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The advantages of using waveguides in Hi-Fi loudspeakers

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In recent years, the use of waveguides for the tweeter, has become more popular. There are many technical reasons for this. The lecture will explain how waveguides can be designed to offer the following advantages:

A. Increase sensitivity
B. Increase power handling
C. Make crossover point transition smoother
D. Reduce time delay difference between woofer and tweeter
E. Control sound dispersion in the room
F. Control indirect sound versus direct sound ratio

In this paper a typical 2 way loudspeaker, with a 165 mm (6.5”) woofer and a 26 mm (1”) dome tweeter is used as a reference. However, the principles shown can also work in smaller 2-way and in 3- way loudspeakers.

In a normal 2 way loudspeaker there is a crossover filter sending the bass to the woofer and the treble to the tweeter. The crossover frequency is normally placed between 2500 Hz and 4000 Hz.

In terms of power handling of the loudspeaker units, this works well. In music the continuous power above 4000 Hz is rather small, compared to below 1000 Hz. The smaller tweeter can only handle small amounts of power, so it gets useful protection by the high crossover frequency.

However, the demands placed upon the woofer are great. It must cover a frequency range of 40 Hz to 4000 Hz, a factor of 100. The tweeter only covers 4000 Hz to 20000 Hz, a factor of 5.

If the crossover frequency could be at 1200 Hz, the factors become 30 for woofer and 17 for the tweeter, which is a much more equal partnership.

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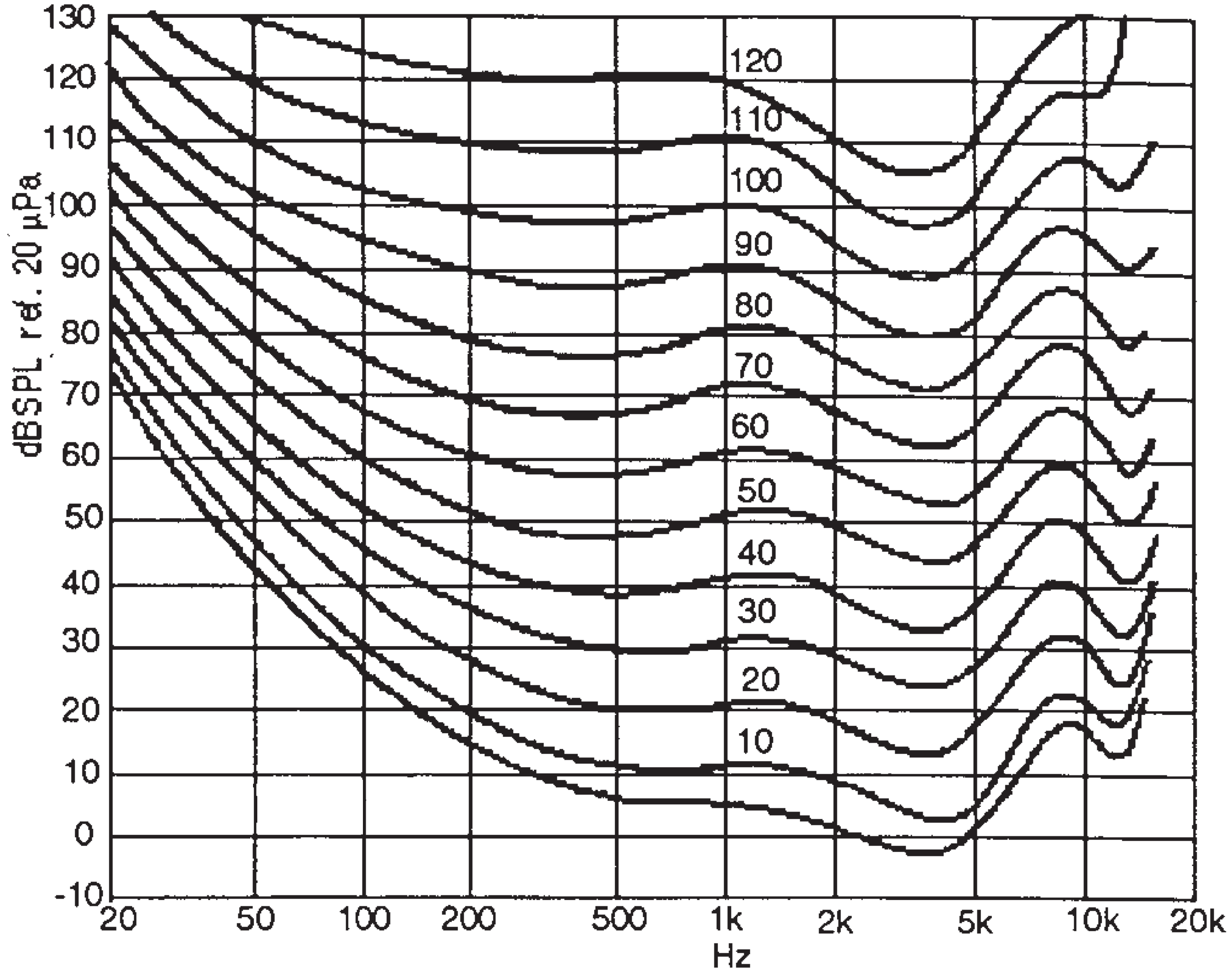
Human hearing sensitivity at different levels



