouth. Let us examine this.

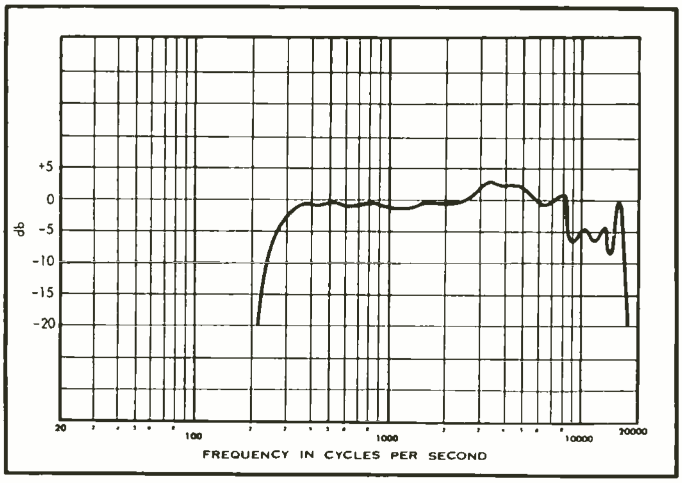

Fig. 2. Axial frequency response using Altec Lansing 288B driver with a concrete sectoral horn having a cutoff frequency of 250 cps and mouth area of 654 sq. in.

The majority of horn designs are what may be called plane-wave horns, that is, they tend to preserve the plane-wave shape from the driver to the horn mouth. This means that the polar pattern for such a horn at a given frequency is the same as that of a vibrating piston of a certain diameter. But with a horn, the effective diameter of the equivalent piston is a function of frequency and the horn constants. This factor can and is used to advantage. For example, with a given piston radiator the polar pattern becomes progressively narrower with increasing frequency. But with a horn the polar pattern can be made essentially independent of frequency. It can be said that a horn does this by reducing the diameter of the equivalent piston with frequency. Or, to put it another way, a horn keeps the ratio of equivalent piston diameter to wave length constant for different wavelengths. The requirement that the polar pattern be relatively independent of frequency is met by extremely few speakers. With a horn this independence is governed mainly by the mouth size and improves proportional to its magnitude. With typical horns designed for hi-fi use, the mouth is usually made small to give wide high-frequency dispersion, but the dispersion is much more frequency dependent than for a larger mouth. However, all is not perfect with the large mouth; it gives a uniform frequency-independent dispersion, but this pattern is quite narrow. A faster flare rate (higher cutoff frequency) can help slightly by broadening the pattern. Also a multicellular type structure is a good choice for wide coverage. For a single high-frequency horn, about a 30-deg. angle of coverage can be obtained with a mouth dimension of at least 15 inches. For home use a 30-deg. angle is certainly adequate for the vertical coverage; however, it is unsatisfactory for the horizontal coverage.

In a horn, starting at the throat, if a plane wave front could be re-shaped into a curved one as it progressed so that it resembled a section of a sphere, and if this spherical shape could be maintained until the surface was large compared to its wavelength, then the frequency response would be independent of position for a listener anywhere in the solid angle determined by that surface. The multicellular horn is designed to accomplish this. Actually, some such curving takes place in simple single plane wave horns, but better results are possible when the horn is particularly designed to promote such curving. The sectoral type of horn efficiently curves the wavefront. But it does this principally only in, say, the horizontal direction if the curved mouth lies in the horizontal plane. On the vertical axis the radiation is still essentially a plane wave. Consequently, the sectoral horn can be said to radiate a cylindrical wave front. The angle of radiation in the horizontal plane will be almost equivalent to the angle between the two straight sides bounding the curved mouth. The vertical polar angle is governed by the same considerations as that of a plane wave horn. The longer the straight sides of the horn, the more perfect the polar pattern for this axis. Also the greater the vertical mouth dimension, the more uniform the vertical pattern. Therefore, a very good design is a sectoral horn with the required horizontal angle and which is long and has a large vertical dimension. Fortunately, these length and height requirements are of the same nature: they both mean a larger mouth. With a sectoral horn, one can obtain wide horizontal coverage, with a vertical coverage of about 30-deg., and be assured of excellent frequency-independent uniformity in the resultant solid listening angle.

