Open Baffle Dipoles

How they work, and how to use them well

Version 12. 08. 2010

Content:

Preamble

All the information presented in this document is from simulations.

The reason is: Understanding the principles should not be compromised by the properties of individual drivers or the room. We don't want to talk about the behavior of certain drivers in specific rooms, but about the behavior of open baffles in general.

With this in mind, all considerations will start from ideal point sources, and later from ideal planar and pistonic sources. Their intrinsic frequency response is assumed to be flat from zero Hz to infinity. And if you later read of "cones" or "domes"- it's all semantics. I always mean a planar, circular and completely rigid source.

Despite these assumptions open baffles show a high potential for sound coloration - if not used in the right way.

Everything presented in this document pages is consistent with reality - but to what extend?

I used the simulation programs The Edge (www.tolvan.com/edge) and Boxsim (www.boxsim.de). Both programs have proven they give realistic results if the room is not part of the equation, and if the particular drivers work within the limits of their simulation model. Both programs don´t account for the fact that cones and domes don't really move in a pistonic way - especially at high frequencies. And they don't consider the complex cone-basket interaction on the back side of a real driver. Because of this there can and will be differences in certain areas. Chapter 5 discusses an example.

Everything presented on the following pages is known stuff.

It is mainly based on the work of Kreskovsky, (www.musicanddesign.com/Dipoles_and_open_baffles.html) Linkwitz (www.linkwitzlab.com/models.htm#A) and Ferekidis (www.wvier.de/texte/Dipollautsprecher-FV.pdf).

Their work shows how the open baffle itself can be responsible for up to 10 dB variability in SPL response - with a driver of ultimate linearity. That's even without considering the dipole loss of 6 dB/ octave at the lower end of the response range.

For many enthusiasts open baffles provide a fast and - supposedly - easy introduction to loudspeaker diy. In many instances though, the quick results hide the fact that the potential for optimization has not been fully exploited.

This paper aims to help the reader to get even better results by gaining a deeper understanding.

I would like to thank Richard Grant from Australia for helping make this readable in English, and for giving much apprecia-ted encouragement and valuable advice.

1 A dipole as point source

In its most abstract form, a dipole speaker consists of two point sources (red and green), which radiate sound uniformly in all directions, but with reverse polarity.

When one source is generating a pressure maximum, the other source generates a pressure minimum - and vice versa. If we consider these acoustic oscillations as waves, we talk of 180° phase difference between both point sources.

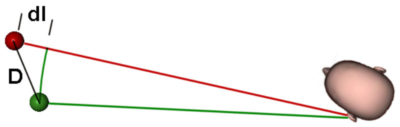

Fig.1.1

The properties of a dipole are characterized *mainly* by the dipole length D, which is the direct distance between both point sources on the so-called dipole axis.

But what we hear is decisively determined by the length difference **dl**, being the difference between the distances from the red point source to the ear, and the green point source to the ear.

1.1 Both point sources on the listening axis

For a better understanding of dipole behavior, we start with a dipole which is pointed directly at the listener. Dipole axis and listening axis coincide and we see that D = dl.
The sum of the red and green generated sources will result (in the diagrams below) in the black wave arriving at the ear.

We look at four different wavelengths λ:

a) Wavelength λ much larger than D (D/ λ << 0.5)

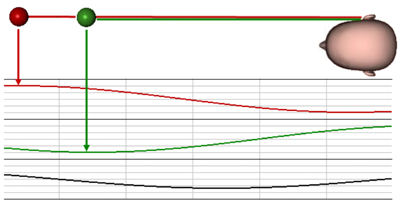

Fig. 1.2

While the red source is in its pressure maximum, the green source is in its pressure minimum. The sum of red and green results in the black wave arriving at the ear. Its combined SPL is considerably less than the SPL of the individual generating waves.

b) Wavelength λ equals to 2 * D (D/λ = 0.5)

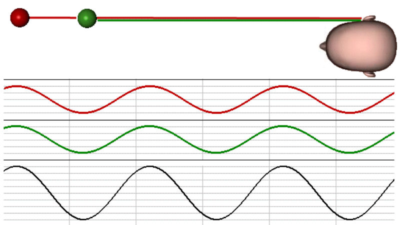

Fig. 1.3

Again the red source is in its pressure maximum, while the green source is in its pressure minimum. Both waves are **in phase**. The sum of the red and green results in the black wave arriving at the ear. Its SPL is **double** that of the generating waves.

c) Wavelength λ equals D (D/λ = 1)

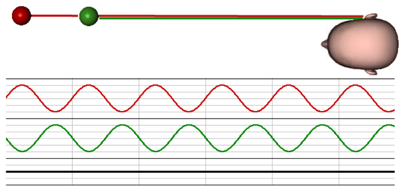

Fig. 1.4

If the wavelength is equal to the dipole length D, at the ear the sound of both sources completely cancels each out.

d) Wavelength λ equals D/2 (D/λ = 2)

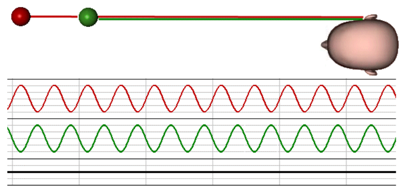

Fig. 1.5

When exactly two wavelengths fit into the dipole length D, the sound portions of both point sources again completely cancel each other out at the ear.

Looking at the SPL response of such a dipole over a large frequency range will result in this behavior of SPL against D/ λ:

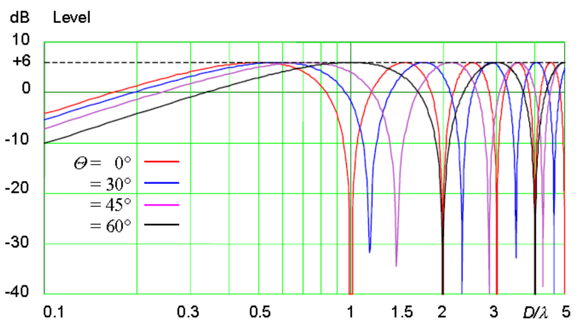

Fig. 1.6 after Ferekidis

The red line represents two dipole point sources along the listening axis, as has been just discussed.

Most people will be more familiar with plotting SPL against frequency.

In this case where D = 34 cm:

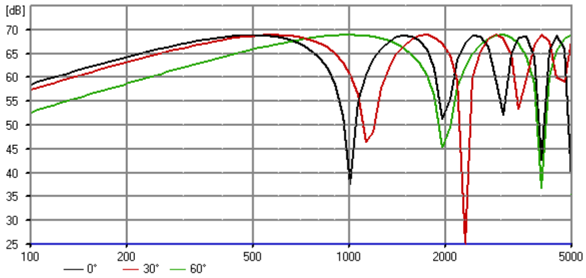

Fig. 1.7

In general:
SPL **peaks** occur at all frequencies, where wavelength is an **uneven** multiple of D/ 2: 1/2 D, 3/2 D, 5/2 D, etc.
SPL ***dips*** occur at all frequencies, where wavelength is an ***even*** multiple of D/ 2: 1 D, 2 D, 3 D, etc.

1.2 Both point sources at an angle to the listening axis

Fig. 1.6 and 1.7 show how response levels on axis and at an angle develop in a similar way only below D/λ= 0.5.

At for instance an angle of 60° it's no longer dl = D, but dl = D/ 2 (because cos 60°= 0.5). This explains why a dipole **at 60°** develops its first SPL **peak** exactly at the same frequency where ***on-axis*** response has its first SPL ***dip***.

For D/ λ= **1**, listening at an angle of 60°, the SPL of both point sources will add to the black line, with double the level of the red and green lines:

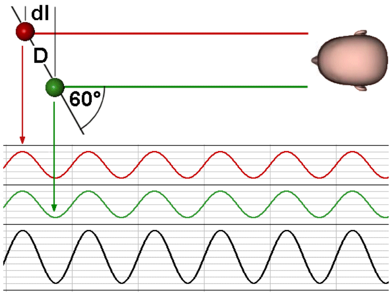

Fig. 1.8

Listening again at 60° but with D/λ= **2** the SPL of both point sources cancel each other out:

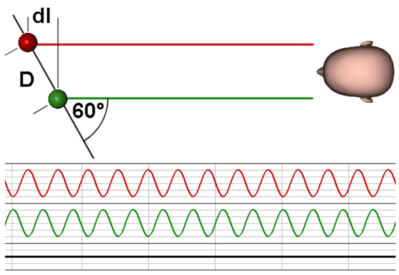

Fig. 1.9

This first SPL dip at 60° coincides with the second SPL dip on axis. Compare Fig. 1.5 and 1.6.

