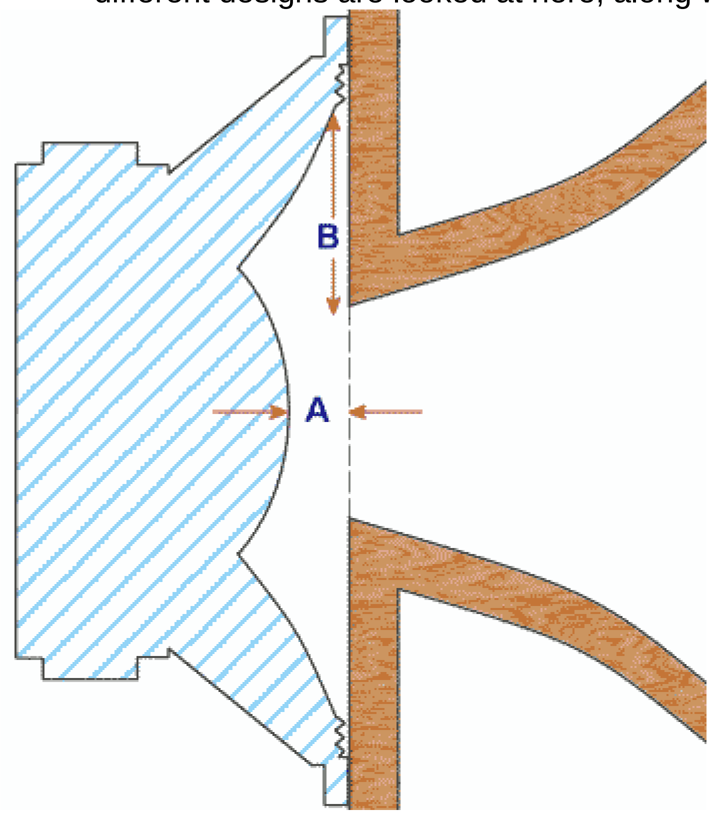
Mysteries of the Phase Plug

On this page I will attempt to de-mystify Phase Plugs as applied to horn loaded speakers (NOT the silly polished bullets sometimes seen on hi-fi speakers...)

Whilst phase plug design and constuction can be involved, it is certainly within reach of the DIYer and can provide worthwhile benefits to home constructed midrange horns. Some different designs are looked at here, along with ideas on how they can be made.



Why are Phase Plugs needed?

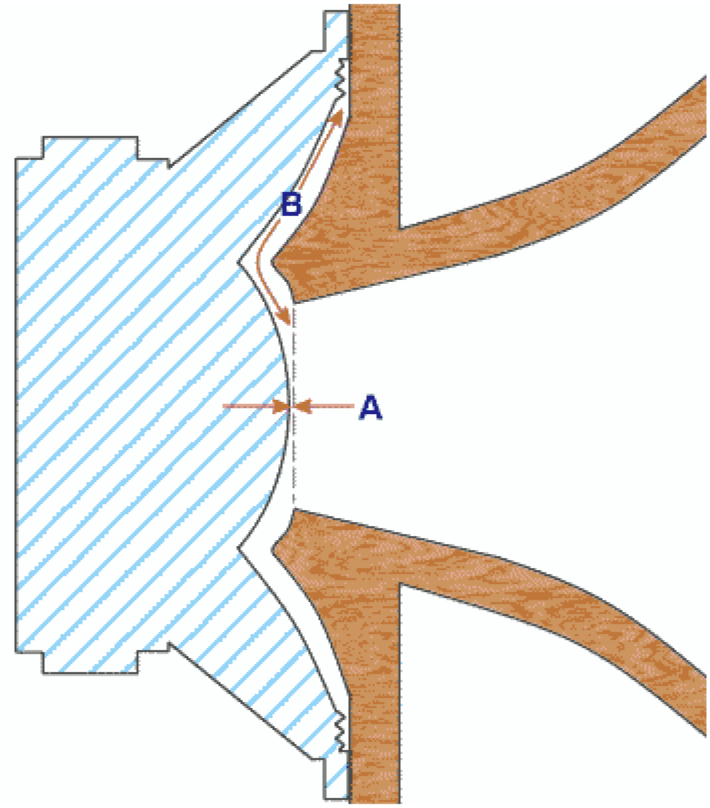
When designing a horn for a cone speaker, the throat area of the horn can have a significant impact on the high frequency efficiency of the horn. Generally, the smaller the throat area, the more the efficiency curve is pushed towards higher frequencies. However, in practice a throat area significantly smaller than speaker cone area can produce a severe reduction in high frequency output. The figure at right shows a cross-section through a speaker / horn combination with a round throat some 1/3 of cone area. Two major problems occur here:

