PROFESSIONAL

Technical Notes Volume 1, Number 31

Progressive Transition™ (PT) Waveguides

Background:

The modern constant-directivity horn has evolved slowly since its introduction over 25 years ago. Advances in horn design have been primary evolutionary in nature. Indeed current popular constant directivity horns appear strikingly similar to the first devices, which at their time, defined a revolutionary change in design philosophy.

Horn design involves balancing compromise. Key performance parameters that can be controlled by the designer include: frequency response (both on- and off-axis), horizontal and vertical beamwidth, directivity index, electrical impedance, harmonic distortion, and low frequency cut-off. The designer may also manipulate the acoustic wave-front to generate a desirable radiation pattern that smoothly transitions from horizontal to vertical.

Horn designers typically optimize one, two, or three performance parameters considered to be of the highest value, and then other areas of performance become an indirect result of the other choices made.

Unfortunately each parameter mentioned influences sound quality, arrayability, and accuracy. This in turn impacts the successful application of a horn in a loudspeaker system. Focus on a limited subset of objective parameters may not yield an optimal performance balance for real world applications.

Since the human ear doesn't discriminate based on a single area of technical superiority, a balance of each area of performance is required.

An Introduction to Progressive Transition Waveguides:

PT™ Waveguide Design:

To achieve balanced response of all parameters, JBL Professional started with a clean sheet of paper and developed Progressive Transition (PT) Waveguides.

Progressive Transition waveguides are unique because a single mathematically-continuous surface defines the waveguide from transducer-throat to waveguide-mouth. Figures 1 through 4 show various PT waveguides. In each case the distinctive feature is the lack of a traditional diffraction slot. Instead the sidewalls transition smoothly from the driver throat through to the square or rectangular mounting flange.

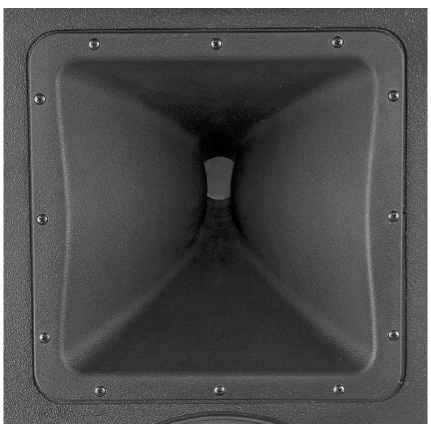


Figure 1: PT-H64HF waveguide (60° x 40°, 12 x 12 inch, rotatable).

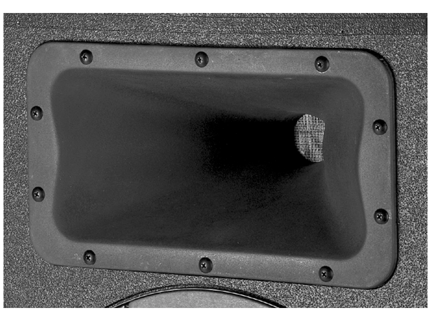


Figure 2: PT-F64HF waveguide (60° x 40°, 6.5 x 12 inch).

Earlier designs consider the throat, the diffraction-slot, and the bell of the horn to be separate. This produces a discontinuity at the diffraction slot, where a roughly exponential loading suddenly becomes a rapid final flare (or bell) intended to provide constant beamwidth. While this approach yields uniform beamwidth and DI, the downside is high distortion, rough electrical and acoustical impedance, and often irregular frequency response. These factors may combine to produce the typical "horn sound".

By applying advanced 3-dimensional surface modeling, it was possible to create a waveguide surface that eliminates the diffraction slot discontinuity. This allows the expanding acoustic wavefront to remain perpendicular to, and attached to, the horn side-wall at all times.

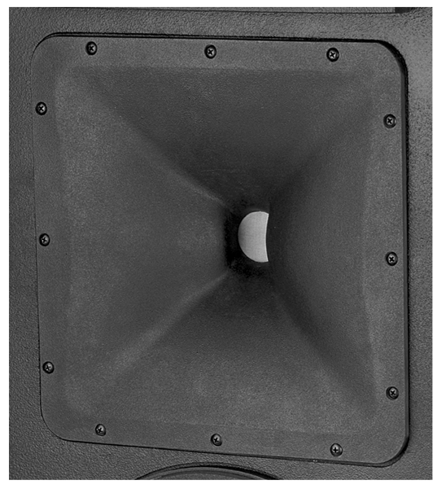


Figure 3: PT-H1010HF wave-guide (100° x 100°, 12 x 12 inch, rotatable).

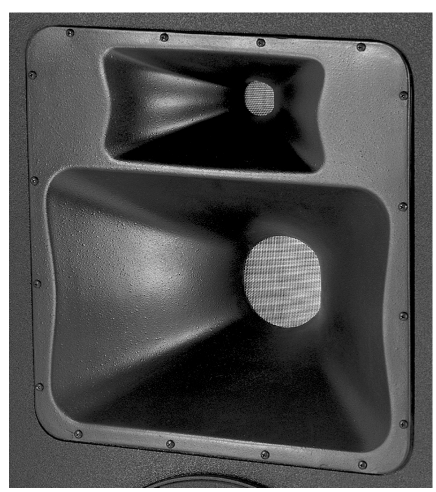


Figure 4: PT-K95MH waveguide (90° x 50°, 18 x 18 inch, rotatable).