At 90° the dipole length is still D, but the distance from both point sources to the ear is of equal length - resulting in dl = 0.

As a result the (anti phase) radiation of both point sources cancels each other at each and every frequency. We get a SPL reduction perpendicular to the dipole axis - the cause of the **dipole figure 8 response pattern**:

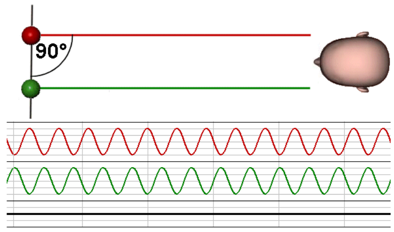

Fig. 1.10

It's not only the frequency response of such point source dipoles which gets very bumpy. The **horizontal distribution** of sound in the room (the **polar diagram**) also needs getting used to:

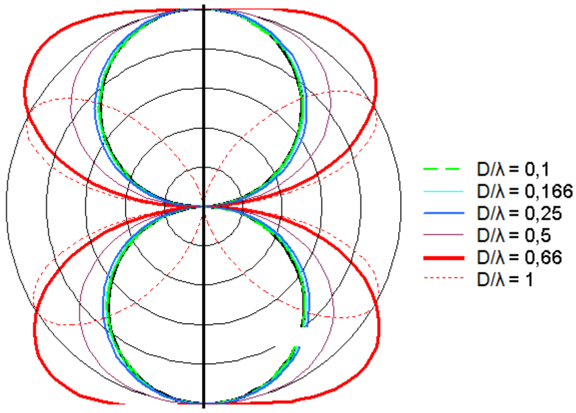

Fig. 1.11 after Kreskovsky

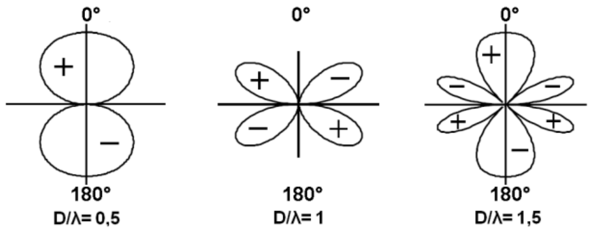

Fig. 1.12 after Ferekidis

A point source dipole radiates in the figure 8 pattern only up to the first on axis SPL peak (D/λ = 0.5).

At higher frequencies such a dipole develops multiple lobes in changing configurations. The only consistent and frequency independent properties are the radiation symmetry to the front and rear, and the contraction perpendicular to the dipole's axis.

Fortunately there are ways to instill a more even frequency response into dipoles. This will be discussed in chapters 2 and 3.

Dipoles work at their best when their directivity remains constant throughout their complete operating range. This mode of operation however is restricted to below the first SPL peak, and will be explained in depth in chapter 4.

2 Point sources in open baffles

If we build a dipole from two point sources we need two separate enclosures. To reproduce low frequencies effectively, between the enclosures we need a large distance on the listening axis. After doing this we will still get a very bumpy frequency response.

Linkwitz (http://www.linkwitzlab.com/models.htm#B) has shown in detail, how we can replace the two point sources of a dipole by the front and back of the cone of a dynamic driver. He also has shown how the dipole length D becomes the radius of a circular baffle, with the loudspeaker in its center:

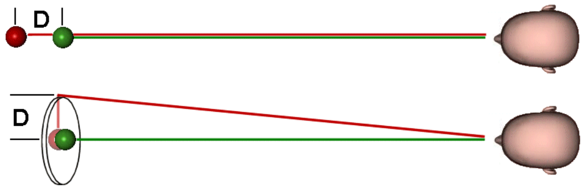

Fig. 2.1

2.1 Drivers in circular baffles

If we put a small driver in the center of a large circular baffle, we can think of it as a point source of positive polarity, which is surrounded by a “ring radiator” of negative polarity. The ring radiator represents the energy which is radiated from the rear point source in the listener’s direction:

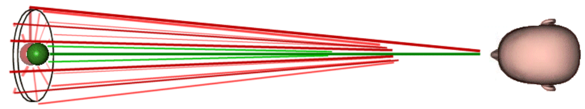

Fig. 2.2

This dipole still features a well defined dipole length D. But the length difference dl is no longer a function only of the angle between dipole axis and listener axis. In contrast to the two-point-source model, dl also varies along the circumference of the baffle, when the listener is off the dipole axis:

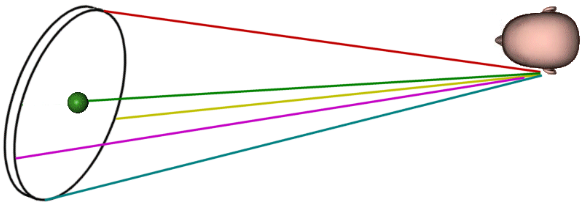

Fig. 2.3

How does frequency response change when we change the size of the baffle or the angle between listening axis and dipole axis?

When D is doubled, the frequencies of the SPL peaks and dips along the dipole axis are halved. SPL at low frequencies rises 6 dB every time D is doubled:

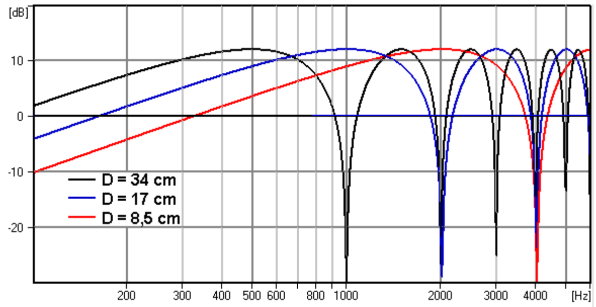

Fig. 2.4

Looking off the dipole axis, we can easily see the influence of the variable length difference dl compared to the dipole length D:

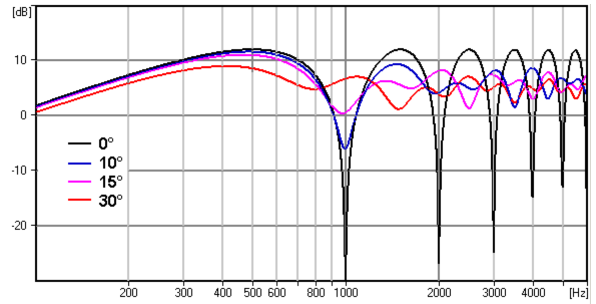

Fig. 2.5

The frequency responses at 15° and 30° have more in common with each other, than with the response on axis (at 0°).

It is evident that it is only advisable to equalize the dipole loss below D/ λ = 0.5 and the first SPL peak. At best an additional correction of the first SPL dip should be considered.

Any other corrections - especially to improve the response on axis - only change the response at other angles for the worse.

2.2 Drivers in square baffles

Square baffles are easier to produce than circular ones. But square baffles not only change dl along the circumference, but also the dipole length D:

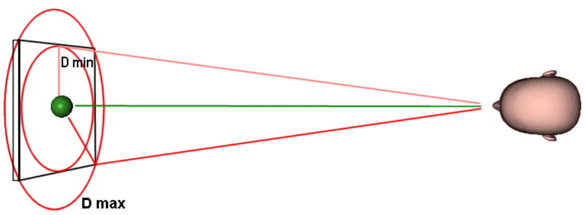

Fig. 2.6

A square baffle has the same dipole length as a circular baffle of the same surface area. But this actually applies only *for the first SPL peak and the first SPL dip*.

Even on axis, because of the varying dipole length the SPL peaks and dips are less pronounced than in a circular baffle:

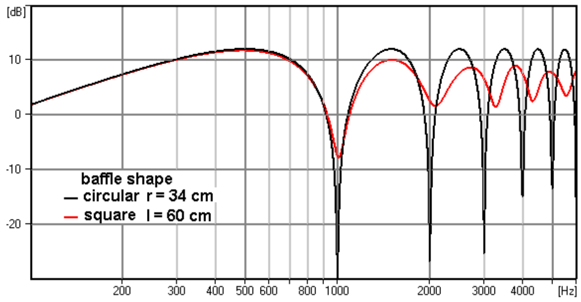

Fig. 2.7

Compared to Fig. 2.5 we see the off axis response also improves:

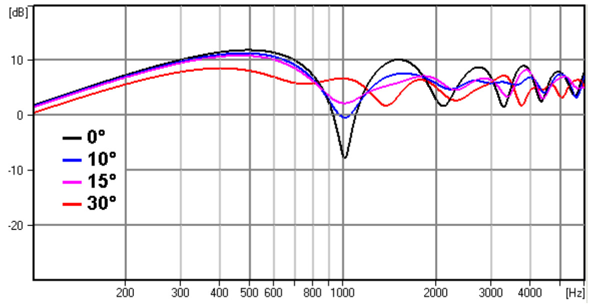

Fig. 2.8

Again we see that any correction of the on-axis-response should be done with utmost restraint - if at all.