Any partitioning of a sectoral horn will cause it to approach multicellular behavior according to the extent of the partitioning. The partitioning of a sectoral horn is, ideally, undesirable.

All the preceding considerations resulted in an exceptional sectoral horn for the Altec 288B driver. The angle between the straight sides was set at 100-deg. and the horn length at 26-in. The radius of the curved mouth was set at 24-in. The throat of the driver is 1.4-in. in diameter. The mating circular horn throat changes, in a short distance, to a square cross section with 1.7-in. sides. With a 250 cps cutoff the 26-in. length results in a mouth area of 654 square inches. The arc length at the mouth is 41.9 inches and the height is 15.6 inches. The cross-sectional dimensions were calculated and recorded in tabular form, for every half inch of length up to the mouth. Note that the cross-sectional surface at each value of radius is a section of a cylinder.

Fabrication

The design was now complete. Fabrication was next. Now we must decide which material is best for horn construction.

For any loudspeaker the vibration of the diaphragm is ideally transmitted directly to the air only. That is, the radiation from the material forming the boundaries (i.e. baffle, horn, and so on) should be zero. Otherwise an undesirable double or multiple radiator situation arises. The boundary being in intimate contact with the driving source can readily absorb sound from the driver, and conduct and redistribute this absorbed energy to a large surface area with good coupling to the air. In other words, the material itself behaves somewhat like a very poor direct radiator. Consequently, various colorations, distortions, and resonances become apparent due to the characteristics and contributions of this second radiator. The velocity of sound in most boundary materials is considerably greater than that in air. This factor alone tremendously complicates and deteriorates the resultant sound reaching the ear. Another factor is that the frequency response of most boundary materials is not flat. There are other coloration factors. Of course these factors are of great importance for musical instruments where pleasing effects are obtained when the boundary materials are encouraged to contribute to the total sound. But, these effects should be strongly avoided for speaker systems. A speaker is not a musical instrument; it is a reproducer!

The boundary material should be very rigid, non-absorbing, and have high internal damping. Wood does not meet these requirements very well, nor do, in fact, most materials. Bracing of the boundaries helps suppress gross resonances, thus easing one of the problems. Applying damping material to the surface helps. However it is better if the desired properties are inherent in the material itself, thereby requiring a minimum of external correction or compensation. The absorption and conduction of the material must be negligible while its internal dissipation is high.

Concrete appears to be about the best material for boundary surfaces of horn speaker systems. The standard engineering texts strongly recommend its use. However, it has rarely been used in sound systems. Where it has been used, the results have been outstanding. Perhaps the biggest objection to its use is its weight. But, note that concrete is actually "lighter" than aluminum. The specific gravity of concrete is 2.6; whereas for aluminum it is 2.7. It is the quantity used that makes the end result heavy.

An exponential sectoral surface is rather complex when compared to the simpler typical horn surfaces. It cannot be formed by bending flat sheets. Casting techniques are preferred. This requires making only one good model and constructing a mold from it. Once the mold is completed, its life is long, permitting many identical units to be cast in it. Of course concrete is a natural media for casting.

A model, mold, and two horns were constructed.

Another frequency-response curve was made with the Altec 288B driver, but this time with the newly completed concrete sectoral horn. The test set up was identical to that used for the multicellular horn tests. The curve is shown in *Fig.* 2. Notice the greater output above 2500 cps for the sectoral design. The slightly extended low response is due merely to a lower effective cutoff frequency for the concrete horn. All the design expectations were fully confirmed.

As a matter of interest, the second-harmonic distortion was calculated for 1-watt (acoustic) input at 1000 cps for this combination. In the listening room where this horn is located, this power produces a level of about 110 db. At this level the second-harmonic distortion is 2.2 percent. To obtain the distortion for other frequencies one must simply remember that it increases directly with frequency for a given level. The per cent distortion for a given frequency is proportional to the square root of the acoustical power input to the horn.