In a PT waveguide, the wave-front is controlled to generate the correct shape to propagate from the waveguide's mouth. Even though geometrical diffraction is eliminated in PT designs, constant beamwidth and constant directivity are achieved. Improved frequency response, and lower distortion result. PT waveguide design principles are patent pending.

PT Waveguide Performance Benefits:

- Smoother frequency response. With JBL's 2451SL compression driver frequency response of ±1.0 dB is realized, with minimal equalization, on many PT waveguides.
- Electrical Impedance is smoother, and is free of typical "high-Q" peaks that compromise passive crossover design, and indicate difficult throat loading of the compression driver.

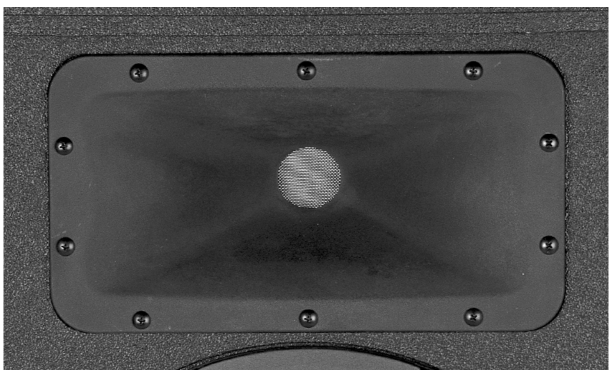


Figure 5: PT-F95HF waveguide (90° x 50°, 6.5 x 12 inch).

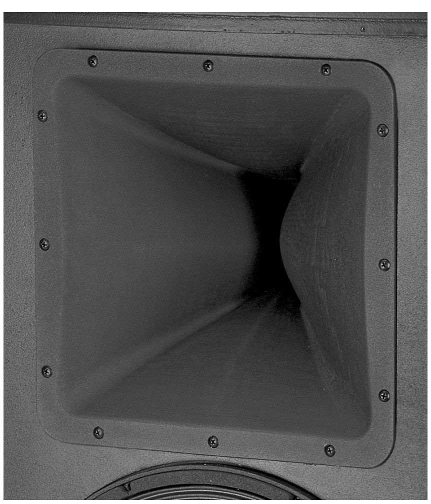


Figure 6: PT-H95HF waveguide (90 x 50°, 12 x 12 inch, rotatable).

- Advanced constant beamwidth and directivity is achieved.
- Wide coverage angles are achieved without compromise. PT waveguides may be as wide as 120° x 120°, but do not have rough frequency response, severe electrical and impedance anomalies, or poor acoustic loading.
- Harmonic Distortion is minimized to allow the maximum SPL capability of the compression driver to be used to its full advantage without a harsh "horn sound".
- A continuous transition from the transducer exit to the rectangular or square waveguide mouth ensures uniform projection in the intended coverage area.

Progressive Transition Waveguide Families:

PT waveguides are grouped into two families. The first is "compact", and second is "optimized coverage/rotatable".

Compact PT waveguides balance performance in favor of small overall package size. Frequency response is optimal, distortion is superbly low, depth is minimized for use where a shallow enclosure is required. Beamwidth and directivity are optimal in the horizontal plane. Vertical beamwidth and directivity are optimized to provide a good match with JBL low frequency and midrange transducers; however, vertical pattern control does not extend as low as optimized coverage PT waveguides. Figure 5 shows a compact PT waveguide.

Systems with rotatable PT waveguides optimize pattern control both horizontally and vertically. Pattern control is extended to a lower frequency. The installer can easily configure the loudspeaker for horizontal or vertical use. In systems using an optimized coverage PT waveguide, smooth frequency response, and the uniformity of off-axis coverage, and arrayability are all superior. A rotatable PT waveguide is shown in figure 6.

Compact vs. Optimized Coverage PT Waveguides:

Each PT design is appropriate for a wide variety of applications:

Compact PT waveguides offer these features:
- Minimized enclosure size.
- Optimized low distortion for maximum output.
- Maximum output and superior intelligibility. Stage monitors, distributed systems, and small arrays are excellent applications.

Optimized Coverage PT waveguides allow for:
- Rotatable systems: Horizontal or Vertical orientation.
- Extremely smooth frequency response at all playback levels.
- Predictable arrayability in engineered loud-speaker systems.
- Superior uniform coverage in difficult acoustical environments.
- Improved intelligibility.

PT Mid-High Rotatable Waveguides:

Combination mid-high, rotatable waveguides are a part of the PT family. The midrange transducer is a JBL Cone Midrange Compression Driver™ (CMCD). Each CMCD design features a cone midrange transducer integrated with a phasing plug, and an optimal rear enclosure. Figure 7 is a section view of a CMCD transducer.

CMCD midrange systems have extended band-width over a full decade. Either from 200Hz to 2 kHz, or from 350 Hz to 3.5 kHz, depending on the specific model.

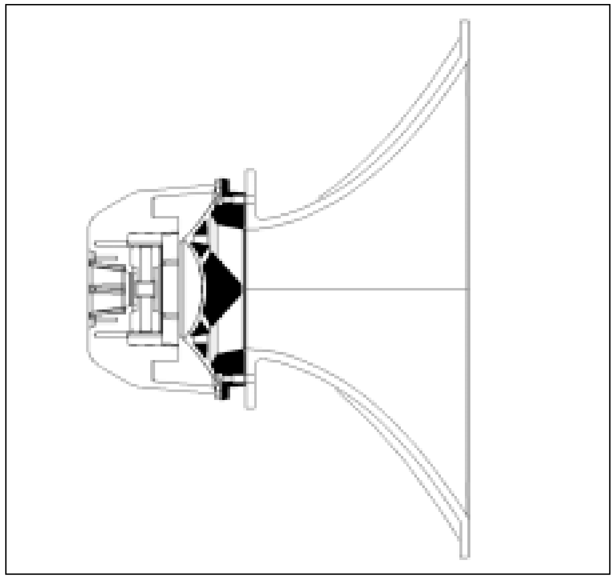


Figure 7: CMCD-81H section-view with PT waveguide.