2.3 Drivers in rectangular baffles

Up to this point all baffles were symmetric - so frequency response to the left and right, up and down are the same.

What happens if we extend the square baffle with its central point source, with a square baffle of equal size at the bottom?

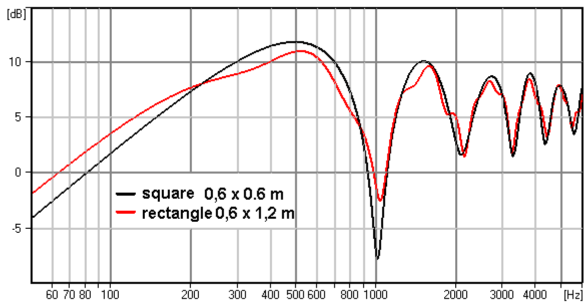

Fig. 2.9

Along the dipole axis we see some small response ripple and a considerable SPL gain at low frequencies. There is no gain at all above the first SPL dip.

Off axis and above the first SPL dip, the response gets a bit more wavy than in the square baffle, but all peaks and dips remain at the same position:

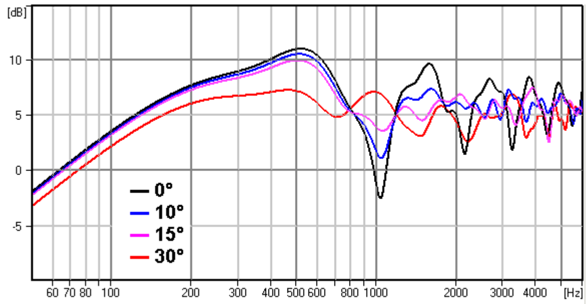

Fig. 2.10

Below the first SPL dip we see less resemblance between on-axis and off-axis response than previously.

2.4 Driver offset in baffles

Chapter 2.3 showed the **vertical offset** of a point source on the baffle. It had no outstanding impact on the simulation results, because they only track horizontal changes. What effect will a ***horizontal offset*** on the baffle have?

a) Offset in circular baffles

On a circular baffle of radius 34 cm, the point source is moved 8.5 and 17 cm from the center to the left:

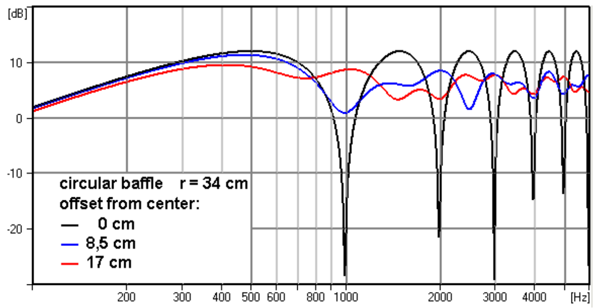

Fig. 2.11

By moving the source that far away from the baffle center, the dipole length D will vary significantly along the baffle circum-ference. The typical dipole peaks and dips are now hardly detectable.

Moving the source away from the baffle center changes the frequency response to the sides. Response left and right from the dipole axis could be very different:

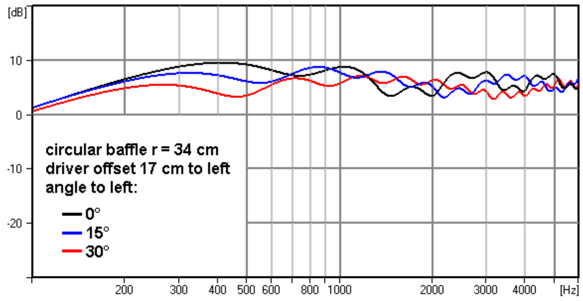

Fig. 2.12

To the left - the side with **the shorter distance** from source to **baffle edge** - the frequency response is **quite balanced**, especially at 15°. To the right - with ***the longer distance*** - we see ***larger differences***, on axis and off axis:

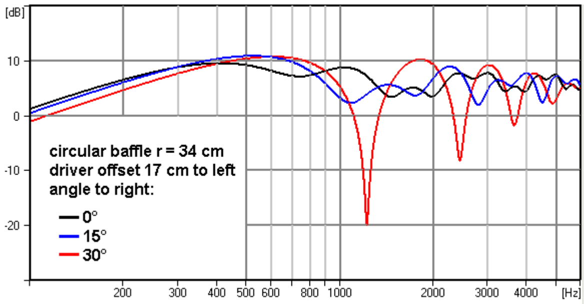

Fig. 2.13

The 30° frequency response (red) is a great illustration of why **the distance between the baffle center and the sound source should not be an even-numbered divider** (eg ½ or ¼ of the baffle radius). As shown in Fig. 2.13, it could result in even-numbered ratios of D to dl, which lead to pronounced SPL peaks and dips.

Note how the angular drop of sound pressure between 200 and 600 Hz is a lot larger to the short side (Fig. 2.12) than to the long side (Fig. 2.13).

b) Offset in square baffles

Next we move the sound source of the square baffle 15 cm from the center to the left. The result is *less* well balanced than on the circular baffle:

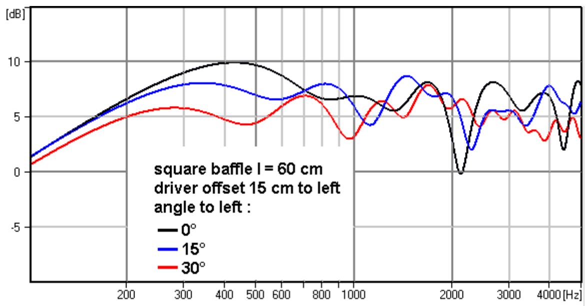

Fig. 2.14

Again we see the response "buckles" to the longer side from 200-600 Hz. Exactly the opposite happens at 1200 Hz, but over a shorter range. At 2200 Hz (D/λ = 2) the dipole figure 8 splits into a quadruple beam, as shown in Fig. 2.17.

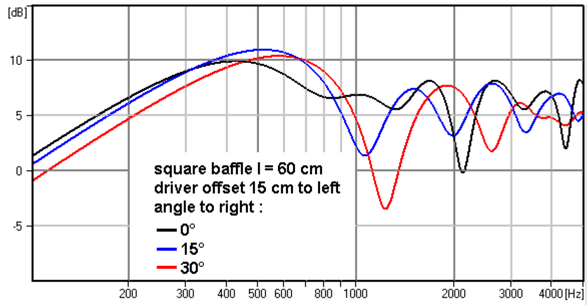

Fig. 2.15

The polar diagram shows the "buckling" of the dipole figure 8 to the longer side of the baffle. This behavior is due to the asymmetric placement of the sound source on the baffle:

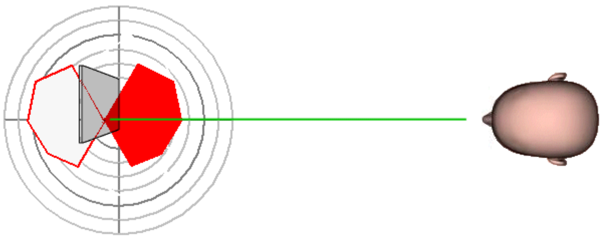

Fig. 2.16

The dipole figure 8 "wiggles" around the dipole axis. Also and depending on frequency, the dipole figure 8 expands, contracts or develops lobes to the sides. Compare to Fig. 1. 12.

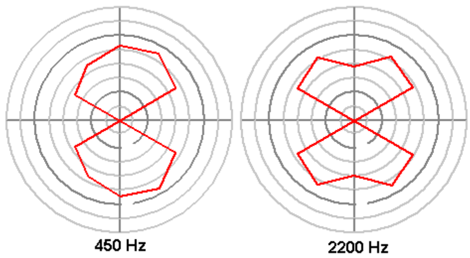

Fig. 2.17

Above D/λ = 1 these effects cannot be avoided. Changing the baffle shape or the position of the point source on the baffle might improve the response for a single frequency or angle - but will change things for the worse at other frequencies and angles.

3 Extended sources in open baffles

All previous descriptions were based on point sources, to show the effect solely of the baffle. But real world loudspeakers consist of a cone, foil, ribbon or dome of some flat expansion.

This chapter will discuss how the relation between baffle size and the size of such extended sources affects sound radiation. We assume the source to be completely pistonic, and the source's frequency response to the rear is identical to the front firing response.

3.1 Dipole loudspeaker without baffle

We can model a wide flat source, by placing an increasing number of dipole point sources around the center of a circular baffle, successively with a total diameter d of 0.2, 5 and 10 cm.

