ONE SYSTEMS®

EQUIVALENT THROAT TECHNOLOGY

Modern audio frequency reproduction systems use transducers to convert electrical energy to acoustical energy. Systems used for the reinforcement of speech and music are referred to as Sound Reinforcement Systems. These systems are used to reinforce the program material (voice, music or other material) by providing an increase in signal level, or gain, in order to generate sufficient sound pressure levels in large spaces.

Sound reinforcement systems often use devices known as compression drivers and horns to reinforce the program material. The compression driver is a simple acoustic transducer that uses a small and light weight diaphragm to convert the electrical signals to acoustic signals. The small diaphragm will exhibit fewer resonant modes than a large diaphragm and the lower mass associated with a small diaphragm can produce a higher conversion efficiency.

The small diaphragm, however, has a lower radiation impedance than a larger diaphragm so a horn is coupled to the “exit” of the compression driver. The horn acts to “transform” the low radiation impedance of the driver to a higher radiation impedance associated with the mouth of the horn. The small entrance of the horn is mated to the small diameter acoustic exit of the compression driver. The acoustic impedance associated with this small area is then transformed to a higher acoustic impedance associated with the larger opening of the horn, referred to as the horn mouth. The rate at which the cross sectional area of the horn changes between the small opening, or throat, and the large opening, or mouth is referred to as the flare rate.

In addition to acting like an acoustic transformer, the horn also acts to direct the radiated energy in a specific location. The walls of the horn act to guide the radiated wave fronts. In this way the total radiated acoustic power from the driver is concentrated into a portion of space smaller than the space had the horn not been mounted to the driver. The acoustic density, or energy per unit area, is increased and, as a result, the sound pressure level in an area is higher than it would be if the horn were not coupled to the driver for long wavelength conditions (i.e. when the radiated wavelength is long relative to the horn it is referred to as a “long wavelength”) . It is a common practice for horns to exhibit circular, elliptical, square,or rectangular radiation patterns.

This horn/driver system has a bandwidth ,or operating range. The low frequency response of the horn/driver system is limited by the length and mouth area of the horn. When the radiated wavelengths become large compared to the length and mouth circumference the horn is no longer able to radiate any appreciable acoustic power and the overall horn/driver efficiency is substantially reduced. For the mouth of the horn to have relatively high acoustic impedance, the following relationship must be maintained: ka greater than 1, where k= (2*pi)/wavelength and a=mouth radius. This equation basically requires that mouth circumference (i.e., 2*pi*a) be greater then the wavelength of the lowest frequency to be effectively radiated. This frequency, where the wavelengths become long relative to the mouth circumference, is referred to as the cutoff frequency.

There are many parameters that affect the high frequency response of the compression driver and horn combination. A specific area of interest is the high frequency limit related to the systems ability to maintain the desired directional pattern. A desirable property of a horn is its ability to maintain a specific directional pattern independent of frequency. These horns, are often referred to as "constant directivity" horns (see "What's SO Sacred About Exponential Horns", Keele, D.B. Audio Engineering Society 51st Convention, May 13-16, 1975). Many sound reinforcement applications require this property for accurate coverage of a specific area.

The ability of a horn to maintain constant directivity is related to the radius of the compression driver exit. As the wavelengths become short compared to the exit radius the directivity of the wave front emerging from the driver exit is reduced,becoming more narrow. The directivity pattern of the radiated waveform is also referred to as the beamwidth. The beamwidth is rated at an angular distance from the axial response of the horn. The specific angle is determined by finding the points on either side of the horn major axis where the sound pressure level has decreased 6dB from the pressure on axis. (This assumes that the acoustic pressure is a maximum on the horn axis). The included angle between the -6dB points is referred to as the beamwidth. If the radiated directivity, or beamwidth, becomes less than the included angles of the horn then the radiation pattern in no longer constant and the wave front radiated by the driver is no longer controlled by the included angles of the horn. (Reference "On the Radiation of Sound from an Unflanged Circular Pipe", Levine and Schwinger Physical Review, Vol 73 Number 4, 1948), ("Acoustics", Beranek, Chapter 4 Radiation on Sound, McGraw-Hill 1954).