JBL Professional Technical Note, Volume 1, No. 30, describes CMCD midrange components, and evaluates the performance in detail.

PT Waveguide Models:

Descriptive model numbers have been assigned to each Progressive Transition waveguide. This allows different systems using the same waveguide to be easily identified, and allows different coverage angle waveguides in the same family to be identified.

A selection of PT waveguide models are indicated in Table 1:

PT Model	Application	Coverage	Physical Description
PT-F95HF	High Frequency	90° x 50°	Compact Rectangular
PT-H95HF	High Frequency	90° x 50°	Optimized Rotatable
PT-K95MH	Mid-High Frequency	90° x 50°	Rotatable Mid-High
PT-F64HF	High Frequency	60° x 40°	Compact Rectangular
PT-H64HF	High Frequency	60° x 40°	Optimized Rotatable
PT-K64MH	Mid-High Frequency	60° x 40°	Rotatable Mid-High
PT-H77HF	High Frequency	70° x 70°	Optimized Rotatable
PT-F1010HF	High Frequency	100° x 100°	Compact Rectangular
PT-H1010HF	High Frequency	100° x 100°	Optimized Rotatable

Table 1

Design and Development:

In developing these waveguides, JBL combined advanced acoustical modeling, computer-aided surface modeling, in-house rapid-prototyping, and an automated acoustical measurement system.

Waveguide Contours:

Proprietary, patent-pending, mathematical models are used to establish the contours that each waveguide surface must pass through. Based on JBL's decades of horn design experience, these models allow the designer to select coverage angles, mouth size, depth, and throat diameter. The vector-splines calculated then define between six and ten boundaries of the PT waveguide surface.

Computer Surface Modeling:

The waveguide contours are then imported into a high-end surface modeling program — typically used by the aerospace and automotive industry. A 3-dimensional model of the waveguide surface is generated. Figure 8 shows the CAD surface model for a design.

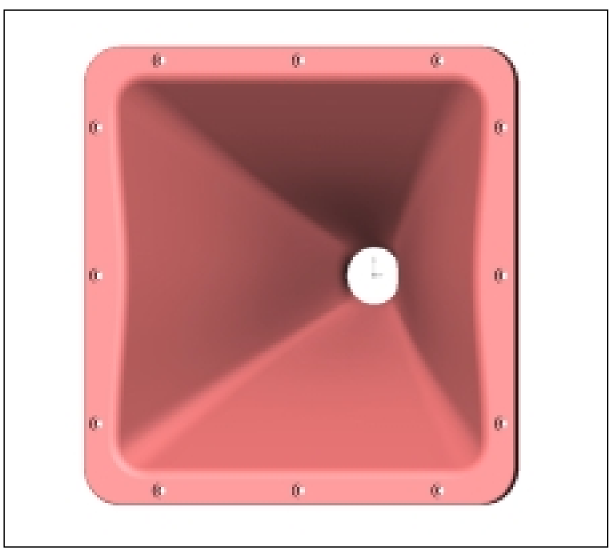


Figure 8: CAD model of PT-F77HF waveguide.

Prototyping:

The unique constantly-varying surface defining a PT waveguide makes it difficult to prototype the design. Most other horn designs have surfaces that change direction simultaneously in only two of the three possible directions. When this is the case, prototypes are easily fabricated by the "model-maker".

PT waveguide surfaces vary in all three directions simultaneously. This makes it impossible to construct a prototype "by-hand". Instead, to rapidly design and evaluate a potential design, a prototype is machined by JBL's in-house CNC machining center, shown in Figure 9. A CNC milled prototype is dimensionally accurate, and requires only a few hours to fabricate. Figure 10 shows a completed prototype.

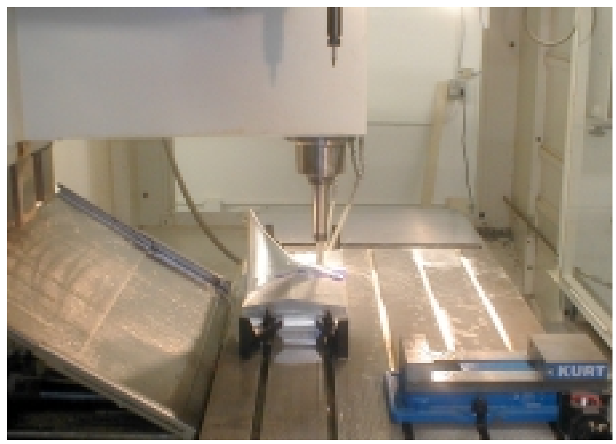


Figure 9: CNC machining-center fabricating a production horn tool.

Figure 10: CNC-milled prototype of PT-F77HF waveguide.

