filter techniques. I'm sure there are other good ones out there too, but I wrote this one specifically to be reasonably readable, to illustrate issues with graphs, and to show the schematics of the circuits involved. It shows first, second and third order networks, and pays particular attention to phase. As you know, phase is another way of saying "delay."The moral of the story: Phase changes in a crossover as a function of frequency. Since phase moves, so does the amount of delay between subsystems. While the idealized first order low pass has a fixed rate, this is a specialized condition that is not found in the tweeter circuit. And it also requires the load be resistive, and that is not the case with speakers with voice coils. Even damped, the speaker is not anywhere close.But let's look at it anyway, just to make things clear.Phase response of idealized first order networkThe graph shown above is the phase response of an idealized first order crossover for a two-way system having a crossover at 1600Hz. This means that the components chosen have pure capacitance for the tweeter circuit and pure inductance for the woofer circuit. It also means that the speaker motors are perfect resistor loads. In this idealized model scenareo, we find that the woofer is shifted 1" further away from us through the points of interest.But the problem is that the tweeter just won't behave. As we draw nearer to the asymptote, the apparent sound source position shifts. As we go further into the passband, the tweeter's apparent position moves. So you can delay the perfectly resistive woofer by a perfectly fixed amount. But you can't do this for the tweeter. As phase moves, so does the offset.Now let's look at the real world. Here's what the phase looks like when a voice-coil woofer and compression horn tweeter are used:Phase response of actual first order networkOuch! That one's "all over the map."The components used in this case are the Eminence Delta 15 and the PSD2002 tweeter on the H290 horn flare. And really, those are more "well behaved" than many because voice coil inductance is unusually low. So all in all, this is typical of what should be expected of two-way speakers having a compression horn and a woofer.The reactance of the tweeter makes a peaky phase curve, and the voice coil inductance of the woofer tends to make the crossover coil act more like a wide-band voltage divider than a frequency splitter. Some don't expect this interaction, and so their crossover filters don't work as they intend and response suffers. But you can also use this behavior to your advantage, as long as you know that it's there. The point is that interaction between driver and crossover reactances alters the frequency and the phase characteristics of an "idealized" network.No passive network - high order or low order - can make a speaker "time aligned" with any baffle offset. This is true of a specific point in space on axis, where all driver diaphragms are fixed in their distance relationship to the listener. So you can imagine what happens when you move in 3D space off axis, where path length changes and one driver is made further from the listener than the other. As movement is made relative to one driver or the other and the listener, we move these offsets around even more.That's why I sometimes bristle when I hear discussions of baffle offsets or fixed delays to create "time alignment." I much prefer to talk about constructive summing, because that is something we can work with.Now then, what good is this information, you might ask. Does this mean there is no hope, no way to provide good sound anywhere except at a single pinpoint "sweet spot" location?When you calculate out all the phase angles, driver positions and arrival delays what you find is that summing becomes destructive at set angles. If you position the drivers so that they sum constructively at the crossoer frequency on the forward axis, then the phase of the crossover and the delay from driver positions make the sound arrive in-phase on the forward axis. This will be the case at frequencies very near the crossover frequency. Naturally, the point of phase-zero constructive summing will shift as a function of frequency, moving the forward axis up as freqency rises. The other thing that happens is there are two angles where nulls appear, one above the forward axis and the other below. The angles are determined by the distance between sound sources and the frequency sound that they are both generating. The reasons these appear is vertical movement causes a path length difference between the listener and the two sound sources. At certain angles, the path length distances are multiples of 1/2 wavelength, causing cancellation. So what you see is a forward lobe of in-phase summing surrounded by anti-phase nulls. Further out, side lobes appear if the sound sources angular coverage is wide. Unless the sound sources are horns with pretty tight pattern control, there is usually enough off-axis energy for the side lobes to appear out beyond the nulls.OK, so now we know there are forward lobes, nulls and side lobes out beyond that. Now what?Remember, you cannot hope to make a multi-driver loudspeaker generate a point-source spherical wave in all directions with uniform coverage. A single driver speaker won't do it because it has collapsing directivity, so high frequencies are much more directional than low. A coaxial driver won't do it because even though it is sort of like a point source, it has collapsing directivity like the single driver does, but when the woofer starts to beam, crossover is made to the tweeter wheich then widens back up again. So coverage is weird, going from wide to narrow to wide again, probably beaming yet again higher up. And a speaker with vertically stacked drivers has anti-phase nulls that form above and below, with an in-phase forward axis that drifts upward slightly through the overlap band.But here's one way to work with all these factors to provide uniform coverage. While we want a wide horizontal pattern, vertical coverage doesn't need to be nearly so tall. The target area is usually much wider than it is high. There is no need to waste energy on the floor and ceiling, so a wide but short pattern is ideal. I like 90x40 because it can set in a room corner and cover the entire room. It is a useful pattern. It also happens that if you crossover around 1.2kHz to 1.6kHz with midwoofer (or dedicated midrange, for that matter) and tweeter center-to-center spacing of about 12", the vertical nulls are about 50o apart. That's a convenient angle when using horns with 40o vertical pattern.Another thing happens around the

