Parabolic Acoustic Reflectors

Shaping the radiation of a high-frequency transducer for wide and flat coverage applications

Introduction

The effect of a simple acoustic reflector is well known and documented, with principles also found in other wave phenomena[1]. Figure 1 shows a solid, homogeneous wedge as the reflective element and the main effect on incident plane waves: the angle of reflection equals the angle of incidence θ.

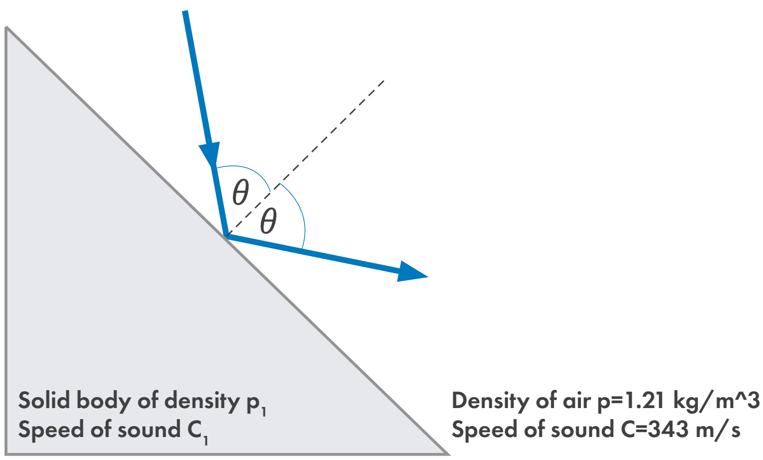


Figure 1

The amplitude of the reflected wave is proportional to the reflection coefficient V, which is a function of the angle of incidence θ and the following two ratios: $m=p_1/p$ (densities of both media) and n=C/C1 (speed of sound in them), and given by:

$$V = \frac{m\cos\theta - \sqrt{(n^2 - \sin^2\theta)}}{m\,cos\theta + \sqrt{(n^2 - \sin^2\theta)}}$$

A simple calculation confirms that molded reflectors using solid polymers with typical values of m≈825 and n≈0.2 have over 99.95% of reflectivity for all angles of incidence, making them ideal for commercial applications. In our specific example, V is a real number for all angles of incidence smaller than approximately 11.5°, being complex for 11.5°<θ< 90°, when (n2-sin2θ/in equation (1.0) becomes negative. The very small imaginary component indicates a negligible phase rotation on the reflected wave, smaller than a fraction of 0.1°, while its modulus equals 1 at all angles of incidence.

Practical Implementation

Although the basic acoustic reflector shown above has the described properties, its disadvantage is the lack of directivity control or shaping of the wave front.

Exploring other shapes, a parabola in its axisymmetric form is a well-known acoustic reflector type.

Figure 2 shows a cross section of such a device, with the transducer located on the focus of the parabola. This principle can be used for incident waves, with a microphone located on the focus, or as a radiator, with the acoustic center of a loudspeaker located on the same point.

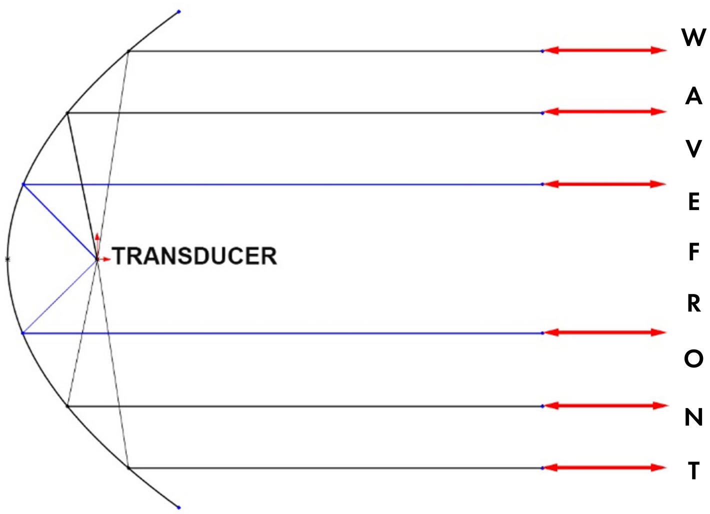


Figure 2

A variation of the parabolic reflector, shown in Figure 3 and ideally suited for some speaker types, consists of a half parabola, linearized or extruded, and a down-firing HF transducer with its acoustic center located on the focus.

