Subject: DI-matched two-way loudspeakers
Posted by Wayne Parham on Mon, 23 Nov 2009 20:38:38 GMT
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Lots of people are experimenting with waveguides and DI-matched two-way loudspeakers these

pleased to see them become so popular. Seems like a good time to look back at some of the concepts that are required to make this kind of loudspeaker system perform best. In particular, I'd like to mention what is required for proper on-axis summing, and consequently to provide a large, clean forward lobe.

The center of the forward lobe is (or should be) where woofer and tweeter are in phase. Their phase relationship is determined by the electrical phase of the crossover, the electro-mechanico-acoustic phase of the drivers and horn and the physical relationships to one another. The physical relationship is set not only by the vertical position on the baffle but also the depth, which sets the distance to the listener, creating a fixed delay.

Each driver is some distance from the listener, which introduces a fixed delay. The electrical crossover and the electro-mechanico-acoustic features set the phase, which represents a delay that changes with frequency. The two things are not the same, but if frequency is fixed, then the phase is also fixed, meaning the delay is too. So at a specific frequency, phase has a fixed delay that can be compared to the fixed delay of path length. Similarly, over a narrow frequency band, phase changes are small and so delay changes are also small. The long and the short of it is crossover phase can be used to sort of offset path length differences over a small audio band, where phase shift is within range. This fact is used when designing crossovers in speakers like these, it is how you set the position of the forward lobe.

If the crossover phase and path length differences combine to bring the sound sources in phase straight in front of the speaker, then you can expect the vertical nulls to line up pretty much where you expect them to be. But if the phase shift is a complete cycle (or multiple cycles), then what is straight in front of the speaker is actually a minor lobe, which is generally smaller than the major lobe. You can sort of get the response to be OK, but the nulls will appear to be abnormally close. So if you're modifying one of our models or building your own speakers from scratch, be careful of that when designing and measuring your speakers.

You can use the Altec procedure of reverse connecting the speakers and looking for a null straight out in front, but be aware that you'll see a null at odd multiples of 180°. Every odd half-cycle shift will create a null. So if the woofer and tweeter are in phase and you reverse connect them, you'll see a notch. But this will also happen if the woofer and tweeter are 360° out of phase - a full cycle shift. Reverse the connections and you'll see a notch. This can sometimes make you think you are in phase when you are really a full cycle out.

Say you set everything up, do the Altec reverse-connection thing to put the notch straight out front, then connect properly and measure polars. If you find nulls aren't where you expect them to be from the CTC spacing and frequency, then there's a good chance there is a full cycle or maybe even a multi-cycle shift between sound sources. Again, if that's what you're seeing, then what's straight in front of the speaker is actually a secondary minor lobe, which is much smaller than the major lobe. The major lobe is probably way off somewhere above or below the speaker. So watch out for multi-cycle shifts due to depth and/or crossover phase. They can be kind of tricky, especially if you're working with relatively wide CTC spacing for the crossover band and are expecting a consequently narrowed forward lobe anyway.

When a secondary lobe is out front, the vertical nulls seem to be too close and sort of shady. What I mean is, you can fiddle with the crossover values, and even small changes that seemingly shouldn't make much difference move a null completely out of the picture but also bring the opposite one view into almost immediately. Secondary lobes are smaller, and the notch at their outside edge seems smaller too. That can make it look like one side has no null but the other seems to be too close. It often looks like one side has a big null that's too close and the other side has a little null or none at all.

A long time ago, I used to meticulously calculate the crossover phase and estimate the electro-mechanico-acoustic phase of the drivers. Now I tend to estimate a little more generally, and rely on measurements for more precise determination. Some quick arithmetic shows the wavelength of 1.6kHz is 8.5" and the wavelength of 1.2kHz is 11.3". So a physical offset of half those amounts will introduce a half-cycle shift, as will a 180° phase shift, be it from electrical crossover or electro-mechanico-acoustic phase from a horn or direct radiator in a box.

Hornresp will show the phase of the horn and box modeling tools will show the phase of direct radiators, so you can simulate the system and include the predicted phase in your calculations. That's what I have done, and then combine the physical offset to estimate the phase of the sound sources. When I begin a new system, I do this initially, and even with measurement equipment, it still is nice to know the phase, at least approximately, to know where to start. Measurements can be used to fine tune the system, changing component values a little bit to slightly adjust the phase to get the position of the forward axis and vertical nulls just right.

Pi horn design philosophies
Phase angles, crossovers and baffle spacing
Baffle spacing, phase angles and time alignment, revisited
Matching directivity in the vertical and the horizontal planes
Crossover optimization for DI-matched two-way speakers
Imaging, placement and orientation

Subject: Re: Lobes and nulls, crossover phase and baffle spacing
Posted by Norris Wilson on Wed, 25 Nov 2009 08:14:35 GMT
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Wayne,

What a great compilation of information about crossover design and DI matching in a two-way speaker using a horn and compression driver for a tweeter.

