



A White Paper on Danley Sound Labs Tapped Horn and Synergy Horn Technologies

Tapped Horn (patent pending)

Horns have been used for decades in sound reinforcement to increase the loading on the loudspeaker driver. This is done to increase the power transfer from the driver to the environment in which the sound is radiated. For maximum power transfer to occur an impedance match between the loudspeaker driver and the free air must be established. A horn is the means to this impedance match.

For a horn to operate properly it must not be acoustically small compared the frequencies (wavelengths) it is to radiate. Conventional horn theory and design formulae are based on this assumption. To meet this requirement the horn needs to be at least one-half wavelength long at the low frequency cut-off of the horn and the circumference of the mouth must be at least one wavelength. When used for low frequency reproduction this can make for a very large unwieldy horn that can become impractical to make or move.

A common practice used to reduce horn size is to make it only one-quarter of a wavelength long at the low frequency cut-off. This "short cut" has some very interesting effects on a horn's performance. Of note is that a quarter wavelength resonance will have a velocity *minimum* at the throat compared to the half wavelength resonance which will have a velocity *maximum* at the throat. The net result of this is that, while there will be output from the horn in its low frequency region, the horn will not yield efficient power transfer until the frequency is increased sufficiently to correspond to the horn being one-half wavelength long.

This begs the question: Can the quarter wavelength horn be driven efficiently? The answer is a resounding yes. To do so one must examine the conditions presented to the driver at the horn's throat and match these conditions for maximum power transfer. The velocity minimum condition requires that the proper loudspeaker driver have a much stronger motor (larger magnet) and a larger moving mass than conventional horn theory dictates. The downside is that this driver is not at all well suited to drive a conventional horn. Once the frequency increases to the point that the horn is at least one-half wavelength a conventional horn is exactly what we have.

So what we need is a loudspeaker driver that can change its mechanical (Thiele-Small) parameters depending on frequency. No problem because we found the magic stash of Unobtainium!

This seemingly impossible feat is accomplished by allowing the radiation from the rear side of the driver to enter the horn at a location (tap) sufficiently far away from the throat (where the front side is driving the horn) and closer to the mouth..

Example of a Tapped Horn

Since the rear of the driver is much closer to the mouth of the horn, at very low frequencies it is effectively de-coupled from the system and its radiation does not affect the total output. This occurs due to the throat end being almost one-quarter wavelength away. The radiated pressure from the rear of the driver is reflected from the throat end back toward the mouth. The total path length traveled is one-half wavelength (one-quarter down & one-quarter back). The reflected wave arrives 180° out of phase with the original radiated pressure from the rear of the driver and is thus cancelled.

As frequency increases the situation changes a bit and the rear of the driver begins to be coupled to the horn as the reflection from the throat end does not cancel its own radiation. When the frequency is such that the horn is one-half wavelength long the rear of the driver is fully coupled to the horn. The pressure from the front and rear of the driver are of reverse polarity; a 180° phase shift at all frequencies. The pressure from the front of the driver (at the throat) and the pressure from the rear of the driver (close to the mouth) are now approximately one-half wavelength apart. This represents a phase shift of 180°. At this frequency both the front and rear of the driver are driving the horn in phase. When this happens the driver's radiating surface area (Sd), as far as the horn is concerned, had significantly increased (almost doubled). Since the driver radiates from the front and back of the diaphragm, this yields very different driver parameters than when at the one-quarter wavelength resonance condition.

To illustrate just how much low frequency extension and overall output can be gained from a small horn loaded box using this technique, modeled simulations of a Tapped Horn and a vented box, loaded with drivers optimized for the performance of each one, are compared in Figure 1. Each enclosure has the same outer cabinet dimensions; 40 in. x 22.5 in x 28 in.

While the SPL is comparable for the two units, one of the real advantages of the Tapped Horn is seen in Figure . The diaphragm excursion of the driver is greatly reduced due to the acoustical loading of the horn. With an input of 63 V (500 W) the vented box exceeds 5 mm (0.2 inches) at 90 Hz. The Tapped Horn is well below this until just above 55 Hz. The vented box reaches 9 mm at 55 & 35 Hz while the Tapped Horn's excursion peaks at just over 6 mm at 46Hz. This decrease in excursion will translate directly into lower distortion and higher output capability from the Tapped Horn.

