Subject: Phase Delay and Group Delay
Posted by Farb Sklarb on Thu, 08 Aug 2002 19:40:35 GMT
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This is a follow-up to the earlier discussion on crossover correction by time alignment. I'm not sure a purely theoretical posting is of much interest to most readers of the forum, but for some reason I'm in the mood for stirring things up, so what the heck.In the previous discussion, it was mentioned that the phase shift through the crossover introduces a delay. The value of this delay, which is called phase delay is proportional to the negative of phase shift divided by frequency. The phase shift in this case can be observed as an offset in the voltage peaks between the input and output of the crossover network.The effect of driver reactance on phase shift was mentioned, but this is really a secondary consideration. In speaker design, the goal is to achieve a target system response which takes into account the electrical interactions between the crossover and the driver, as well as the acoustical response of the driver itself. So we can ignore all that complexity and approach this phase delay question purely in terms of the relationship between the acoustic signal coming out of the speaker driver and the electrical signal at the input to the crossover.In the case of the LF driver, the ideal first-order crossover has a phase that starts at zero degrees at DC, is relatively flat up to a couple octaves below the crossover frequency, declines smoothly to minus ninety degrees, and is relatively flat again out to infinity. This is evident if the response is plotted logarithmically, which is usually the case. The graphs in the earlier discussion were plotted against linear frequency axes which hides some of the nice symmetry of the phase response. Due to the minus sign in the equation, the phase delay associated with this target crossover function is everywhere positive and there is apparently no philosophical conundrum since the output of the crossover clearly arrives after the input.In the case of the HF driver, the phase starts at ninety degrees and varies to zero, being positive at every frequency. This means the phase delay is everywhere negative. If phase delay is physically meaningful in the conventional sense of cause and effect, then this leads to the absurdity that the output of the speaker arrives before the electrical signal that produces it. Again, this has absolutely nothing to do with driver reactance or the capacitor in the crossover network. It's a fundamental property of the electrical-to-acoustic transfer function of the tweeter channel of the loudspeaker.We could replace the loudspeaker with a communications channel having the same phase and frequency response, and the result would seem to be a device for sending messages backwards in time. This violates fundamental principals of communications theory and tells us that phase delay is not the same as "delay" as we commonly think of it.What this tells us is that there is no causal relationship between, say, a peak of the AC signal waveform at the input to the crossover and a peak of the acoustical signal waveform at the output of the speaker. If there were, we could use this relationship to encode messages going into the past through phase-lead networks. For continuous, unvarying sinusoidal test signals we cannot send any information over this channel. And we also can't measure the phase shift because we have no way of knowing how many cycles have "slipped" between the input and output.In fact, the only way to measure the phase shift, which is also the only way to send a message over the channel, is to modulate the signal. For instance, we can abruptly shut the input off and see how long it takes for the output to respond. A more methodical way to make this test would be to mix the input signal with another sinewave having a very slightly different frequency. The result of adding these two signals would be a "beat note", which is a form of amplitude modulation. With a bit of work, we can measure the time it takes for the modulation to make it through the system. We will find it is not equal to the phase delay, but to the negative slope (i.e., change with respect to frequency) of the phase-versus-frequency curve. This is known as group delay, and it must be positive for all

causal (i.e., realizable) analog filters. Group delay is what determines the observable delay of systems like filters. It follows that the phase shift must always decrease (become more negative) as a function of frequency for all crossover filter functions, else we are violating causality by sending music backwards in time.Music is reversible, time is not. Go back... Go back...A delay line is, in fact, a type of filter, having uniform frequency response and linearly decreasing phase. Because the slope of phase for a delay line is constant, the group delay is constant, and so signals passing through it are delayed equally regardless of frequency. Physically offsetting a driver on the baffle is equivalent to adding a delay filter to the crossover function. It can't "correct" the phase at all frequencies, but it can be used to adjust the group delay over a range of frequencies. I can think of several cases where this could be a useful trick for crossover design.Apologies in advance for any errors in this message. I have an interest, but lack expertise, in the subject matter. Corrections are invited.Have fun.