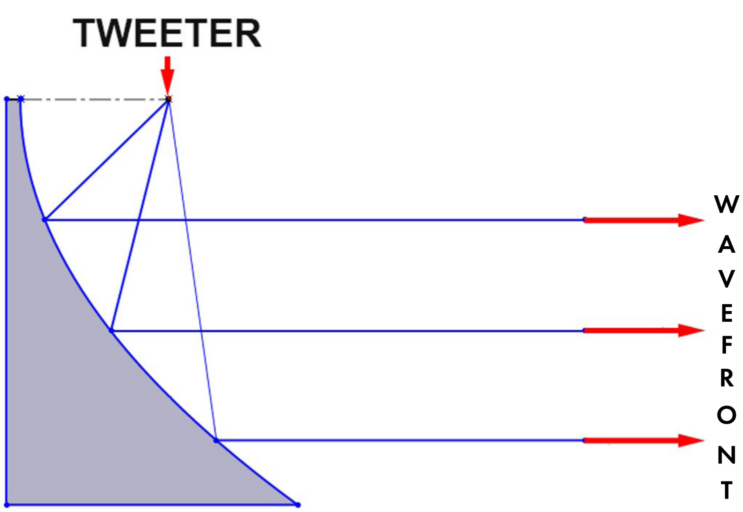


Figure 3

This arrangement has the described effect of widening the radiation while keeping it shallow. Figure 4 shows the effect, which varies with frequency, and displays singularities at frequencies for which the dimensions of the reflector are related to the reflected wavelength.

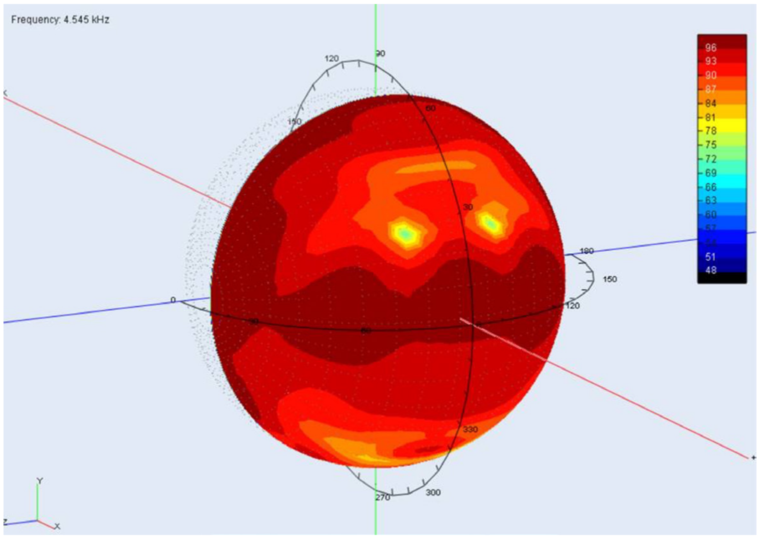


Figure 4

Figure 5 shows the reflector in its simplest form, with half-space radiation and a single HF transducer, while Figure 6 shows a full-space version (front and back radiation), useful for applications requiring circumferential coverage.