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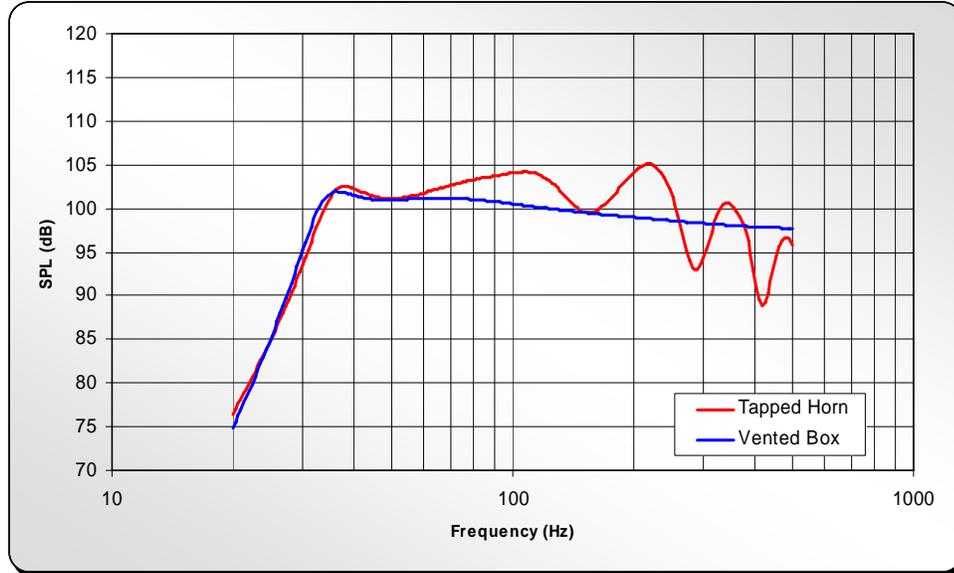


Figure 1 – Model simulation of a Tapped Horn and vented boxes (28 V, 10 m – equivalent 1 W, 1 m)

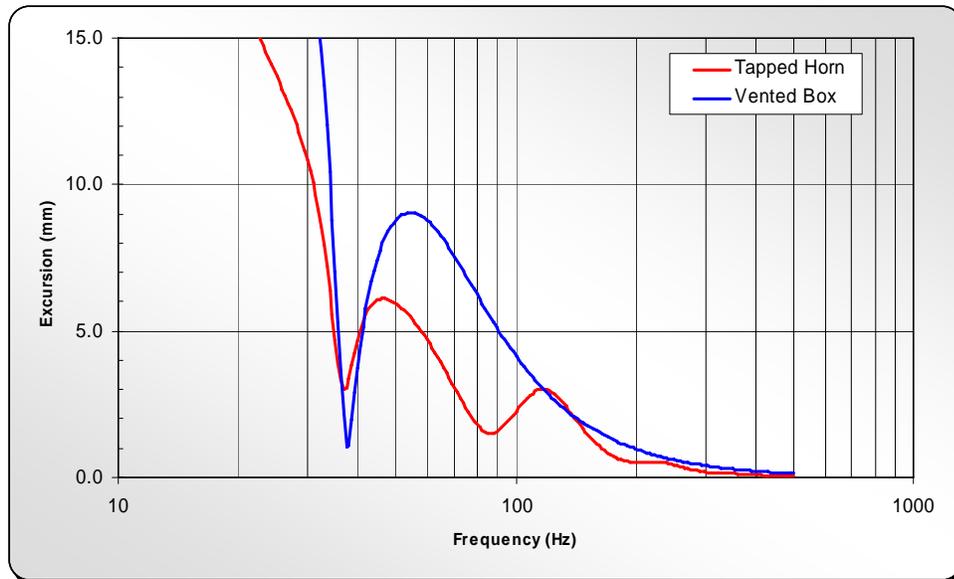


Figure 2 – Driver diaphragm excursion with 63 V input (500 W)

This type of comparison is possible because this is a computer model. Realistically, the driver required for the vented box has a very small moving mass for a 15 inch driver, only 100 g. As a result, there is no way this driver can be built with a strong, heavy cone and a large diameter, long travel voice coil. The power handling (heat dissipation) and excursion capability (Xmax) of this driver will be severely limited. Approximately 3-4 mm would be the expected limit for this driver.

The driver used for the Tapped Horn is much heavier, almost 200 g. It has a long, large diameter voice coil. This allows for high power handling and long excursion. Its linear Xmax is in excess of 9 mm.