About a year after the completion of two of these concrete horns. Altec Lansing began marketing an improved driver: the Altec 288C, which has a flatter response out to 16,000 cps (see *Fig.* 3). A new horn was designed for these newer models based on past experience. This is the unit which appears on the cover and is shown in detail in *Fig.* 4, and results in slightly less horn distortion. The new horn cutoff is set at 300 cps. Its length is 21 inches, with a radius of curvature of 20-inches. The mouth area is 552 square inches with a 34.9-in. arc length and a 15.8-in. mouth height. With the construction of these new horns and their testing, the high frequency part of the system was considered to be successfully completed and to be the best possible for some time to come.

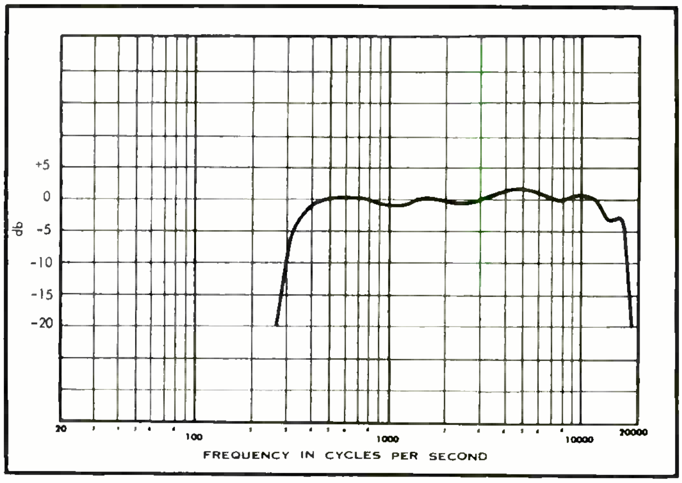

Fig. 3. Axial frequency response using an Altec Lansing 288C driver with a concrete sectoral horn having a cutoff frequency of 300 cps and a mouth area of 552 sq. in. as in **Fig. 4**.

The Bass Horn

With an excellent high-frequency end for the system accomplished, efforts were next directed towards the design and construction of a complementary bass horn section. It was decided to use concrete for the bass horn in spite of the fact that its weight would be very great. The sand shielding tests and the good experiences with the high-frequency section were the initial justification for its use again.

The exponential sectoral type of horn was selected again as it permitted good matching in many respects with the

