Subject: Crossovers and phase shifts
Posted by Wayne_Parham on Sat, 24 Mar 2001 07:38:53 GMT
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There seems to be some confusion about how much phase shift is caused by crossovers, and also about the difference between phase and delay.Here's the scoop: The three values - Resistance, (L) Inductance and Capacitance are each 90 degrees out of phase with each other. Capacitors provide impedance that's 90 degrees ahead of an equivalent value of resistance. And inductors have impedance that's 90 degrees behind.This is literally the way power runs through these things. In a capacitor - voltage rises across it before current can run through it. And in an inductor, voltage cannot rise across it until after current has already begin to flow through it. With a resistor - voltage rises across it at the exact same rate that current flows through it.So what we have here truly is a phase relationship, where things happen at different times.This makes simple RCL circuits very easy to calculate. Everything is two dimensional. You can calculate total impedance and phase angles with the same formulas you would use to calculate a right triangle. Right triangles have 90 degree angles, and that's the exact same relationship between the three values, inductance, capacitance and resistance.When we have a 6dB/octave crossover - we have only two of these. A cap and a resistor or an inductor and a resistor. What that means is that the phase difference can be a maximum of 90 degrees.But wait - that's a bit misleading. I tell people that a 6dB/octave crossover can't shift the driver's output more than 45 degrees, and here's why:Let's use the tweeter circuit, just for sake of example. The woofer acts the same, so there's no point in doing both of them. When the tweeter is fully cutoff - at very low frequencies - the phase angle is very nearly 90 degrees. That's because the capacitor's impedance approaches infinity, while the tweeter is sitting there at 8 ohms. So the phase angle is 90 degrees -- but you can't hear anything. The tweeter is fully cutoff.As we approach the crossover point, the capacitor approaches 8 ohms. At this point, the tweeter is 8 ohms (hopefully you've crossed it much past resonance so it isn't 25 ohms or something). Now, we use that 2D math stuff. Pythagoran's theorem tells us what the impedance is:Z = (R^2 + Xc^2)^0.5 Our impedance is 11.3 ohms. We find power distribution by calculating a divider network using 8 ohms and 11.3 ohms. We're about 3dB down at this point. An octave lower, we're about 7dB down. That's where you'd probably want to consider your true crossover to be.At the -3dB point, we had 8 ohms or resistance and 8 ohms of capacitive reactance. That's exactly a 45 degree difference. So at this point, we're shifted 45 degrees. Much below this point, you cannot hear the tweeter - because it's attenuated by the crossover. So that's the point. While the network is capable of presenting signals to the tweeter that have been shifted 90 degrees, it is precisely these signals that have been attenuated sufficiently that you can't hear them.By definition, the speaker motor driven by a 6dB/octave crossover cannot possibly provide output that is shifted 90 degrees. Because at the point where phase shift is ninety dgrees - by definition - the attenuation created by the network is infinite. In practice, the motor will begin to become audible (barely) when phase shift is 60 degrees and will be only -3dB at 45 degrees. So it's gotten pretty loud by 46 degrees.Therefore, it is reasonable to say that a speaker driver with a 6dB/octave crossover will present audible signals of 45 degrees phase shift or less. It cannot possibly provide audible output shifted much more than that.12dB/octave crossovers aren't much more difficult to calculate, since they still have the same three "nodes." We can still use simple "Phythagoran-style" math. What you'll find is that all the same things occur, but the maximum shift is now 90 degrees. That can be a problem when two are used contiguously, because the tweeter shifts 90 degree in one direction and the woofer shifts 90 degrees in the other. That means in the crossover region - they're very nearly 180 degrees apart.Two 12dB/octave crossovers on contiguous drivers will cause complete cancellation of the crossover frequency. In practice, it can be shown that this really does happen. There is about -20dB to -40dB, depending on placement of the two drivers on the baffle. So I'd recommend this kind of system have the two motors connected out of phase.Some would perhaps object to running a woofer 180 degrees out of phase with a tweeter. I don't really like it either - it just "doesn't feel right." But if you're gonna run two 2nd order networks side by side, and the two drivers are mounted on the same baffle, it's the lesser of two evils. be 180 degrees out of phase in the passbands, or have a 40dB dip in the crossover frequency.Honestly, you can't hear the 180 degree thing. The woofer's phase changes to "meet" the tweeters at the crossover frequency and the the tweeter's phase continues to rotate through to 180 degrees. That's what the phase relationship "looks" like when you run two 12dB/octave crossover slopes with "cross connected" motors.When you consider higher order slopes, you can't use this kind of