Figure 1 is a cross sectional view of a typical compression driver. A diaphragm mounted to a flexible membrane has an annular coil attached. The annular coil, or voice coil, is suspended in the magnetic gap and the diaphragm is spaced over the phase plug. Acoustic radiation from the diaphragm is transmitted thru the openings in the phasing plug. The phase plug openings may be radially oriented, circumferentially oriented, or a series of simple holes. The summation of the cross sectional areas associated with the phase plug openings forms the acoustic loading of the diaphragm. This phase plug cross sectional area can be made equal to the diaphragm area but is usually substantially lower. The change in cross sectional area between the diaphragm and the phase plug openings is the source of the loading. The volume of air between the diaphragm and the phase plug is compressed due to this reduction in area. The radiation impedance is increased by the square of the ratio of the diaphragm area and the phase plug initial area.

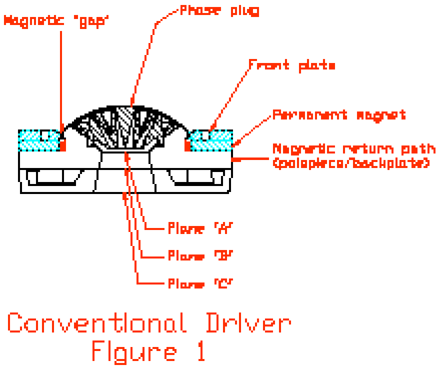


FIGURE 1

The individual channels of the phase plug add to an overall area, still smaller than that of the diaphragm area, at the plane defined in figure 1 as "plane "A"". Typical compression driver design then includes some linear distance proceeding toward the outlet, or throat of the driver, that expands the cross sectional area in some fashion. This section may be the length defined by the thickness of the magnetic return path backplate. This length is shown in figure 1 as the distance between plane "A" and plane "B". In other common designs an adaptor plate is added to the rear of the magnetic return backplate and is the thickness defined by the distance between plane "B" and plane "C". The area at plane "B" or plane "C" is always larger than the area of plane "A" in order to not introduce acoustic reflections associated with a reduction in area.

As a consequence of moving farther away from plane "A", and the necessary increases in cross sectional area, the associated radius at any plane away from the summation point of the phase plug (plane "A") is increased. This increase in the radius then limits the ability of the driver to produce a wide dispersion and broad radiation pattern as frequency is increased.

Inspection of figure 1 indicates that the most ideal location for a throat with a minimized radius is at the location shown in the drawing as "plane"A"'. This is the point where the cross sectional area is the smallest and, as a result, the radius is minimal for any given design.

There is no specific radius or associated area the will best optimize the performance. The optimal area will be a function of the plane immediately at the summation point of the phase plug. The area at the summation point of the phase plug will be related to design features such as compression ratio and driver diaphragm area. What is important in order to maximize the high frequency radiation pattern bandwidth is that, for any given summation plane area, the “driver throat” begin at this plane.

Figure 2a illustrates a conventional compression driver with a radius of 0.4375 inches 0.875” diameter) at the summation plane of the phase plug. This figure shows a length that connects this summation plane to the “nominal” exit of the driver. This 1 inch radius (2” diameter) is a very common exit dimension for professional compression drivers. This 1 inch radius produces a high frequency limit of 5400Hz for a 100 degree radiation pattern. The configuration represented in figure 2b has the same phase plug summation plane radius but in figure 3 this is also the effective throat of the driver. At this plane the elements of the horn that provide directional information to the wave front are implemented. This is as opposed to the situation in figure 2a where the conventional horn would be coupled to the driver at the 1 inch radius, rather than the 0.4375 radius.

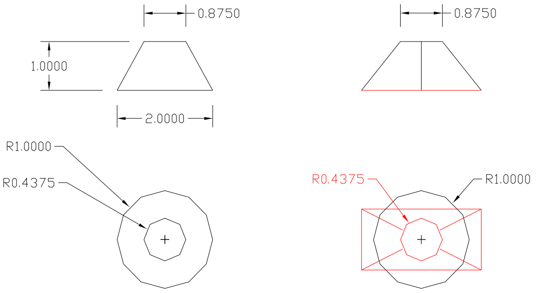


Figure 2a
2” diameter
conventional
throat

Figure 2b
0.875” diameter
Equivalent
Throat

FIGURE 2a and 2b

Coupling the required radiation geometry to the driver (i.e. the horn) at the phase plug summation plane results in a high frequency limit of 13,500Hz. From this example, it can be seen that there is substantial advantage in have a horn that imparts directional information to the wave fronts coupled to a driver using the smallest possible radius.

