Bose® Panaray® MA12 Modular Line Array: Technical Information and Polar Data

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Bose® Professional Systems

Summary

ONE uses polar plots to describe the behavior of conventional speakers such as constant directivity horns or small arrays built up using smaller transducers. Line arrays produce cylindrical waves in the near field and therefore, the vertical polar plots change as a function of distance. To describe the vertical radiation of a line array an industry accepted method is to use validated modeling programs and *paint* a picture of the radiation as a function of distance. This paper addresses the radiation characteristics of the MA12 and in addition shows measured polar plots, on-axis frequency response, controller curves, and impedance curves.

Professional Systems
Bose Corporation, Framingham, MA, USA
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0. INTRODUCTION

WHEN designing sound systems using conventional speakers - such as constant directivity (CD) horns or small speaker arrays built up of multiple transducers - designers use polar plots (two dimensional), or directivity balloons (three dimensions). These plots describe how much sound radiates from a speaker in a given frequency band and at a given angle. When measured in the far field, polar plots accurately show the radiation pattern at any distance outside the near field. For a constant directivity horn, the polar plot at 5 m is the same at 50 m, the only difference is a drop in level. In fact, the level drops by 6dB per doubling of distance; these speakers are *spherical* speakers, as sound radiates in all three dimensions[1]. Polar plots provide designers a first order image of how a speaker performs in a given space.

A *line array* behaves very differently from a spherical speaker. It produces *cylindrical* waves in the near-field. A cylindrical wave propagates only in two dimensions, out and to the side, not up and down. Therefore, level drops by only 3dB per doubling of distance[1], and little, or no energy radiates up or down.

Many line array manufacturers[2], including Bose, agree that the vertical polar plot is dependent on the distance from the speaker and that therefore, simply providing polar plots of a line array at *one* distance – as for a spherical source - does not tell the true story. In fact, using only this data may result in sound system design flaws.

The purpose of this paper is:

1 To describe the fundamental behavior of polar plots for a spherical source (such as a CD horn) and for a line array as a function of distance. This shows that a single polar plot at one distance cannot present the overall behavior of the MA12, or any line array

2 To describe a method accepted by the industry for displaying the behavior of line arrays

3 To use this method to present the radiation behavior of a single MA12 and a stacked pair of MA12s

4 To show how one can visualize the radiation of an MA12

5 To show measured horizontal and vertical polar plots of the MA12 at 25 feet (8m)

6 To show the on-axis frequency response of the MA12 along with the controller and impedance curves

1 See MA12 whitepaper: "Bose® Panaray MA12 Modular Array; Technical Foundation & Discussion" by Morten Jørgensen & Ken Jacob, Bose Corporation available on http://pro.bose.com.

2 See for example "Some notes on modeling the directivity of DSP controlled loudspeaker arrays" from Duran Audio, available on their web-site www.duran-audio.com

1. USING POLAR PLOTS TO DESCRIBE SOUND RADIATION

FIRST, we look at the vertical polar plot of a traditional spherical source, such as an ideal constant directivity horn with a vertical pattern of 40°. Figure 1 shows polar plots at 3 feet (1m) and at 25 feet (8m). The waveform being shaped in the waveguide, to first order, follows this 40° angle, so the –6dB points will follow the lines extended from the waveguide walls. As shown polar plots are independent of distance.

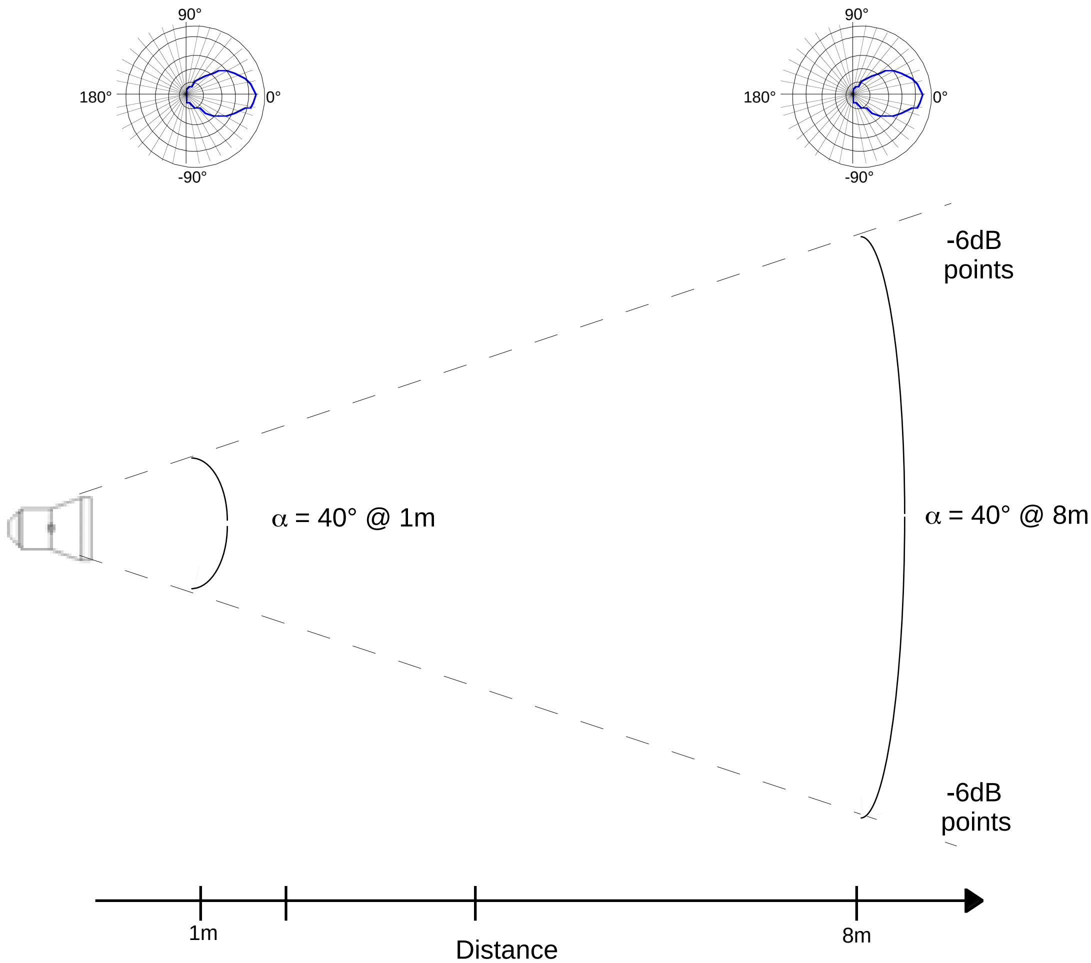


Figure 1. The figure shows the vertical radiation pattern of a 40° CD horn. The polar plots remain unchanged as a function of distance, except for a 6dB drop in level per doubling of distance.

