Subject: Question for Wayne
Posted by DFaulds on Mon, 30 Apr 2001 11:39:11 GMT
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I've been watching the postings and looking at your web site now for several weeks. Must say that I am very interested in your horn loaded speakers, and I'd like to know more about them. I'm somewhat familiar with folded horns, having owned some vintage EV Centurians, as well as spending quite a bit of time with a friends K-horns and another friends EV Georgians. I'm interested in your speakers, but since I can't audition them first, I would like to better understand the engineering in the design before I invest the money.Thanks.

Subject: Pi horn design philosophies
Posted by Wayne Parham on Tue, 01 May 2001 03:46:15 GMT
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Pi Speakers are best described as high-efficiency, controlled directivity loudspeakers. They've always used high-efficiency drivers like those from Eminence and JBL. They evolved from my early designs concentrating mostly on flat amplitude response to having more controlled directivity and consistent response within the intended coverage angle.My earliest speakers were simple bass-reflex cabinets with direct radiators, two-way for small systems and three-way for larger ones. I put most of my attention on finding cabinet alignments that gave smooth bass response, and designing crossovers that worked well on-axis. The cornerhorn was an attempt to use the room corner as an advantage, much like Klipschorns do. But I wanted a speaker that was simpler, both because it is easier to build but also because I didn't like the sound of midrange going through the basshorn like it does in the Klipsch design.The cornerhorn quickly evolved into a uniform directivity experiment. I noticed right away that the Pi cornerhorn did something special, even when loaded with only direct radiators. I built them in several varieties, always with a rear-facing woofer but some with mid and tweeter in front, some with mids and tweeters in front and back, others with mids in front and back but tweeters in front only. I also experimented with different driver sizes. What I learned was that the cornerhorn speaker could be made to produce a wide, smooth sound field with the right combination of position and sizes of drivers. As I continued to study and experiment, I came to the conclusion that what it was doing that was so special was to provide a uniform reverberent field.
Getting a uniform reverberent field requires having flat power respsonse. The total sound output on all axis be equal in amplitude. It doesn't have to be omnidirectional, in fact, it is better that it is not. Omnidirectional sound sources suffer from early reflection interference problems. The best speaker is one that combines controlled directivity with uniform polar response. It directs the sound towards the listeners within the room, rather than bouncing sound off the walls, floor and ceiling. The sound in any direction has uniform spectral balance, although the volume level within the pattern is much louder than at the edge of the pattern, and outside the pattern it should not be loud at all. This is the goal.The Pi cornerhorn tended to naturally obtain much of this goal, because sound is constrained by the walls, even when driven by direct radiators. The angular coverage of a direct radiator is very wide at frequencies where it is acoustically small, and it narrows only at high frequencies when it becomes large with respect to wavelength. So a uniform

reverberent field is practically ensured. However, early reflections are also ensured ffrom direct radiators so more directional sound sources at medium and high frequencies is a better solution.As I realized the importance of directivity and I started using constant directivity horns exclusively. I chose a 90x40 flare because it roughly matched the wall angle of the cornerhorns, and because it was a useful angle for room coverage from a stereo pair of speakers. I also began to build what I call DI-matched two-ways, which use a large midwoofer up to the point where its directivity collapses to match that of the tweeter.There are a couple of challenges that face the designer of a constant directivity speaker with compression horns. One is compensating for the power response of the drivers. The other is proper summing between adjacent sound sources through the crossover region through the arc of the desired coverage angle.Dealing with the problem of power response compensation, the idea is to identify the power response and provide electrical EQ that is the conjugate of that. If directivity is constant, then the amplitude response anywhere in the pattern is the same as the plane wave tube of the compression driver. What the crossover needs to do is provide a conjugate of the driver's power response. In other words, it must provide electrical EQ for the driver.A 1" exit compression driver is generally flat to 3kHz or 4kHz or so, and then falls off at 6dB/octave, except in cases where diaphragm breakup creates peaks and notches along this general trend. The conjugate filter, then, is a shelf of flat response, followed by 6dB/octave augmentation above 4kHz or so. This is fairly easy to do with passive RLC networks, and is done very nicely in the Pi crossover.Getting proper summing is a matter of finding the angles where path length differences will cause anti-phase cancellation, and limiting the radiation pattern to angles smaller than that. If two sound sources are stacked vertically, then movement along the horizontal plane doesn't change the difference in distances between the listener and the sound sources. So as long as summing is in-phase on the forward axis, it will be off-axis in the horizontal plane up to relatively wide angles.But movement along the vertical plane changes the distance between the sound sources and the listener, delaying the more distant driver by a small amount. At frequencies and positions where the delay represents a 180 degree shift, nulls appear in the polar response.No loudspeaker system with more than one driver on a baffle can have the two sound sources in phase at all locations and at all frequencies. Somewhere, there is going to be destructive interference. But the idea is to place your anti-phase nulls outside the coverage angle. A clever designer makes it impossible for nulls to form within the wall angle of his horn, or at least uses them to abbreviate the cutoff at the edge of the pattern.That's why I like using asymmetrical horn flares with 90x40 degree patterns. The relatively wide horizontal angle provides a large coverage area. The 90 degree angle works out well for another reason, it matches the narrowing directivity of a large-format midwoofer at around 1.2kHz to 1.6kHz. And the narrow vertical angle matches the null angle from vertical spacing of the drivers. If you space everything right, the nulls form just outside the vertical coverage angle of the tweeter horn. In the crossover region, the nulls set the edge of the vertical pattern and at higher frequencies, the tweeter horn's wall angle maintains the relatively tight vertical control. Axisymmetrical horns won't do this, instead, the vertical pattern will widen back up above the crossover band.