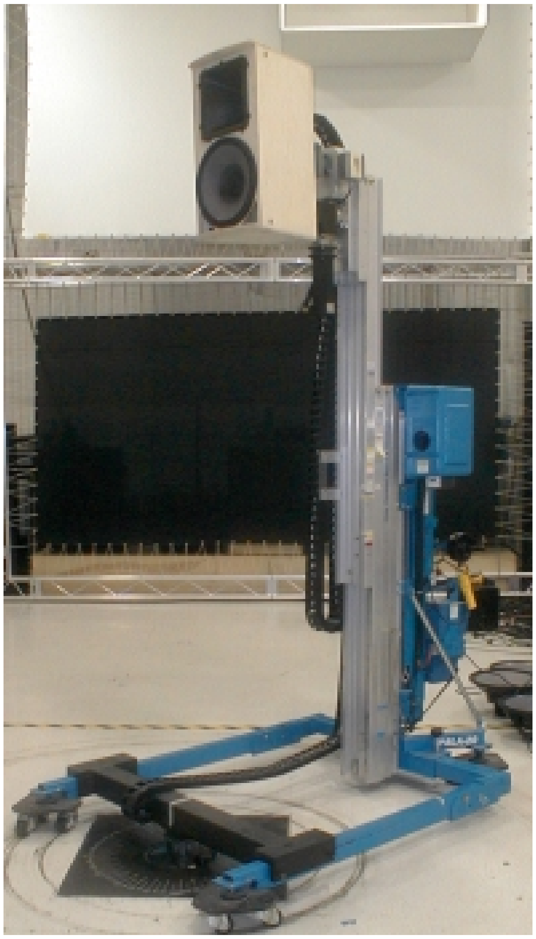


Figure 11: JBL Professional Automated Measurement System.

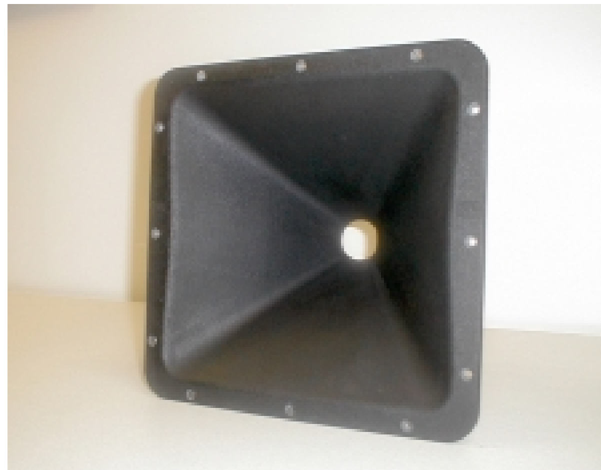


Figure 12: Final Production PT-F77HF waveguide.

Measurement:

The prototype is then measured acoustically with JBL's Automated Measurement System (AMS). JBL's AMS, shown in Figure 11 can rotate simultaneously in two axis to measure either full spherical data, or horizontal and vertical data. Five-degree resolution horizontal and vertical polar data is collected in 20 minutes. Five-degree resolution, full spherical measurements are completed in 3 hours.

Production:

Each PT waveguide in production is a perfect 3-dimensional duplicate of the approved engineering prototype. Tooling is made from the same CAD file used to make the prototype. This assures final performance equals the initial prototype. Figure 12 shows the production waveguide component we've discussed.

A Performance Analysis:

The balanced technical performance achieved by PT waveguides is explored here. Measurement data is compared with previous JBL horns, and against a competitor's solutions. Two rotatable 300 mm x 300 mm (12 x 12 inch) PT designs were selected. Performance evaluated includes: frequency response, impedance, beamwidth, directivity index, and harmonic distortion, in each case.

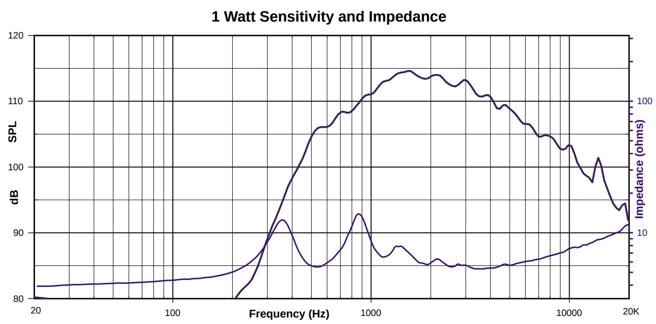
Medium Format, 90° x 50°, PT Waveguide:

This section compares a PT-H95HF waveguide against two equivalent 90° x 50° horns. JBL's previous 2381 horn, and a current horn design from another well established manufacturer are used. The competitor's horn is also a rotatable design.

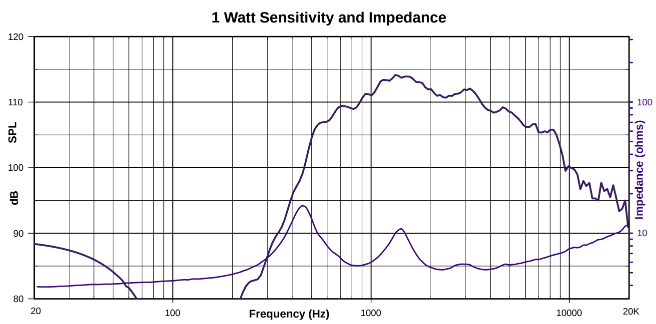
The PT waveguide was measured with a JBL 2450SL HF driver. The JBL 2381 used a JBL 2446H driver, and the competitor's horn used the popular european-sourced driver that came with the system the horn was removed from.