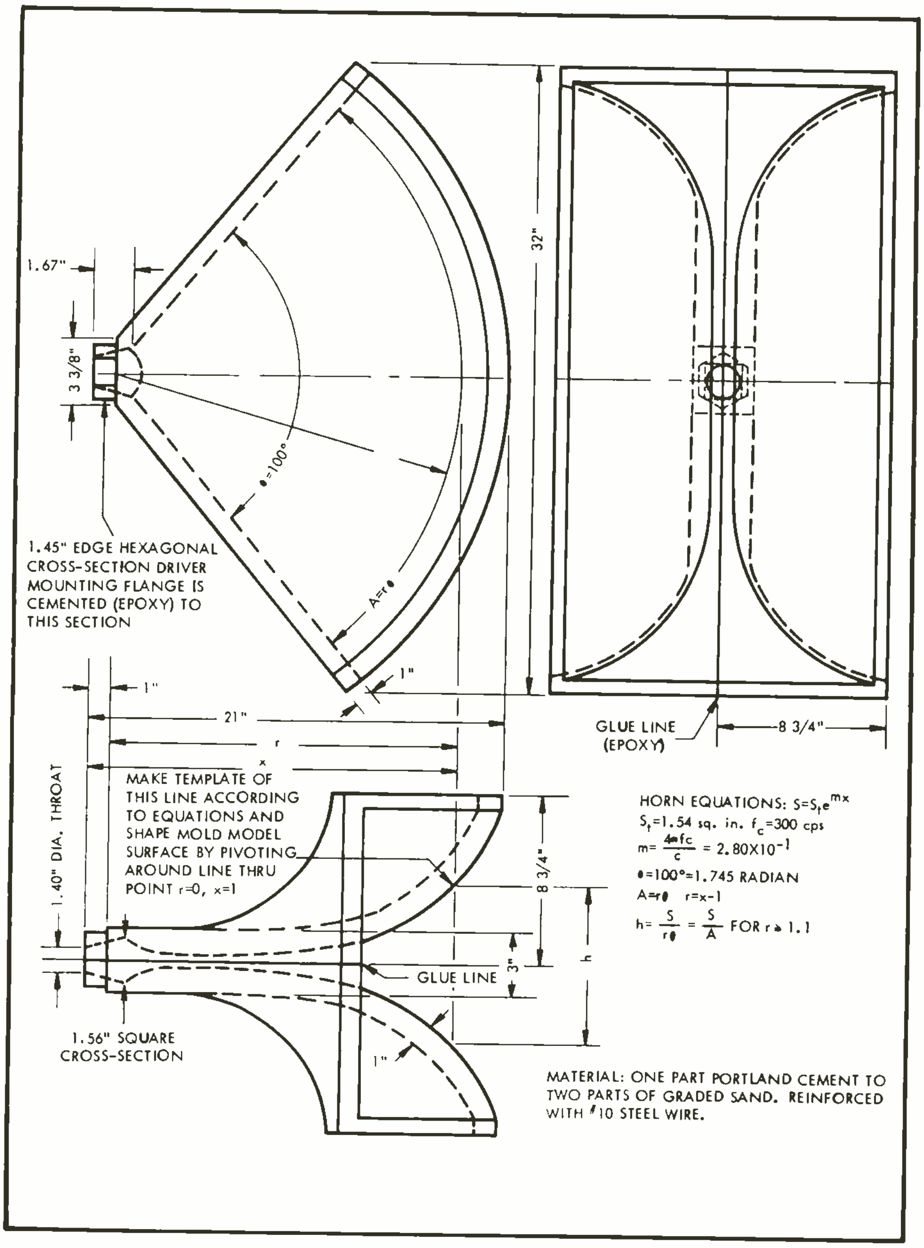

Fig. 4. High frequency concrete exponential sectoral horn for Altec Lansing 288C driver. Horn consists of two idential castings cemented together and a hexagonal flange for mounting the driver. Flange is made from two pieces of 1/16-in. sheet steel and is not shown in this drawing.

high-frequency section. Not only acoustical, but also, appearance matching was thus obtained.

It was again noted that most theater bass systems are not pure horn, but use the bass reflex principle to extend the low-frequency response below the horn cutoff frequency. In such cases the horn is straight and shorter than the longer folded horns.

The typical use of two close-spaced 15-in. drivers for practically all theater systems appeared to be a good procedure to follow. This has several advantages: The efficiency is almost doubled, driver distortion is decreased, horn distortion is decreased, power handling is increased, and the horn itself can be much smaller for a given performance. The main disadvantage of multiple drivers is the possibility of irregular frequency response in the upper range. But for a pair of close-spaced 15-in. drivers these interference effects begin to become serious only above 500 cps where the power input to the drivers is already 3-db down.

Experiments were conducted with a short straight 1-in. thick plywood corner horn having a cutoff of 110 cps and bass reflex loading below. This unit used two 15-in. drivers vertically stacked. Tests were made using a proper bass reflex porting with different values of damping. A closed box condition was also tried. The best over-all fidelity was obtained only with the ports closed and cavity completely filled with an absorbing material. With port loading, the lower bass was better, but among other things, there appeared to be some sacrifice in quality in the upper bass ranges. From this it was learned that it is better to have a good response over a narrower range, than a compromised response over a wider frequency range as from hybrid combinations. Therefore, it was decided to use the radiation from only one side of the driver diaphragm. The design procedure was to go as low as possible with pure horn loading, while retaining reasonable proportions.

For best loading with maximum efficiency, the throat area is highly dependent on the driver motor efficiency. For a given diaphragm diameter, the best throat area will be inversely related to the motor efficiency—higher motor efficiencies requiring smaller throat areas. For a typical high-efficiency 15-in. driver the optimum throat to diaphragm ratio is about 1:2. But by sacrificing 1 to 2 db in over-all efficiency, the throat area can be made equal to the effective diaphragm area. This will help keep the horn size down. Another advantage of a large-throat short horn is a more gradual low-frequency cutoff. On the other hand a maximum efficiency loss of 3 db at the higher frequencies (above 500 cps for 15-in. drivers) may occur with a 1:1 throat to diaphragm ratio. Also, the range over which the driver must have good linearity must be greater in order to compensate for the greater diaphragm excursions due to this lighter loading.