Subject: Re: Pi horn design philosophies
Posted by DFaulds on Tue, 01 May 2001 11:50:49 GMT
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Wayne, thanks for a great response.

Subject: Re: Pi horn design philosophies
Posted by specopsda on Tue, 01 May 2001 16:09:50 GMT
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Great post. I have a related question. There are many different kinds of CD horns. Some like Biradials and Mantarays have a slot in the throat. Others don't. Some CD horns have two sections, the outer one with a wider angle than the inner one. How is that CD? Why are there so many seemingly completely different approaches for making CD horns?

Subject: Re: Pi horn design philosophies
Posted by Wayne Parham on Tue, 01 May 2001 23:01:18 GMT
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There are a handful of horn features that determine the way a horn behaves. This is a list of a few of them, the main ones:1. Flare shape sets the acoustic loading as a function of frequency. Some shapes (exponential, for example) load low frequencies better than high. So they will modify the power response according to the acoustic load impedance.2. A similar issue, reflections from abrupt transitions within the horn cause standing wave nodes to form, changing the acoustic impedance and modifying power response.3. Acoustic filter chambers and other acoustic devices are sometimes added to modify the response. An expansion chamber in the throat forms a low-pass filter. While not usually seen in tweeters, they're common in basshorns. For that matter, rear chamber size modifies diaphragm resonance and can be set to cancel the first reactive peak of a standing wave node in a truncated horn.Each of these will manifest themselves with changes in amplitude response compared to a plane wave tube (or CD) measurement, and they will show up off-axis as well as on-axis.The following additional features modify horn directivity, and show up mostly as differences off-axis compared with the forward axis:4. Phase plugs are used to reduce path length differences between the diaphragm and the throat entrance. It extends high frequency response by improving the coherency of the wavefront entering the throat. However, since its job is to match the shape of the diaphragm to the shape of the horn entrance, each horn should have its own phase plug. Since the phase plug is an integral part of the compression driver, some drivers are better suited to a particular horn than others.5. Diffraction slots are sometimes used to make the source orifice smaller, increasing the frequency before throat beaming sets in. However, this causes off-axis astigmatism because the apparent source location is the diffraction edge. On axis, the source location is the phase plug but off-axis, it is the diffraction edge.6. Horns with deeply curved side walls (like exponential and tractrix) have collapsing directivity throughout the passband. As frequency rises, the coverage angle narrows. This creates acoustic EQ on-axis, because as frequency rises, the sound becomes more and more focused, increasing HF amplitude on-axis at the expense of reduced output off-axis.7. Horns with straight walls have constant directivity. The wall angle sets the pattern, down to the frequency where the mouth dimensions cause it to act as a diffraction slot. The sound coming from the compression driver is roughly planar (because of the phase plug) so the throat angle is usually radiused to gradually match the flare angle or it is formed with an initial diffraction slot to widen the pattern at high frequency.8. At low frequency, the mouth acts as a diffraction slot, widening the pattern. This is the point where the horn is said to lose pattern control. If the horn is round, it will widen at all angles at some frequency determined by its diameter. If the mouth is square, then it will lose pattern control in the vertical plane and the horizontal plane at the same frequency, but the diagonal distance is greater, so pattern control is slightly different on the diagonals. If the mouth is asymmetrical, then pattern control is lost at a higher frequency along the narrow axis before the wider one. So at low frequency, a horn with a wide mouth will lose control in the vertical before losing control in the horizontal plane.9. Just before the pattern widens, over a narrow range of frequencies above the frequency where pattern control is lost, it narrows. So for a horn with 60 degree pattern, for example, it will narrow to 45 or 50 degrees briefly at the low end just before it widens up as it loses pattern control. Some CD horns are slightly curved or have a final flare section at a slightly greater angle. This serves to keep the pattern more constant at the low range just before the pattern widens.10. Asymmetrical horns provide angular coverage that matches their wall angle at high frequency. At low frequency, the narrow dimension loses directivity control first. So there is a range of low frequencies where the narrow dimension has lost control and has a wide pattern. In this range, the horn is said to pattern-flip.In any of the above mentioned cases where directivity changes becomming narrower for whatever reason, it will be accompanied by increased output on-axis and within the coverage pattern. Narrowed directivity is beaming, a focusing of the sound in a tighter pattern, so it is louder in that area at the expense of reduced sound off-axis. Likewise, any condition that causes directivity to widen spreads the sound out more, distributing the acoustic energy over a larger area, and decreasing the on-axis sound pressure level.

Subject: Re: Pi horn design philosophies
Posted by specopsda on Wed, 02 May 2001 15:47:14 GMT
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Thanks for taking the time to reply. It makes sense now! You are more than generous with your time, and I really appreciate that. I still owe you big-time for the high frequency compensation circuit.