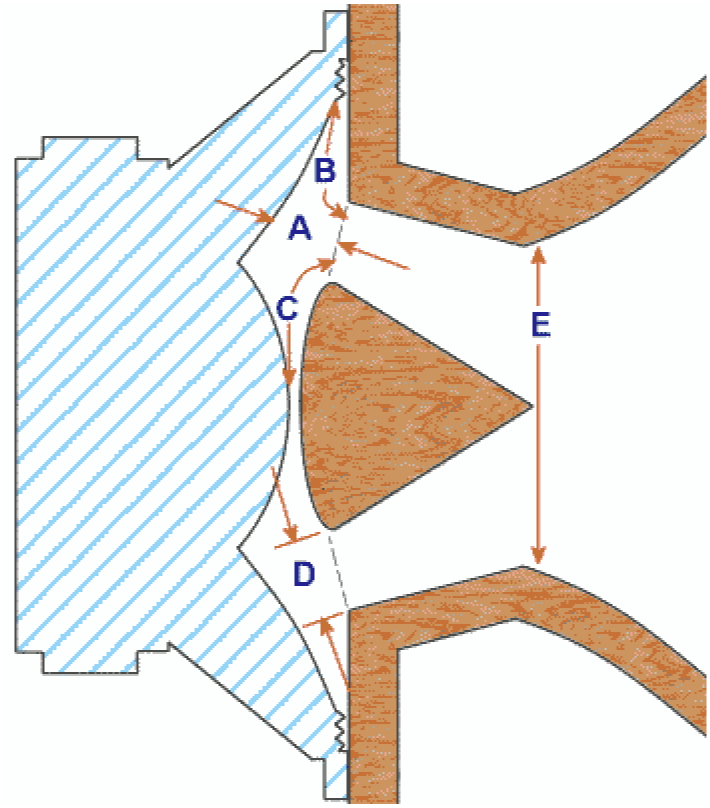
Firstly, the distance the sound has to travel from the dust cap at point A is considerably shorter than the distance from the cone edge at B. If the difference in these distances is 1/2 wavelength of any frequency, then severe cancellations will occur at that frequency. For example, consider a 12" speaker. The distance difference can easily be as much as 100mm, 1/2 wavelength of 1.72kHz.

Secondly, there is a considerable air space between the speaker cone and the horn throat (dotted line). This air volume acts as a low pass filter, attenuating high frequencies.

One method of reducing front chamber volume is to extend the horn throat closer to the speaker cone as shown in the second diagram. This has the obvious disadvantage of making the path length differential worse.