Figures 13a-c show frequency response of each design. Note the PT-H95HF waveguide has smoother frequency response, and a smoother electrical impedance curve. The improved electrical impedance allows more accurate results in systems using a passive crossover. The PT-H95HF also has the highest sensitivity.

a) PT-H95HF waveguide.



b) JBL 2381



c) Competitor's design

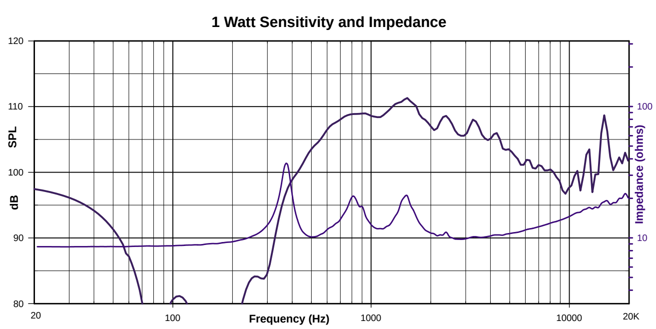
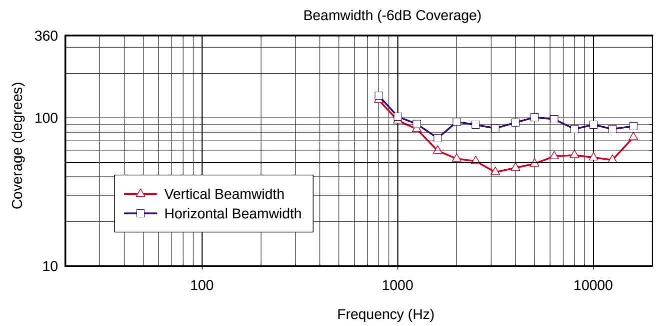


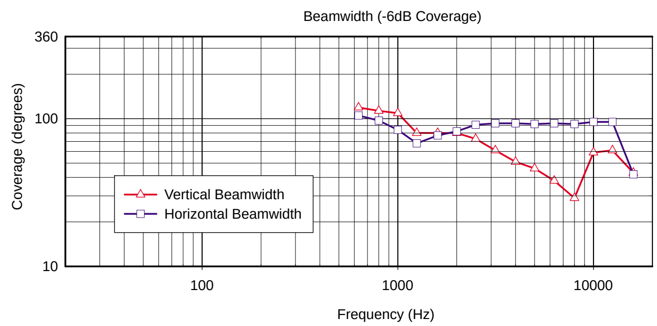
Figure 13: Frequency response and impedance at 1w/1m.

Figures 14a-c show -6 dB beamwidth for each design. The performance of the PT-H95HF is greatly improved compared to the 2381. Compared to the competitor's horn, the PT waveguide has equally good beamwidth.

a) PT-H95HF waveguide.



b) JBL 2381



c) Competitor's design

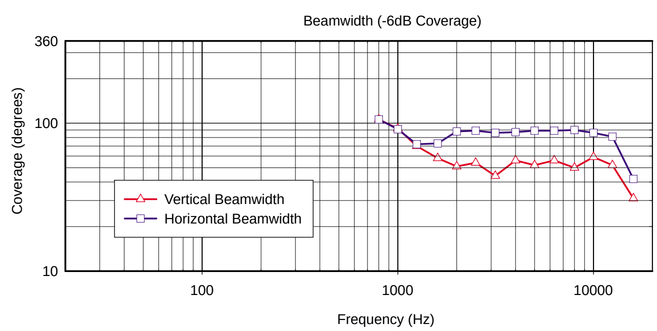
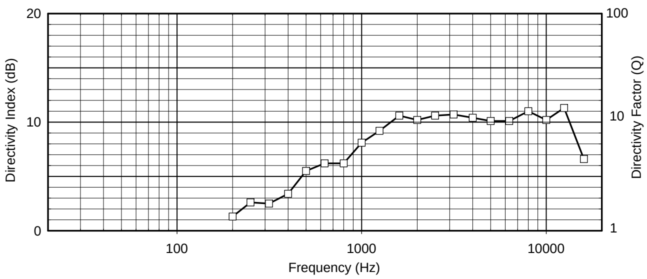


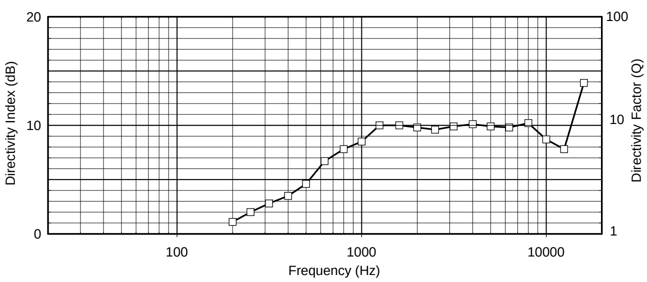
Figure 14: -6dB beamwidth

Figures 15a-c show the directivity index of each design. Again the PT waveguide shows improved power response compared to the two other examples.