The human hearing is most sensitive from 2000 Hz to 5000 Hz. See human hearing curves.

Is it a good idea to place the problems caused by the crossover in our most sensitive range?

Is it a good idea to use the woofer at 40 Hz and at 4000 Hz at the same time?
A lot of intermodulation distortion in the midrange will happen for every loud bass note.

The woofer cone weight is 12.7 gram. The cone area is 125 sq cm, the effective diameter is 126 mm, and it can move linear 8 mm peak to peak.

See woofer data sheet.

The tweeter cone weight is only 0.39 grams and it has a cone area of 8 sq cm, the diameter is 26 mm and it can move linear 1 mm peak to peak.

See tweeter data sheet

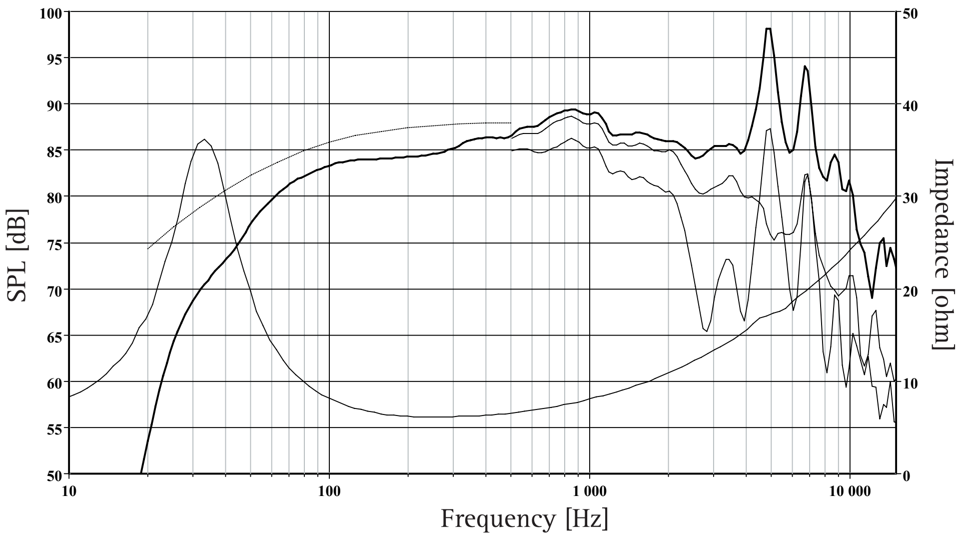
Please note this unit is a normal high quality tweeter shown as an example. The unit used by Amphion is a special design made for use in waveguides.

SEAS PRESTIGE

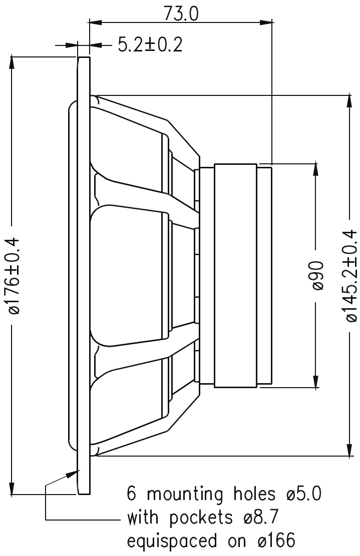
L18RCY/P H1085

L18RCY/P is a 6,5” High Fidelity woofer with an injection moulded metal chassis, intended for bass reflex and transmission line designs. The stiff, yet light aluminum cone and the low loss rubber surround show no sign of the familiar 500-1500 Hz cone edge resonance and distortion assosiated with soft cones. On the other hand, the cone break up modes at higher frequencies call for special attention in the crossover design work.