Obviously, this has taken many hours, even years to gain such knowledge where it could be offered here.

It is an act of selfless devotion to the DIY speaker building community to present this information, a passion.

I thank you for such passion and sharing of your time and knowledge.

This has enriched all of us here who enjoy your offerings.

Norris

Subject: Re: Lobes and nulls, crossover phase and baffle spacing
Posted by Matts on Wed, 25 Nov 2009 15:23:12 GMT
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Yeah, what Norris said.... thanks!

Subject: Re: Lobes and nulls, crossover phase and baffle spacing
Posted by Wayne Parham on Fri, 27 Nov 2009 01:40:24 GMT
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Thanks for the kind words, guys. This was prompted by a private conversation and it seemed worthwhile to post here. Here is some more dialog from this continuing conversation.

Three (and a half) quick points that I am pretty sure you already realize but a reminder doesn't hurt:

1. Electrical crossover slope almost never is the same as the combined acoustic slope + electrical crossover slope, especially where horns are concerned. The acoustic rolloff "adds an order" or two usually.

2. Our sound sources in a design like this are directional in the crossover region and this affects the shape of the lobes somewhat, mostly the minor lobes. The major lobe is within the drivers' patterns so it usually looks the same as it would if the sound sources were omnidirectional. But the secondary lobes are usually at least partially outside the pattern and so are smaller than they would be if the sound sources were omnidirectional.

3. You actually can shift the lobes predictably with crossover phase (from minor component value changes) if everything is close to right, meaning the (major) forward lobe is pretty close to the baffle normal and the side lobes are pretty symmetrical. That takes some effort to begin with, and I usually calculate first and then tweak the crossover to fine tune. If the forward lobe isn't pretty close to straight out front and the secondary lobes aren't pretty symmetrical, then the whole system gets kind of "twitchy". That's what I was trying to say earlier in my post when I said "the vertical nulls seem to be too close and sort of shady". Multi-cycle shifts are one culprit, another is when the electrical and acoustic phase simply points the forward lobe too far up or down.

This is where the work comes in. Play with various slopes and crossover points until you find a combination that gives symmetrical side lobes. You want the nulls to be pretty symmetrical - that's a clue. Even though the side lobes are smaller even when things are right (because of the directivity of the individual sound sources), you can still use the depth of the nulls as a clue. They should be pretty equal. If not, the forward lobe is probably aimed up or down a bit, sort of like what you see in the sims of an odd-order crossover. As an aside, remember that those usually are sims of idealized acoustical crossover slopes and omnidirectional sources, so they don't completely apply but they do give a good picture of a lopsided lobe situation. Again, you can get this oddball lobing from multi-cycle shifts or from just having the forward lobe pointed off too far. The latter can be corrected by crossover but the former will probably take physical movement or a delay line. Could possibly do it with two very different slopes, but I wouldn't want to do that with a passive crossover 'cause I don't like going past third or fourth order. Too much insertion loss or (large) expensive components or both.

Look back at my "Crossover optimization for DI-matched two-way speakers" thread. Notice that the Spice model I use has every (textbook BW) filter from first-order to fourth-order between 1kHz and 2kHz. That's so I can easily swap them in when designing. Those make good starting points, but I almost always modify the basic filter to something that isn't Butterworth, Bessel, Linkwitz, Chebychev, or anything like that. I'll modify values to dial in the phase. That's what really matters.

Man, that WTPro ICD is really great for doing this. I got soooo spoiled with it. I used to wrack my brain trying to calculate the estimated phase to the Nth degree, using Hornresp to see the acoustic phase, combine that with electrical phase and baffle spacing and try to set the forward lobe that way. Then I'd model in Spice to get the electrical amplitude response and phase that I wanted and hope for the best. It was really hard work, and frankly isn't as accurate as just plugging in the numbers, building the crossover (in the ICD) and measuring the end result. Then when I build a physical model with caps and coils, it's right on the money. It is absolutely wonderful for this, and I honestly attribute it for why I'm able to get the results I get. Without it, you'd have to build a dozen physical models or more to dial it in, and you'd probaby give up and call it good after three or four, tops. But with the ICD, I can do a dozen in an hour, no sweat. Sweeeeeeet.

Subject: Re: Lobes and nulls, crossover phase and baffle spacing
Posted by Wayne-o on Fri, 27 Nov 2009 02:47:41 GMT
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At what freq. are the nodes on the Pi-three that appear at 30 degree in the vertical plane ? Question about video. thanks.

Subject: Re: Lobes and nulls, crossover phase and baffle spacing
Posted by Wayne Parham on Fri, 27 Nov 2009 03:37:12 GMT
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fully out by 1.0kHz at the bottom and 1.5kHz up top. They only occur at fairly wide vertical angles, like you saw in the video, around +/- 30° from a midpoint between woofer and tweeter. The tweeter's vertical pattern is only +/- 20° from about 2.5kHz up, so the nulls are well outside the desired coverage angle and sort of punctuate the vertical pattern down low.