a) PT-H95HF waveguide



b) JBL 2381



c) Competitor's design

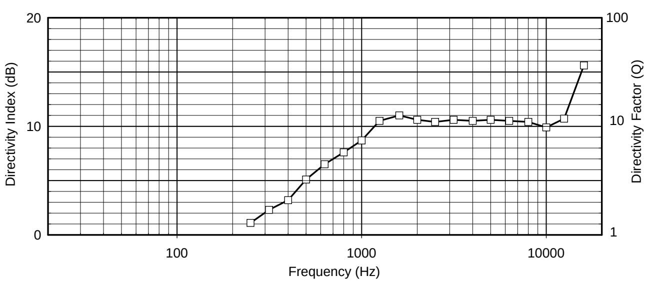
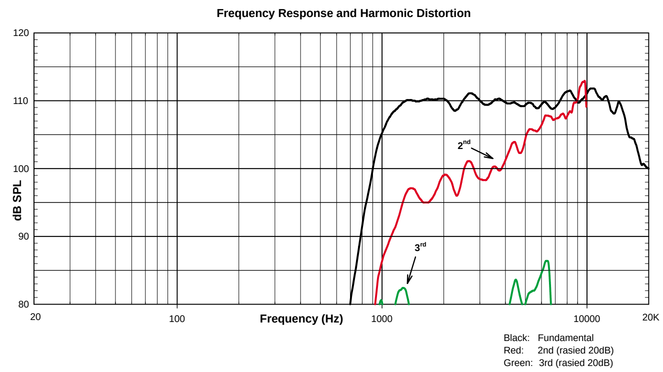


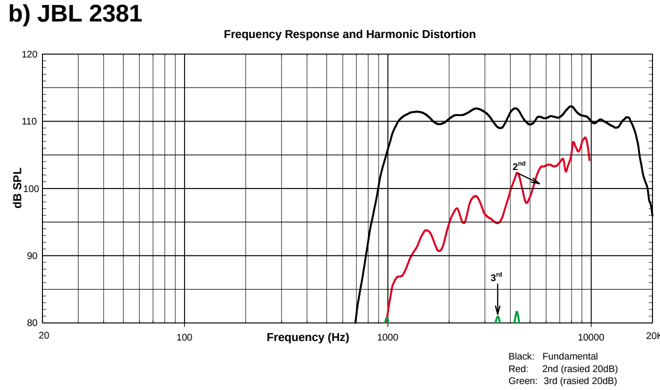
Figure 15: Directivity and Q.

Figures 16a-c present harmonic distortion data. The response shown was measured with a JBL DSC-260A loudspeaker controller. On-axis response was equalized flat with a 1 kHz crossover frequency. Input voltage was adjusted to achieve 110 dB SPL at 1m. The on-axis response, and harmonic distortion were then measured.

a) PT-H95HF waveguide



b) JBL 2381



c) Competitor's design

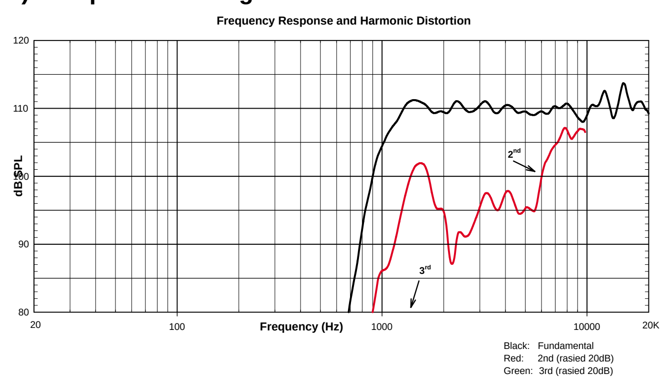


Figure 16: Harmonic Distortion at 110dB/1m.

In a high-frequency, horn the primary source of distortion is ideally limited to second harmonic distortion. This is a due to the non-linearities of air at high pressure, and is unavoidable. References 1 and 2 discuss this in detail. JBL's Optimized Aperture horns were designed specifically to reduce this distortion. As a result the 2381, shown in Figure 16b, has the lowest distortion, at the expense of compromises in frequency response, impedance, and beamwidth. The PT-H95HF waveguide produces textbook distortion characteristics, but the distortion is approximately 3 dB higher than the 2381 When the absolute lowest distortion is required, the rapid-flare compact PT-F95HF waveguide is the alternative and it matches the distortion performance of the 2381.

The competitor's solution in Figure 16c, shows 6 dB more second harmonic distortion between 1 kHz and 2 kHz. This indicates non-linearities in the design not produced by air distortion. This unanticipated additional distortion in the vocal region may be very audible.

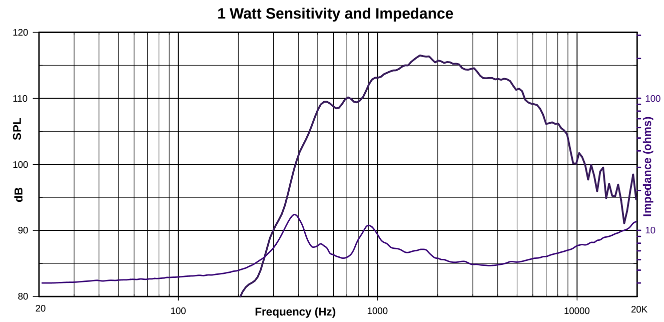
In all, the PT-H95HF waveguide shows better frequency response, and impedance. Beamwidth and DI are improved over JBL's previous waveguides, and distortion is a textbook example, without unexpected results. This PT design offers real world improvements in coverage and accuracy of reproduction.