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Accounting for the excursion limitations of each driver, and limiting the input so as not exceed the X_{max} of each driver, the maximum SPL output capability of each is shown in Figure . This is given for a distance of 10 meters. The vented box is limited to an input of 30 V (113 W) while the Tapped Horn can accept 90 V (1,013 W). From this the advantages of the Tapped Horn should be obvious.

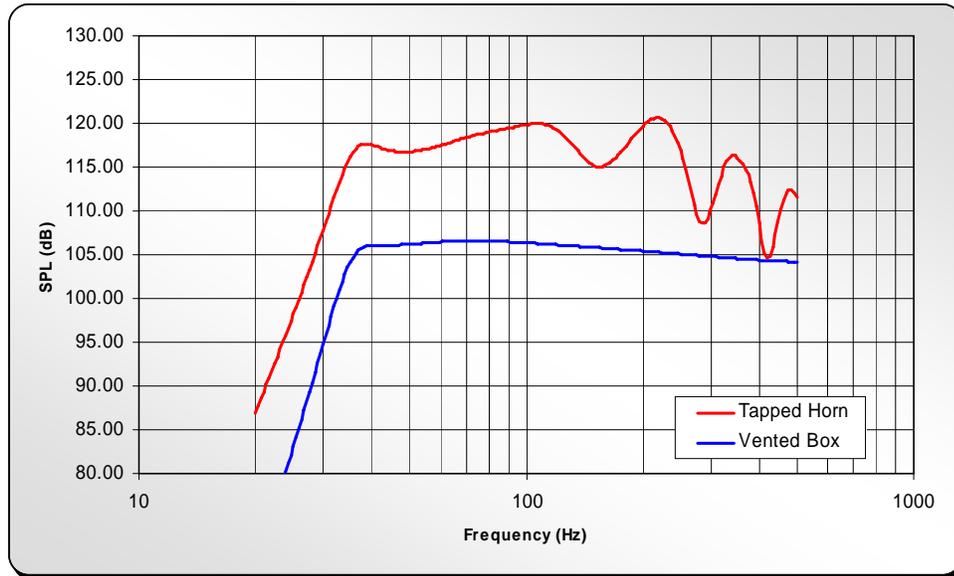


Figure 3 – Driver excursion limited maximum SPL at 10 m (add 20 dB for SPL at 1 m)

Synergy Horn (patent pending)

Horns are also beneficial in the radiation of higher frequencies. At these higher frequencies it is important to not only provide good loading for the loudspeaker driver but also to provide uniform directivity control across as wide a frequency span (bandwidth) as possible. This can prove to be quite challenging. Simply reproducing the frequency spectrum from below 100 Hz to beyond 10 kHz typically requires that multiple drivers of varying sizes, best suited to reproduce a particular frequency region, be used. In many, if not most, designs this puts the loudspeaker drivers (direct radiators) and/or horn mouths at different physical locations. In such designs it is subsequently difficult to maintain a uniform radiation pattern through the crossover region from one device to the next.

For directivity control at low frequencies (long wavelengths) size is required. A generally accepted equation relating horn mouth size, directivity control and frequency is

$$f_{\theta} = K / (d_{mouth} \times \theta), \text{ where}$$

f_{θ} is the frequency at which loss of directivity control begins,

d_{mouth} is the dimension (height or width) of the horn mouth in a plane,

θ is the design coverage angle of the horn in that plane,

K is a constant; 1×10^6 inch*degree*Hz (2.54×10^4 meter*degree*Hz).

To achieve 50° pattern control from a horn at 500 Hz a mouth size of approximately 40 inches is required. It becomes readily apparent how much of an advantage it is to be able to use a large horn.

The question now becomes how one makes use of a large horn while maintaining reasonable enclosure size. Coaxial horn arrangement, nesting a smaller high frequency horn inside a larger mid frequency horn, has been used by several manufacturers. A design approach undertaken by a few has been to have the previously mentioned multiple drivers, for each frequency region (pass band), all drive the same horn. Each of these methods has the advantage of utilizing the entire front area of the loudspeaker enclosure as the horn mouth.

The Synergy Horn successfully couples the radiation from multiple drivers into a single horn to yield the effective performance of a single horn/driver system with high sensitivity (efficient power transfer), excellent directivity control and true modular array ability.

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A conical (straight wall) horn can yield very consistent directivity control over a wide frequency range. The problem with using a conical horn is that it does not provide good low frequency loading to its driver. The loading a horn presents to a driver can also be viewed as the expansion rate of the horn. A 125 Hz exponential horn has an expansion rate that doubles its cross sectional area every 6 inches of horn length while a 500 Hz exponential expansion doubles its area every 1.5 inches.