This is accomplished by altering the geometry of the magnetic return circuit back plate. The portion of the back plate that is coincident with plane “A” (figure 1) has an opening that is made equal to the radius of the circle defined by the phase plug summation plane.

The geometry of the plate then immediately begins to form the desired horizontal and vertical (or radial in the case of a circular or elliptical radiation pattern). As an example, the horizontal included angle beginning at the phase plug summation plane could be 100 degrees and the vertical could also be 100 degrees, or any other included angle that would be less than the limit imposed by the phase plug summation plane radius. (A typical practice would be to have a 100 degree horizontal pattern and a 60 degree to 40 degree included angle in the vertical plane).

As a reference, data taken from the text “Acoustics” by Beranek can be configured as shown below:

TABLE 1

Ka	Included angle directional response (-6dB)
0.5	Nearly Omni directional
1.0	Nearly Omni directional (but reducing included angle)
1.5	Approximately 150 degrees
2.0	Approximately 120 degrees
2.5	Approximately 100 degrees
3.0	Approximately 75 degrees
3.8	Approximately 65 degrees

Where k=(2*pi)/wavelength and a= exit radius

To continue the example, if an included angle of 100 degrees is required the data above suggests that the value of ka should be approximately 2.5. This value can be substituted into the equation ka=2.5, which becomes (2*pi*a)/wavelength.
After rearranging to solve for the wavelength, the expression becomes:

Wavelength=(2*pi*a)/2.5

This expression can then be solved for various values of the exit radius. Once the exit radius is established the associated wavelength is calculated and the corresponding high frequency dispersion,or radiation angle limit (for sound in air) can then be determined. This is the frequency where the radiation dispersion angle becomes less then the included angle of the horn walls and the horn is unable to provide directional control of the waveform.

TABLE 2

a (inches)	wavelength (approx.)	corresponding frequency (approx.)
0.4”	1.0”	13,500Hz
0.5”	1.25”	10,800Hz
0.55”	1.38”	9820Hz
0.6”	1.51”	9000Hz
0.7”	1.76”	7715Hz
0.75”	1.88”	7200Hz
1.0”	2.51”	5400Hz

It can be seen from the above data that as the throat radius, “a”, is reduced, the high frequency limit is increased implying that the horn/driver combination is capable of directional control at higher frequencies. This data describes the directional behavior of an unflanged tube. When an acoustic “flange” is added the directional behavior will be altered. This change in the radiation pattern is shown in “Acoustics” by Beranek, Figure 4.20. The dispersion in actually increased (the beamwidth increases) between ka=1.5 and ka=4. The data shown compares a piston in an infinite plane baffle, a piston at the end of a long tube (the data from tables 2 and 3) and a piston in free space (no baffle). The addition of a horn to the exit of a driver will alter the directional response and, for certain values of ka will increase the dispersion angle, or beamwidth. The horn will alter the dispersion characteristics much like the addition of a baffle in figure 4.20 of Bernaek. This effect is shown in the actual measured data.

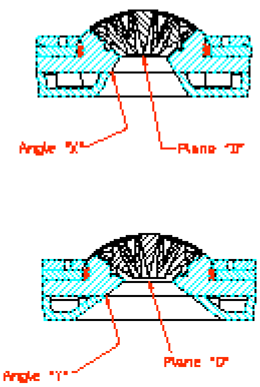
Prior art designs have resolved this inherent inability of a driver/horn combination to control dispersion at frequencies above the point where the exit radius became larger than the radiated wavelengths by utilizing a diffraction slot. This diffraction slot is placed at some distance beyond the plane referred to as plane “B” or plane “C”.
Diffraction is an effect the produces spreading of a wave form when that wave form encounters a gap, or slit. The smaller the slit relative to the wavelength, the wider the resultant spreading of the waveform relative to its original. This spreading will increase the dispersion pattern, or beamwidth of the radiated wave. Diffraction slots are an effective way to broaden a wavefront that has become narrow due to the exit radius of the driver being large relative to the radiated wavelengths.

The use of diffraction slots can present two basic problems. The first problem is that diffraction slots represent a change in cross sectional area. This area change, or discontinuity, will produce a reflected wave in the horn. The reflected wave produces both time domain distortion as well as a change in the amplitude versus frequency response of the horn/driver system.