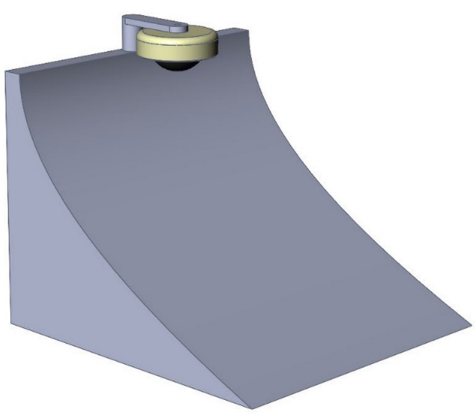


Figure 5

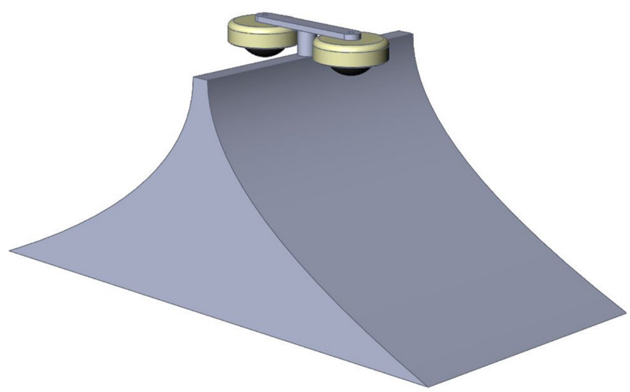


Figure 6

The models shown here have overall dimensions of approximately 150 mm per side, and cover a frequency range of 2 kHz to 25 kHz. Directivity control at low frequencies can be improved, if required by the application, by making the reflector physically larger.

These reflectors also lend themselves to aiming the radiation up or down. Figure 7 shows a side view of the same half-space reflector with a 10-degree up-tilt, suitable for application in which the speaker sits below ear level. The same idea can be applied to the full-space version of the reflector.

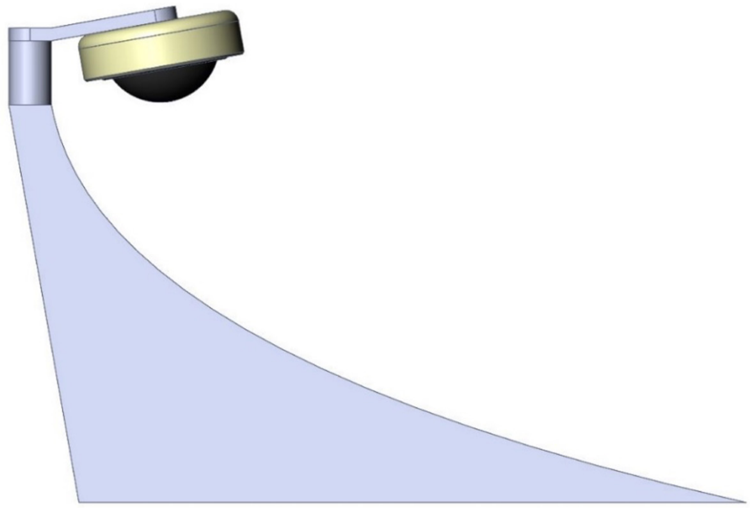


Figure 7

Same as with the common axisymmetric parabolic reflectors used with microphones, these linearized versions can be used to capture a blade of sound when a microphone cartridge is placed on the focus of the parabola. This can be useful to pick up sounds present at a certain height, but reject others above or below it, as in conference rooms in which we are only interested in talkers sitting down or standing up, but not in sound sources above or below them

A more detailed ray analysis displays the effect on reflections on-axis, and on planes at 30° and 60° off-axis, showing the widening of the radiation and a perfectly horizontal radiation on axis, as well the slight raise of the pattern at angles approaching ±60° off-axis.