When one views a conical horn expansion in this same manner a very interesting item is revealed. The expansion of the conical horn is very rapid close to its apex (throat). That is it doubles its area in a very short distance. As the distance from the apex is increased toward the mouth, the expansion rate seems to decrease. That is to say it takes a longer distance down the horn from that point for the area to double. In essence for every point along the axis of a conical horn there is a different expansion rate and, in turn, a different low frequency cut-off. This is illustrated in Figure .

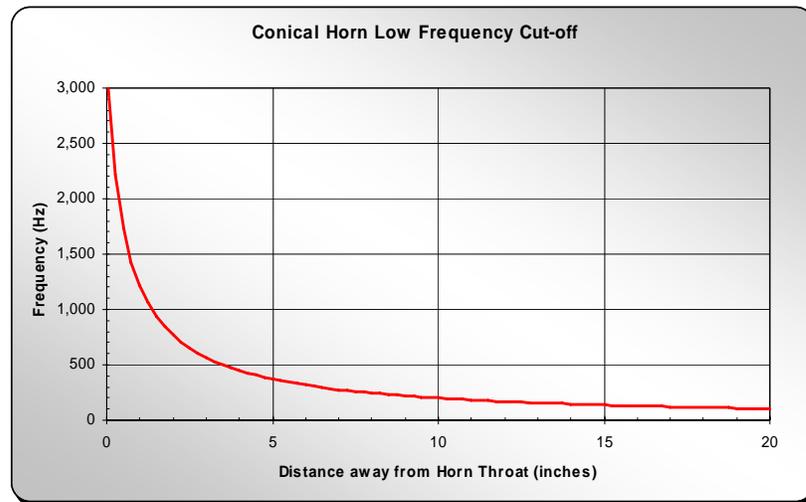


Figure 4 – Approximate driver loading of SH-50 based on where along the horn the driver is located

By utilizing this effect a conical horn can be driven at the appropriate place along its length to yield good low frequency loading on the driver. This is one of the principles governing the driver placement within the Synergy Horn. The lower frequency drivers are placed closer to mouth where the horn provides better loading within the frequency region (pass band) where these drivers are used Figure .

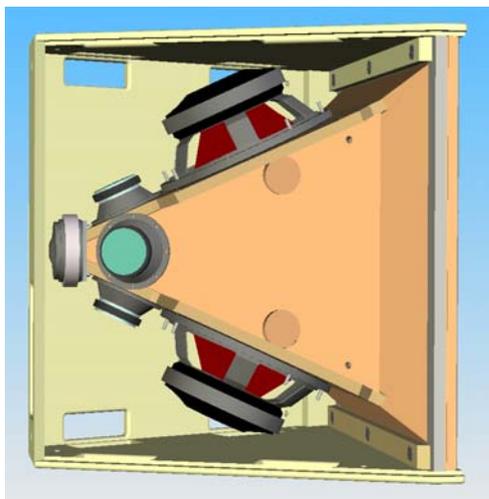


Figure 5 - 3-way Synergy Horn showing HF, MF and LF driver placement

There are several other similar principles that dictate the driver placement for each pass band within the Synergy Horn. When these constraints are observed the result is that multiple drivers operating in multiple frequency ranges are very effectively coupled into a single horn.

The crossover is a very important and integral part of the overall system design of the Synergy Horn. The loudspeaker drivers are in close proximity to each other and are loading into a mutually coupled horn passage such that they interact (feel) each other acoustically. Taking the driver's individual magnitude and phase response into account is imperative to the crossover design. When this is done, it, along with the close coupling between each pass band and the horn geometry allow a crossover design that greatly minimizes the group delay, or "phase distortion", throughout the operating range of the system. This is evidenced by the flat phase response seen in Figure and the impressive impulse response and group delay in Figure .