The polar plots accurately show the fundamental behavior of the speaker. For example, if one desires to cover a very narrow rectangular room, this may be a great choice. On the other hand, if one desires to cover a wide fanshaped auditorium from a central cluster, a single horn does not provide enough coverage.

Next, we examine a simplified model of an ideal, theoretical line array. The vertical radiation pattern is a band of constant height, defined by a line perpendicular to the top of the array and a line perpendicular to the bottom of the array, as shown in Figure 2. A 3-foot (1m) tall array is explored, which at some frequency will exhibit this behavior. When listeners are inside the band they receive direct sound. When they are outside the band they receive *no* direct sound.

Now imagine a listener on-axis, 3 feet (1m) away from the speaker. If the listener moves 1.5 feet (0.5m) up, he is right on the border between receiving direct sound and not receiving any direct sound. Using geometry, 1.5 feet (0.5m) vertical height at a distance of 3 feet (1m) from the array corresponds to an angle of 27°. The corresponding polar plot is shown in figure 2 (left), with a coverage angle of 2x27°, or 54°.

Now imagine a listener on-axis, 25 feet (8m) away from the speaker. Again, if the listener moves 1.5 feet (0.5m) up, he is right on the border between receiving direct sound and not receiving any direct sound. Using geometry, 1.5 feet (0.5m) vertical height at a distance at 25 feet (8m) is an angle of 3.5°. The corresponding polar plot is shown in Figure 2 (right).

This shows that the vertical polar plots change as a function of distance: It gets narrower and narrower the farther away you get[3].

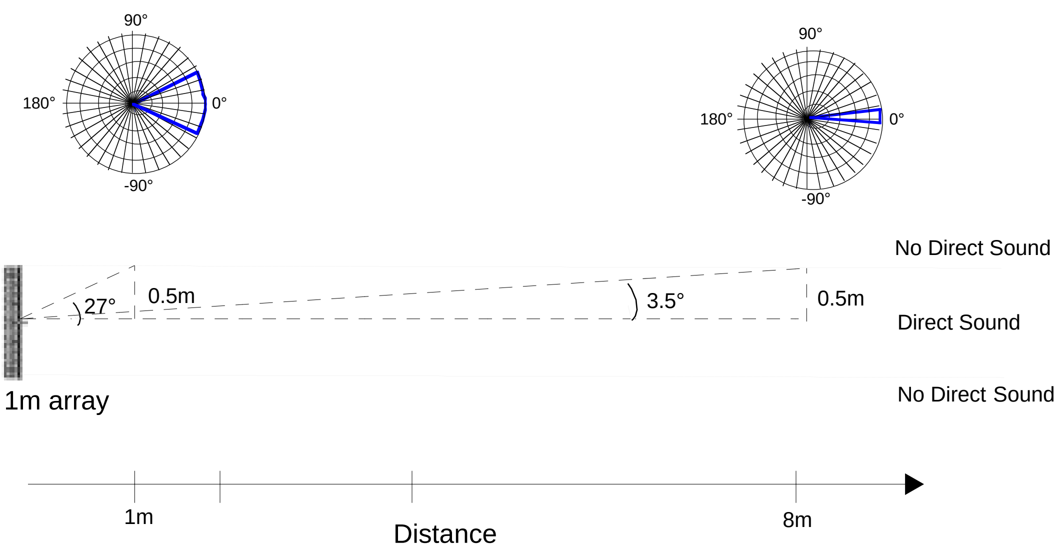


Figure 2: This figure shows polar plots at 3 feet (1m) and 25 feet (8m) for a 3-foot (1m) tall ideal, theoretical line array. The radiation pattern is a band of constant height. This shows that the vertical polar plots change as a function of distance.

With such dramatic change in polar plots as a function of distance, knowing the polar plot of a line array at ONE distance does not provide sufficient information. In fact, when used

[3] It should be mentioned that as one moves from the near-field to the far-field, radiation broadens and the spreading becomes spherical.

improperly, sound quality deteriorates. Similarly if a speaker were installed and the designer thinks the coverage angle is 54° and this is needed to cover the audience, but the actual coverage angle is only 7°, major audience areas would receive no direct sound. People would suffer from poor intelligibility and poor clarity.

Using a single polar plot is a great way to describe the behavior of conventional (spherical) sources. Using a single polar plot to describe the behavior of line arrays is not sufficient. A *painting* of radiation as a function of distance is needed.

2. INDUSTRY METHOD FOR DISPLAYING BEHAVIOR OF LINE ARRAYS

SINCE polar plots change as a function of distance and they get extremely narrow at long distances, one needs an enormous amount of data to describe line arrays. These very narrow radiation patterns at long distances show that if polar plots are measured, standard measuring resolution of 5° or 10° are far from adequate to describe the behavior. Measurement resolution of about 1-2° is needed. Therefore, acoustics modeling programs are used to describe line arrays[4]. Bose uses the Modeler® Design Program where the fundamental algorithms used for predicting array behavior have been validated and the results published[5].

3. RADIATION CHARACTERISTICS OF THE MA12

VERTICAL

USING Modeler® Design Program, the vertical radiation patterns of a single MA12 (left) and a double MA12 (right) as a function of distance are shown in Figure 3. Graphs are shown on a 20dB scale with 2dB steps using distances up to about 100 feet (32m). As a reference, for a spherical source the level drops by 18dB at 24 feet (8m). Location and height of the MA12 is indicated to the left of each graph as a black column.