The second difficulty with diffraction slots, if they are located between the driver exit and the horn mouth, is that they can introduce path length differences associated with the physical geometry required to transition from the driver exit geometry to the narrow slot required to produce the necessary diffraction to achieve a requires dispersion, or beamwidth. These path length differences can result in uneven acoustical summing of the waveforms due to the phase differences associated with the different path lengths.

It should be noted that when a horn is designed to produce a specific radiation, or dispersion pattern discontinuities are typical. The designers goal is to minimize the number and of magnitude of those discontinuities.

A more detailed view of a typical implementation of an Equivalent Throat driver can be seen in figure 3 and figure 4. In both of these figures plane “D” is the same as plane “A” in figure 1. In this implementation, both drivers have identical phase plug summation plane radii. The conventional driver, shown in figure 1 has an exit radius that is larger than the phase plug summation radius. The Equivalent Throat drive (figures 3 and 4) has an exit radius that is identical to and coincident with the phase plug summation plane. Based on the data in Tables 1 and 2, a smaller exit radius will produce a wider dispersion pattern (and larger included angle and larger beamwidth).



Equivalent Throat Driver
Figures 3 and 4

It can be seen in Figure 3 that angle “x” begins at plane “D”. Because this angles begins at plane “D” the driver/horn combination provided directional control to the wavefront at the optimal point, where the radius is smallest and the high frequency limit bandwidth is greatest. Figure 4 is the same driver but shows angle “y” beginning at plane “D”. It is typical for a horn with a rectangular radiation pattern (i.e. 90 degrees horizontal by 40 degrees vertical, 120 degrees horizontal by 60 degrees vertical, 60 degrees horizontal by 40 degrees vertical, or any of a set of possibilities of horizontal by vertical rectangular geometries) to have two different angles beginning at plane "D". It is also possible to have identical angles if the desired radiation pattern is square or a single angle if the desired pattern is oval in nature. (i.e. circular or elliptical or any other "round" geometry).

Figure 5 is a photograph of a prototype Equivalent Throat (ET) driver. The rectangular black line is the perimeter of the equivalent throat (this line was added for clarity. The photograph did not clearly show the perimeter of the equivalent throat section). As can be seen in figure 5, this prototype was designed to develop a rectangular radiation pattern. The silver colored geometry is the section of the magnetic return path steel back plate that is shaped to form a portion of the actual throat geometry. The equivalent throat design uses the entire thickness of the magnetic return path steel back plate to form the initial portion of the desired horizontal and vertical (for a rectangular implementation) radiation pattern of the driver/horn combination. The white portion of the photograph is an adaptor plate but is not necessary for proper operation of the equivalent throat design. The salient feature of the design is that the desired radiation geometry begin at the phase plug summation plane where the exit radius can be made a minimum for any given driver design. This requires that the thickness of the back plate, from plane "A" in figure 1 have the shape required to form the desired radiation geometry of the wavefront. This differs from a conventional design in that the conventional design has an exit radius on plane "B" of figure one. The conventional design exit radius is displaced from the phase plug summation plane by the thickness of the magnetic return path steel back plate. The conventional design exit radius is larger than the radius at the phase plug summation plane. (The conventional design could if fact be an unintentional subset of the equivalent throat design if the included angle between the phase plug summation radius and the larger exit radius were the desired included acoustic radiation angle for a horn of circular cross section.)

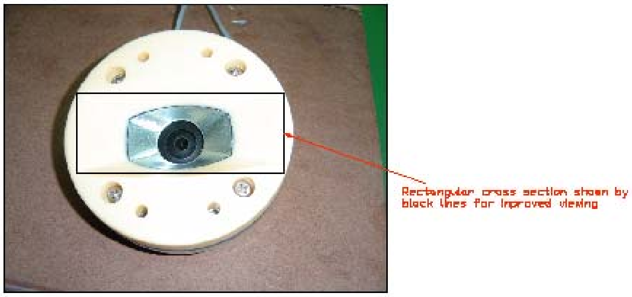


FIGURE 5

Figure 6 is a photograph of an equivalent throat driver with a matching equivalent throat horn. An equivalent throat horn differs from a conventional horn in that the entrance geometry of the horn must match the exit geometry of the driver or be adapted to the radius of the phase plug summation plane. In the example shown in figure 6, the horn's widest included (in the case of a rectangular pattern implementation) matches that of the widest angle that the radius associated with the phase plug summation plane.