math anymore. Now the phase generated by the first "node" must be calculated against the proceeding nodes using vector math. But you can see the trend. You're right in that there's 90 degrees per node, but that's a number that you can't ever hear. The audible phase produced is exactly half that.A technical description of a first-order filter defines it as exhibiting a 45 degree phase shift at crossover, with 90 degrees at the asymptotes. But for loudspeaker crossover networks - the word "asymptotes" can be interpreted to mean "places you can't ever go." The crossover will approach this limit as it enters its stop-band.Now to give you some "concrete" formulas to use when designing crossover networks:Remember on first order (6dB/octave) crossovers that I said the place where Xc = R is the -3dB point, and that response is down -7dB an octave away. An octave further and we're at -13dB, and the slope continues to fall by 6dB/octave.The best way to calculate a 1st order network is by using this "octave away" method - and not by setting reactance equal to driver (advertised) impedance.So here's our formulas: [details that you can pass over if you wish]For low pass: Xl = 2 * PI * F * Lrewritten to find for L = Xl / (2 * PI * F)And High Pass: Xc = 1 / (2 * PI * F * C)rewritten to find for C = 1 / (2 * PI * F * Xc)Note that Xl and Xc are reactive impedance, and the general rule is to set this equal to the impedance of the driver. Also note that L is Henries and C is Farads, so millihenries is 1/1000 Henry and microfarads is 1/1000000 Farads.Since we actually want to find a part that is -6dB down at a specific frequency, we really want to find a frequency that's an octave higher than these formulas indicate for high pass or an octave lower for low pass. You can easily use the formulas above, or we can just rewrite them to find the exact -6dB point, which is exactly an octave from the frequency where reactive impedance equals resistance:For low pass: L = Xl / (2 * PI * (F/2))and high pass: C = 1 / (2 * PI * (F * 2) * Xc)or to simplify:[here's where the details end - these are important but easy]1st order (6dB/octave) network calculation:Low pass: L = speaker impedeance / (PI * crossover frequency)High pass: C = 1 / (4 * PI * crossover frequency * speaker impedance)Those two formulas will get you where you need to be on 1st order networks. Just choose the frequency you want, and the value of the speaker's impedance. If you have an impedance chart - or you can measure its impedance at this frequency - then do so. Your results are more accurate. If not, just use the advertised impedance.But if you use advertised impedance, be careful. A speaker motor is a reactive device and this makes it have a big change in impedance with respect to frequency. Most speakers have significantly higher impedance at resonance than the "advertised" (8 ohm) value, and they also have greater impedance at their upper cutoff.So it is wise to crossover well above speaker resonance when using a 6dB/octave crossover. If you cross an octave above - you're in the midband of the driver and you can reasonably expect it to maintain advertised impedance for a few octaves. This is an acceptable design method. But just don't forget that a very high impedance at resonance can exceed the reactive impedance of your 6dB/octave crossover device and, in this case, no crossover has been performed.For example, let's assume you have a tweeter rated from 800Hz to 16Khz and you want to use a 6dB/octave crossover. I would not recommend anything below

1.6Khz, and it would be better to go even higher - like 3Khz. So but for the sake of example, let's see what happens with a 2Khz crossover having a 6dB/octave slope. This is formed with a 5uF capacitor, assuming the tweeter has advertised impedance of 8 ohms.At 4Khz, we'd have 8 ohms reactive impedance, and the tweeter would be at -3dBat 2Khz, we'd have 16 ohms reactive impedance, and the tweeter would be at -7dBat 1Khz, we'd have 32 ohms reactive impedance, and could expect the tweeter to be -13dB, andat 500Hz, we'd have 64 ohms reactive impedance, and would expect -19dB from the tweeter.But what if the tweeter's impedance at resonance is 40 ohms at 600Hz? The reactive impedance of our 5uF crossover capacitor is only 42 ohms at this point - so the tweeter will be only -3dB attenuated at its resonant frequency. That's a long way from our expected -18dB, and we'll probably destroy this tweeter.So be careful with 1st order networks. Check the motor's impedance at resonance when you can, and use a different network or shift the 1st order crossover frequency very far away when you can't.Application of 12dB/octave crossovers doesn't require as much analysis. All high order networks are relatively safe. They have shunt reactances that make driver impedance a relatively trivial matter in determining slope. A 12dB/octave crossover should be built where Xc and Xl are equal to the motor's advertised impedance at the intended crossover frequency. That's pretty much all there is to these little guys.So just use the standard reactive impedance formulas to determine values for your inductor and for your capacitor:2nd order (12dB/octave) network calculation:L = speaker impedance / (2 * PI * F)and C = 1 / (2 * PI * F * speaker impedance)Nothing to 'em. Sling some solder and you're ready to rock-n-roll.