[4] See footnote 2, and look at technical information from manufacturers like Duran Audio, Meyer, and SLS.
[5] See for example "Prediction of the Full-Space Directivity Characteristics of Loudspeaker Arrays" by Jacob et al, J. Audio Eng. Soc. Vol 38, No. 4, 1990 April

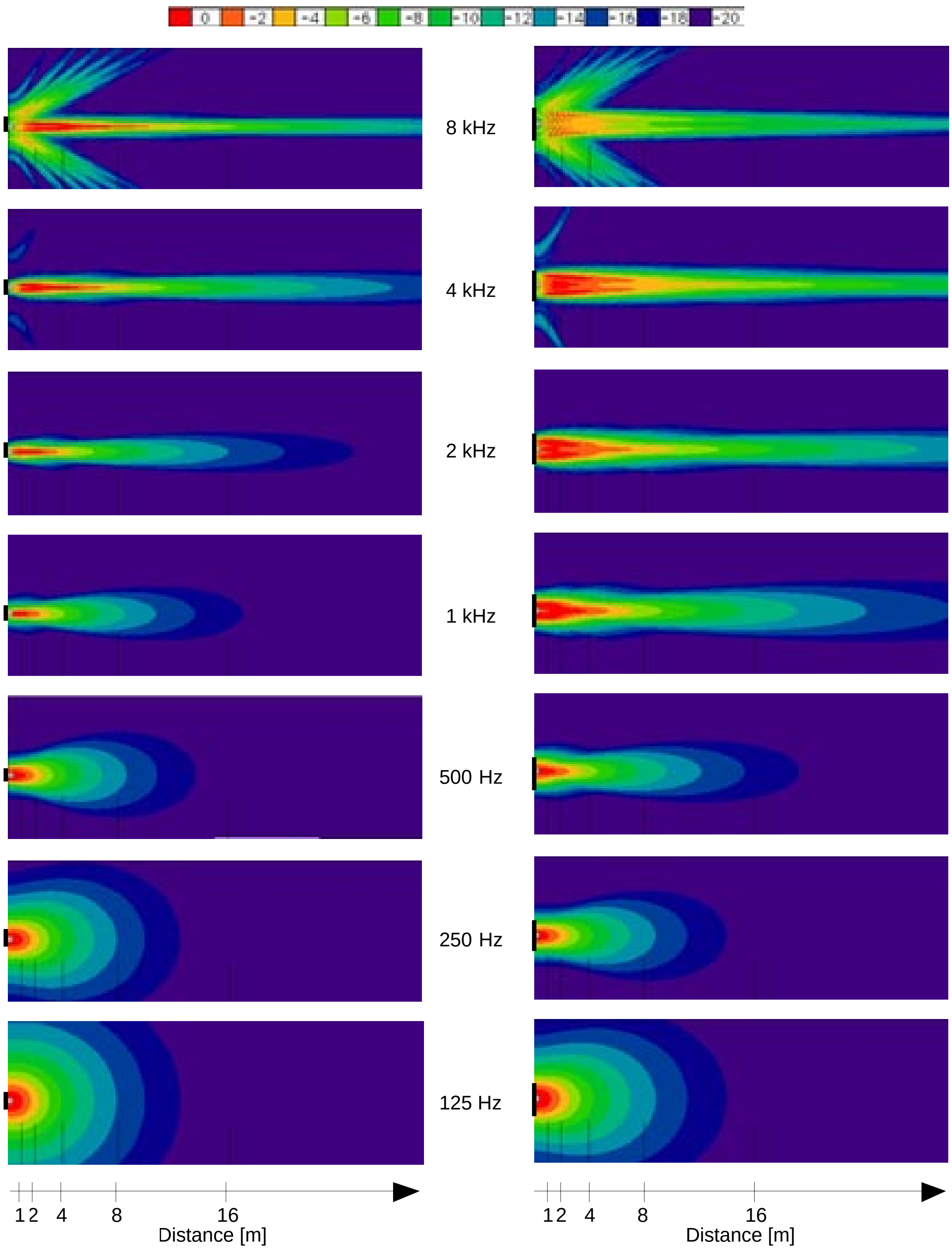


Figure 3. Vertical radiation patterns ("side view") of a single MA12 (left) and a stacked pair of MA12s (right) as a function of distance. For a single MA12, radiation is a band of constant height above approximately 500Hz. For a stacked pair of MA12, this is true above about 250Hz, with substantial control even at 125Hz.

Examining a single MA12 (left), there are a number of observations:

- Above about 500Hz, the vertical radiation characteristics can be described as a band of constant height. At these frequencies, energy falls off rapidly outside this band, so to be covered, people's heads must be *within* the band.
- The radiation gets narrower the farther away you get.
- High frequencies have a farther throw than low frequencies.
- At 4-8 kHz, aliasing occur due to the linear spacing of drivers.
- At 250Hz, while there is substantial narrowing in the vertical pattern, some energy goes up and down.

Examining a stacked pair of MA12s (right), there are a number of observations:

- The vertical radiation characteristics can be described as a band of constant height from about 250Hz and up.
- When doubling the MA12s, the vertical coverage doubles, or the band is now twice as high.
- There is significant and substantial vertical radiation control even at 250Hz.
- At 4-8 kHz, aliasing occur due to the linear spacing of drivers.

Including the reduction in sound pressure level as a function of distance (not shown here) and listening evaluations, we find that the following *general guidelines* are appropriate:

A single modular MA12 exhibits line array characteristics above about 2kHz within a distance of about 40 feet (13m). Even at lower frequencies there is substantial narrowing of the vertical pattern. A single MA12 is an ideal choice for throws of up to about 40-50 feet (13-16m).

A stacked pair of MA12s exhibits line array characteristics above about 500-1kHz within a distance of about 80 feet (25m). There is substantial narrowing in the vertical pattern down to 250Hz. For throws longer than about 50 feet (16m) and more difficult acoustic spaces, doubling the height of the array, results in significant improvement in clarity, especially at lower frequencies.

Vertical lines using three or more MA12s exhibit line array characteristics substantially over the entire frequency range.

HORIZONTAL

The horizontal radiation characteristics is substantially that of a single 2.25 inch (6cm) driver and can be described by polar plots (remember, however, that the energy drops by 3-6 dB per doubling of distance dependent of frequency and distance.) Anechoically measured, horizontal, octave-band polar plots for a single MA12 are shown in Figure 4.