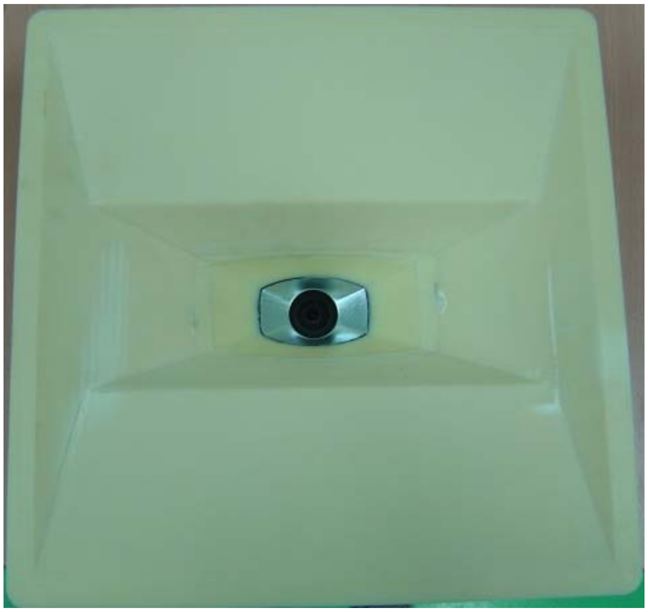


FIGURE 6

Figure 7 is a photograph of the entrance side of the horn and illustrates the geometrical match with the exit geometry of the driver.

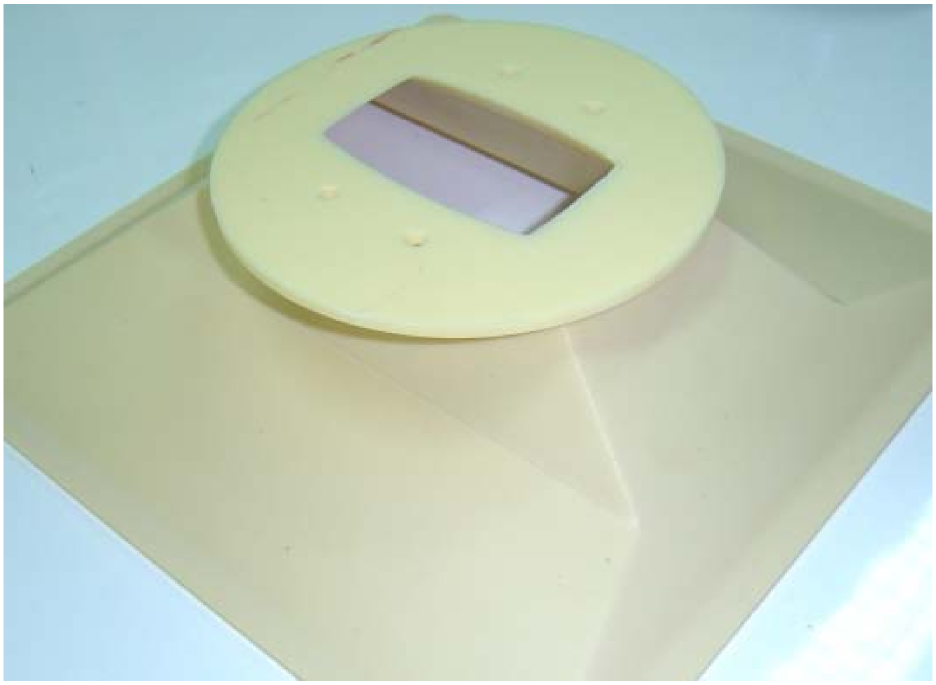


Figure 7

Other horn geometries, all with a rated beamwidth less than that supported by the phase plug summation plane radius may certainly be used with an equivalent throat driver. Figure 8 is the rear view of a prototype horn with a rated -6dB beamwidth of approximately 70 degrees in the horizontal plane and 40 degrees in the vertical plane. The unique geometry on the entrance side of the horn matches the exit geometry of the equivalent throat driver. The radius of the horn entrance matches the radius of the driver phase plug summation plane radius. The internal portion of the horn shown in figure 8 then becomes the required geometry to produce the desired acoustic dispersion. As is the case with all equivalent throat horns, the geometry of the horn in figure 8 begins the desired included angle at the plane of the horn entrance, which is coincident with the plane labeled “A” in figure 1.