to become directional as frequency rises. The pattern is nearly omnidirectional at low frequencies, but by the time wavelength equals diameter, the pattern has narrowed to a cone shape of roughly 90o. So 1.2kHz to 1.6kHz crossover between a 12" or 15" midwoofer to a 90x40 horn just above it on the same baffle results in a pattern that narrows in the horizontal to 90o, and then hands off to the tweeter horn with matching directivity. The vertical angle is "squeezed" by the nulls down to 50o, and then as the tweeter takes over, it eventually narrows to 40o through the rest of the band. This is a great way to provide uniform directivity through a useful coverage angle.There is one more thing to consider, and that's crossover slope. Low-order crossovers have a very wide overlap, so they aren't attractive for this solution. The wider the overlap, the greater the shift of the in-phase forward axis and the anti-phase null angles. As frequency rises, the forward axis drops and the null angles get closer together. So it is important to limit the overlap band. Of course, high-order slopes add more phase shift, so there are some limits to what you can do. High-order crossovers tend to also introduce more insertion loss, so second and third order filters are probably the best compromise between reducing the width of the overlap band without causing too much insertion loss.

Subject: Re: Phase, delays and offset baffle spacing
Posted by JLM on Thu, 01 Aug 2002 08:30:38 GMT
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Wayne:Your point regarding baffle offsets/slopes and time delay circuits is well taken. I really apreciate you posting this information (even if most of it is over my head). But how does this affect the sound?

Subject: Re: Phase, delays and offset baffle spacing
Posted by pickle on Thu, 01 Aug 2002 11:06:36 GMT
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This is an explanation of why claims of various schemes for time alignment are fooey. Basically, as long as the differences in time arrival are within a window, it isn't important. Even a single driver can be shown to have this problem as sound emanates from different areas of the cone, and bounces from areas within the cone. Dr Edgar had a graph from a German study which showed the ability of subjects to discern delay, and it was also very frequency dependent. As long as the delay was kept under the window, all was well. You could chase the time delay "problem" ad infinitum, but also, your solution only works for one exact listening position, so again, do whats reasonable and get on to other issues, like motor distortion, box tuning, x-overs, etc. And now for something completely different, anyone ready for Waynes "audiophile" series TAD based three way?!? That'd be fun.

Subject: Re: Phase, delays and offset baffle spacing
Posted by Wayne Parham on Thu, 01 Aug 2002 16:40:35 GMT
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That's right, Mike.The point I was making was that perfect time alignment isn't possible in a speaker system, at least with current technology. Even a single driver is not immune because it is not really a point source. It is a moving plane that only acts like a point source at low frequencies.But with careful choices of directivity, baffle spacing and crossover, you can provide constructive summing (i.e. good response) over a wide angular coverage angle.