For optimum response near the bass horn cutoff, it is quite standard practice to balance out the horn mass reactance at frequencies below the diaphragm resonance. This is done by having a suitable total compliance for the driving system. Once the horn and driver is determined, the required compliance can be calculated. This compliance is made up of two principals: the diaphragm suspension compliance and the compliance of the air in the enclosing back cavity. The driver compliance is fixed by its design. And, in turn, in most cases a definite volume of air will contribute the necessary compliance for a given driver. For a given horn, the driver with a lower free-air resonance will demand less volume in the back cavity. The importance of a low free-air resonance can be demonstrated by calculating the many fewer pounds of required construction material.

Eight different makes of 15-in. drivers, all intended for woofer service only, were obtained and tested before deciding on the best driver. Of the eight types tested, three involved at least four samples of that particular type. Most of the drivers for this test were obtained on loan from friends.

A simple optical setup was used to accurately measure diaphragm displacement. This facilitated the measurement of several important factors: B_l factor (or the product of gap flux density with the length of conductor in the gap), the compliance of the suspension system, and the linearity of the driver. These in combination with other simple measurements yielded about 20 points with which the drivers were compared and rated.

The linearity test became important since a number of the drivers possessed what was judged to be poor linearity for the application in mind. The linearity test was the plotting of the diaphgram displacement verses the current through the voice coil. In some cases the poor linearity was due to design limitations and in others, poor manufacture. Predominately, the voice coil lengths were either much longer or much shorter than the magnetic air gap depths. The short type of coil is capable of much better conversion efficiency with good linearity. However, unless the voice coil is accurately centered axially (radial centering is of little consequence in this matter) in the uniform region of the magnetic field the linearity will be poor. In one make of speaker with a short voice coil, only one unit of four had proper axial centering of the coil in the magnetic field. On the other three units, it could even be visually observed that some of the voice coil turns were outside the air gap when the speaker was in a vertical plane and with no electrical connection to the voice coil. And all these units were brand new! The same fault was observed on another make of short coil speaker also. On the other properly centered short coil type speakers the linearity was found to be good, but over a smaller range than that observed for the types with the long voice-coil design. Therefore, a long voice-coil speaker seemed a better kind to use for this design in spite of the fact that its efficiency would be lower than that of the short types. Actually all the long-coil types tested showed acceptable linearity. Good short-coil types are made but there are risks involved in getting one that is properly assembled.

Four units of the Jensen P15-LF were purchased after very encouraging data were obtained from the manufacturer. All four of these units tested practically identical in agreement with the manufacturer's claims.

The Jensen P15-LF has a free-air resonance of about 19 cps. It is capable of peak excursions of ±0.5-in. with excellent linearity over a range of ±0.20 in. from neutral. This is more than adequate linearity for horn loading with several acoustic watts output at 50 cps. In spite of the necessarily long voice coil it still has good motor efficiency. The cone is heavy, straight sided, and the front is completed sealed from the back. It probably was never intended for horn use, however it was judged to be the best all-around unit for this horn design.

Using a 1:1 throat-to-diaphragm ratio permitted a horn throat area of 250 square inches for a driver pair. A maximum over-all depth for the bass horn was set at 50 inches, of which 10 inches was allotted to the driver. All the system drivers were to be vertically stacked. It was desirable to keep the high-frequency horn axis not much above ear level when seated. This meant that the low-frequency section height had to be minimized. A 33-in. over-all height was selected and permitted a 32-in. height at its mouth. The axis formed by the origin of the radii of the bass horn was made to coincide with that of the high-frequency horn. The radius was made to be 38 inches for this reason. This results in all the driver voice coils lying in the same plane with