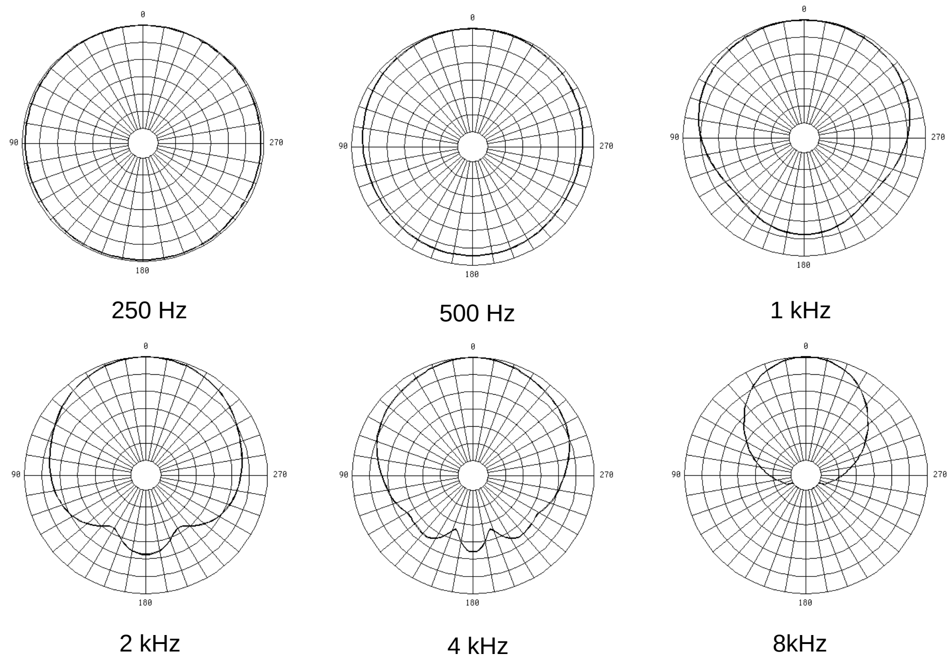


Figure 4. Measured, anechoic, horizontal, octave-band polar plots at 25 feet (8m) at 250Hz to 8kHz using 5dB/division. Horizontally, an MA12 behaves coverage-wide substantially as a single 2.25” (6cm) driver. It is very wide up to about 5kHz, after which narrowing occurs.

For those interested, measured, anechoic, horizontal, 1/3 octave-band polar plots are shown in appendix A.

4. VIZUALIZING THE RADIATION CHARACTERISTICS OF AN MA12, OR A LINE OF MULTIPLE MA12s.

THE previous section shows the radiation characteristics of an MA12 and a stacked pair of MA12s in two-dimensional graphs. In this section, we show a simple three-dimensional graphic that illustrates how one can vizualize the behavior of a single MA12, or a vertical line of multiple MA12s.

In a simplistic model, vertically, the MA12 radiates sound in a band of constant height defined by the top and bottom of the array as shown in Figure 3. Horizontally, the coverage is wide and substantially that of a single 2.25-inch (6cm) driver as shown in Figure 4. The simplified radiation pattern of an MA12 in three dimensions is shown in Figure 5.

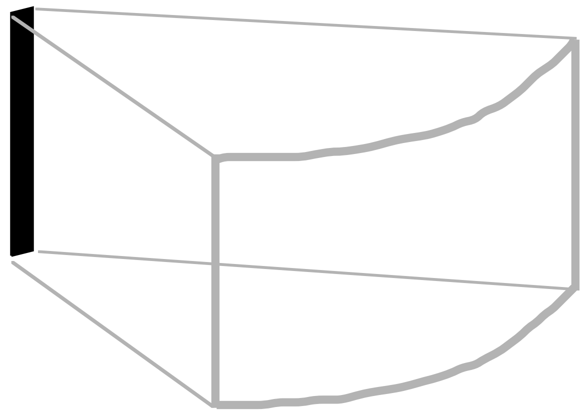


Figure 5. The radiation pattern of the MA12 is wedge-shaped. As shown in Figure 3, the high frequency energy falls off quickly outside the top and bottom of the wedge, so to be covered, people must have their heads within the wedge.

The radiation pattern of an MA12 (or multiple MA12s) is wedge shaped. To be covered with sound, people's heads must be within this wedge.

5. MEASURED VERTICAL POLAR PLOTS OF THE MA12

FOR completeness, Figure 6 below shows measured, octave-band, vertical plots of the MA12 at 25 feet (8m) at representative frequencies.

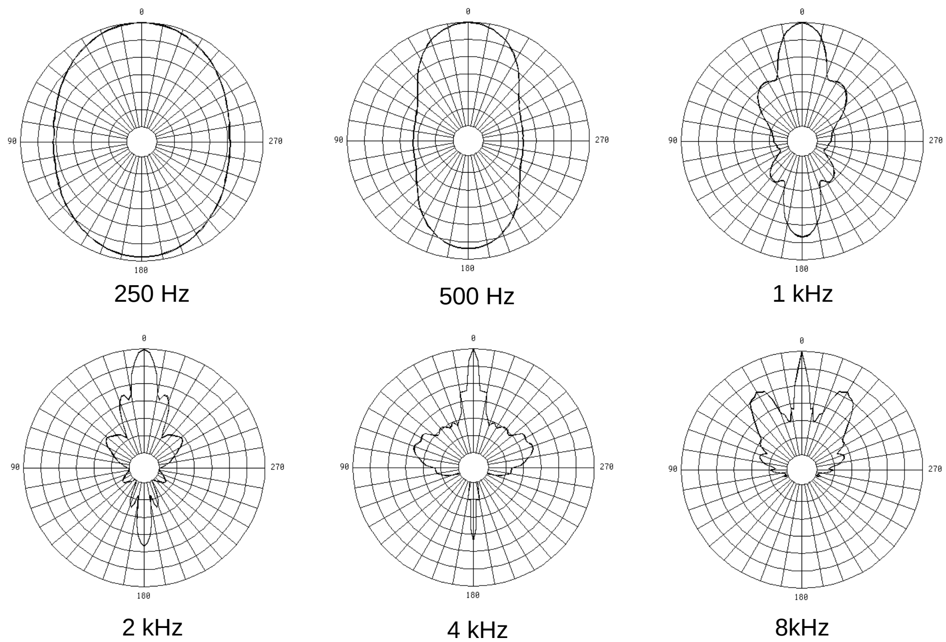


Figure 6. Measured, anechoic, vertical, octave-band polar plots at 25 feet (8m) from 250Hz to 8kHz. As shown in the previous section, notice the tight dispersion at 500Hz to 8kHz, the aliasing at 8 kHz, and how the polars open up at lower frequencies, yet still provide significant radiation control.

NOTE: These polar plots are valid only at 25 feet (8m), and are not representative of the MA12 behavior at any other distance!

For those interested, measured, anechoic, vertical, 1/3 octave-band polar plots are shown in appendix A.

6. ON-AXIS FREQUENCY RESPONSE, CONTROLLER CURVES, AND IMPEDANCE CURVE

IN the final section, we present some of the basic curves for the MA12, including the on-axis frequency response, the controller curves and the impedance curve.