A high temperature voice coil wound on an aluminum voice coil former gives a high power handling capacity. The phase plug reduces compression due to temperature variations in the voice coil, eliminates resonances that would occur in the volume between the dust cap and the pole piece and increases the power handling capacity. The large magnet system provides high efficiency and low Q.



The frequency responses above show measured free field sound pressure in 0, 30, and 60 degrees angle using a 20L closed box. Input 2.83 VRMS, microphone distance 0.5m, normalized to SPL 1m.The dotted line is a calculated response in infinite baffle based on the parameters given for this specific driver. The impedance is measured in free air without baffle using a 2V sine signal.



Nominal Impedance	8 Ohms	Voice Coil Resistance	5.6 Ohms
Recommended Frequency Range	35 - 2500 Hz	Voice Coil Inductance	0.92 mH
Short Term Power Handling *	250 W	Force Factor	6.5 N/A
Long Term Power Handling *	80 W	Free Air Resonance	33 Hz
Characteristic Sensitivity (2,83V, 1m)	88 dB	Moving Mass	12.7 g
Voice Coil Diameter	26 mm	Air Load Mass In IEC Baffle	0.81 g
Voice Coil Height	14 mm	Suspension Compliance	1.8 mm/N
Air Gap Height	6 mm	Suspension Mechanical Resistance	1.39 Ns/m
Linear Coil Travel (p-p)	8 mm	Effective Piston Area	125 cm²
Maximum Coil Travel (p-p)	16 mm	VAS	38 Litres
Magnetic Gap Flux Density	1.25 T	QMS	2.01
Magnet Weight	0.42 kg	QES	0.37
Total Weight	1.42 kg	QTS	0.31

T29AF001
E0039

SEAS EXCEL

The T29AF001 is a High End, High Efficiency 29mm aluminum/magnesium alloy dome tweeter.

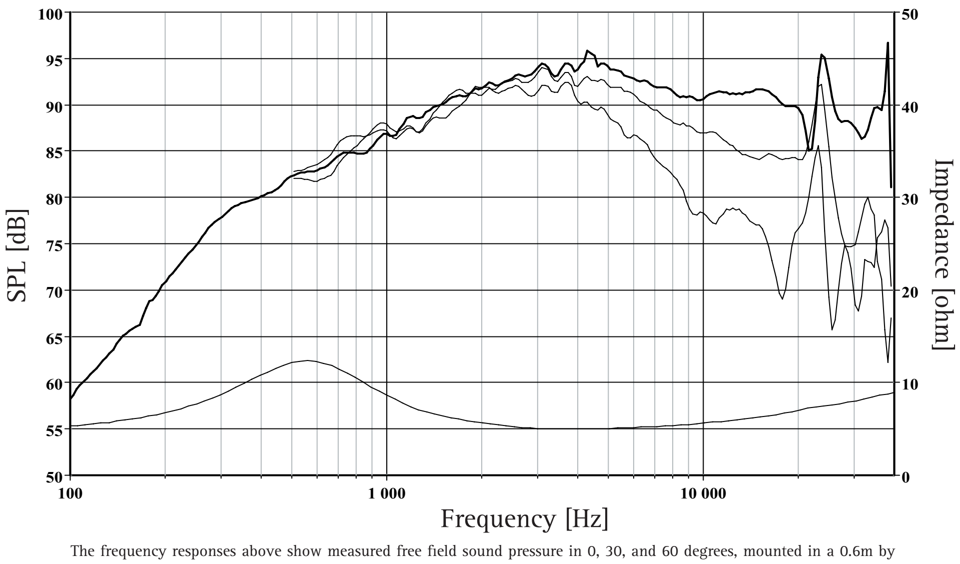
An optimally shaped dome and a wide SONOMEX surround, both maufactured by SEAS, ensure excellent performance and consistency.

A powerful magnet system based on an axially magnetized NdFeB ring magnet provides efficient ventilation and damping of the cavity behind the dome. Low viscosity magnetic fluid provides excellent cooling while maintaining a low resonance frequency.