For a better comparison we use the baffle of Fig. 2.4 and 2.5 with a radius of 34 cm. This way the dipole length D stays the same for all cone diameters. For each and every point source, there is an additional difference length dl from the baffle center, which can take any value from "0" to the cone diameter. Those varying difference lengths see to it that most sharp SPL peaks and dips are leveled on axis:

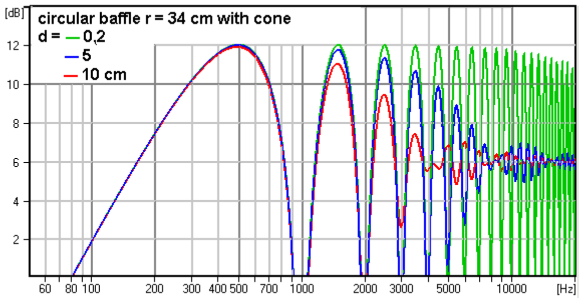

Fig. 3.1

It is obvious how the treble performance improves dramatically compared to the single point source - even at small cone diameters. This trend continues to lower frequencies when we **enlarge the cone size**:

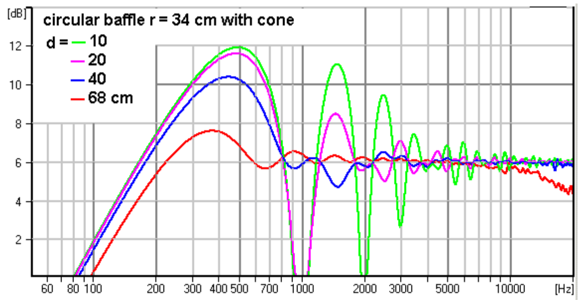

Fig. 3.2

When the cone size equals the baffle size, only the dipole roll-off and the first SPL peak will remain. Even the first SPL dip is only a shallow depression. You may notice the dipole peak moves to lower frequencies, while the coverage of the baffle increases. I have no explanation for this behavior yet.

Dipole and beaming

As already explained in chapter 1, the characteristic figure 8 of a dipole results from the cancellation of sound which become increasingly anti phase perpendicular to the dipole axis. The dipole figure 8 may change its shape depending on frequency, but irrespective of frequency the contraction to the sides keeps this fundamental character.

The fact that drivers increasingly beam as frequencies rise, has a similar cause. Again it is about the cancellation of anti phase waves - depending on wavelength and cone diameter.

There is a strong relationship between dipole characteristics and beaming, which is very relevant **for dipole drivers without a baffle**:

All circular cones with the radius D (dipole length) have their first on-axis dipole peak at $\lambda = 2$ D and their first dipole dip at $\lambda = 1$ D. The same cone will start to beam anywhere between $\lambda = \pi$ D and $\lambda = 2\pi$ D (the exact value is up to people's individual definition).

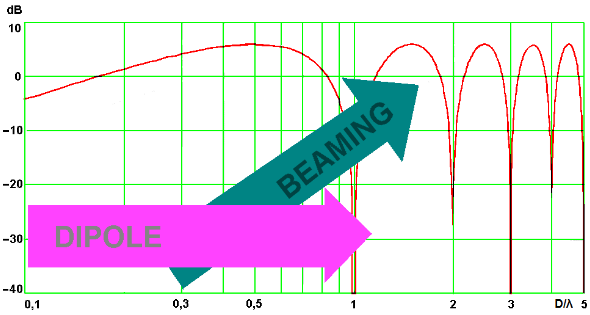

Fig. 3.3

What does this mean? **For all frequencies around and above the first SPL peak**, beaming takes over from the constant directivity which the dipole principle provides up to the first SPL peak.

Beaming first starts at large angles from the dipole axis and at high frequencies. This gives the impression that the dipole peak is moving to lower frequencies when the angle off dipole axis increases. What *really happens* is that beaming is successively "biting off" the dipole peak at higher frequencies:

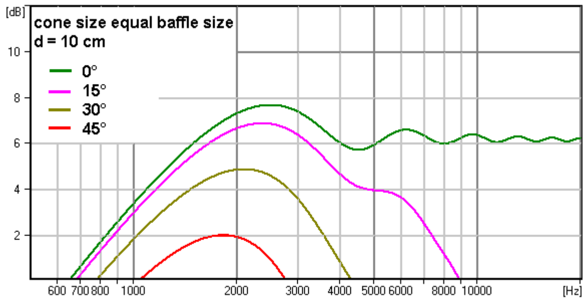

Fig. 3.4

We can raise the point where a dipole loses its constant directivity, up to higher frequencies by reducing the cone's diameter. Unfortunately at the lower end the onset of dipole loss also moves to higher frequencies:

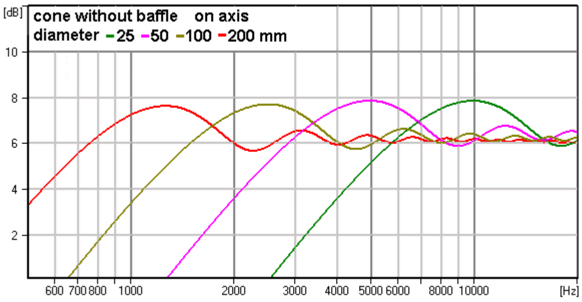

Fig. 3.5

To escape this dilemma, different sized drivers have to be used for different frequency ranges. Otherwise real dipole behavior is lost - most likely starting at the highest frequencies.

3.2 Dipole drivers in baffles

In real life, every driver is larger than its cone or dome. When calculating the effective dipole length D, we need to add the space occupied by the surround and basket.

Also we have to add any offset in the *depth*, which the sound from the back source has to travel to reach the plane of the acoustic centre of the forward radiating source:

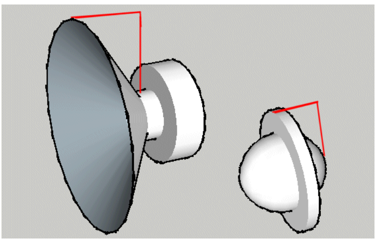

Fig. 3.6

How does a larger baffle size affect the dipole's behavior? Let's first surround our 10 cm cone (from Fig. 3.4) with a small border, 1.5 cm wide on each side:

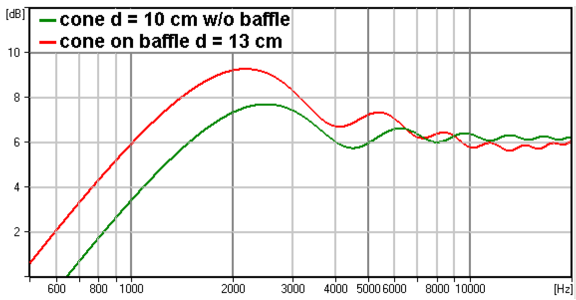

Fig. 3.7

Adding baffle size (the red curve) moves the SPL peaks to lower frequencies, and gains some SPL at low frequencies. Also the second SPL peak will develop considerably.

Making the baffle diameter larger and larger leads to the following changes:

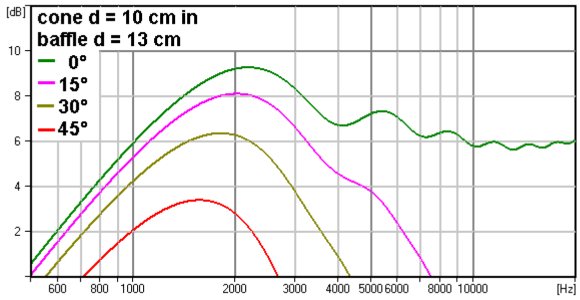

Fig. 3.8

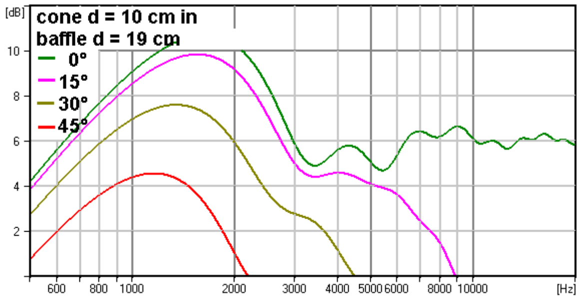

Fig. 3.9

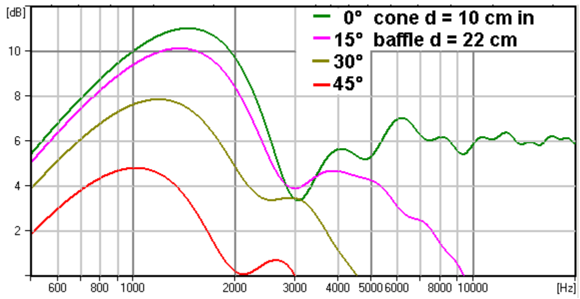

Fig. 3.10

Fig. 3.10 shows clearly why **the effective diameter of a baffle should not exceed the double the diameter of the cone**. If the baffle width increases any more, a zone of constantly changing radiation patterns develops between the upper end of the first dipole peak (D/ λ = 1, defined by the baffle diameter) and the start of beaming (defined by the cone diameter):