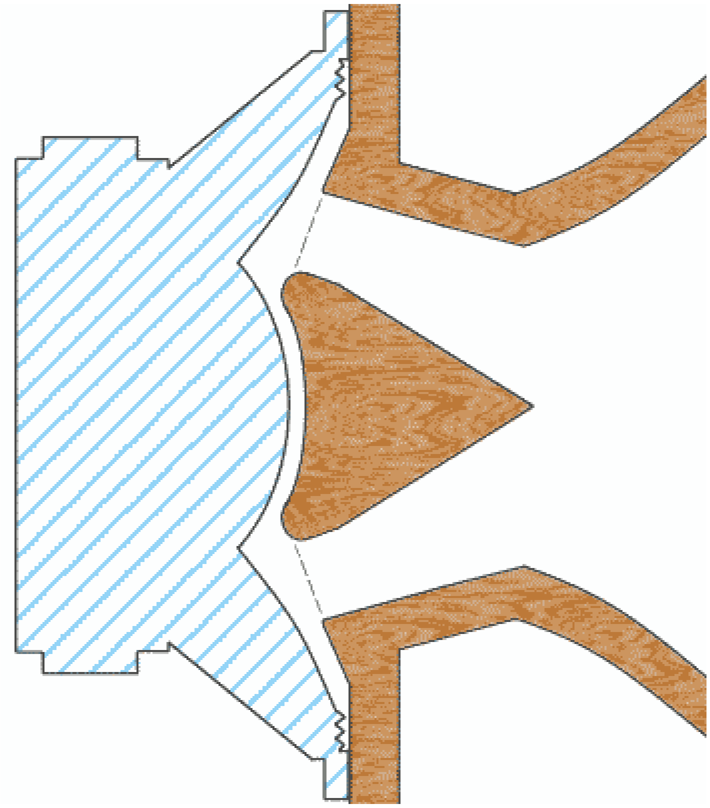
What is needed is a means of evenly distibuting a small throat area over the entire surface of the cone, and as close as possible to it. Whilst this is physically impossible, the phase plug provides a usable compromise to this goal, and has been employed in compression drivers for quite some time. There is some good info on this on the JBL web site and from the AES.





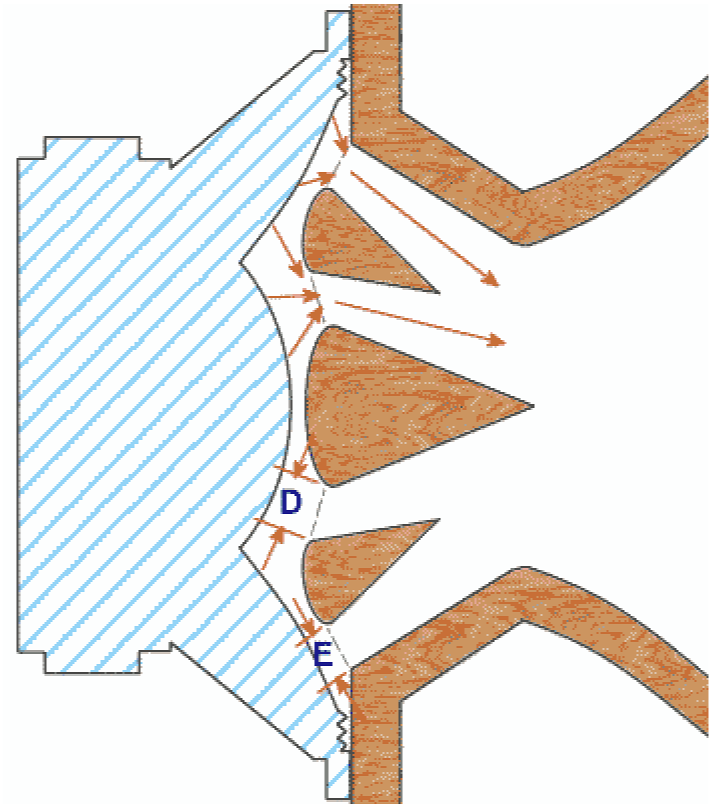
A simple Phase Plug

One of the simplest phase plug implementations involves increasing the baffle cutout diameter and suspending a conical shaped wooden (or other solid material) plug in the centre. It may be supported by thin timber legs or steel wire, as long as these supports don't impact on sound transmission or throat area. The throat is now a ring with width D, and area is baffle cutout area less plug area. Care should be taken to design the plug taper and baffle / horn angle to maintain the proper flare rate out to point E, which will be the normal flare area for that particular horn length. Note that distances A, B& C are now much closer to each other than in the previous diagrams. The front chamber volume is only slightly reduced here, and this type of plug is suited to applications where path length cancellations are more important than high frequency efficiency. I utilised this type of plug in my twin 8" design, and it allowed operation of an 8" speaker up to a crossover point of 2.5kHz.



A variation (type 2?)

If the rear of the above plug is contoured to follow the shape of the dustcap and a ring is added to the speaker side of the baffle, the throat can be effectively brought closer to the speaker cone, reducing front chamber volume. As noted above, the tradeoff is increased path length differential, and this method can be used where maximum efficiency is required right up to the point of onset of cancellations. This type gave excellent efficiency up to the crossover point of 1.5kHz in my 12" midrange box.