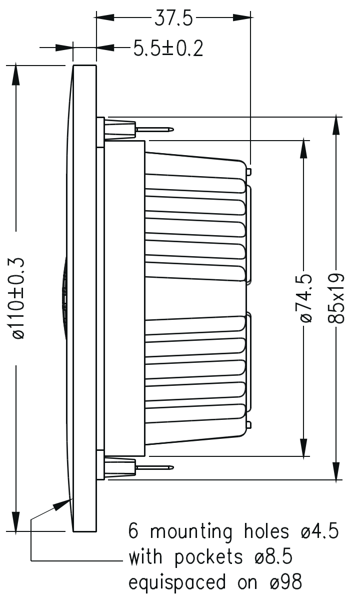
A generously underhung voice coil with flexible lead-out wires ensures low distortion and allow this driver to be used with low crossover frequencies.

A 6mm precision machined aluminum front plate with moderate horn loading characteristic combines linear frequency response with high efficiency. The front plate is Nextel painted to obtain a durable and attractive finish.

A substantial injection moulded rear chamber made from zinc eliminates unwanted chamber wall resonances and conducts heat away from the magnet system.



The frequency responses above show measured free field sound pressure in 0, 30, and 60 degrees, mounted in a 0.6m by 0.8m baffle. Input 2.83 VRMS, microphone distance 0.5m, normalized to SPL 1m. The impedance is measured without baffle using a 2V sine signal.



Nominal Impedance	6 Ohms	Voice Coil Resistance	4.7 Ohms
Recommended Frequency Range	2000 - 22000 Hz	Voice Coil Inductance	0.05 mH
Short Term Power Handling *	220 W	Force Factor	3.9 N/A
Long Term Power Handling *	100 W	Free Air Resonance	500 Hz
Characteristic Sensitivity (2.83V, 1m)	92 dB	Moving Mass	0.39 g
Voice Coil Diameter	26 mm	Effective Piston Area	8 cm^2
Voice Coil Height	1.5 mm	Magnetic Gap Flux Density	1.9 T
Air Gap Height	2.5 mm	Magnet Weight	53 g
Linear Coil Travel (p-p)	1 mm	Total Weight	0.67 kg

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*IEC 268-5, via High Pass Butterworth Filter 2500Hz 12 dB/oct.

SEAS reserves the right to change technical data

ET29-002

The woofer can move 100 cubic cm of air; the tweeter can move 0.8 cubic cm of air.

The woofer can move much more air than the tweeter. Why do not let the woofer do the job alone?

Firstly because the big woofer cone is like a big truck, (LKW) it can move a lot of air, but it has trouble going fast on a narrow winding road. If we use the woofer cone at too high a frequency, the cone breaks up, resonates and sounds bad. This we want to avoid.

Secondly because the low bass moves the woofer cone so much, that the midrange sound have a lot of intermodulation distortion. The midrange sound therefore lacks clarity.

What we need above 1200 Hz is a small light sports car, like the tweeter. It does not break up in the sensitive 2000 Hz to 5000 Hz range. The crossover prevents the loud bass notes from moving the tweeter cone. So the bass does not cause intermodulation distortion in the tweeter.
Therefore the Amphion waveguide improves clarity in the midrange.

A lot of good engineering time has been spent by many companies on trying to get woofers to behave better at and above 4000 Hz. However the laws of physics are not easy to bend. The two main problems are

- The directivity index (DI) of a cone increases 6dB/octave at higher frequencies. For a plane piston of 126 mm diameter it begins with 3dB at 867Hz, for a 26 mm dome it begins at 4200 Hz.

- At high frequencies the woofer cone stops moving like one piece, it breaks up in parts that are moving in opposite directions from each other, and resonate.

In case of an aluminium cone woofer, the resonance peak is 12 dB at 5000 Hz. See woofer data sheet.

Here we clearly need our fast small sports car, the tweeter. See tweeter data sheet.

But clearly a crossover at 4000 will not work well, and even using 2500 Hz, a 12dB/octave filter only reduce level at the 5000 Hz resonance by 12 dB, just matching the peak of 12dB!

However, if we could use a crossover at 1200 Hz, 2 octaves down from the resonance at 5000 Hz, it will be reduced by more than 24 dB, more than the 12 dB peak.

The stiff aluminium woofer cone offer better, more precise bass, but we need to reduce the resonance peaks. The 1200 Hz crossover frequency is better at reducing the resonance peak.

As you can see, we have many good reasons to want a lower crossover frequency. So how can we get the tweeter to work well at 1200 Hz?

Amphion does it by using a waveguide together with the tweeter.

This waveguide is a carefully calculated shape around the tweeter. This waveguide guides the sound waves, when they move away from the tweeter membrane, therefore the name.

How does the Amphion waveguide work?

