The Design and Performance of the REM™ Ribbon Emulation Manifold Waveguide

by Perrin Meyer

This technical article describes the research and development behind U.S. Patent #6,668,969 B2, Manifold for a Horn Loudspeaker and Method, inventors John D. Meyer, Perrin Meyer, and Richard D. Herr.

On December 30, 2003, Meyer Sound was awarded a patent for the REM™ ribbon emulation manifold waveguide, an innovative design at the heart of Meyer Sound's line array and curvilinear array loudspeakers. The REM waveguide's main advantages over other designs - lower distortion and tighter pattern control - are achieved due to its short length and exponentially increasing waveguide channels.

Extremely Narrow Vertical Coverage

The REM ribbon emulation manifold waveguide couples to a compression driver and creates a narrow beam of sound radiation in the vertical direction and a wide coverage pattern in the horizontal direction. As the name suggests, it allows a standard compression driver to emulate a ribbon tweeter.

Why is this emulation necessary? The answer can be found by looking closely at how line arrays work (see *DSP Beam Steering with Modern Line Arrays* - MSPN 18.010.436.01, and *Can Line Arrays form Cylindrical Waves?* - MSPN 18.990.158.01 for some appropriate theoretical background). To summarize, modern line arrays use a hybrid technology that employs:

- Direct radiating transducers for low frequencies
- Compression drivers coupled to specialty waveguides for high frequencies

At low frequencies, as the length of a line array grows, directional control increases and the vertical pattern becomes narrower as the length of the array exceeds the wavelength of the frequency being reproduced. At high frequencies, the REM waveguide takes the exit from a compression driver and creates a sound field that is narrow vertically and wide horizontally — matching the narrow vertical pattern created by the summation of the many direct radiating low frequency transducers. This very narrow vertical sound field is necessary to reduce interaction between adjacent elements of the array and to maximize coupling, allowing energy to project over long distances.

A natural question is, "Why not just use a ribbon?" Meyer Sound engineers studied existing ribbon drivers and even built a state-of-the-art prototype. The conclusion reached was that adapting existing, mature compression driver technology was a more effective solution for satisfying the need for high-frequency line array behavior than trying to design around the inherent characteristics of a ribbon driver to develop one suitable for high-level sound reinforcement. Compression drivers are proven to be efficient, capable of providing high SPL with low distortion, and able to hold up to the rigors of the road.

The other option for narrow vertical coverage is to use closely spaced small dome tweeters. In fact, the M1D ultra-compact curvilinear array loudspeaker uses three tightly spaced 0.75" dome tweeters and a custom horn waveguide (patent pending) to create a ribbon-like narrow vertical high frequency pattern and a wide (100-degree) horizontal coverage pattern. But it is impossible to get high SPL out of dome tweeters.

The design challenge was to create a waveguide that couples to an existing compression driver and creates the desired sound radiation pattern. Figure 1 shows a sketch of two REM waveguides (the configuration used in the M3D™ line array loudspeaker), with their circular apertures visible where compression drivers would mount.

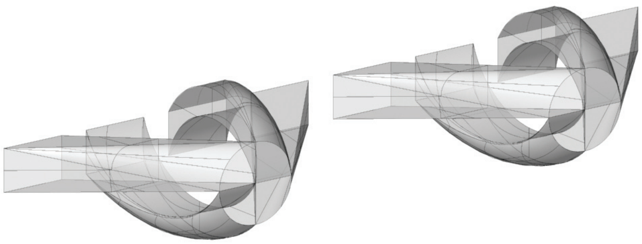


Figure 1: A 3D lit wireframe drawing of two REM waveguides

The exit to all Meyer Sound manufactured compression drivers is circular, and the sound pressure output of all our compression drivers is isophase at the exit throat. Isophase simply means that the sound wave produced at the compression driver exit would be similar to that produced by a single vibrating disk (although at much higher SPL). The REM waveguide takes the isophase circular output and divides it into four separate waveguides, each channeling sound to one of four lined-up output apertures. Since the distance between exits is very small, these closely spaced multiple exits creates tight directional control over frequencies whose wavelengths are smaller compared to the length of the REM waveguide.

This configuration emulates a rectangular ribbon driver. Figure 2 below shows a sketch of a full M3D manifold, with an eight-output aperture (four from each of the M3D's two compression drivers) in a straight line.