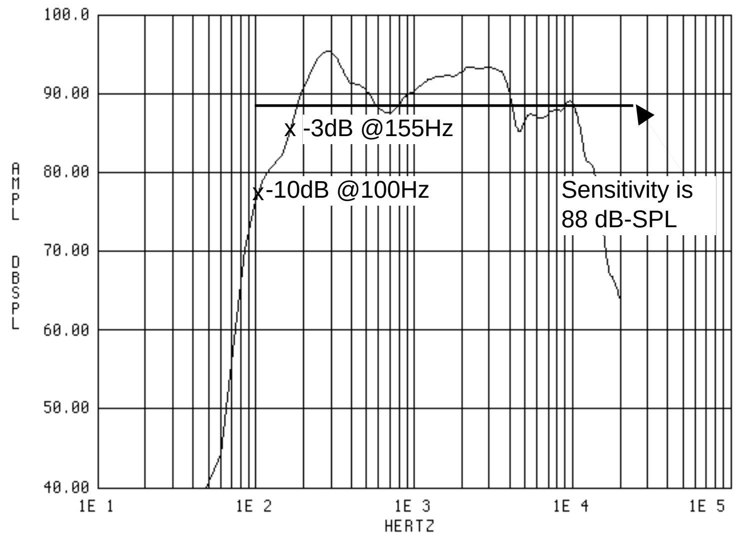


Figure 7. The on-axis frequency response of a single MA12 measured anechoically. The low-end cut-off is about 155Hz (-3dB) and 100Hz (-10dB).

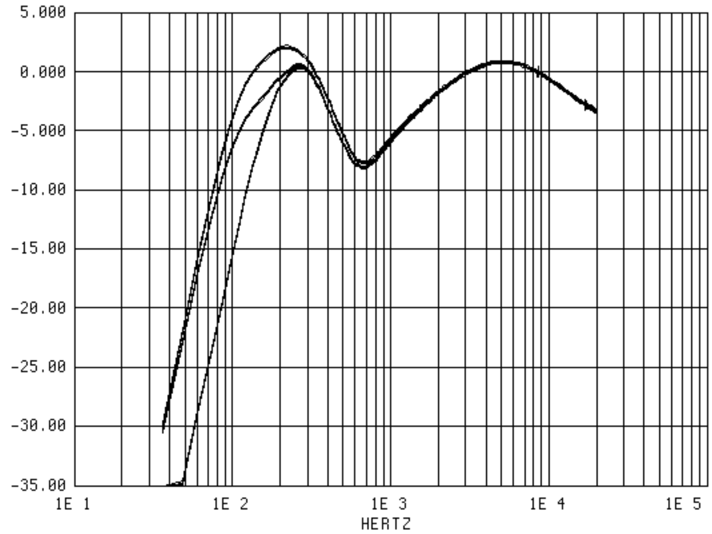


Figure 8. This figure shows three controller curves implemented in the Panaray System Controller, free-field (top), boundary-loaded (middle) and high-pass (bottom). Notice that they all have the same response above about 300Hz.

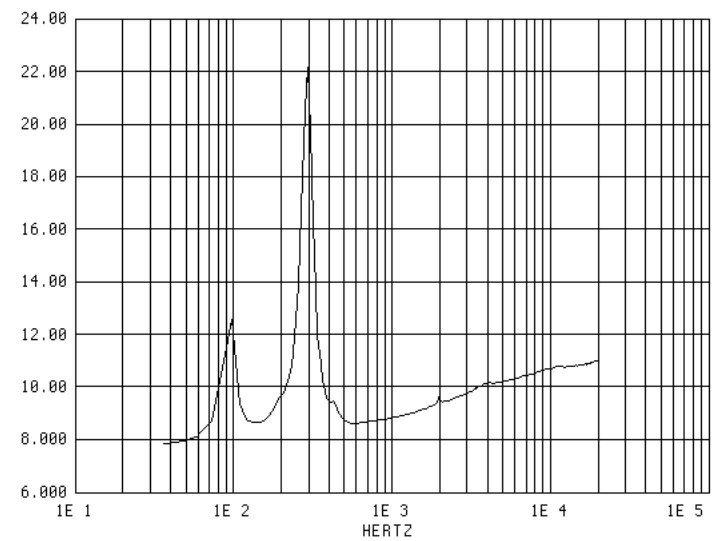
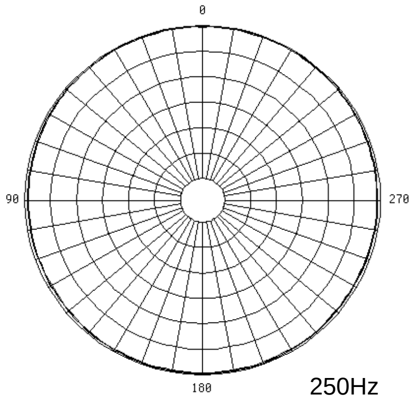


Figure 9. This figure shows the impedance curve of a single MA12. DC impedance is about 7.6Ohm. The nominal impedance in the pass band is 9.6 Ohm. This speaker is rated an 8-Ohm speaker.

Appendix A

MEASURED 1/3 octave band polar plots of the MA12 at 25 feet (8m). Please notice that these polar plots are valid only at this distance.



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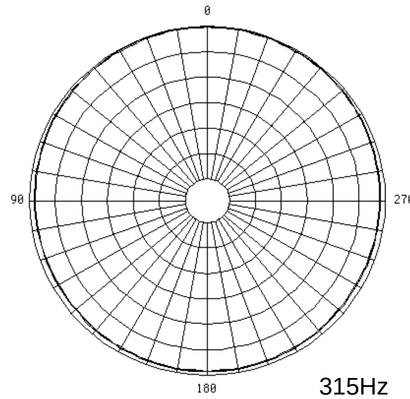
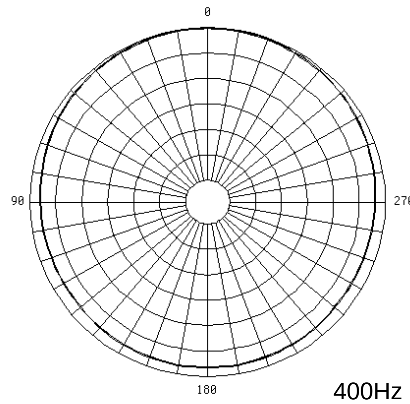
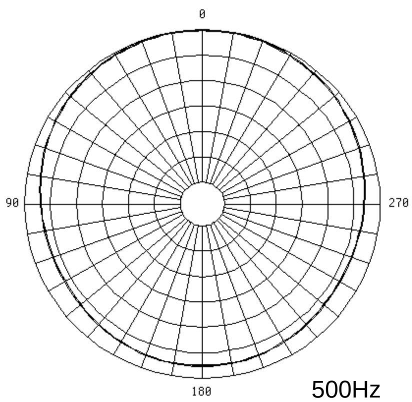