A bit more complex - type 3

For higher frequency operation, path length differences become more critical. To further distribute the throat area, the area can be split into two rings by inserting a teardrop shaped toroid between the centre plug and baffle cutout, as shown at left. The total throat area is now the sum of area of ring width D and area of ring width E. This approach both shortens path length differentials and reduces front chamber volume, however it is more difficult to design and build - but not impossible. Best approach here is to draw (by hand or via CAD) the actual speaker profile and scale the required throat area, juggling things until you are satisfied BEFORE trying to make it (this applies somewhat to the simpler types above as well). This type is common in compression drivers, although quite often up to 5 path rings are used. I used this type of plug in a 6" design detailed below, which gave good response to beyond 4kHz, as well as an experimental 12" version.

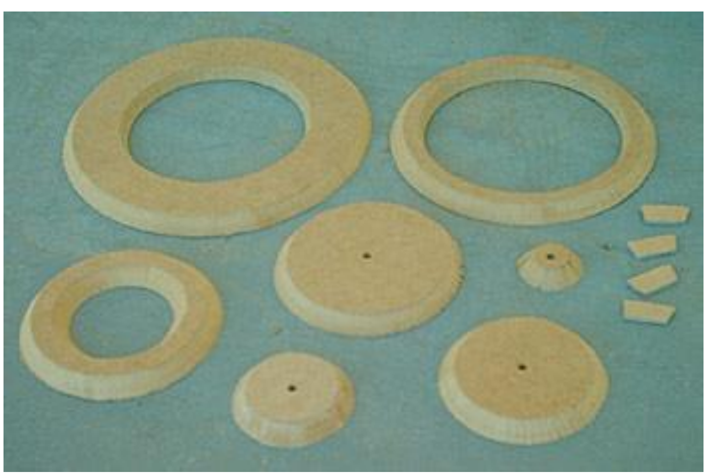
Practical construction

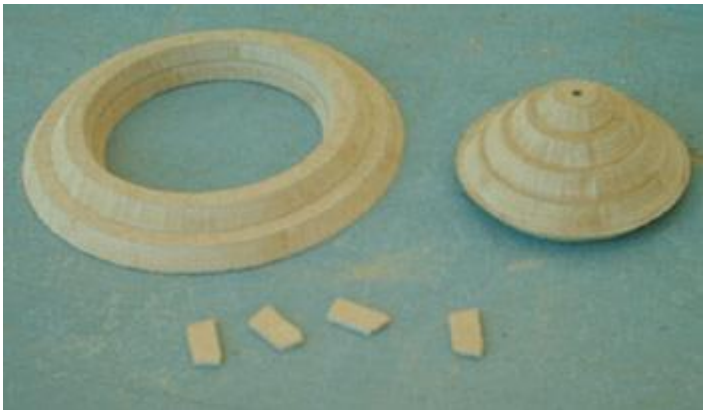
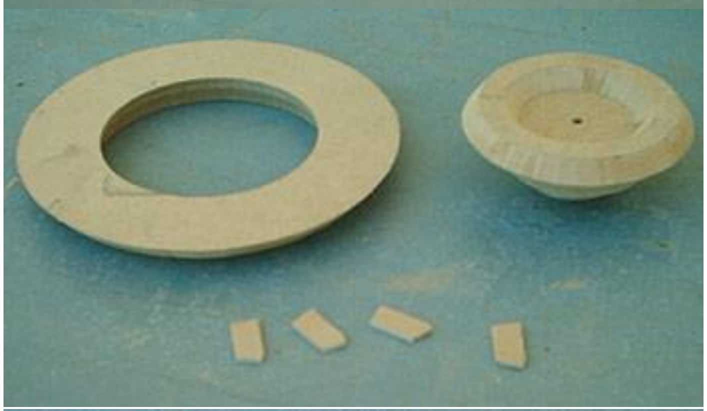
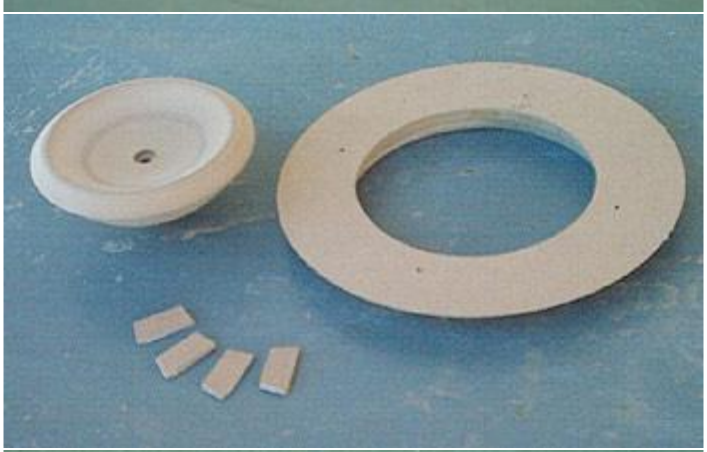