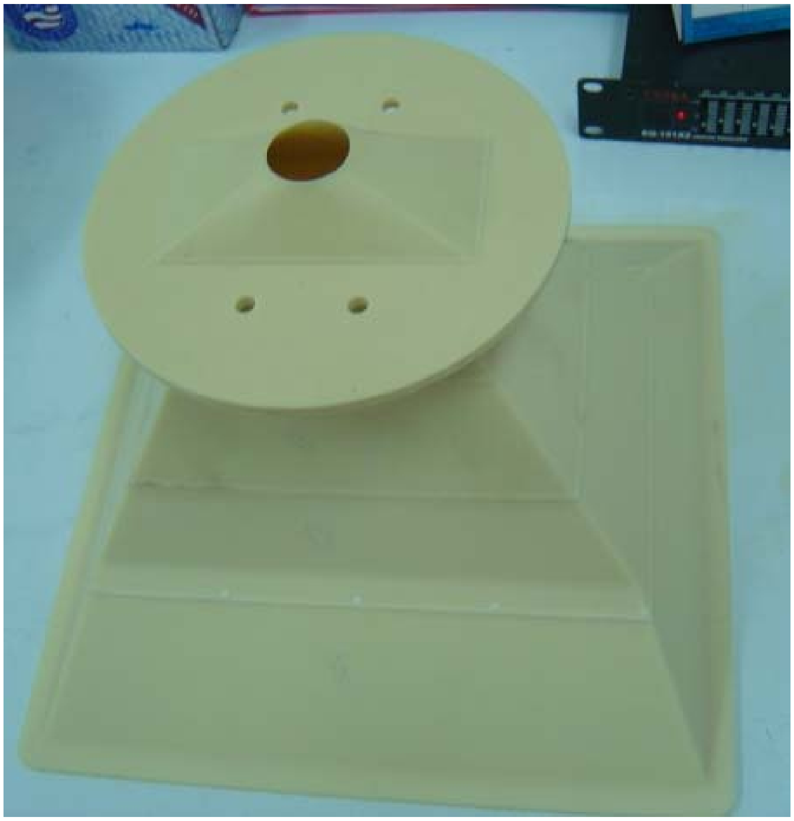


FIGURE 8

Acoustical measurements of the horn driver combination indicate good agreement with theory. The radius of the phase plug summation plane for the equivalent throat driver is 0.55 inches. The radius at the exit of the conventional driver is 0.675 inches. The predicted difference in the high frequency dispersion limit is 1757Hz. The measured difference is approximately 1800Hz. This represents excellent agreement. The absolute magnitude of the included angle (-6dB points) and associated frequency, however, is different. The -6dB included angles for a radius of 0.55 inches (the equivalent throat horn/driver combination) is approximately 9820Hz. The measured included angle is approximately 11,400Hz. (The conventional horn/driver, with an exit radius of 0.675 inches produces a measured included angle of approximately 9600Hz). In both cases, the difference between the data calculated in tables 1 and 2 and the measured results are thought to be associated with acoustic end correction and boundary conditions. The data shown in tables 1 and 2 (“Acoustics”’ Beranek) was performed on unflanged pipes. The addition of the horn to the system will alter the acoustic conditions and modify the data shown in tables 1 and 2. The dispersion pattern is wider, and is in good agreement with the changes seen in Beranek’s figure 4.20 between ka=1.5 and ka=4. The important result is that the difference between the equivalent throat driver and horn and the conventional driver and horn is very close to the theoretical prediction.

In as much as the acoustic loads and boundary conditions presented by the two horns are similar it is expected that the delta between the two systems should be maintained.

Figure 9 represents the amplitude versus frequency response of the equivalent throat driver shown in figure 5 and the horn shown in figure 6. The top curve is the response of the horn and driver on the major acoustic axis of the horn. The lower curve is the amplitude versus frequency response 50 degrees off the horizontal axis. (The horn shown in figure 6 has a nominal horizontal included angle of 120 degrees and a vertical included angle of 60 degrees). This initial prototype was designed with a horizontal included angle greater than what the phase plug summation plane radius would support, per tables 1 and 2. The data presented in this figure clearly indicates a separation of greater than 6dB above 10 kHz.