The length and shape of each waveguide channel is designed to carefully guide the output from the compression driver and to ensure that the distinct output of each waveguide channel is in-phase with the other outputs. All four waveguide channels have the same length from the origin at the throat of the compression driver to the exit. The four in-phase outputs are then further coupled to other horn waveguides to refine the narrow vertical coverage pattern and the wide horizontal coverage pattern. The result is that the measured polar response of the REM waveguide shows an extremely narrow vertical coverage pattern.

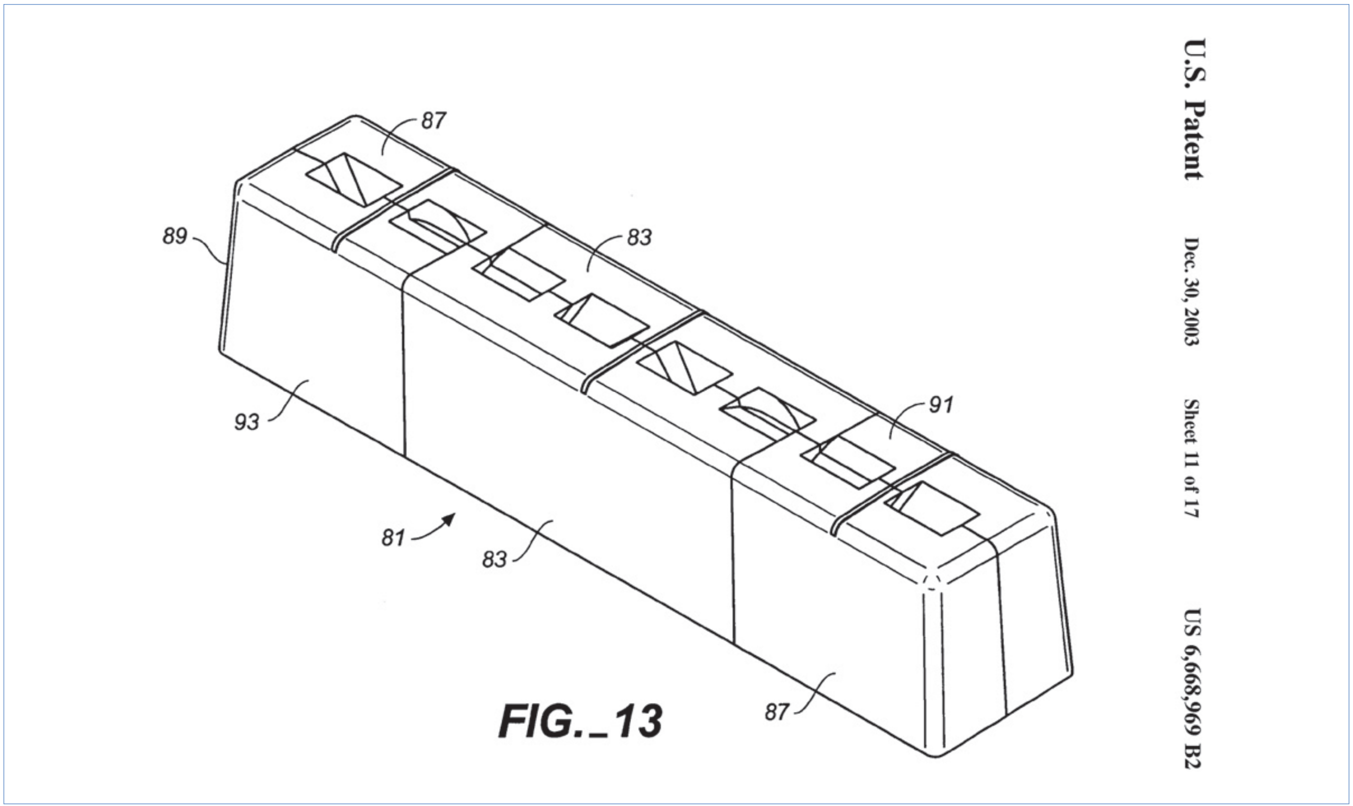
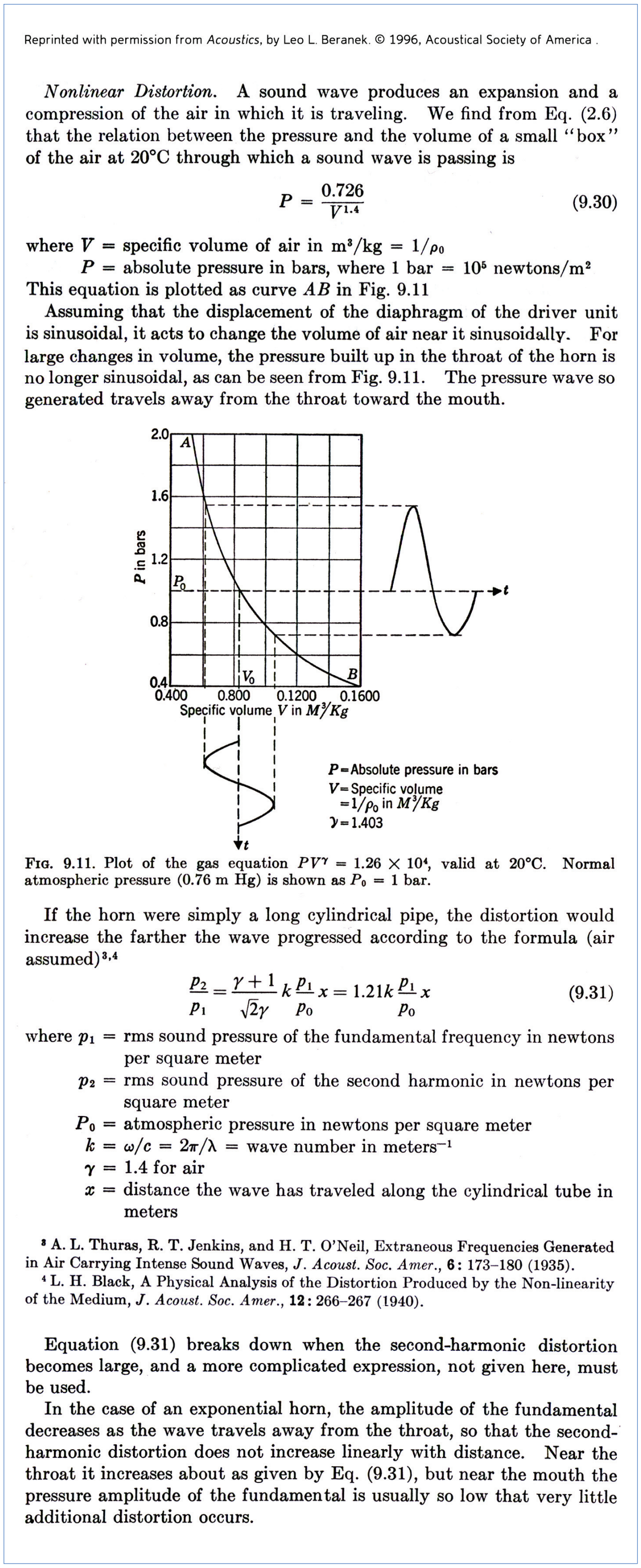