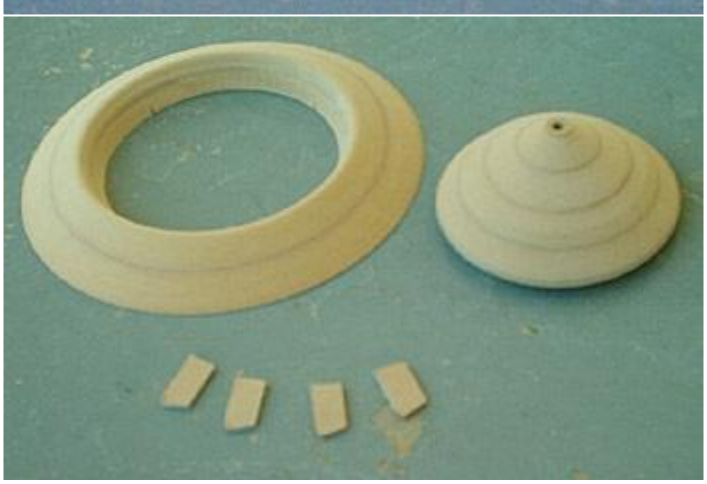
These plugs aren't too difficult to make with the right tools. One thing you will need is a lathe - it doesn't have to be an expensive one, and you can even make one yourself utilising your electric drill - see the tools section on my main DIY page for details! (all of the examples shown below were turned on this).

The construction method I use is to cut circles or rings from MDF, stack and glue them together, and then machine them to shape. The stacks are mounted on a 1/4" threaded rod which runs chuck to chuck in my DIY lathe, or in the case of rings, temporarily screwed to a backing plate. Photos below will make this clearer.

Simple type 1

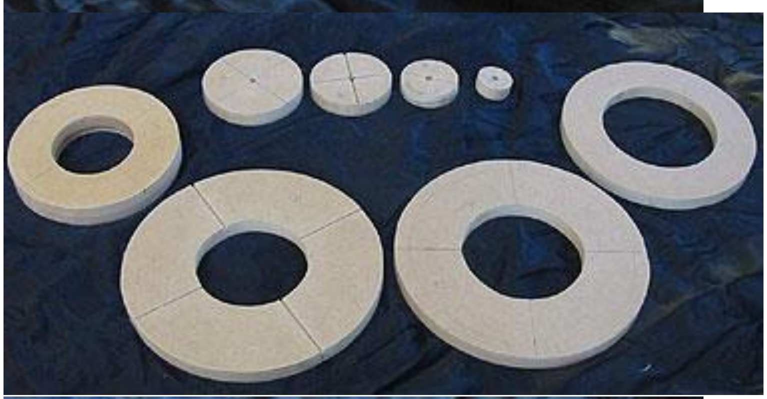
This was used in my twin 8" box, and plug size is 62mm dia x 44mm long. Using a hole saw, I cut 4 discs from 12mm MDF : 2x 62mm dia, 1x 44mm dia, and 1x 18mm dia as shown in photo below left. These were then glued together (centre photo), then machined to shape (right photo). The central hole was then plugged with 1/4" dowel. No supports were designed into this plug, as it was glued to a central flare divider. For mounting options, see others below.