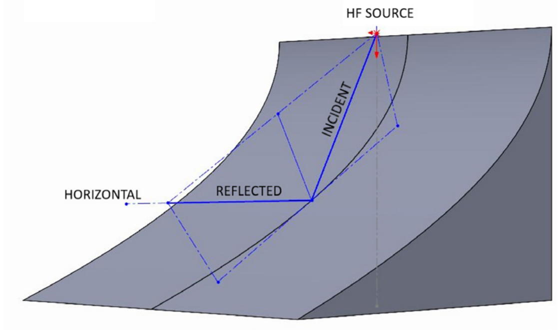


Figure 8 - On-axis reflections from the source

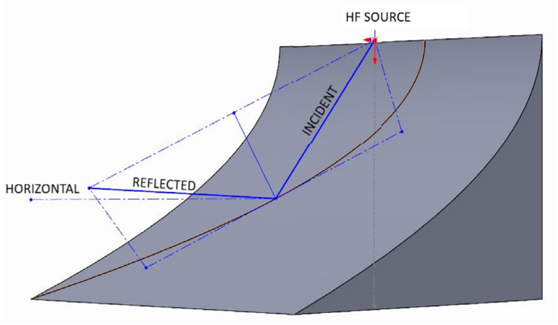


Figure 9 - 30° off-axis reflections from the source

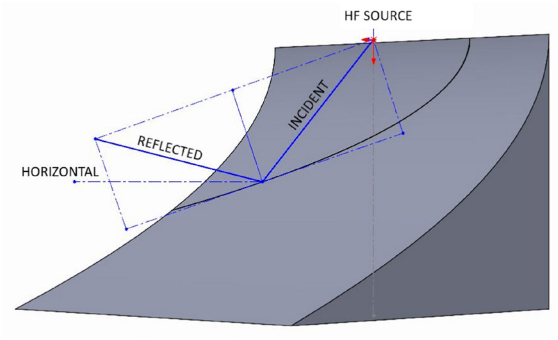


Figure 10 - 60° off-axis reflections from the source

FEA Simulations

The next set of figures show the meshing of the parabolic reflector and the HF transducer used for the simulations, as well as the effect of the linear reflector on an HF transducer (tweeter) on standard 1/3-octave center frequencies between 2 kHz and 25 kHz, displaying the described effect of a wider-than-taller radiation at all frequencies:

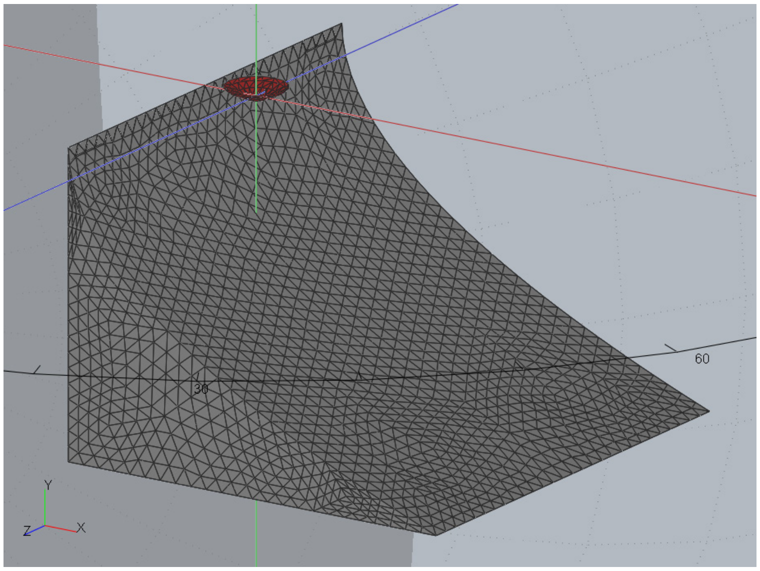
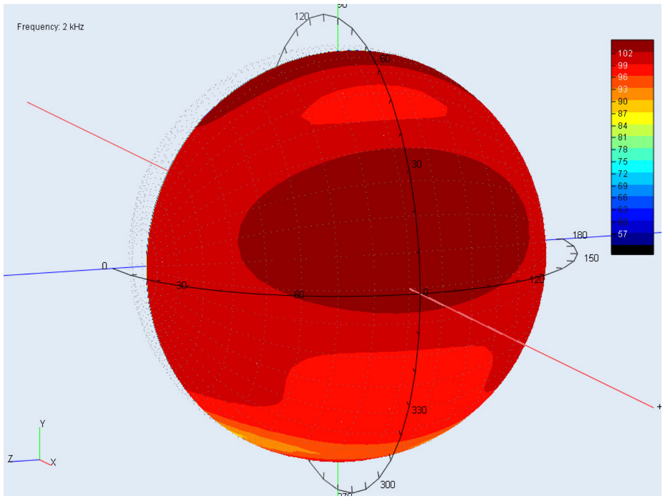
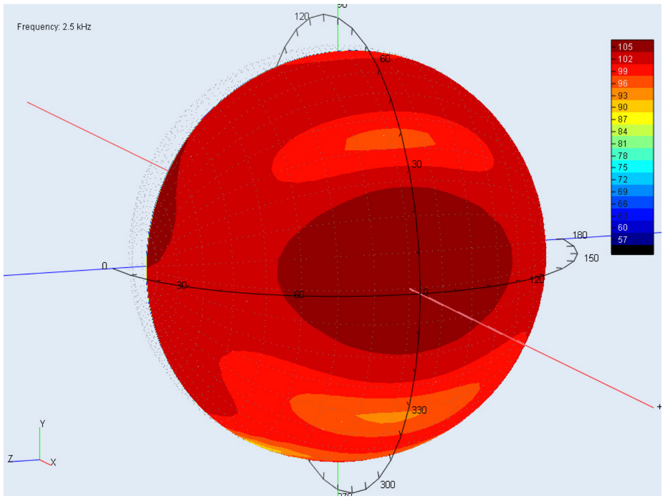