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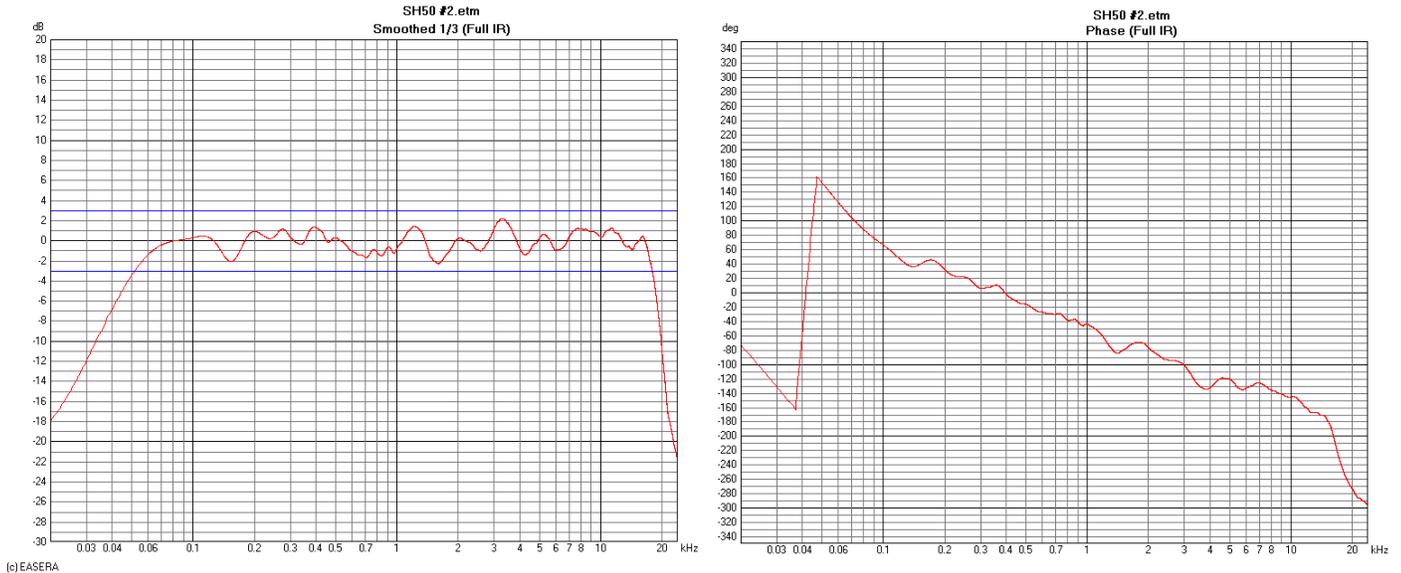


Figure 6 – Magnitude & phase response of a three-way Synergy Horn (SH-50)

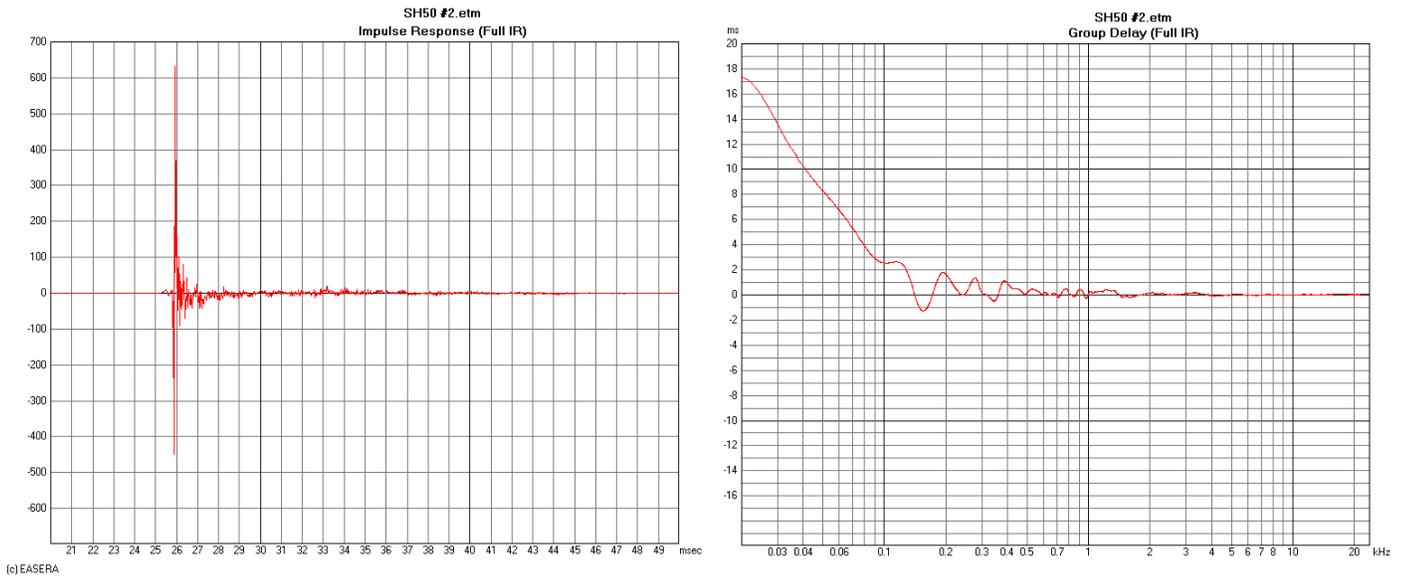


Figure 7 – Impulse response & group delay of a three-way Synergy Horn (SH-50)