<u>Medium Format, 60° x 40°, PT Waveguide:</u>

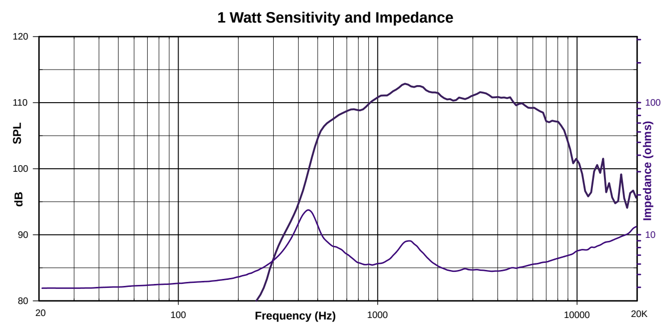
In this second evaluation, the analysis follows the format of the previous section. Here a PT-H64HF waveguide and two other 60° x 40° horns are compared. A previous generation JBL 2383 and a competitor's horn, from the same product line as the previous example, are used.

Figures 17a-c show that the PT–H64HF waveguide has smoothest frequency response and a impedance curves. Also the sensitivity of the PT design is the highest.

a) PT-H64HF waveguide



b) JBL 2383



c) Competitor's design

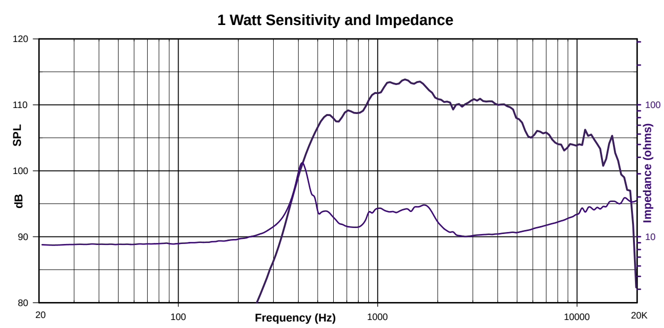
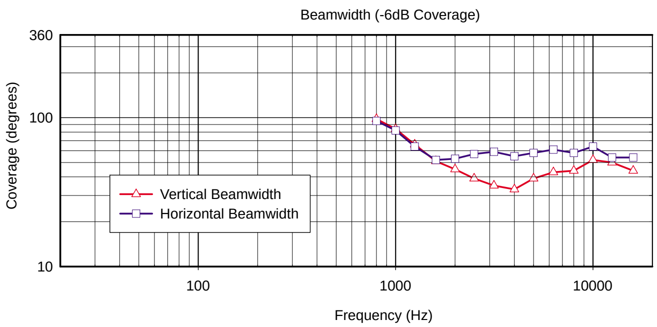


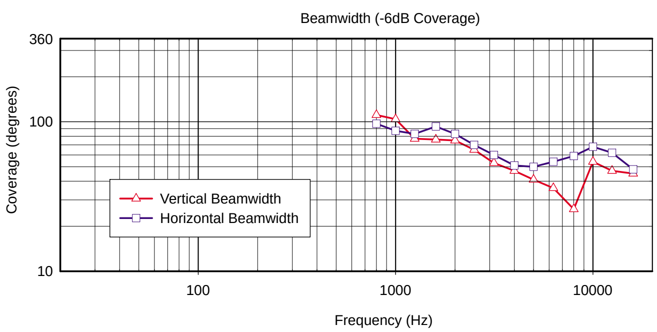
Figure 17: Frequency response and impedance at 1w/1m

Figures 18a-c show that constant coverage performance of the PT-H64HF is greatly improved over the 2383, and is equivalent to the competitor's solution.

a) PT-H64HF waveguide



b) JBL 2383



c) Competitor's design

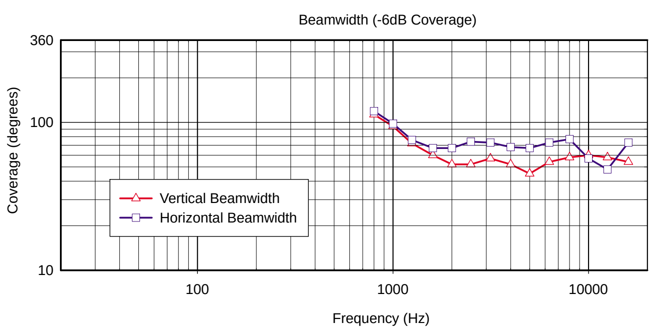
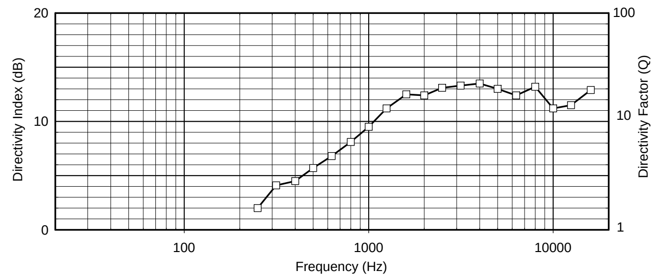


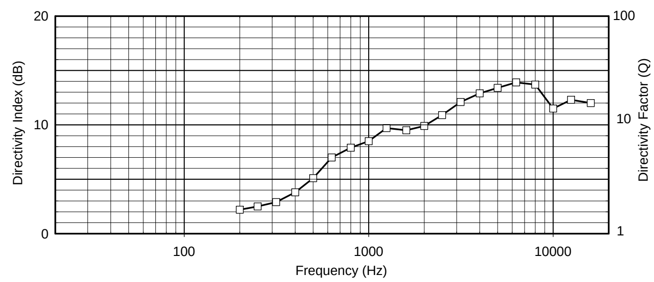
Figure 18: -6dB beamwidth.