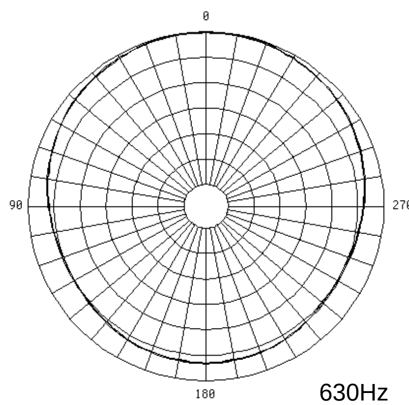
315Hz



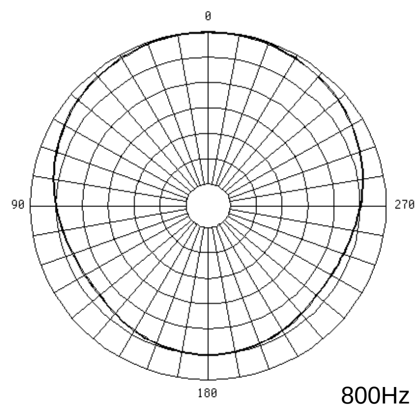
400Hz



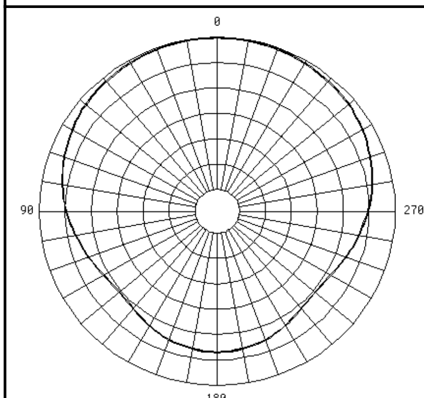
500Hz



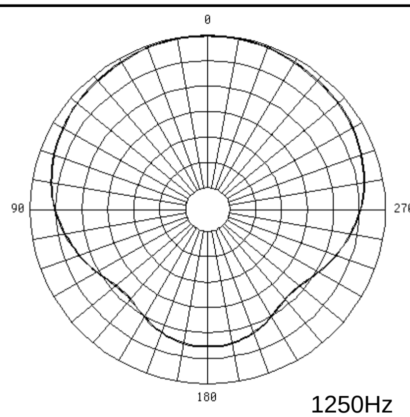
630Hz



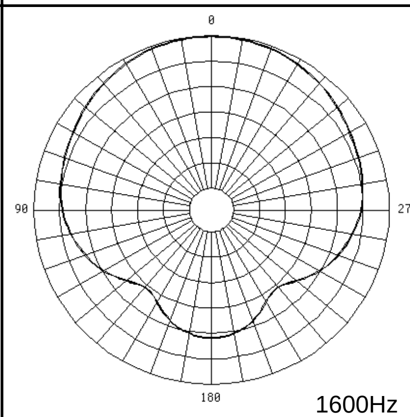
800Hz



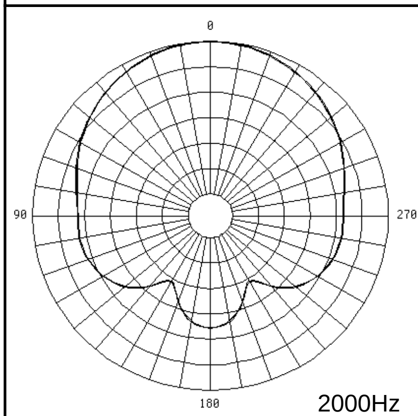
1000Hz



1250Hz



1600Hz



2000Hz

Bose Panaray® MA12

Measured, horizontal, 1/3 octave-band polar plots (5 dB/div)

Note: These polar plots are valid only at 8m.

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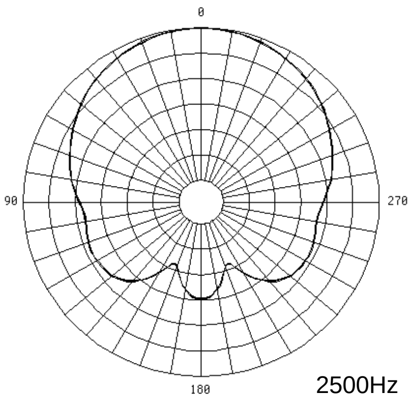

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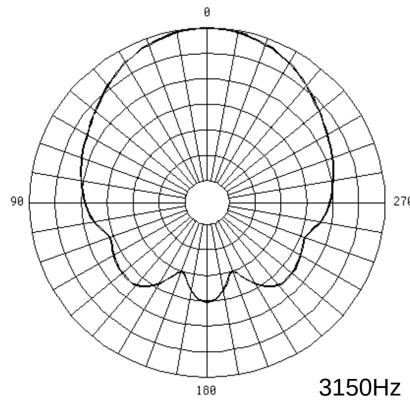

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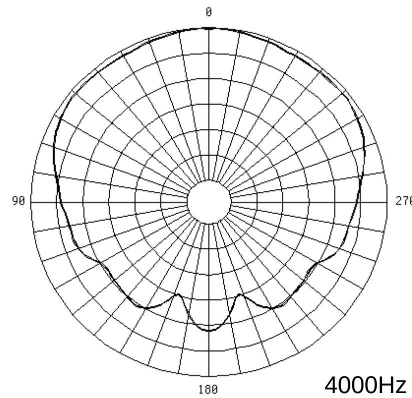

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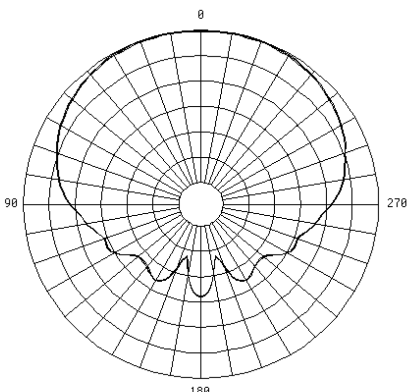

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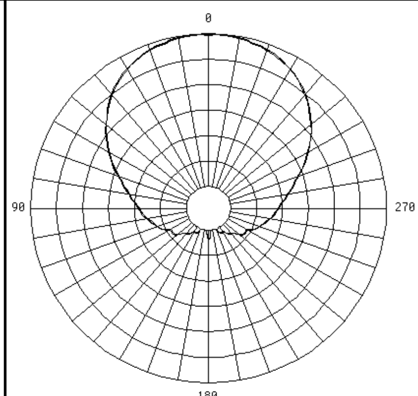