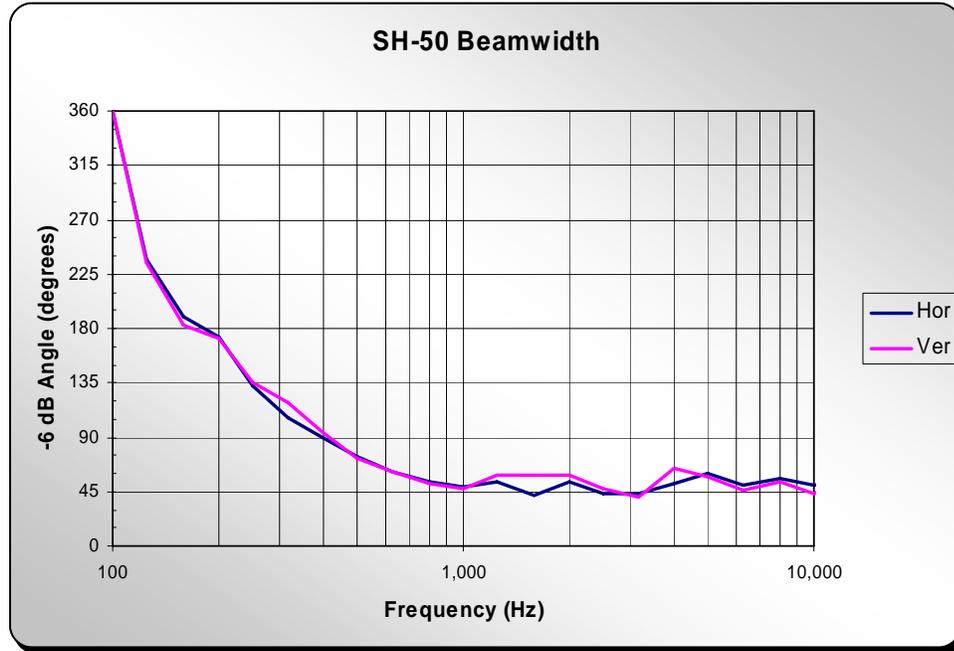


Figure 8 – SH-50 measured beamwidth

The use of a conical horn flare yields the consistent directivity response of the Synergy Horn. This occurs over a broad frequency range as seen in Figure 8 which is the measured beamwidth response of a production SH-50. Multiple units may be arrayed with an extremely low amount of interference between adjacent units. This is accomplished by matching the radius of curvature of the wave front emanating from each unit. When the wave front curvature does not match, the result is ripple interference and comb filtering. This is caused by errors in the summation of the wave fronts in the overlap region (Figure 9). If the wave fronts match, this interference and the comb filtering that can result, is virtually eliminated.

For the SH-50 the proper relationship between the enclosure side wall angle and the coverage angle of the horn was constructed. This allows adjacent enclosures to be tight packed and the condition for wave front matching is achieved with only minor wave front summation error (Figure 1).

This is further illustrated by close correlation between the predicted performance of an EASE model and the actual measurement of the combined directivity of a horizontal array of two SH-50 units. The polar graphs at several key frequencies are shown in Figure 2.