Simple type 2

This is the plug used in my 12" mid/high box. As with the plug above, construction started with a collection of discs and, in this case, rings as well, as shown at left. These were glued together to form the plug and outer ring, front view below left, rear view below right. After machining, the profiles can be seen in the next photos. The assemled plugs are shown at the bottom. With this assembly, I used small pieces of MDF to support the centre plug.



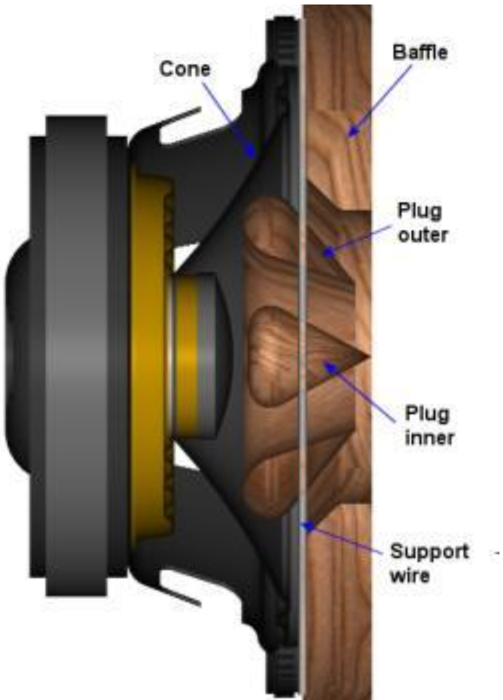



Type 3 - 12" version

This was an experiment to get more top end from my 12" box. It did achieve an improvement, but not enough to warrant its use.

Note the slots cut in some of the parts - these formed holes through the parts after assembly, and facilitated mounting by steel wires as shown below.

View of the plug assembly mounted in the box - the 12" speaker mounts down over top of this. The top path is clearly visible around the centre plug, the other path is between the ring and baffle plate.