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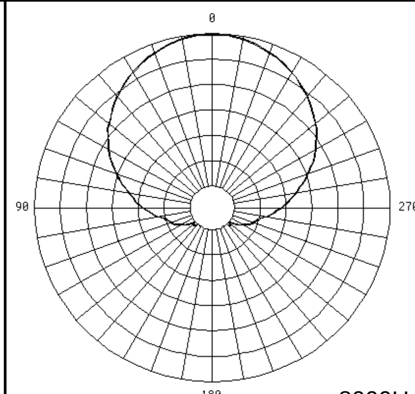

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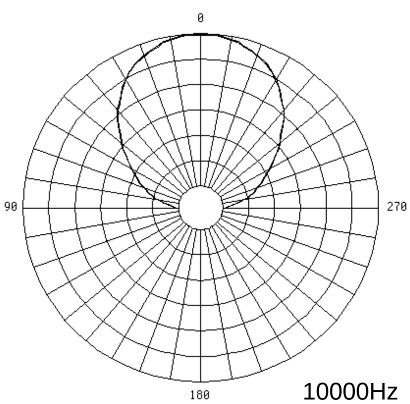

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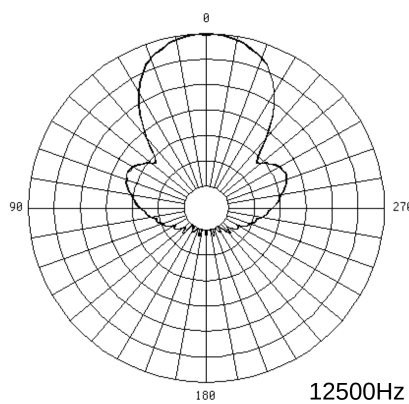

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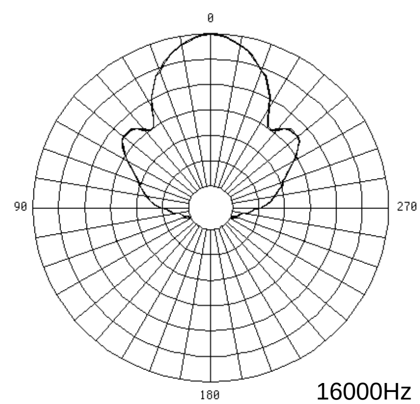

16000Hz

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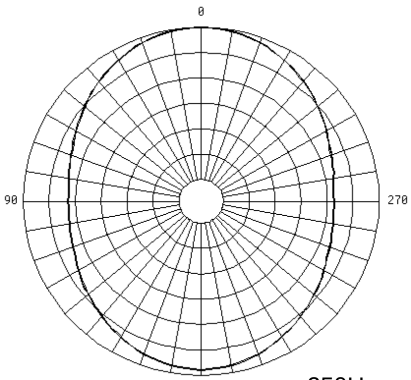
Bose Panaray® MA12

Measured, horizontal, 1/3 octave-band polar plots (5 dB/div)

Note: These polar plots are valid only at 8m.

April 02



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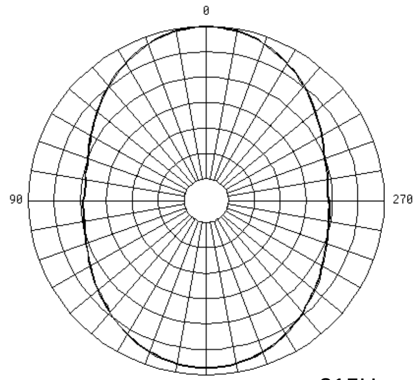

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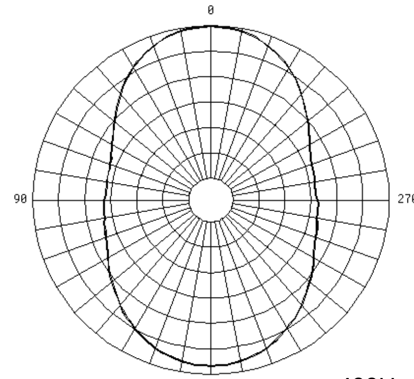

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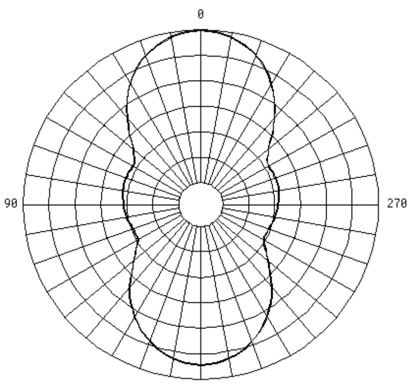

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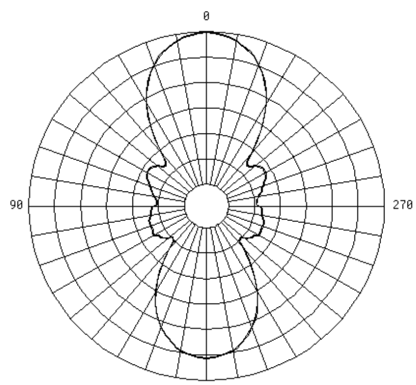

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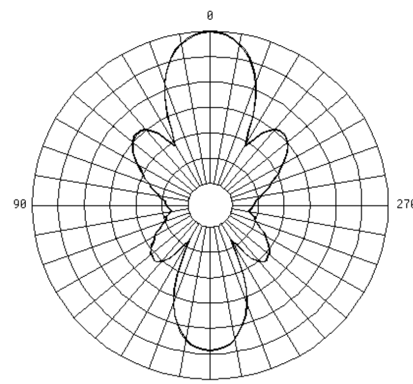

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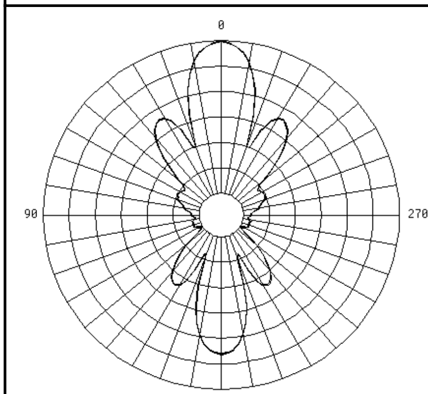

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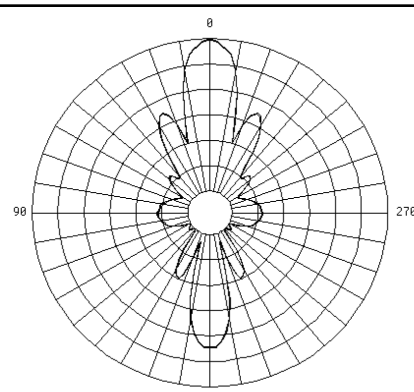