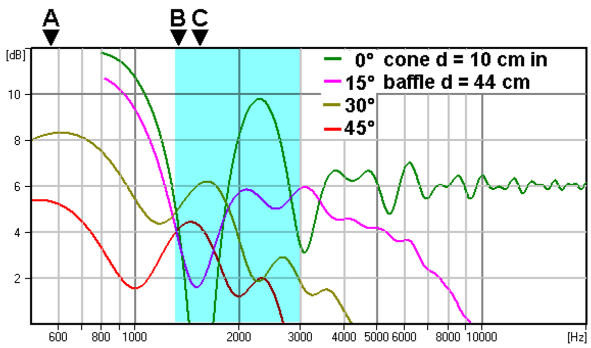

Fig.3.11

As the frequency rises, different polar patterns develop in rapid succession (compare to Fig. 1.11 and 1.12). The "normal" dipole figure 8 breaks up into ever more "petals" - each with a polarity opposite/inverse to the neighboring ones:

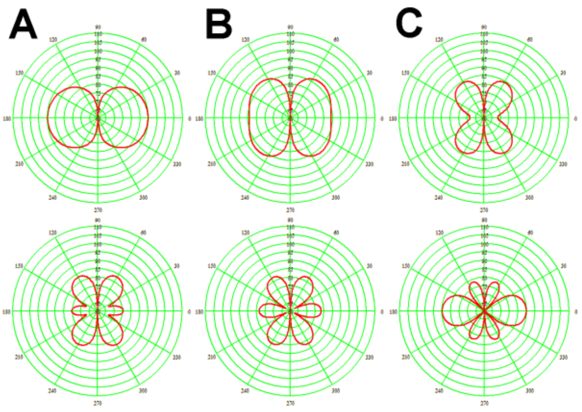

Fig. 3.12

This process only stops when the frequency rises high enough that the driver's naturally narrowing beam no longer illuminates the baffle edge. The dip in off-axis response is no longer due to dipole cancellation, but to the sideways radiation that is missing due to the driver's narrowing beam. From that point on, it is questionable if we should still call the speaker system a "dipole".

The diagrams in Fig. 3.12 do not correspond exactly to the frequencies indicated A, B C in Fig. 3.11. But reading from top left to bottom right, they show how patterns can change with rising D/λ. They increasingly digress from the ideal.

From the past considerations we know that all wide and rectangular open baffles have in common three different acoustic zones:

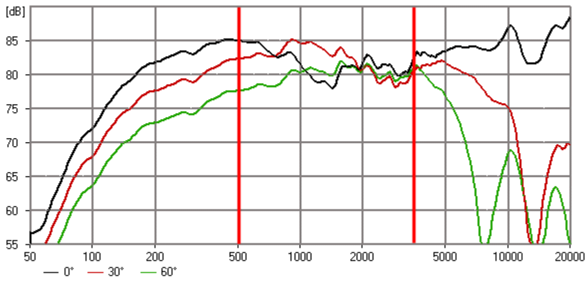

Fig. 3.13 Visaton FRS8 on OB 110x50 cm

- At all frequencies below the first dipole peak (D/λ = 0.5) the baffle conforms to the ideal dipole pattern. Off axis, SPL decreases rather quickly.
- In the intermediate zone, the dipole changes its pattern rapidly. The dipole figure 8 tends to break up into multiple lobes.
- When the cone starts to beam, the dipole figure 8 progressively changes to a single dominant forward and rearward radiation lobe.

With this in mind, there seem to be two design alternatives:

1. Accept the changing radiation pattern along the frequency axis, and try to keep pattern and SPL deviations of the dipole to a minimum. This alternative will be discussed in the chapter 3.3.
2. Try to keep the ideal dipole figure 8 pattern for as long as possible throughout the hearing range. This strategy of constant directivity will be explained in chapter 4.

3.3 How to optimize open baffles

Chapter 3.1 showed how **large cones** (relative to baffle size) **help to level dipole peaks and dips**. Chapter 3.2 showed how ***large baffles*** (relative to driver size) can degrade the polar response at high frequencies. Obviously one size does NOT fit all.

As a consequence open baffles should not be planned as a single wide rectangular board, but as two or more different baffles (or baffle regions), each with a baffle width and driver size suiting the designated frequency range.

Passive crossovers don't allow any boost of frequency ranges - only attenuation. In this case a combination of three first dipole peaks, together covering a large part of the hearing range, lends itself to a smart 3-way dipole system:

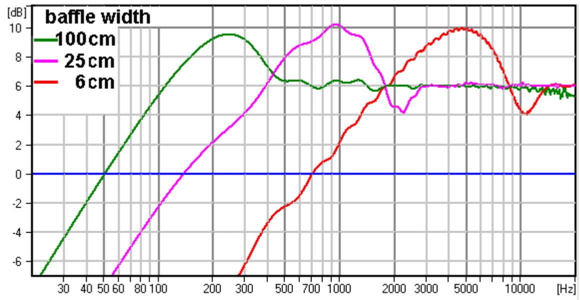

Fig. 3.14

This example covers a range from 100 Hz to 10 kHz, affording only decent and almost symmetric corrections of the baffle response. The dipole dips can be reduced by mounting the drivers off the baffle axis. The simulation of Fig. 3.14 presumes driver diameters of 38 cm, 12 cm and 2.5 cm.

Note how with rising frequency baffle width has to decrease rapidly. Baffle width has to be quartered with each change to the next driver. By the way: The efficiency of this arrangement is the same as for the same drivers mounted on an infinite baffle. There is no efficiency loss to speak of.

Fig. 3.7-3.10 demonstrated how at larger angles off axis, the dipole peak moves lower in frequency. Also the second dipole peak becomes noticeable, if the baffle is much wider than the cone.

That's why the combined frequency responses of the three baffle ranges at 30° doesn`t merge as well together as at 0°:

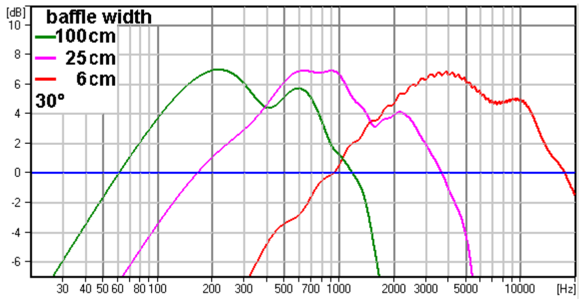

Fig. 3.15

The listening angle should be within 15° of the dipole axis. Another insight: with crossovers at 400 Hz and 2 kHz, this 3-way concept is fully used and cannot be taken any further.

Some more recommendations for open baffles

1. Don`t design or equalize a loudspeaker for flat response on-axis; and don‘t listen on-axis. If designed for linearity at 10-15 (or even more) degrees off axis, the response should harmonize much better with other angles.

   By the way: If in The Edge you choose the “Mic distance” as 4 m, and place the microphone 1 m sideways from the sound source it will be about 15° off-axis.

2. In comparison to its surrounding baffle, a driver should not look like a “point” source. The baffle should be no wider than three times the cone diameter. If this is not possible, the driver should at least be moved close to one baffle edge. This will help harmonize the response in the direction of that “shorter” side. Let`s look at an example with a 12 cm cone on a 50 cm wide baffle. First with the driver mounted centrally:

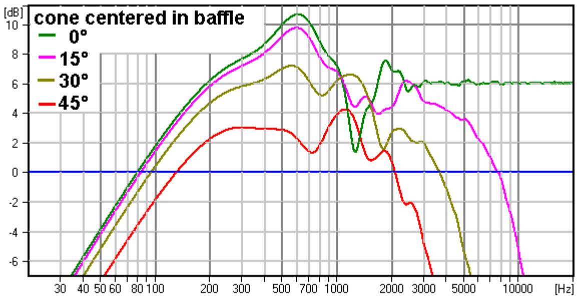

Fig. 3.16

The result is a series of off-axis response curves, which diverge over central parts of the frequency range.

