

## CROSSTALK IN INDUCTORS

We've all heard of inductor crosstalk, but what exactly is it, and how can we eliminate it? Well, first a little background on inductors...

Inductors store and release energy. They do not pass it straight through, like a resistor; rather, there is a finite time from when the energy is first "given" to the inductor to when it will "release" the energy. It is this phenomenon of energy storage that allows the inductor to perform as a low pass or high pass filter! The crossover designer uses the delay time of the inductor to create the desired frequency response function.

Now, an inductor is physically a coil of wire, sometimes wrapped around a metal core. Regardless of its physical construction, all inductors are basically the same thing; that is, a coil of wire that stores energy. But where is the energy stored?

The inductor stores its energy in a field - specifically, the magnetic field. All electrical circuits can be thought of as interacting with two fields: the electric field, or the magnetic field. The electrical circuit can either put energy into a field and then draw it back out later (like capacitors and inductors), or just ignore the fields altogether (like resistors). A prime example of an inductor and its magnetic field is an electromagnet: here, a large coil of wire is energized by a current of electricity, creating a magnetic field that can pick up ferrous metals (if you want to make your own electromagnet, connect a two ohm resistor in series with an inductor, then connect the network across a battery. In one direction, you'll be able to pick up paperclips!).

So, now that we know the inductor stores the energy into the magnetic field, it becomes pretty obvious how two inductors can "crosstalk". What happens is that their magnetic fields interact. A change in one inductor's magnetic field causes the other field to change as well; so a signal put into one inductor can crosstalk, or couple, to the other inductor. In fact, this is the basic principle of a transformer: put a signal at a given amplitude into one inductor, it stores it into the magnetic field, and the other inductor pulls the energy back out, at a different amplitude (if so desired).

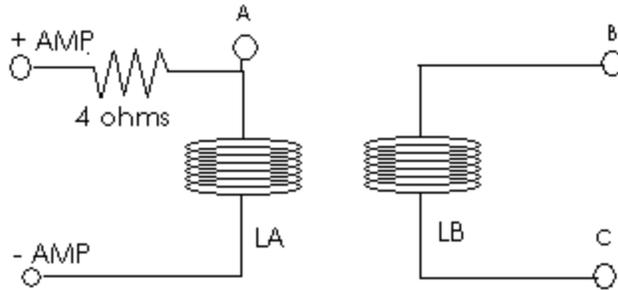
So, why is this bad? Well, imagine you've got an inductor on your woofer, and one on your tweeter. Enough said? No? Well if the two inductors are coupled or crosstalking, when the bass notes are fed to the woofer, they're also fed to the tweeter! And tweet notes fed to the tweeter are also coupled to the woofer! In essence, crosstalk can make your tweets woof and your woofs tweet - NOT a good thing!

So, how can we eliminate crosstalk? Simple: make sure the inductor's magnetic fields do not interact! Now there are two ways to do this: one is to physically separate the inductors, and hence the fields. The interaction takes place over a few inches; space them apart by a few feet, and no problem! However, this is often not practical, as a crossover with many inductors could quickly occupy several tens of square feet!

The second approach is to place their fields at 90° to each other. Huh? Well, the fields can be thought of as "aligned" with the coils themselves. If a field is not aligned with the coil, then the coil can't see it. Think of polarized lenses. Light is polarized to all have the same "polarity". Pass light through one polarizing lens, and the light is polarized in one direction. Try to pass it through a second polarizing lens at a different angle (direction), and it won't make it! The light is polarized to the first lens, not the second.

The same is true with the magnetic fields. Physically align the field of one inductor, and you can either cause great crosstalk by perfectly aligning the second inductor to match the first, or no crosstalk by setting the alignment completely out.

Now, the alignment can be considered "out" when the two inductors' magnetic fields are 90° rotated to each other; in fact, a exact 90° rotation will create a perfect out-of-alignment situation - no crosstalk! But how do we get there? Well, here's an approach to measure the crosstalk, and thus eliminate it:



- Connect a 4 ohm resistor in series with inductor LA.
- Connect the 4 ohm resistor/inductor A network to the output of an amplifier (between +AMP and -AMP).
- Play pink noise through the amplifier.
- Connect one channel of an oscilloscope to the output of the resistor, point A - this is the input level.
- Connect the other channel of the oscilloscope to inductor LB (points B and C).
- Rotate the two inductors until a minimum signal is detected from inductor LB. Note that using an oscilloscope allows one to measure the total loss in volts (and hence in dB, which is  $20 * \log(V_b/V_a)$ ) of the input signal.
- Glue everything down!

If you do not have access to an oscilloscope, you can just connect a sensitive driver (like a tweeter) in place of CH2 probe (from point B to point C), and listen for a minimum output. We've had good results with a Focal T120K in place of the oscilloscope - nothing like 94+ dB sensitivity to listen to the coupling! When you hear a minimum output from the driver, you've got things pretty well aligned!

While a 90° orientation will minimize the output, it needs to be 90° in two axes; one axis is not enough! So, for instance, lay one inductor "down", and set the other on end and rotated 90 degrees. This will create a 90° rotation in two axes, and minimize the overall crosstalk.

Also, 88° will result in significantly more crosstalk - you need to get as close to true 90° as possible; oftentimes just lining up the middles won't work, because the overall field is slightly offset (due to a few more windings on one half of the inductor versus the other). Shoot for 90°, every time. And with this technique, you can get there pretty quickly, with little pain.