Let me use the Amphion Argon2 loudspeaker as an example.

The waveguide expand rapidly away from the tweeter membrane, and the waveguide ends at close to 180 degree between the walls, matching the front panel of the loudspeaker. At high frequencies, the 26 mm diameter tweeter membrane works as a normal tweeter, it is very directional, and the sound waves do not follow the shape of the waveguide walls.

When the sound frequency goes below about 12 kHz, the tweeter membrane begins to use the waveguide, and it moves more and more of the air inside the waveguide. Therefore the effective diameter of the tweeter becomes larger, as we go down in frequency. Below 2 kHz it uses all of the waveguide, and the effective diameter of the tweeter is the largest diameter of the waveguide. This is about 160 mm in the Amphion Argon2.

Why is the larger effective tweeter diameter so important?

Because the effective diameter of the tweeter has become so much larger, it can play louder and work well at a lower crossover frequency. It is like the tweeter has grown in size, and it can move much more air. By using a proprietary waveguide shape Amphion can achieve a number of important design coals:

A. Increasing sensitivity

The waveguide increase the sensitivity from 800 Hz to 12 kHz by up to 10 dB.

B. Increasing power handling

Now the tweeter power level can be reduced by up to 10 dB by the crossover. The movement of the cone is much less, and distortion is much less. Effectively the power handling has been increased.

In the Amphion Argon2, the crossover frequency is 1200 Hz. So in our most sensitive hearing range from 2000 Hz to 5000 Hz, the sound is created only by the tweeter (our sports car). The result is a much better sound quality in this critical midrange.

C. Making the crossover point transition smoother

Normal loudspeakers have the crossover frequency inside the sensitive 2000 to 5000 Hz range. So we clearly hear any errors done by the crossover. The Amphion Argon2 has a crossover frequency of 1200 Hz, so any errors are much less noticed.

With a normal loudspeaker the effective tweeter diameter is only 30 mm, versus the woofers 126 mm. Due to this big difference in size, they have a very different dispersion of sound in the room at a 4000 Hz crossover frequency. The bass unit is very directional, and sends only little sound off axis towards the side walls of the room. The tweeter is not directional, so it sends a lot of sound towards the side walls of the room.

Therefore the indirect sound coming back from the sidewalls changes dramatically in level, from below to above the crossover frequency. There is a sudden change of sound character

Using the Amphion Argon2, the woofer and tweeter sounds like one unit, because the off axis frequency response matches the direct sound frequency response both above and below the crossover frequency. There is no sudden change of sound character.

D. Reducing time delay difference between woofer and tweeter

In a normal loudspeaker the tweeter is placed outside the cabinet, and the sound from the tweeter arrives too early to the listener, compared to the sound from the woofer. Many loudspeakers are angled backwards to reduce this fault.

The Amphion waveguide allows the tweeter to be placed inside the cabinet. This has the advantage of matching the placement of tweeter voice coil with the woofer voice coil. So sounds from the tweeter and the woofer travel the same distance, and arrive at the same time to the listener.

The Amphion waveguide offers the same time delay advantages as a coaxial unit. And it does not suffer from the many problems caused by the moving woofer cone surrounding the tweeter.

See drawing of cabinets.