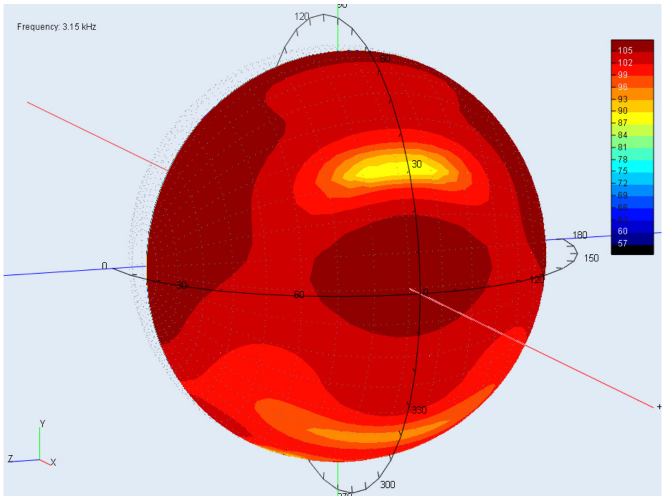
Figure 11 - Mesh and radiating dome on focus of parabola



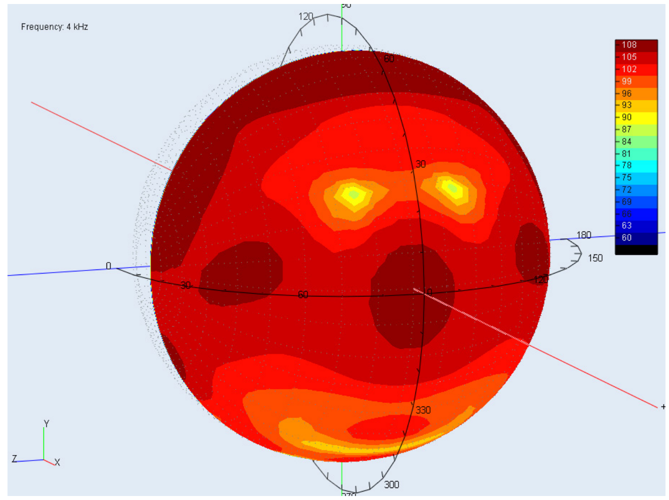
2 kHz



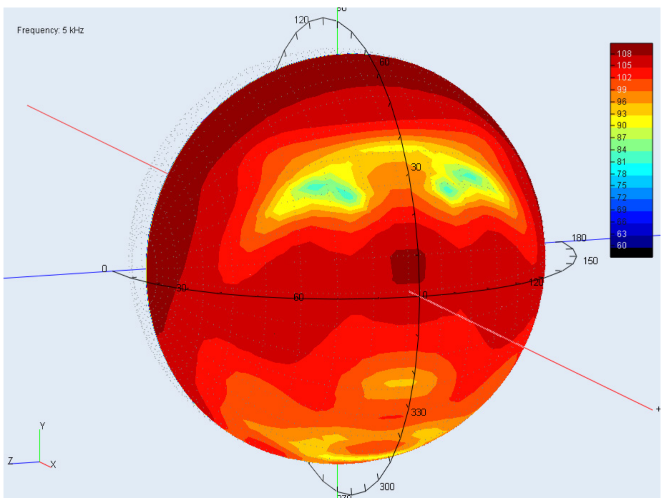
2.5 kHz



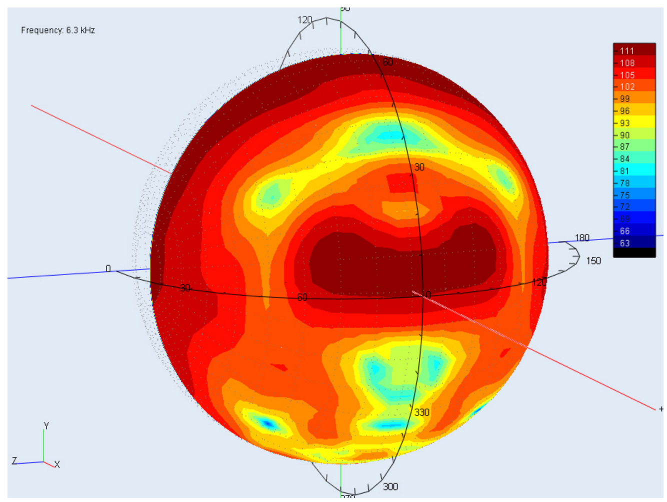
3.15 kHz



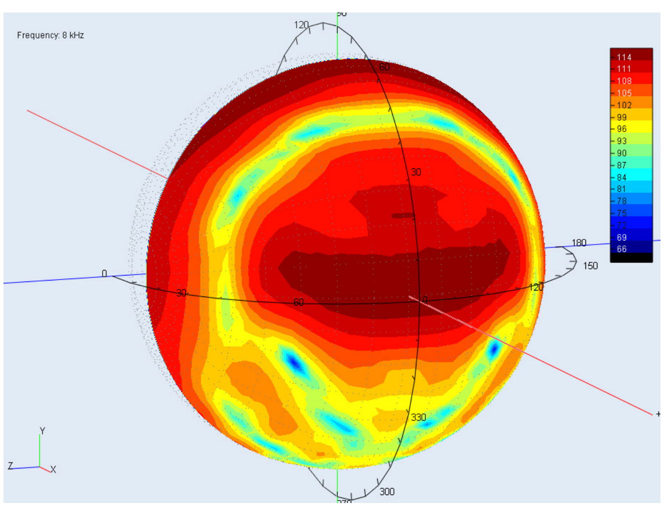
4 kHz