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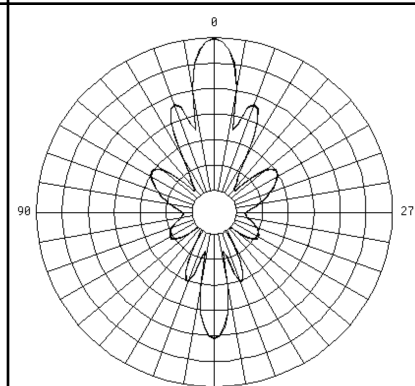

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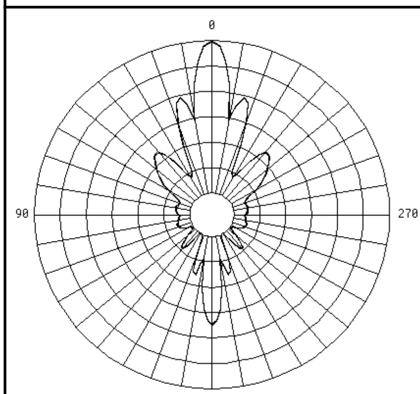

2000Hz

Bose Panaray® MA12

Measured, vertical, 1/3 octave-band polar plots (5 dB/div)

Note: These polar plots are valid only at 8m.

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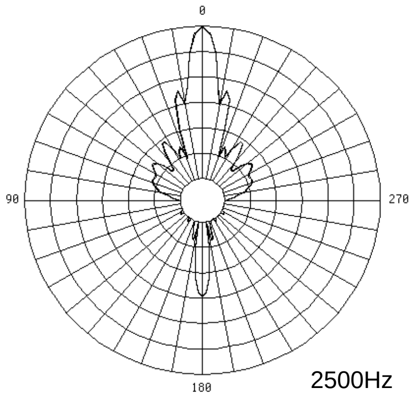

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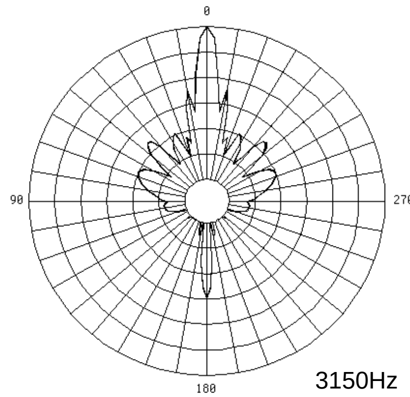

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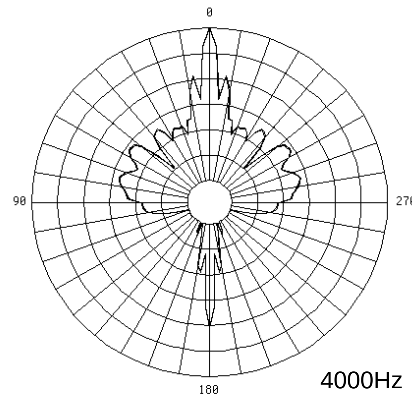

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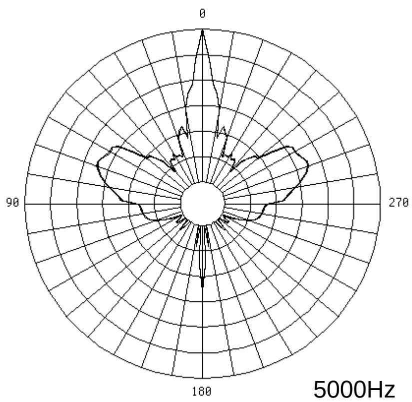

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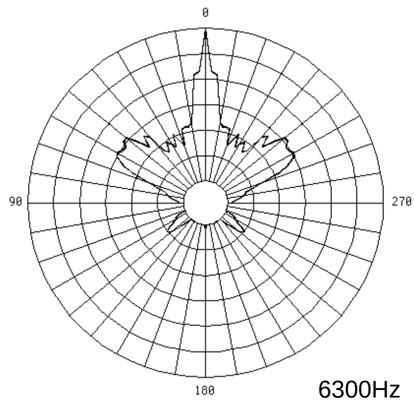
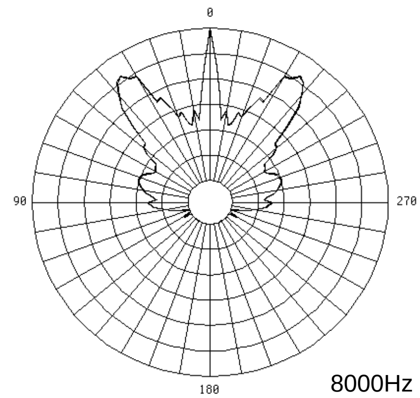
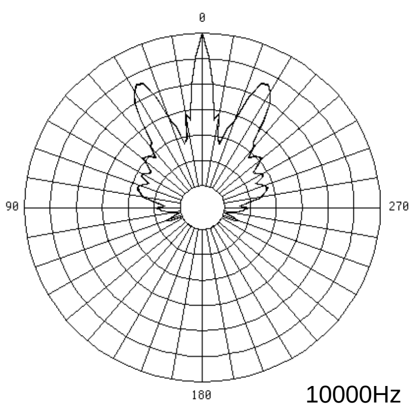


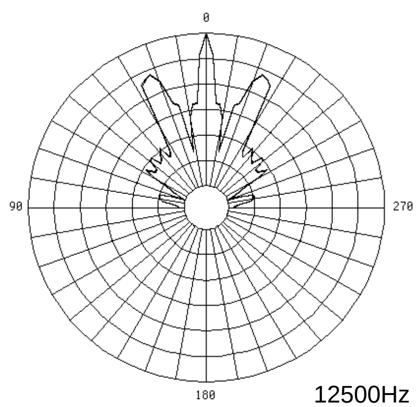
6300Hz



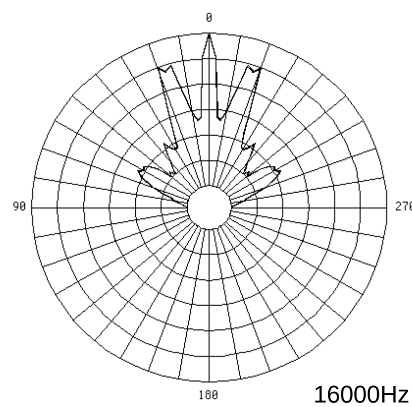
8000Hz



10000Hz



12500Hz



16000Hz

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Bose Panaray® MA12

Measured, vertical, 1/3 octave-band polar plots (5 dB/div)

Note: These polar plots are valid only at 8m.

April 02