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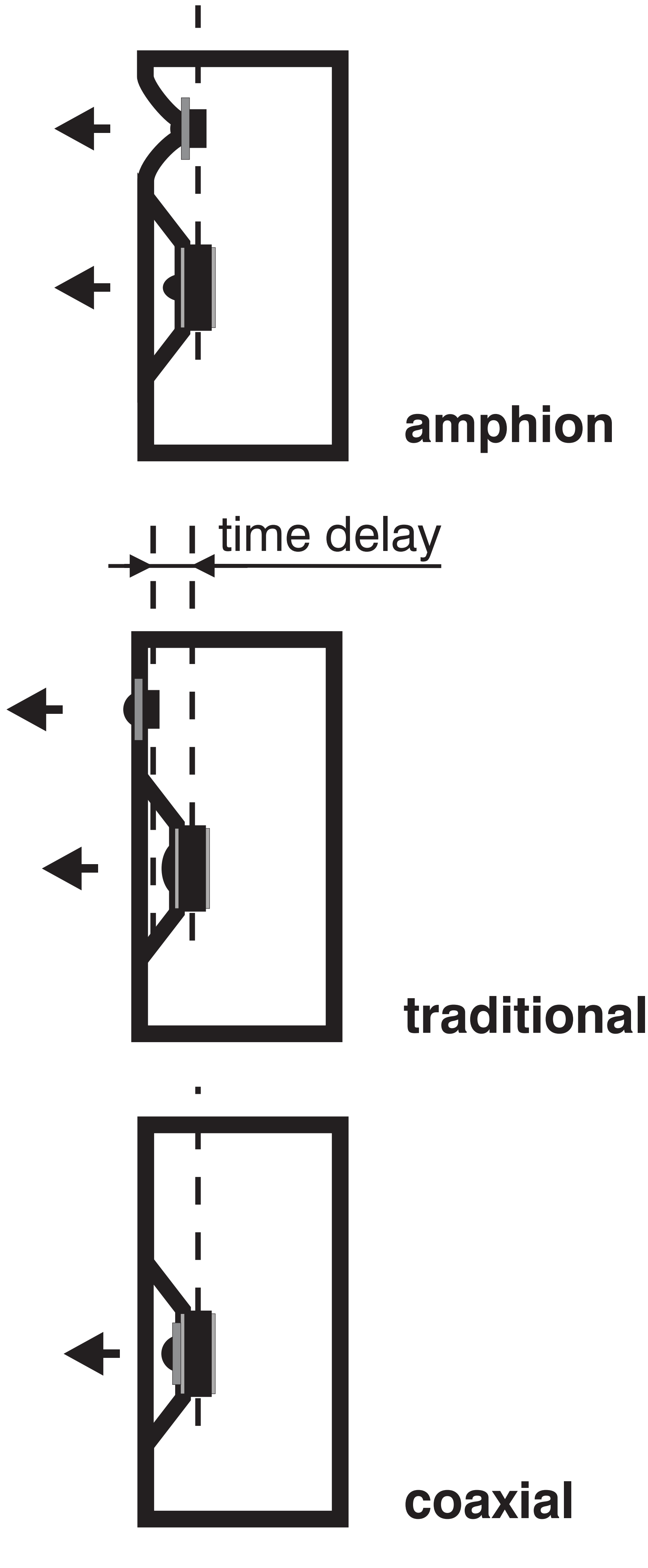

E. How does the Amphion waveguide help with dispersion of sound in the room?

A big advantage of the waveguide is the large effective tweeter diameter of 160 mm.
It is a much better match than a 26 mm dome to the effective 126 mm woofer diameter at the crossover frequency of 1200 Hz.

Dispersion of sound (Directivity Index) depends on the membrane diameter size, so in Argon2 the tweeter and the woofer have about same dispersion of sound in the listening room at the crossover frequency.

Therefore the off axis sound is similar above and below the crossover frequency. This is important because in a normal room, most of the sound energy you hear comes to you as off axis sound via the walls, ceiling and floor. This we call indirect sound. And the sound that comes straight to you from the loudspeaker, we call direct sound.

So if you use a normal loudspeaker, the frequency response of the indirect sound is very different from the frequency response of the direct sound. Your brain senses this difference, and you notice that tweeter and woofer sounds are separated and different.

F. Control indirect sound versus direct sound ratio

In many rooms the acoustics is very live in the midrange, with big glass windows, hard concrete walls and ceilings.

A normal tweeter sends sounds in all directions, the Amphion waveguide concentrate the sound towards the listener. So with the Amphion waveguide your hear less of the room, and more of the music.

Is the Amphion waveguide just another horn?

Waveguides do have some of the benefits of a horn, but not the negative effects.

In a classical horn tweeter the tweeter membrane is inside a compression chamber, and about half of the membrane is covered, so that the sound waves only can get out though holes, that is smaller than the tweeter membrane. Near the compression camber the horn is a very narrow tube, expanding slowly, and only at the end of the horn does the shape get wide. It ends suddenly, with normally 60 to 90 degrees between the inside walls of the horn.

Such a construction has a high distortion at high levels (often 20%) and a very resonant sound quality. The classical horn tweeter has a very high efficiency, but also a certain horn sound, which disturbs many people.

The Amphion waveguide do not have a compression chamber, and it does not have a long narrow tube, and it does not end suddenly with a 60 degree angle.

The Amphion waveguide does not have high distortion, and it does not resonate. It simply does not sound like a horn, because it is very different from a classical horn. In fact the waveguide is shaped like the missing part of the classical horn. The part, which goes from 60 degrees to 180 degrees.

For more information about the Amphion waveguides technology and products, please visit the Amphion stand Hall 1 K 12 or see www.amphion.fi