Figure 2: REM in an M3D line array loudspeaker



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Nonlinear Distortion. A sound wave produces an expansion and a compression of the air in which it is traveling. We find from Eq. (2.6) that the relation between the pressure and the volume of a small "box" of the air at 20°C through which a sound wave is passing is

$$P = \frac{0.726}{V^{1.4}} \tag{9.30}$$

where V = specific volume of air in $\mathrm{m}^3/\mathrm{kg} = 1/\rho_0$
P = absolute pressure in bars, where 1 bar = 10^5 newtons/m²
This equation is plotted as curve AB in Fig. 9.11

Assuming that the displacement of the diaphragm of the driver unit is sinusoidal, it acts to change the volume of air near it sinusoidally. For large changes in volume, the pressure built up in the throat of the horn is no longer sinusoidal, as can be seen from Fig. 9.11. The pressure wave so generated travels away from the throat toward the mouth.

FIG. 9.11. Plot of the gas equation $PV^\gamma = 1.26 \times 10^4$, valid at 20°C. Normal atmospheric pressure (0.76 m Hg) is shown as P_0 = 1 bar.

If the horn were simply a long cylindrical pipe, the distortion would increase the farther the wave progressed according to the formula (air assumed)[3,4]

$$\frac{p_2}{p_1} = \frac{\gamma + 1}{\sqrt{2}\gamma} k \frac{p_1}{p_0} x = 1.21k \frac{p_1}{p_0} x \tag{9.31}$$

where p_1 = rms sound pressure of the fundamental frequency in newtons per square meter
p_2 = rms sound pressure of the second harmonic in newtons per square meter
P_0 = atmospheric pressure in newtons per square meter
$k = \omega/c = 2\pi/\lambda$ = wave number in meters^{-1}
γ = 1.4 for air
x = distance the wave has traveled along the cylindrical tube in meters

[3] A. L. Thuras, R. T. Jenkins, and H. T. O'Neil, Extraneous Frequencies Generated in Air Carrying Intense Sound Waves, *J. Acoust. Soc. Amer.*, **6**: 173–180 (1935).

[4] L. H. Black, A Physical Analysis of the Distortion Produced by the Non-linearity of the Medium, *J. Acoust. Soc. Amer.*, **12**: 266–267 (1940).

Equation (9.31) breaks down when the second-harmonic distortion becomes large, and a more complicated expression, not given here, must be used.

In the case of an exponential horn, the amplitude of the fundamental decreases as the wave travels away from the throat, so that the second-harmonic distortion does not increase linearly with distance. Near the throat it increases about as given by Eq. (9.31), but near the mouth the pressure amplitude of the fundamental is usually so low that very little additional distortion occurs.

Figure 3: Pages 272-275 of Acoustics. *Reprinted with permission from* Acoustics, *Leo L. Beranek, © 1996, Acoustical Society of America*

Low Distortion

An often overlooked aspect of waveguide design is distortion, and a fundamental tradeoff in waveguide design is length versus distortion. As the length of a waveguide increases, the distortion produced also increases. The mechanism for this distortion are the non-linearities associated with high SPL sound waves propagating through air; however, it is often easier to get the desired coverage pattern with a long waveguide than a short waveguide at the expense of distortion.

For this reason, many modern line array cabinets use long waveguides coupled to compression drivers in order to create a narrow vertical coverage pattern. The Meyer Sound REM waveguide is, we believe, the shortest possible design that achieves the desired narrow vertical pattern.

Figure 3 (at left) reprints a page from Beranek's classic textbook *Acoustics*. In this passage he eloquently describes the non-linear distortion mechanism in a cylindrical waveguide (a tube).

Let's analyze the quote:

"If the horn were simply a long cylindrical pipe, the distortion would increase the farther the wave progressed...."

Even in this simple description, it is clear that doubling the distance would double the second harmonic distortion. The technical explanation for this would be that the distortion increases linearly with distance. This is a bit confusing, since the non-linear second harmonic distortion is increasing linearly with distance — here the term "linearly" refers to the length of the horn waveguide.

Even though Beranek's passage refers to sound propagating through a tube, the distortion characteristics also hold for any waveguide where the cross-sectional diameter remains constant. Even if the waveguide was a more complex shape instead of a simple cylinder, distortion increases as the length of the sound passage increases.

Exponentially Increasing

Clearly, waveguides that have a constant cross-sectional area along the length of the waveguide create distortion that is a linear function of distance. For this reason, a second quote found in Figure 3 is also illuminating:

"In the case of an exponential horn, the amplitude of the fundamental decreases as the wave travels away from the throat, so that the second-harmonic distortion does not increase linearly with distance."

This quote describes another theory behind the REM waveguide, namely that each of the four individual waveguides that make an REM waveguide is an exponentially increasing horn waveguide. Not only is the REM waveguide short compared to other, similar waveguides, it is comprised of four waveguides which act to minimize distortion, unlike constant, cross-sectional area designs.

Performance

Let's take a look at some real-world examples of REM waveguide performance. Figure 4 below shows vertical directivity patterns of a single MILO™ high-power curvilinear array loudspeaker at different frequencies.

The figure shows the vertical directivity patterns as a Meyer Sound MAPP Online® sound field color plot. Each color sound field shows a 1/3 octave-averaged sound field. These measurements were made in Meyer Sound's anechoic chamber, and data was measured every 1 degree for a total of 360 measurements.The microphone was located at four meters from the center of the cabinets, which was also the point of rotation.

