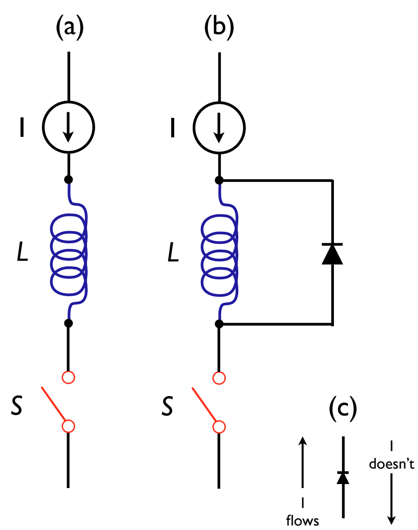
NAME & ID

PH 102 / LeClair Summer II 2009

Quiz 8: ac circuits

1. A current source I is used to drive a large inductor (say, a wound wire electromagnet) as shown at right. Driving inductive loads can be problematic - what happens when you open the switch providing current to an inductor in circuit **(a)** Why does adding a diode across the inductor, circuit **(b)**, add protection? Recall diodes only allow current through in one direction, as shown in **(c)**.



Because inductors have the property $V = -\Delta I/\Delta t$, it is not possible to turn off the current suddenly - if $\Delta t = 0$, that would imply an infinite voltage across the inductor, a violation of numerous physical laws (and good common sense). What does happen is that the voltage across the inductor rises rapidly after the switch is opened, and keeps rising until it *forces* a current to flow – for example, by making a spark jump across the poles of the switch. This is BAD, and may let the magic smoke out of the circuit. Electronic devices controlling inductive loads can be damaged in this way, since essentially some component has to "break down" to satisfy the inductor's desire for constant current.

In the second circuit shown, a diode is used to protect the magic smoke in our devices, and stop the "inductive kick"[i] that may damage other components. When the switch is initially closed in this circuit, current flows through the inductor. Current does not take the path through the diode, since it is not conducting in the direction of current flow. Now, what happens when the switch is suddenly opened? The inductor tries to keep current flowing toward the switch, as it had been moments before, and develops a negative voltage. This means that the bottom of the inductor becomes positive relative to the top, and a large current tries to flow *up* through the diode, back around to the top of the inductor, to maintain continuity. Basically, the diode lets the inductor source current around back to itself and allow the current to decrease at a reasonable rate. There are other details of diode behavior that make this circuit even nicer

[i]One of you called this the inductor's "angry current" in your solution; I like it.

than it sounds already, but the basic principle remains the same. This sort of circuit is known as a "diode snubber" or a "flyback diode." See, for example:

`http://en.wikipedia.org/wiki/Snubber` `http://en.wikipedia.org/wiki/Freewheeling_diode`
Without the diode snubber in parallel with the inductor, the inductor would try to pull charge current from the switch or a nearby component to force current to flow, leading to a nasty spark somewhere in the circuit.[ii] When we have the diode protection, however, after the switch is thrown the back-current from the inductor can flow up through the diode - it is conducting in this direction. Basically, the induced current from the inductor will be short-circuited by the diode, but the forward current during normal operation will not be.

The back-voltage on an inductive load can easily be 1000 V, enough to kill nearly any solid state electronics. Of course one problem is that inductive loads are rather common, in the form of *relays*, which are basically current-controled switches. It is virtually certain that you have used a relay at some point today, and it is equally certain that said relay had a protection diode or its RC equivalent.

`http://en.wikipedia.org/wiki/Relay`

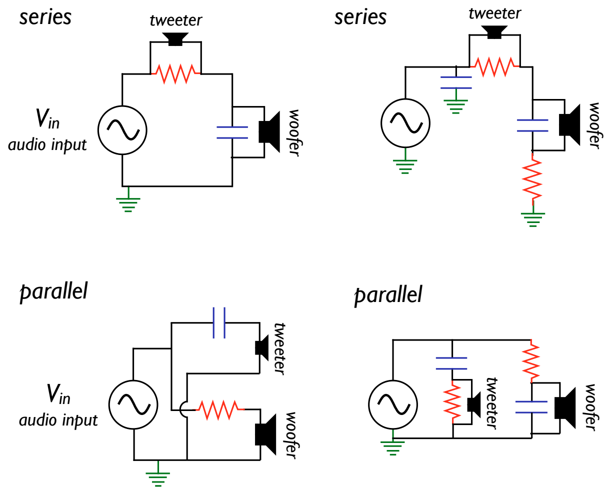
2. Using capacitors, resistors, and inductors, sketch a circuit to split an audio signal composed of many frequencies in to a low frequency part and a high frequency part, for distribution to speakers. That is, filter the incoming signal into separate low frequencies and high frequencies to send to a woofer and tweeter, respectively. Such a circuit is known as an "audio crossover." You do not need to specify the values of your components.

Even with only passive components like capacitors, inductors, and resistors, there are many ways to go about this problem. For simplicity, we will use only resistors and capacitors. We know that capacitors allow higher frequency signals through easily, while blocking lower frequency signals. A resistor, on the other hand, lets all frequencies through equally. What we can do, then, is use a capacitor to direct high frequency signals away from the woofer and toward the tweeter.

The circuit in the upper left portion of the circuit below shows the simplest possible crossover. If you look closely, it is identical to the low-pass filter in the next problem! All we have done is connect the output - which will be preferentially low-frequency signals - to the woofer. The tweeter takes the full range signal developed across the resistor, which will include the high frequencies. Another way of thinking of this circuit is that the capacitor "shorts out" the high frequency signals, and keeps them away

[ii] In older cars, this is more or less how an ignition coil works.

from the woofer. One serious way that this circuit is lacking is that we don't send *only* high frequencies to the tweeter.



We could cure that problem by putting a low-pass and high-pass filter in series instead of just a resistor and capacitor, as shown in the upper right panel in the figure above. The low pass filter connects across the tweeter, and shorts the low frequency signals around it, such that it sees only high frequencies. The high pass filter does the reverse for the woofer, so it only sees low frequency signals. This is a perfectly workable crossover, and on paper it does just what we want. A major disadvantage (or, an advantage depending on your viewpoint) is that the two filters interact with each other - each filter is sending some signal to ground that really should be going to the other. Further, changes in any one component affect *both* high and low pass filter sections - to keep the same overall flat response, one must change all components, not just one, when one tries to tune the crossover frequency. Finally, this circuit is very sensitive to component variations and (in)accuracy. Still, the design is sufficiently simple to be appealing.

How can we do better? We can make a voltage divider to split the input signal into two, and send half to each filter and speaker. This is a *parallel* crossover. Rather than make a voltage divider out of resistors, we make one out of a pair of filters. In the lower left panel of the figure above, the audio input signal is split into two. On the branch going to the tweeter, we put a capacitor in series, which ensures that only the high-frequency part of the signal will take this path to the tweeter. The leftover low-frequency parts of the signal take the other branch to the woofer. This design is much more common, mainly because the two filter sections do not interact, which means they can be designed separately. Further, the sensitivity to component variation is far less. The lower right diagram is a re-rendering of the same circuit, adding a shorting capacitor and resistor for the woofer and tweeter. In this geometry, it is (perhaps) easier to see that both filters receive the same signal, and thus act independently.