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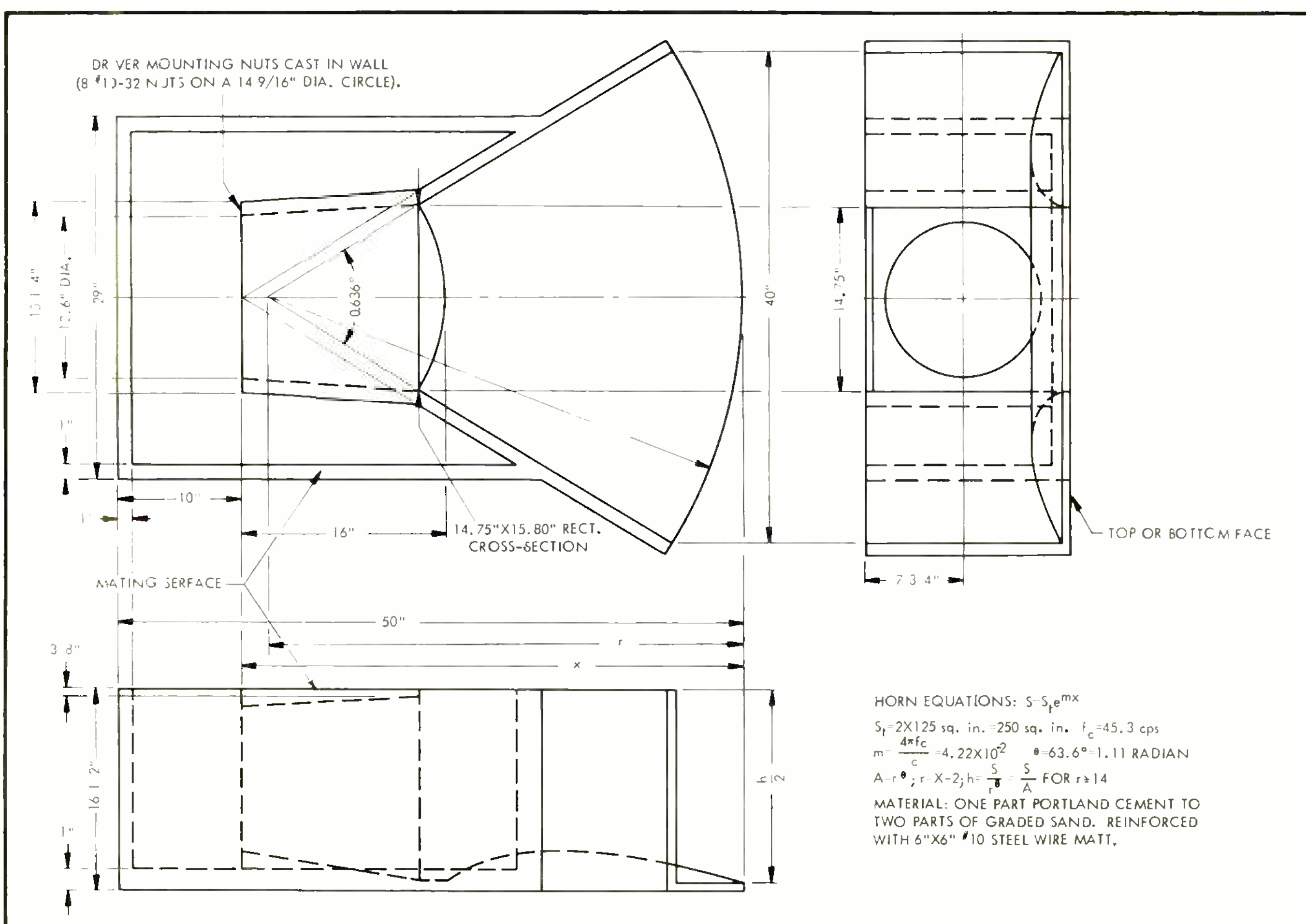

Fig. 5. Low frequency concrete exponential sectoral horn for Jensen P15-LF driver. Complete horn consists of two identical castings, one stacked over the other. Seam is packed with a non-hardening caulking compound.

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a common vertical axis for the two cylindrical section horns.

A sufficient number of parameters had now been fixed so that the cut-off frequency and mouth area evould be selected. Several mouth areas were selected and the corresponding cutoff frequencies calculated for a 40-in. horn length. Next graphs were studied showing the variation in specific acoustical impedance at the throats of exponential horns as a function of frequency for various mouth areas. The best combination for this particular design was thought to be a 1350 square-inch mouth with a 45 cps flare cutoff frequency. For this situation the graphs predict some horn resonances near cutoff. These graphs are for free-space conditions. With the horn set on the floor and close to room walls, the horn behavior should be considerably better than predicted by the graphs. Another mitigating factor is that the beneficial damping effects of the driver and its generator are also neglected in such graphs. The absence of any serious resonance conditions in this horn driver system was confirmed outdoors without any nearby aiding surfaces except for the ground.