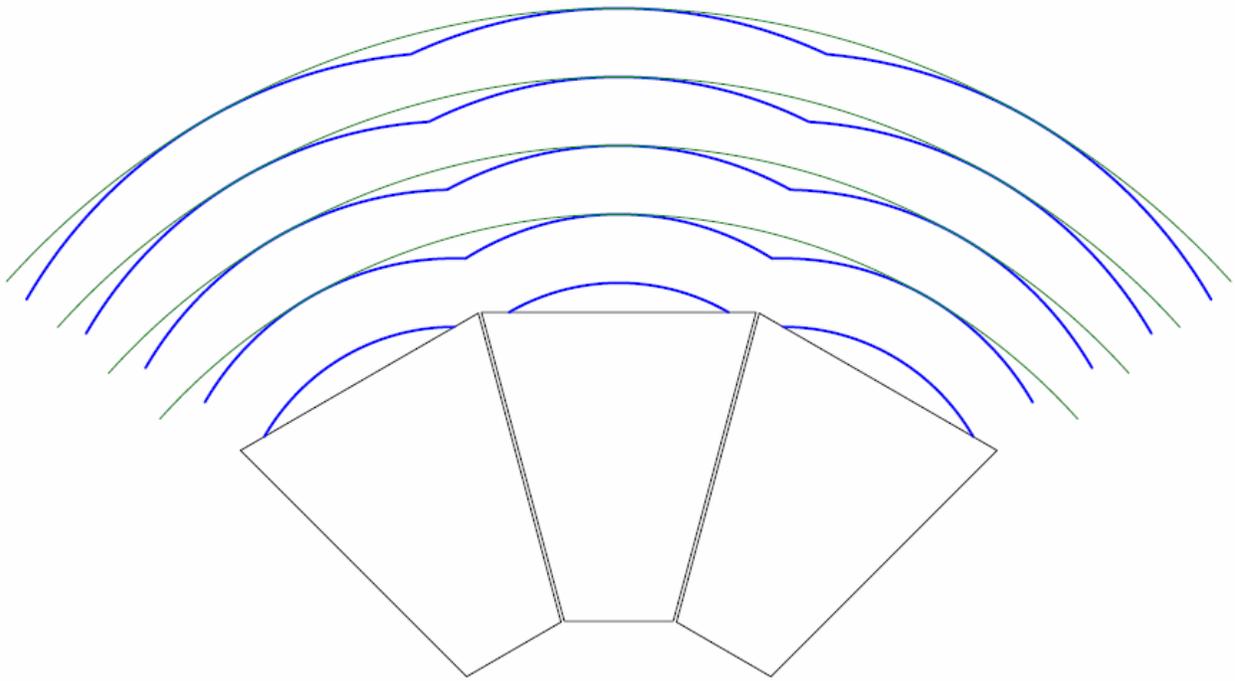


Figure 9 – Comparison of ideal wave front summation (green) and that of a conventional loudspeaker (blue)

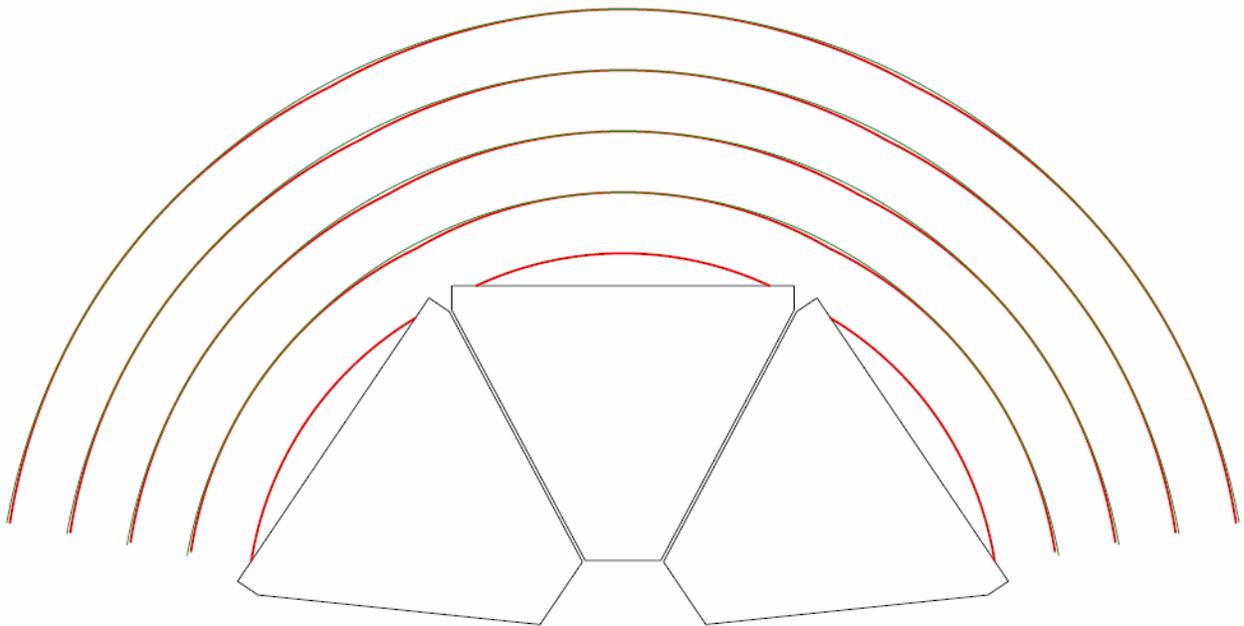


Figure 1 – Comparison of ideal wave front summation (green) and that of the SH-50 Synergy Horn (red)