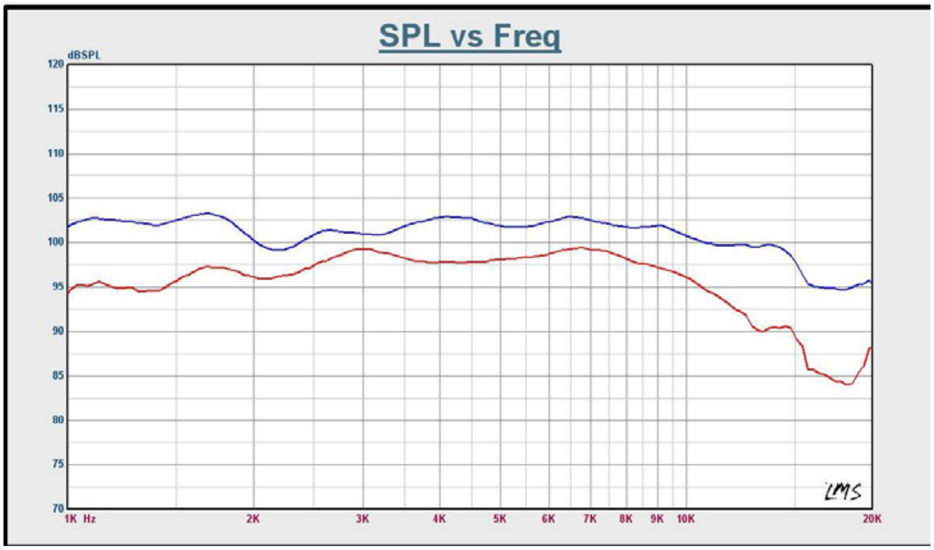


FIGURE 9

Figure 10 represents the on axis and off axis response of a conventional (i.e. non Equivalent Throat) driver and horn combination. It is clearly evident that the delta between the on axis response and off axis response begins to increase above 8kHz. Table 3 is a list of selected data points for both the equivalent throat driver/horn combination and a conventional driver and horn. This table lists the on/off axis delta for each drive and horn combination

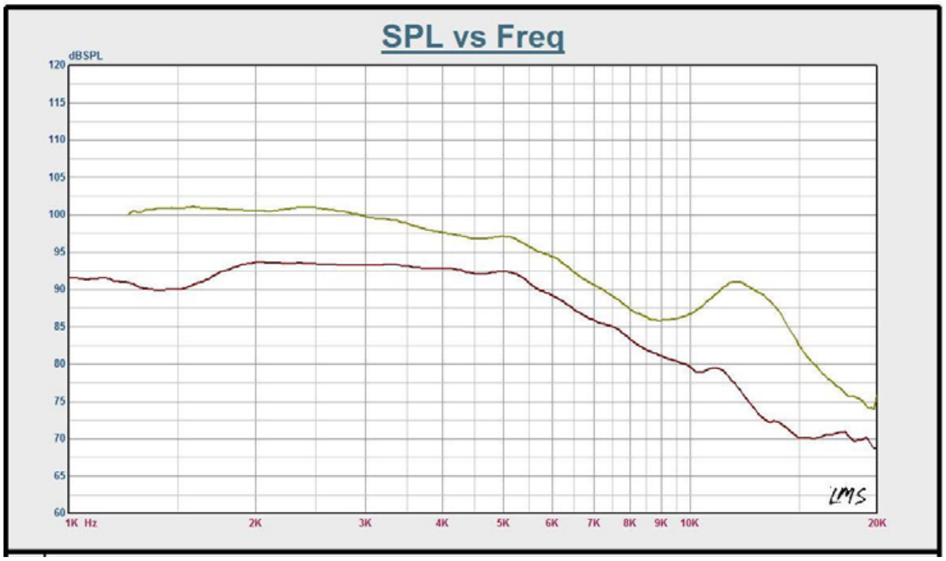


FIGURE 10

TABLE 3

Frequency (Hz)	Equivalent Throat Delta	Conventional Delta
9.6kHz	4.7dB	6.0dB
9.9kHz	4.7dB	6.8dB
10.5kHz	5.0dB	9.1dB
11.0kHz	5.5dB	10.1dB
11.5kHz	6.1dB	12.0dB
12.0kHz	7.2dB	14.5dB

As shown in table 3, the equivalent throat driver/horn combination maintains a smaller delta between the on axis response and the off axis response, indicating the ability to maintain a wider frequency response at a higher frequency.
It should also be stated that the –6dB included angle for the equivalent throat driver/horn combination is 100 degrees and occurs at 11.5kHz. The conventional driver/horn combination -6dB included angle is 90 degrees and occurs at 9.6kHz.