By moving the cone 15 cm to the right, the response curves harmonize much better to this “short” side. Over the range 200-2000 Hz, there is almost no need for correction:

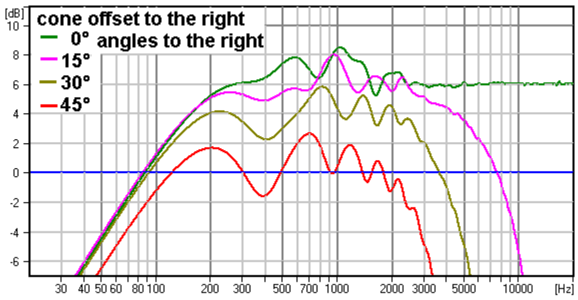

Fig. 3.17

The frequency response to the “long” side looks ok up to 1000 Hz, but would certainly need more equalization than on the “short” side:

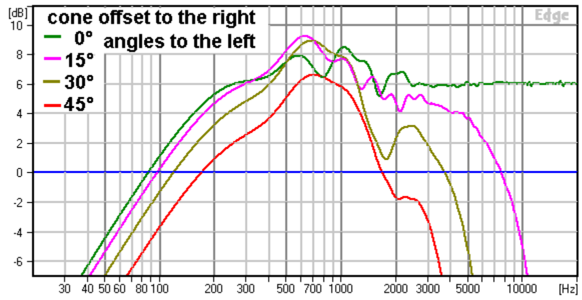

Fig. 3.18

At any rate there will be a “good” and a “bad” side, which has to be accounted for when designing such a loudspeaker or placing it in the room.

4 Dipoles with Constant Directivity (CD)

Open baffles cover a certain frequency range where the off-axis sound pressure is similar to the on-axis SPL, but on a lower level. The off-axis SPL drops proportionally to the rising off-axis angle. This constant directivity (CD) reaches from the lowest frequencies up to below the first dipole peak (D/ λ = 0.5). Or to be exact, up to D/ λ = 0.25.

CD has two advantages:

First the indirect sound, which is radiated to the sides, will have the same frequency character as the direct sound. This is perceived as most balanced and satisfying.

Second the early reflections, especially those from the nearest room wall, arrive at the listener at a lower level and with a more congruent frequency spectrum than from a loudspeaker without constant directivity.

These are good reasons indeed to use the constant directivity of dipoles over as wide a range as possible.

4.1 A theoretical example

The acoustically most balanced area of a dipole's response is located completely within the dipole loss region. That means it has to be equalized over its complete range. The following example will show how a constant directivity dipole can be achieved. We assume a 3-way dipole with a total EQ of 12 dB for every driver. That is demanding but viable.

Chapter 3.2 showed how for any given driver, the first dipole peak will be highest in frequency when the baffle is as small as possible. This leads us to discard any baffle, and mount the driver in free space. With this in mind our circular baffle is just the loudspeaker basket outside the surround.

Let's start with the midrange:

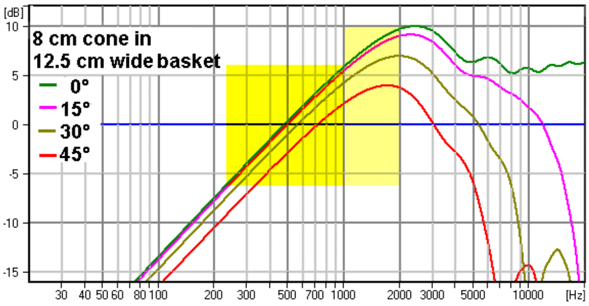

Fig. 4.1

In the 250-1000 Hz yellow area, we linearize the dipole loss over two octaves with 12 dB boost at the lower end, or 12 dB attenuation at the upper end.

Also we equalize the lower shoulder of the dipole peak (the light yellow area). This way we can use the midrange driver over three octaves - from 250 Hz to 2 kHz.

For the region below 250 Hz, we look for a driver size which is still in the CD zone at 300 Hz. This could be a very big driver. Even a driver of 53 cm diameter has its first dipole peak not before 500 Hz. For our example we will stay with a cone diameter of 25 cm:

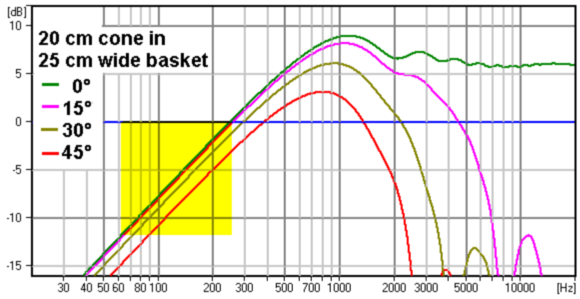

Fig. 4.2

With 12 dB EQ we can linearize the two octaves 60-250 Hz.

Lastly the tweeter:

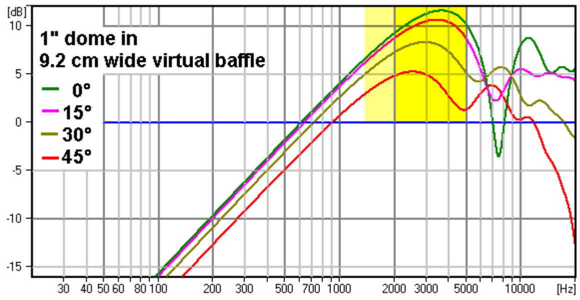

Fig. 4.3

Here we get into trouble. We assume a pair of 2.5 cm neodymium dome tweeters, mounted back-to-back with a total front to back distance of only 3 cm. Even this tiny construction leads to a dipole length of D = 4.6 cm (similar to. Fig. 3.6, front). The baffle diameter is calculated as twice the dipole length, making it 9.2 cm.

This comparatively large baffle size leads to the response above 5 kHz that is not satisfactory.

To this day no dipole tweeter exists with a dipole length of less than 4 cm. As a consequence, all dipole tweeters have to be used at their first dipole peak and beyond. In this example, the best way to minimize this non optimal behavior would probably be to linearize the 30° response in the yellow area, and to listen at least 15° off axis.

4.2 Practical examples

Lately in diy audio there have been examples of dipole loudspeakers without baffles, and dipoles with a second rearward tweeter. Things can be learned from them.

NOBBI from Klang + Ton magazine April/Mai 2010

Under the name of “NOBBI” the German loudspeaker diy magazine Klang + Ton published a “proof of concept” for a no baffle 3-way loudspeaker (with Visaton drivers):

Fig. 4.4

No measurements were published for NOBBI, but the article featured a building plan and a description of the active crossovers and filters used. This allowed a simulation in Boxsim, showing the off-axis response at 30° and 60°. Fig. 4.5 presents the frequency response simulation with a dipole tweeter of minimal dipole length, which is highly theoretical, as we have just learned. But it helps to get a better picture of what such a dipole tries to achieve:

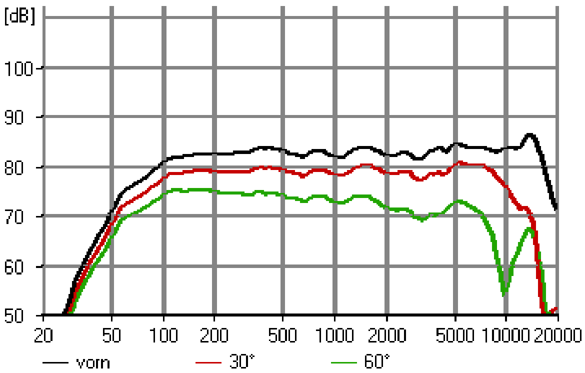

Fig. 4.5

The next diagram illustrates the responses with crossovers:

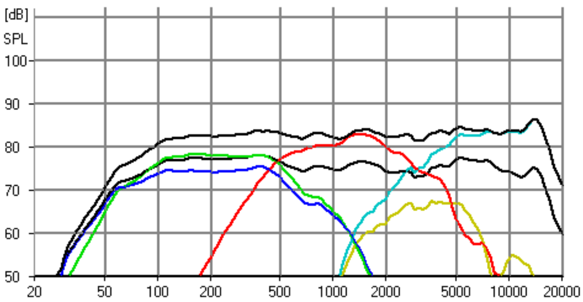

Fig. 4.6

The lower black line represents the power response, which is the complete energy radiated into the room - summed horizontal and vertical over 360°. It is very consistent with the response on-axis.