The MILO high frequency section (above 4 kHz) consists of three REM waveguides coupled to three 3/4-inch exit, 2-inch diaphragm neodymium compression drivers. An alternate cabinet design, referred to as the "sound wave guide," was measured under the exact same conditions as the MILO. The "sound wave guide" presents an alternate design for coupling compression drivers to a waveguide in order to create a narrow vertical coverage pattern.

The 14 sound field images in Figure 4 show that both waveguide designs did an excellent job of producing a narrow high-frequency beam of sound. It is difficult to say which design is "better," since what really matters is how these single elements interact to form arrays. However, except for the 16 kHz 1/3 octave band, the MILO REM waveguide shows tighter patterns over all other 1/3-octave bands. In comparison, these polar measurements confirm that the REM waveguide achieves the smoothest and most precise vertical directional control. At the same time, due to its short length and the use of multiple exponentially increasing horn waveguides, the REM waveguide substantially minimizes distortion.

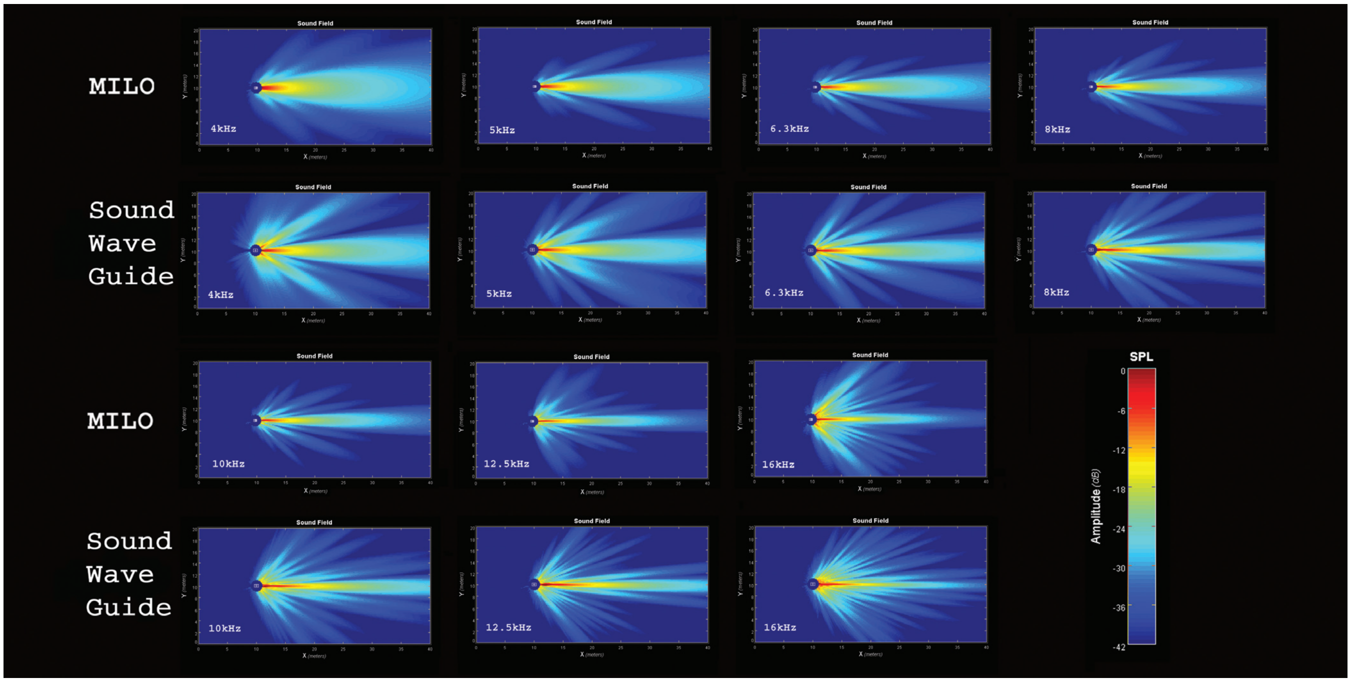

Figure 4: A MAPP Online comparison of vertical directivity patterns

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