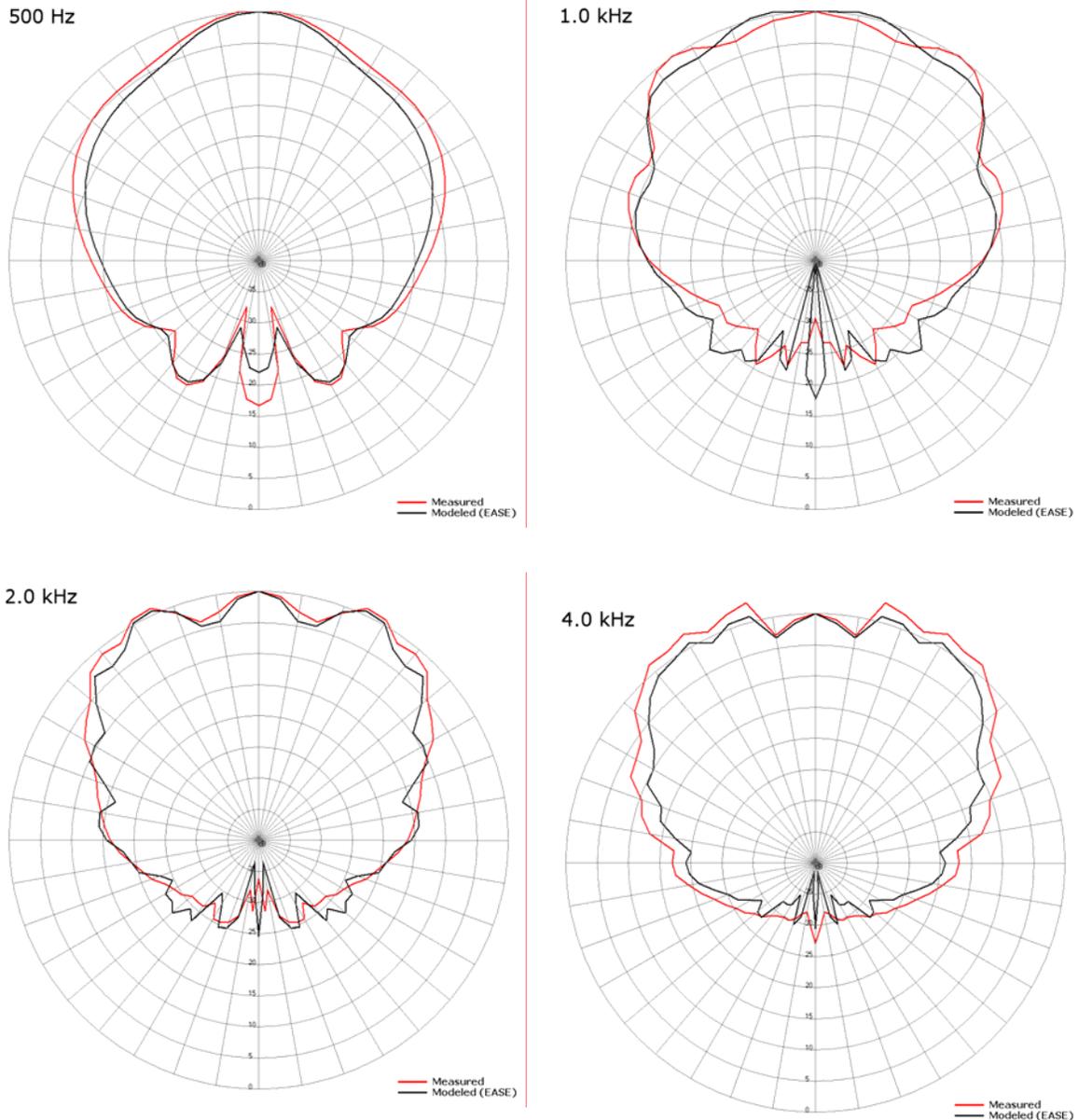


Figure 2 – Horizontal polar plots of an array of two SH-50 loudspeakers
Measured – Red Modeled – Green