Since the bass horn is relatively short, excellent control over its polar characteristic is not very feasible. Good control is possible only when the horn length is large compared to the radiated wavelength. The pattern is narrowest when the horn mouth dimensions are about one wavelength. For longer wavelengths, control is lost as the pattern begins to become very broad. With this in mind, instead of using the same 100 deg. angle as in the high-frequency horn, the bass horn angle was made narrower in order to try to compensate a little for the excess broadening at the lower frequencies. This angle is about 64 deg. Actually, other factors also were involved in this angle determination, such as mouth area. But, the objective was to try to match as well as possible the polar patterns of these two horns.

With the drivers selected, and the bass horn parameters fixed, the design could now be completed. The volume of the back cavity was calculated to be 3.7 cubic feet per driver. A test showed no detectable difference whether a partition was used or not between the back cavities of the two drivers. Weight and design complexity were lessened by the omission of such a partition. In the final design a small partition divides the speakers on the front side. This was done mainly for structural rigidity in that high pressure region.

Horn section models and a mold were constructed, and bass horn sections cast with concrete according to the design shown in *Fig.* 5.

The low- and high-frequency channels are each directly connected to individual power amplifiers. The crossovers are high-impedance electronic type ahead of the power amplifiers. Originally, all the electronics were vacuum tube type with four 50-watt power amplifiers for a two speaker stereo system. The tube electronics have now been replaced with transistorized units.

The room where this system is located has a volume of about 3000 cubic feet. All the walls are concrete. The floor is concrete over earth and is covered with a wall-to-wall rug. The roof is an open beam type using heavy timbers and it is in turn covered by a 3-in. thick layer of concrete. The entire environment is therefore quite solid. But the environment was not built for this speaker system. It was in existence long before this system was conceived or built.

This completed system was originally used outdoors with very thrilling results. It is planned someday to build a larger system for permanent use in this garden area. Here the two speakers were about 25-feet apart, while the listening area was about 60-feet away. The fidelity of reproduction at even the loudest levels was phenomenonally good. The instantaneous peak power inputs to the individual drivers for the loudest levels tolerable were about 40 watts. Indoors, for the same tolerance, the input peaks measured about 1 watt. Calculation showed that in the room the sound level is about 110 db for one acoustic watt into the room.

The high-frequency channel has an electrical-to-acoustical conversion efficiency of about 45 per cent, while the low channel is about 25 per cent. For indoor use four one-watt amplifiers would suffice for the loudest listening levels. However the transistor amplifiers used are capable of much more: about 35 volts peak into each of the 8-ohm bass channels, and similar peak voltages into each of the 24-ohm treble channels.

Any possible deleterious effects due to grill cloths were avoided by not using any such obstructions in the sound path. In fact, when the first high frequency sectoral horns were completed it was remarked by some that the curved surfaces of the horns are quite pleasing and that they could be left in direct view. Thus the horn system has no enclosures. With the application of several layers of linen-white latex wall paint to all the concrete surfaces the decoration of this system was easily and very satisfactorily accomplished. It fits very well with the decor of its present environment.

It must be emphasized that these two horns are intended for use only with the Altec Lansing 288C (or older 288B) drivers and the Jensen P15-LF units. To attempt to directly mount other types of drivers to these two horns with no design modifications will most certainly result in poorer performance. For top performance attention must be paid to details.

With this system any distortions or flaws in the source material is readily apparent. The biggest problem now is finding the rare extremely high quality source material which will permit the full realization of the system's capabilities. The best recorded source material used is in the form of 15 ips and 7.5 ips two-track stereo tapes recorded with two condenser microphones.

Several individuals contributed heavily to the successful accomplishment of this project. Primarily, gratitude is expressed to Mr. William Kloepfer for his considerable help and encouragement. Also, Mr. David Richardson and Mr. and Mrs. Ralph Cappelli are thanked for their efforts. Æ