Subject: on the subject...
Posted by dbeardsl on Thu, 01 Aug 2002 17:19:56 GMT

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On the subject of moving planes and drivers producing HF...How does a driver accurately produce sounds with wavelengths that are smaller than the diameter of the driver? And when they do, does the beaming exhibited mainly come from the path length cancellation thing where two edges are producing the same wave but since the observer is off axis, the edges are different distances away from him?DannyP.S. Two Pi's are done, and sound beautiful, will post pictures.

Subject: on the subject...
Posted by Wayne Parham on Thu, 01 Aug 2002 18:50:02 GMT
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Bingo. You've hit it right on the head.

Subject: Re: on the subject...
Posted by dbeardsl on Thu, 01 Aug 2002 19:40:13 GMT
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I remember reading about a new idea for speaker drivers, some guy from the place where they make those Zen amps was experimenting and tried inverting a cone. He cut it out, and turned it upside down and devised a method of connecting the voice coil to the tip of the inverted cone. The cone actually protruded from the basket. Supposedly This really helped a lot of things, making a more even dispersion and some other stuff. Now he makes them and sells em...Here's a link

http://www.decware.com/radials/radials.htm

Subject: Coax point source drivers??
Posted by Robert Hamel on Fri, 02 Aug 2002 01:35:22 GMT
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From what you are all saying is if a single driver is not a point source then 2 can't be either. Funny thing the Urie Coax monitors were "Time Aligned" point sources. When you look at the measured data in the Improvements in Monitors AES article they measured better than the other 2 but all 3 are below the audible threshold. If they are all below this then any diferences should not be audible? So why go to the trouble??? Marketing tool??? Am I missing something???

Subject: Could this
Posted by Peter Krojgaard on Sat, 03 Aug 2002 06:35:43 GMT
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Hi mikebake,Sorry to interrupt, but I have question:You wrote:

Subject: Phase and "time alignment" revisited
Posted by Wayne Parham on Sat, 03 Aug 2002 09:20:05 GMT
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Best thing would be to do a search here and look over the posts about "phase" or "time alignment."You'll find several hours of reading material on this subject, just from the discussions in the last month alone.

Subject: Re: Could this
Posted by mikebake on Sat, 03 Aug 2002 10:17:57 GMT
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I have emailed Bruce Edgar to see if he can send me a copy of the graph.

Subject: Re: Could this
Posted by mikebake on Sat, 03 Aug 2002 10:21:28 GMT
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If I recall, they were measuring how many milleseconds delay was discernible. The delay was less noticeable in the bass region, sloped to be most noticeable in the 2.5 5k region, then became less noticeable as the freq went up from there. I have emailed Bruce Edgar to see if he can email the graph.

Subject: Re: Coax point source drivers??
Posted by mikebake on Sat, 03 Aug 2002 10:23:15 GMT
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You aren't missing anything, and the Urei weren't a true point source, of course.

Subject: Re: Could this
Posted by Peter Krojgaard on Sat, 03 Aug 2002 16:43:03 GMT
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Hi mikebake,Thanks for your reply!I just did a search at the 'high efficiency' forum that hit a message from Bruce Edgar (see below) that may be the one you refer to - at least it corresponds quite well with your memory!http://www.audioasylum.com/forums/HUG/messages/24987.html(I hope it's o.k. to refer to other peoples post in this way - if not please let me know)Here Bruce Edgar claims that only misalignments larger than 1 foot can be heard and primarily at higher frequences.In a related post Bruce Edgar states that using 1. order crossovers minimizes the errors even further.Have you any idea whether 4th. order crossovers would makes potential alignment problems worse - and if yes why?RegardsPeter K.

Subject: Re: Phase and "time alignment" revisited
Posted by Peter Krojgaard on Sat, 03 Aug 2002 16:46:30 GMT
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Hi Wayne,Thanks for your reply. Yes, there is a lot of good information in your archives (a lot for me to read and learn!)RegardsPeter K.