Next we model NOBBI with a realistic tweeter dipole length. At the 3000 Hz crossover from the midrange, the dipole tweeters just start to lose their constant directivity. Above 5 kHz the larger dipole length doesn’t make much difference, because the tweeters are increasingly beaming:

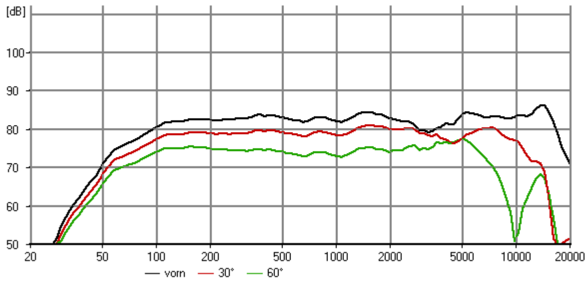

Fig. 4.7

Lastly the same drivers with the same distances between drivers, but mounted on a single baffle of 40 cm width:

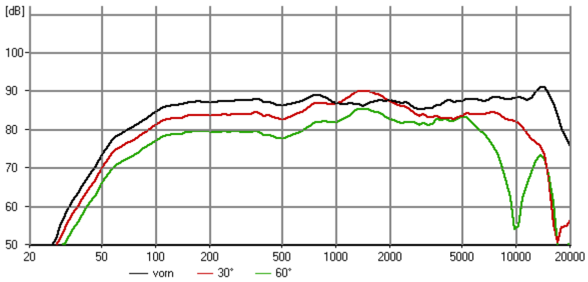

Fig. 4.8

It is apparent that below 500 Hz the wide baffle doesn‘t hurt at all. On the contrary: without a baffle the woofers just waist efficiency.

Between 500 Hz and 2000 Hz the midrange driver performs better without a baffle.

Over 2-5 kHz the difference is debatable - no clear winner. Above 5 kHz there is again hardly a difference to Fig. 4.7 - the beaming tweeters no longer care about baffle width.

Learning from Linkwitz

We all have at least heard about the ORION loudspeaker by S. Linkwitz (www.linkwitzlab.com/orion_challenge.htm). What happens to the radiation pattern of such a loudspeaker, if a rear facing dipole tweeter is installed (as in the ORION+) or if we reduce the baffle size?

Since we are basically discussing the performance of the baffle and not of specific tweeters, let’s take the liberty to replace the SEAS Millennium by the Visaton tweeter KE25SC. The data of the KE25SC are available in Boxsim. I simulate it in the top part of the ORION’s baffle, without considering its lower region:

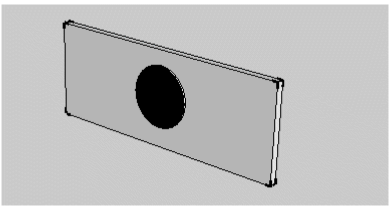

Fig. 4.9

Without any crossover components the **horizontal** frequency response looks like this:

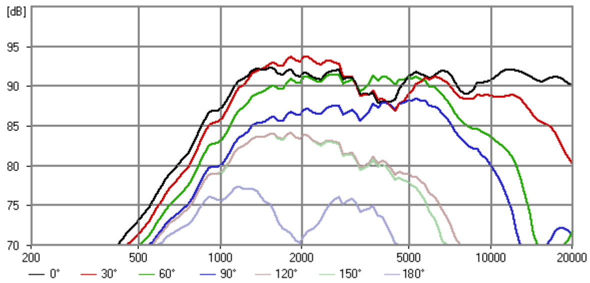

Fig. 4.10

The radiation pattern starts with some mild forward directivity, and develops sideways lobes at 4 kHz, while losing much of the backward radiation. From 5 kHz upward, beaming takes over.

The **vertical** radiation pattern looks much smoother - due to the assumed small baffle height:

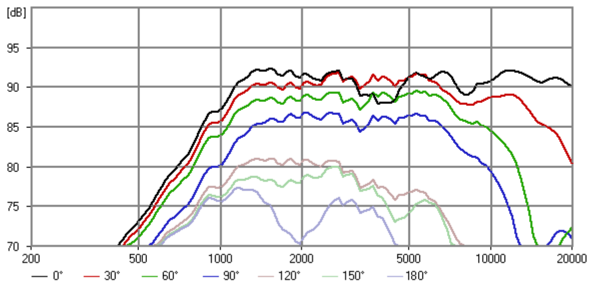

Fig. 4.11

Next we add a rearward tweeter similar to the dipole upgrade from ORION to ORION+:

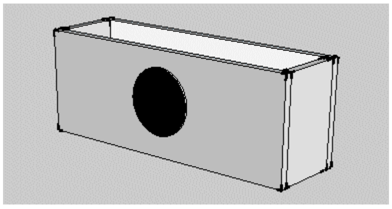

Fig. 4.12

In comparison to fig. 4.10, are there any advantages in the horizontal radiation?

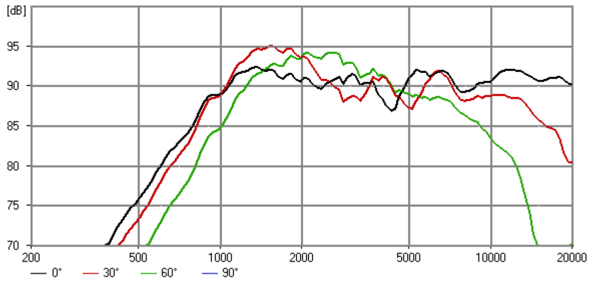

Fig. 4.13

In the ORION+ both tweeters work from 1440 Hz upward. That is completely above the baffle’s first dipole peak. As explained in chapter 3.2, we see a wide area of changing radiation patterns - resembling Fig. 4.10. But at least those undulations are confined to a range of a modest 6 dB. And radiation perpendicular to the dipole axis no longer occurs.

Also the vertical radiation pattern looks significantly more dipole-like:

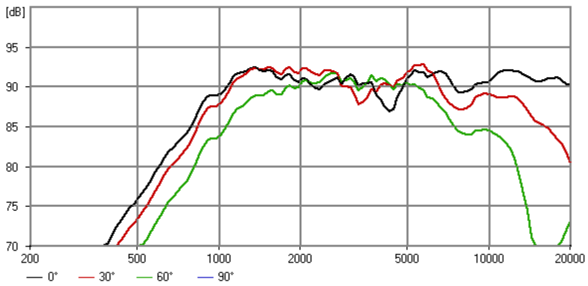

Fig. 4.14

So let’s get daring and reduce the baffle width to the same size as the baffle height, resulting in a frame of 15x15 cm, (with 6 cm depth):

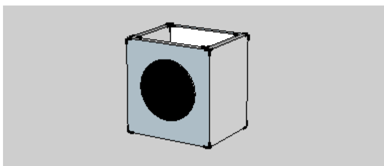

Fig. 4.15

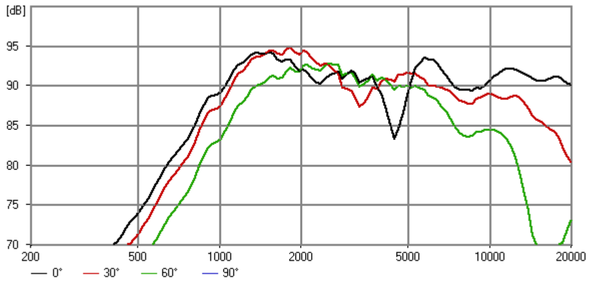

Fig. 4.16

On-axis response clearly has changed for the worse. What has happened? We were able to move the first dipole peak upward by reducing the baffle width, but now both drivers are centered on square baffles. The high degree of symmetry leads to response characteristics similar to those in chapter 2.2.

Reducing the baffle size again to just 6x8 cm, which is not even possible with our drivers, makes everything even worse:

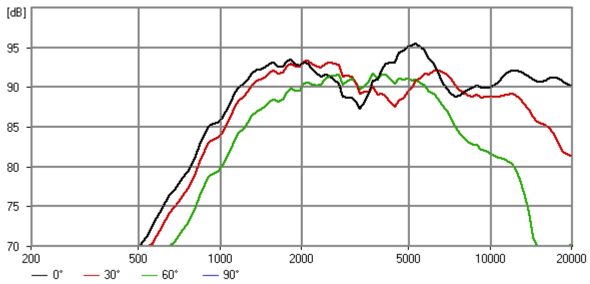

Fig. 4.17

Once again directivity improves - now up to 2000 Hz, but above that there are heavy changes in the radiation pattern.

Linkwitz did very well in keeping the rather large and deep SEAS tweeters on this wide baffle - not trying to achieve the most smooth directivity.