Analysis of the second prototype equivalent throat horn (rear side shown in figure 8) demonstrates the ability of the overall design concept to a variety of directional characteristics. As noted, the equivalent throat driver must incorporate the widest included angle to achieve the necessary dispersion. Additional horn geometries may then be designed with narrower dispersion angles. The response shown in figure 11 is that of the 70 degree horizontal by 40 degree vertical. Figure 11 demonstrates that additional, but narrower dispersion pattern horns, will function in a traditional manner as long as the horn entrance radius matches the phase plug summation plane radius on the equivalent throat driver.

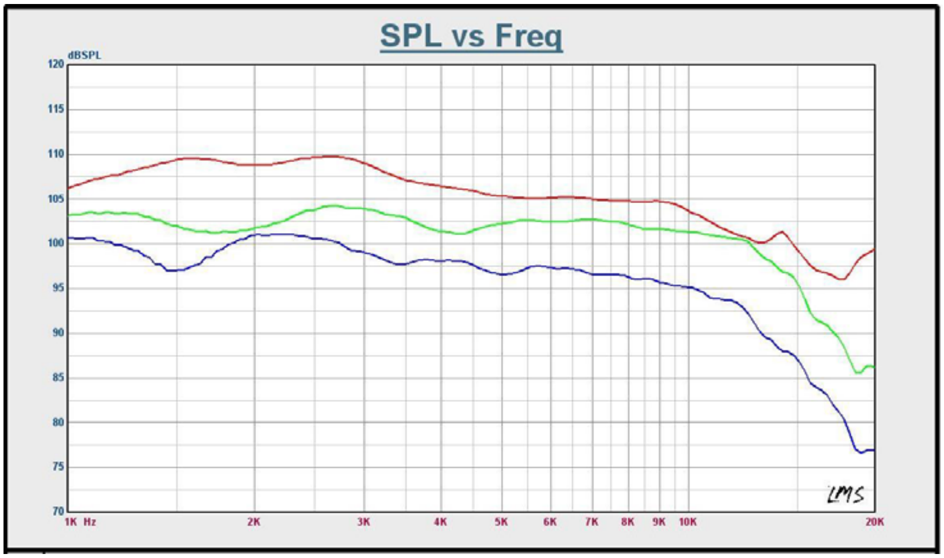


FIGURE 11

Conventional art compression drivers have an exit radius that is larger than the phase plug summation radius and is separated some distance from the plane where the phase plug summation radius is located. Because the exit radius on conventional art devices is larger than the summation plane radius the high frequency dispersion performance of the driver is limited by the exit radius.

Equivalent throat driver/horn combinations utilize the compression driver summation plane radius as the exit throat. By utilizing the summation plane radius the high frequency dispersion limit is increased.

Equivalent throat driver/horn designs utilize the compression driver magnetic return back plate to provide an included angle (or combination of angles) to provide directional information to the emerging wavefront.

The widest dispersion horn has a rear geometry that matches the exit geometry of the equivalent throat driver. Other horns may easily be used with the equivalent throat driver providing the horn has its widest dispersion, or beamwidth , that is equal to or less than the included angle, or angles, on the equivalent throat driver.

The novel and unique aspect of the Equivalent Throat system is that the driver is capable of producing wider dispersion and beamwidth than a conventional driver because the exit radius is coincident with the phase plug summation plane. As has been shown, a smaller radius exit will produce a wider dispersion.

The Equivalent Throat system is also capable of generating dispersions, or beamwidths, narrower than the included angle of the Equivalent Throat driver when other Equivalent Throat horns, of reduced dispersion angle are coupled to the driver. These reduced dispersion (higher Q) horns are coupled to the exit geometry of the Equivalent Throat driver by having an “inverse” geometry that will mate with the Equivalent Throat driver and allow the entrance radius of the horn to mate with the phase plug summation plane radius.

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