Figures 19a-c show the PT-H64HF has excellent power response, due to the uniform and flat directivity index. Performance is better than the competitor, and improves on the 2383.

a) PT-H64HF waveguide



b) JBL 2383



c) Competitor's design

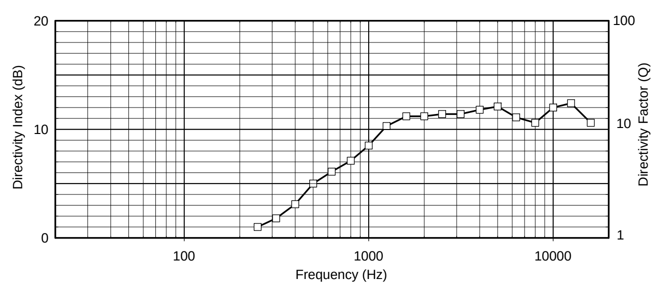
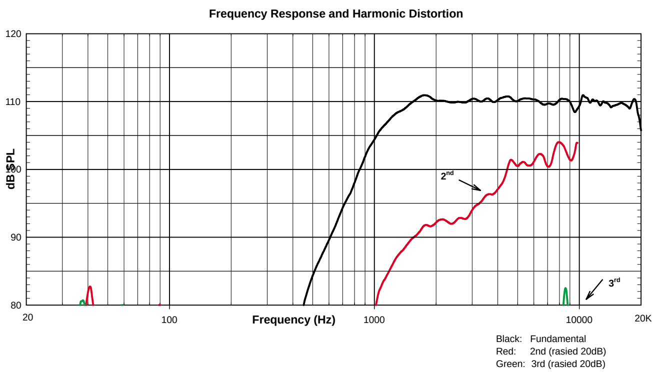


Figure 19: Directivity and Q

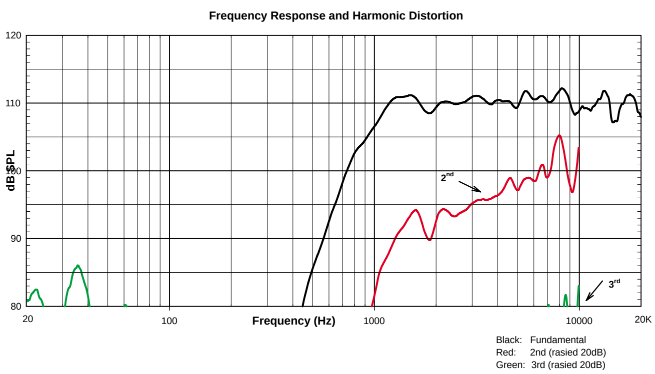
Figures 20a-c show this PT waveguide has text-book distortion performance, and the competitor's solution again suffers from distortion products that are unexpected and are introduced by non-linearities other than 2nd harmonic distortion due to air compression. Note when even lower distortion is required, the PT-F64HF waveguide matches the distortion of the 2383.

To summarize, the analysis again shows all area of performance are balanced by the PT-H64HF waveguide. This suits real world applications requiring accurate reproduction, improved fidelity, and uniform coverage in the audience area. No area of technical performance is compromised, and equivalent or improved performance is achieved by the PT design.

a) PT-H64HF waveguide



b) JBL 2383



c) Competitor's design

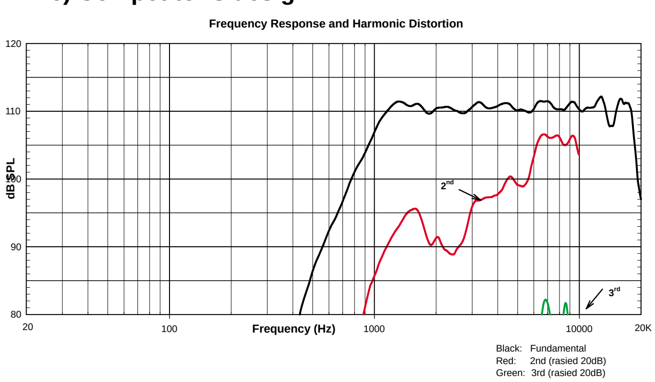


Figure 20: Harmonic Distortion at 110dB/1m:

Conclusion:

JBL's Progressive Transition waveguides were developed to achieve improved real world performance. By balancing technical performance in the areas of frequency response, pattern control, and distortion, improved sound reproduction results.

Compared to JBL's previous generation of horns, the PT series offers dramatically improved constant-coverage response, and improved frequency response, while keeping distortion low.

PT waveguides fall into three basic families: compact; optimized/rotatable; and mid-high rotatable. Compact PT waveguides offer extremely low distortion, and smooth frequency response in smaller sizes. Optimized and rotatable PT designs achieve low distortion, uniform coverage in the audience area, and ideal frequency response. Integrated Mid-High PT waveguides are rotatable, and provide matched dispersion and pattern control through the mid/high crossover region. Midrange PT designs utilize JBL CMCD Cone Midrange Compression Drivers for clear and uniform midrange response.

PT waveguides are integrated into the Application Engineered™ (AE) series of fixed installation loud-speakers, and are available in JBL Professional Custom Shop loudspeakers to meet unique acoustical challenges. Please visit www.jblpro.com for up-to-date information, or contact JBL Professional for further details.

References:

1. A. Thuras, et al., *Extraneous Frequencies Generated in Air Carrying Intense Sound Waves,* J. Acoustical Society of America, Vol. 6, No. 3 (January 1935)

2. J. Eargle and W. Gelow, *Performance of Horn Systems: Low-Frequency Cut-off, Pattern Control, and Distortion Trade-offs,* Preprint 4330, Presented at 101st AES Convention, November 1996.

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