Cone
Baffle
Plug
outer
Plug
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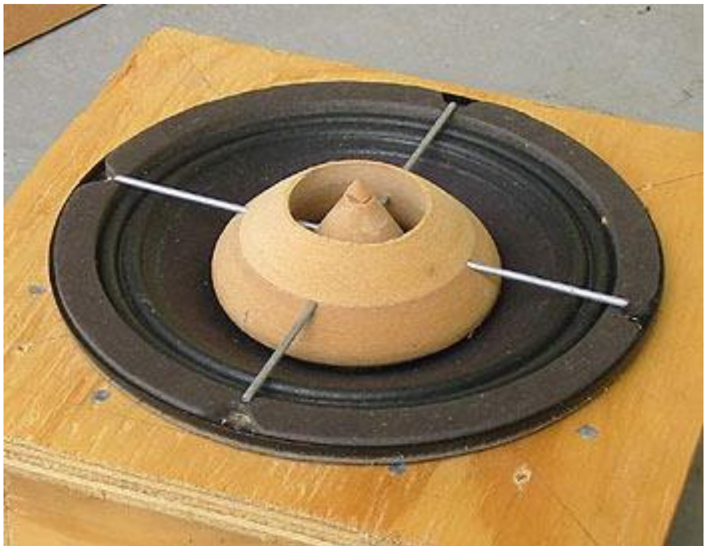
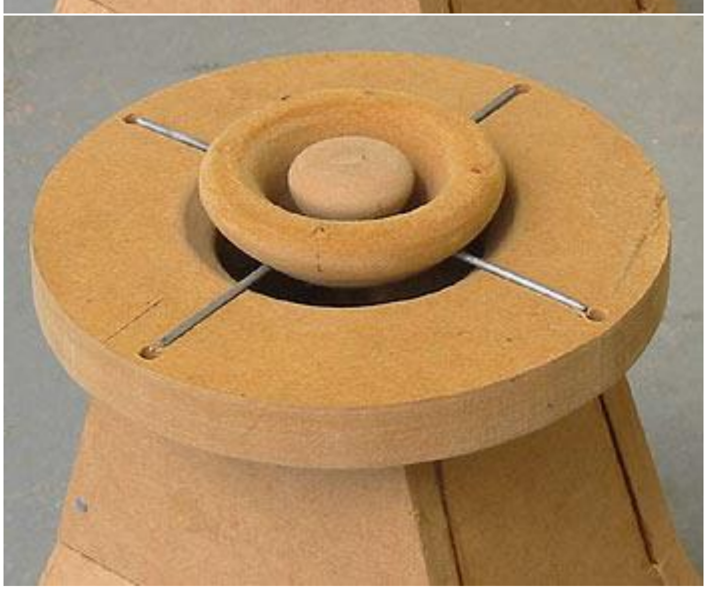
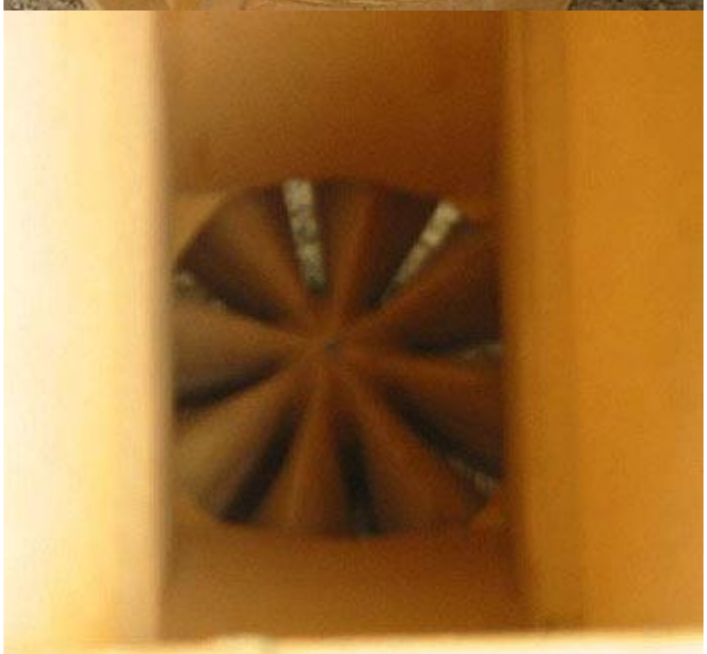
Support
wire







Type 3 - 6" version

Oops, forgot to take pics of the components before building, however construction pretty much the same as 12" version above - just smaller and more fiddly.

At left is an Autocad render of section through plug and Eminence Alpha 6 speaker - the paths can be clearly seen. Centre plug is 25mm dia x 31mm long, made with 2 disks of 16mm MDF 25mm dia & 17mm dia. Outer toroid is 80mm dia outside, 36mm dia inside x 27mm deep, made with two MDF rings 80mm OD, 36mm ID x 16mm thick & 65mm OD, 36mm ID x 12mm thick. The assembled view is shown below left, while below right shows how close the plug sits to the Eminence cone.

Below this is shown the treatment of the baffle - 72mm dia hole chamfered 45 degrees to a depth of 9mm. Note the support wire retention slots.
View down the throat of an experimental straight exponential flare. In this configuration

response extends past 4kHz, and suits situations where limited beamwidth is acceptable (eg small rooms, home hi-fi etc)

For my application, I wanted wide horizontal dispersion which means transforming the flare to a narrow vertical slot. However, the steep transition from 72mm hole to 250mm high slot resulted in other cancellations below my target 3.5kHz crossover point. I am therefore working on a different throat approach, meaning this plug will not be utilised further (unless I make up some home stereo horns).

Other plug types - Radial Slot

Another type of plug is the Radial Slot type, sometimes seen in piezo tweeters, but not commonly used. EAW use a variation in some of their boxes, but don't run them to a high crossover frequency - see link.

Here is shown an experimental version I tried for an 8" speaker - extremely difficult and time consuming to make (and to visualise while designing it), and it gave absolutely no benefit over the simple type ultimately chosen. I include it here as an interesting oddity, and suggest no-one try it.

Below left is the back (speaker side) of the plug in its baffle - it is easy to see where the name radial slot came from. Directly below is a view down the throat - sorry about fuzzy pic.