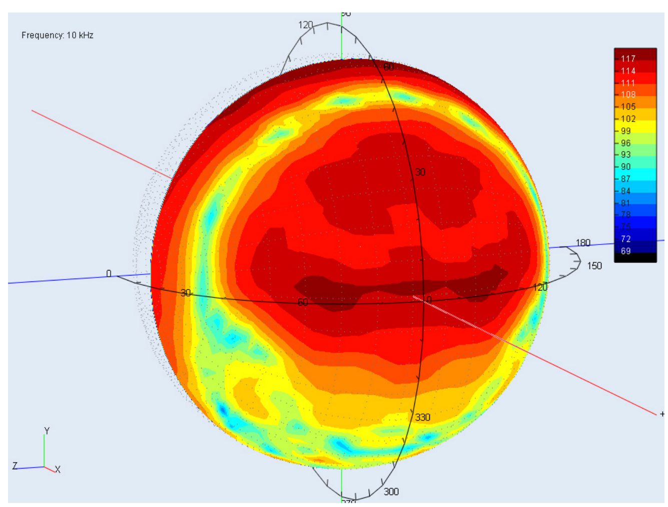
5 kHz



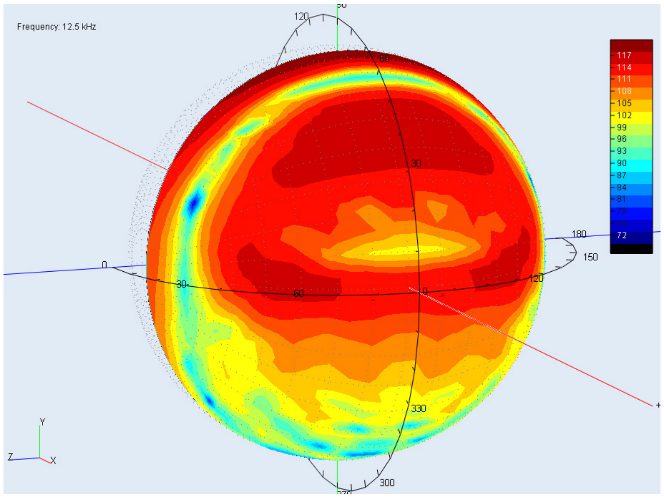
6.3 kHz



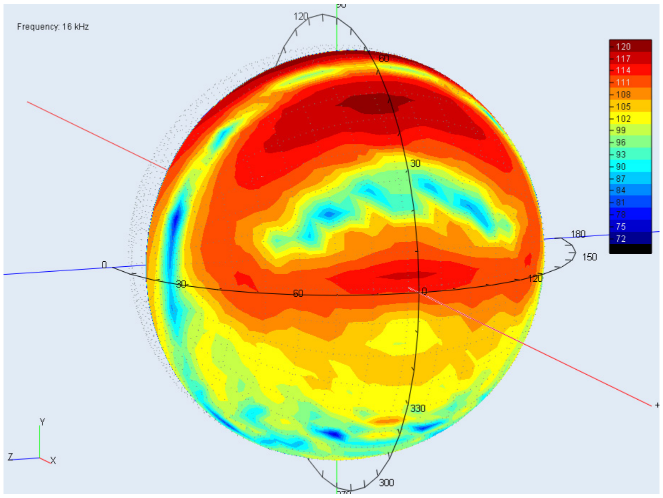
8 kHz



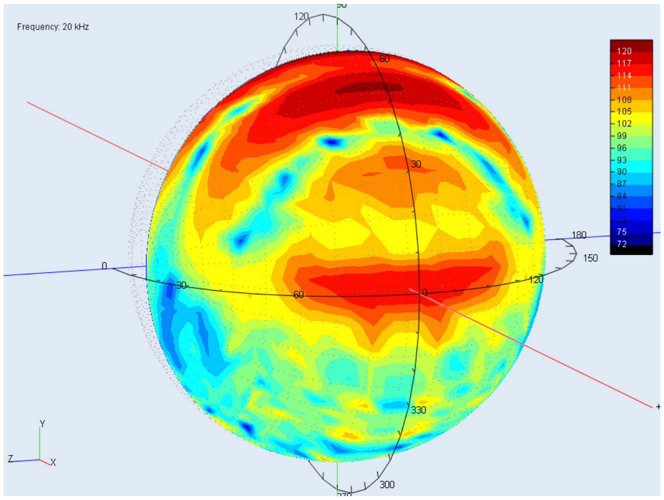
10 kHz



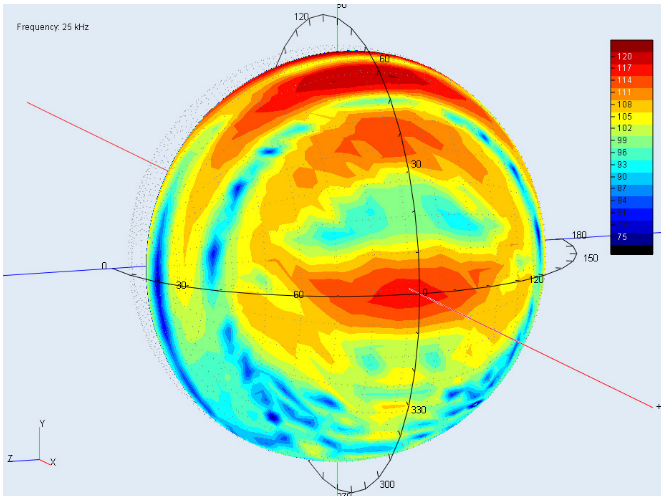
12.5 kHz



16 kHz



20 kHz



25 kHz

Conclusion

In summary, this analysis confirms the expected effect on an HF transducer with a wide and shallow radiation, which combined with optional tilt, is useful for numerous practical applications on loudspeakers and microphones alike.

Reference

1. BREKHOVSKIKH – Waves in layered media, Academic Press (1960).