Subject: Re: Could this
Posted by Tom Brennan on Sat, 03 Aug 2002 18:17:01 GMT
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Pk---This all goes back to the famous "double-tap" incident at MGM in the 1930s. The sound track of Eleanor Powell tapdancing was being played back through a WE monitor with a 12 foot mismatch between the bass and treble horns. Double clicks, an echo, were heard. John Hilliard, a sound engineer at MGM investigated the problem and found the echo was caused by the path length difference. When he moved the tweeter horn back into the same plane as the basshorn driver the echo was gone. Hilliard'd subsequent experiments determined that the effect was frequency dependant and that 3ms (about 3 feet) mismatch was inaudible when the crossover was between 500 and 800hz.This incident was one of the things that spurred Hilliard to get his boss at MGM to finance the development of an improved theater playback speaker, the famous Shearer Horn. Hilliard went on to be the big Kahuna of engineering at Altec and is the Zeus of The Horn Gods.

Chicago Horn Club

Subject: Re: Could this
Posted by Peter Krojgaard on Sun, 04 Aug 2002 05:58:43 GMT
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Hi Tom,Thanks for bringing up this nice and illustrative piece of history! RegardsPeterP.S.: Nice Chicago Horn Club website!

Subject: Re: Phase, delays and offset baffle spacing
Posted by Farb Sklarb on Sun, 04 Aug 2002 21:59:19 GMT
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Thanks for an interesting article. May I make a couple of comments?The apparent offset of the driver is proportional to phase shift divided by frequency. Phase shift is proportional to the arctan of the measurement frequency divided by the crossover frequency. When this ratio is small (i.e., when f

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Subject: Re: Phase, delays and offset baffle spacing
Posted by Wayne Parham on Sun, 04 Aug 2002 22:46:21 GMT
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It looks like you grasp this stuff pretty well. But I might point out that the delay from the crossovers is not some kind of "virtual" or abstract thing. It is a very real property, and is expressed as movement in the time domain. Work is only done when power is applied to the motors. And for power to be presented to the speaker motors, it requires that current be flowing. Reactive components change the rate of change of current flow in a circuit. That's how the delays happen in a crossover, and why there is achange in phase.It isn't so much that there is an abstract concept of time and that capacitors cause a "time warp." But it is that current leads voltage in a capacitor, and that voltage leads current in an inductor. Current and voltage rise at the same rate in a resistor. That's why the delays are described as they are in a reactive device, and the issues that are represented by phase are actual, measurable and identifiable properties in the time domain.

Subject: Re: Phase, delays and offset baffle spacing
Posted by Farb Sklarb on Mon, 05 Aug 2002 15:09:38 GMT
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Thanks for the reply. I agree with what you're saying, but let me clarify my point as well. Consider two filters, one a first-order low-pass at 1600Hz, and the other a 156.25uS pure delay with a 3dB pad on the output. Drive both with a continuous sine wave at 1600Hz and compare the outputs. They will be the same, -3dB and -45 degree phase (assuming I didn't screw up my math!).Now, change the input signal to a 1600Hz toneburst. Whereas the output of the low-pass filter will begin to change just as soon as the leading edge of the toneburst arrives (ignoring propagation delay, i.e., the speed of light), absolutely nothing will come out of the second filter until 156.25uS have passed. So, while both filters have a delay, in some qualifiable way, the nature of the delays is different. I suppose you could say, sT compared to 1 / (1 + sT).Anyway, I guess I'm getting a bit too esoteric. It's just something I started thinking about after reading your article. Again, sorry if this is inappropriate material for the forum.

Subject: Re: Phase, delays and offset baffle spacing
Posted by Wayne Parham on Mon, 05 Aug 2002 22:40:27 GMT
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A filter and a delay line are two different things. A delay line creates a fixed duration delay, just like is formed by distance offset. A filter's delay is related to frequency, and some frequencies are delayed more than others. So there truly is no way to time-align all frequency components in a system that uses crossover filters like these.