Only if the frame is reduced to eg 4 x 4 x 4 cm - which at present can only be done with the tiniest neodymium tweeters - can we achieve a well balanced frequency response. Constant directivity is extended to 3000 Hz. But let's not forget that we lose at the lower end of the frequency range the higher efficiency given by a wide baffle:

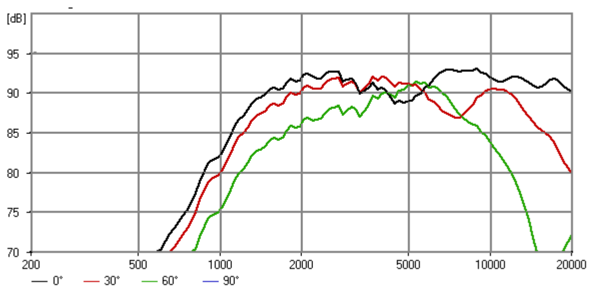

Fig. 4.18

5 Simulation and reality

The dipole simulations currently in use calculate with limited data sets. In the upper midrange and treble for instance, they don`t include the partial cone resonances or the complex situation between cone and basket at the back of the driver. What difference do these missing data make when comparing the simulation with real world measurements?

I measured a 3" fullrange driver Visaton FRS 8 in a 3 mm thick square baffle of 22 x 22 cm. The driver is mounted intentionally in the baffle center to clearly show the first dipole dip. The gating of the measurement produces a high pass below 1 kHz. SPL is not calibrated. We first look at the frequency response in the front hemisphere at 15° intervals:

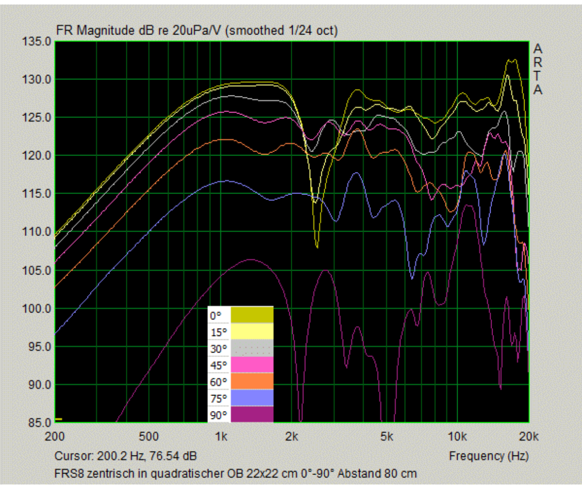

Fig. 5.1

Up to ca. 5 kHz the measured response follows the simulated expectations - halfway between fig. 3.10 and 3.11. Note how the FRS 8 is employed well below its capabilities in such a big baffle. As a dipole it only starts beaming at 5-6 kHz. Up to that region the directivity is well controlled - excluding around the on-axis dip at 2.5 kHz.

What does the measurement of the rear response tell:

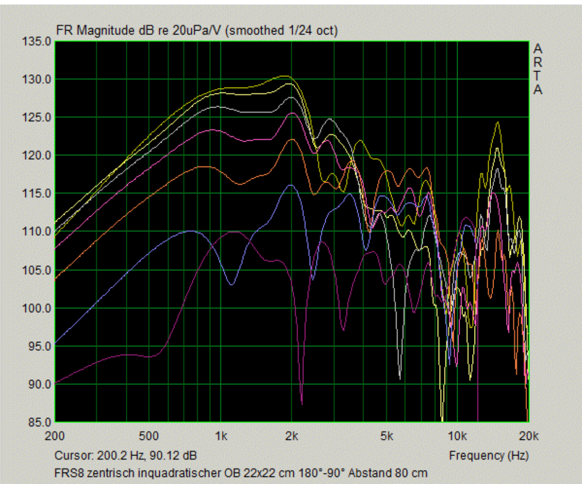

Fig. 5.2

The response is also fine up to 2 kHz. It does not deviate too much on the front side. But the rear of the dipole figure 8 collapses completely above 2.5 kHz. I don't have any explanation for the intermediate response rise at 15 kHz. This prevents the FRS 8 from being usable as a real dipole beyond 2 kHz – independent of its position on the baffle.

In comparison let's go to the simulations. The response curves are shown in black (0°), red (30°) and green (60°), Starting with Boxsim:

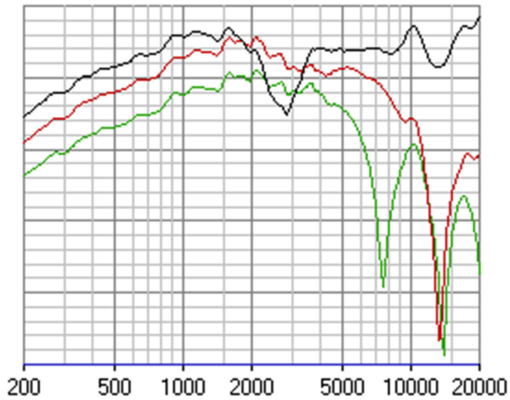

Fig. 5.3

The dipole worksheet of Martin J. King (www.quarter-wave.com) simulates response as:

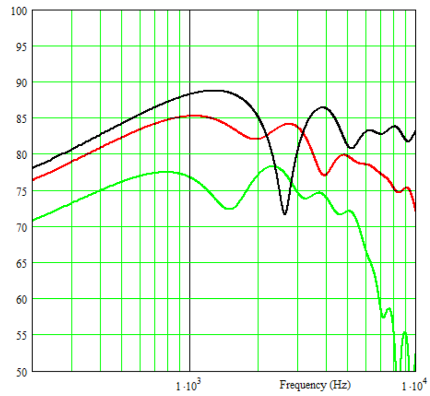

Fig. 5.4

Lastly The Edge :

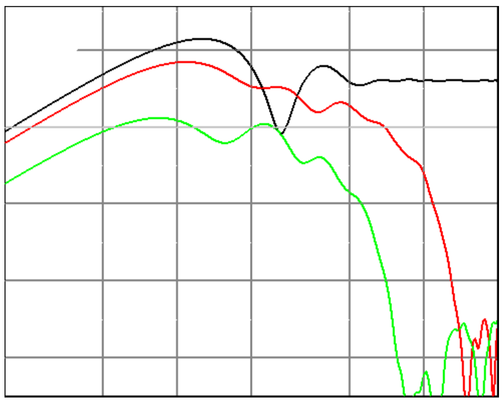

Fig. 5.5

The similarities are obvious: The response rises with 6 dB/oct to the dipole peak at about 1.5 kHz. The dipole dip is located on axis at 2.5 kHz, followed by increasing beaming beyond 5 kHz.

But when we look into the details we find clear differences between Boxsim on the one hand and MJK/Edge (which have much in common) on the other. Let us compare which simulation fits better with the measurement.

The simulated curve is shown in black (0°), red (30°) and green (60°). The measured response is dashed. This is Boxsim:

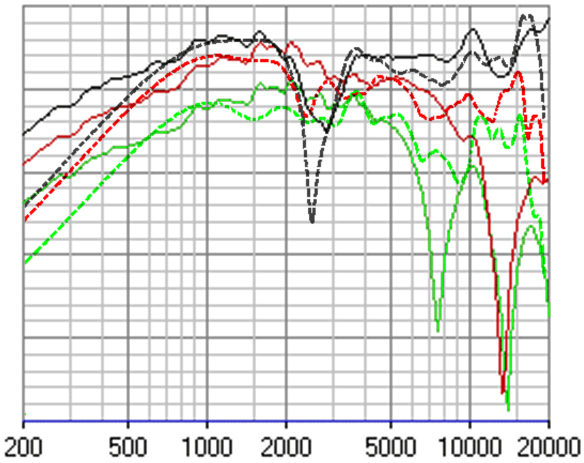

Abb.5.6 Comparison measurement (dashed) vs. Boxsim

In general there is good compliance of the off-axis levels up to 6 kHz, but we see quite some differences at 1.5-3 kHz. Above 6 kHz the correlation is lost almost completely.

And this is the MJK worksheet:

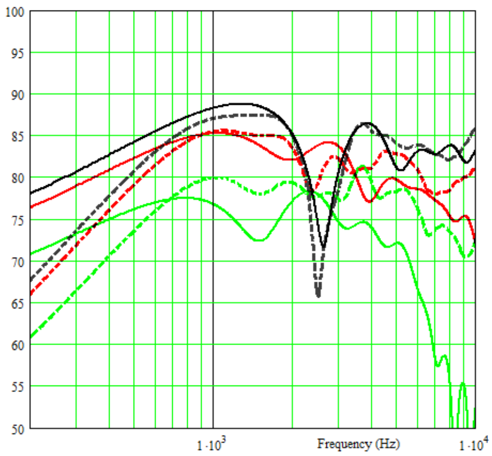

Fig.5.7 Comparison measurement (dashed) vs. MJK worksheet

The simulation of the dipole dip is exact, but we see the simulated 30° and 60° levels quite below their measured counterparts. The simulated response suggests more beaming of the dipole 8 than the measured response.

It goes without saying that none of the simulation programs allows for a separate rear response. They don't ignore it, but it is automatically assumed to be identical to the frontal one.