Estimating wire & loop inductance: Rule of Thumb #15

Eric Bogatin - September 04, 2014

Spoiler summary: The loop inductance of a circular loop is about 25nH per inch of circumference.

Remember: before you start using rules of thumb, be sure to read the Rule of Thumb #0: Use rules of thumb wisely.

Previous: Resistance of a copper trace: Rule of Thumb #14

The concept of inductance has the highest [importance × confusion] product in the industry, followed closely by impedance. This is partly due to how it's taught in school – hidden behind a lot of math – and partly due to how most people pick it up on the "street", from "technical" articles written by folks who don't understand inductance themselves.

If you really want to understand inductance and its many flavors, such as self, mutual, loop, partial, total, internal, and external, you might want to read the *Inductance* chapter in my book, Signal and Power Integrity-Simplified, published by Prentice Hall.

I find much of the confusion arises from not adding the appropriate adjective to inductance. Just talking about "inductance" is way too ambiguous. You should get in the habit of referring to the "loop self" inductance or the "total" inductance.

In 58 words, inductance is: "a measure of the efficiency of generating rings of magnetic field at the cost of current. It is a measure of how good a conductor is at generating rings of magnetic field lines per amp of current. A conductor with a high inductance will generate lots of rings of magnetic field lines for a small amount of current."

The adjectives tell us around which part of the conductor we are counting the field lines, and in which conductor we are measuring the current.

The inductance associated with a collection of conductors has nothing to do with the current; it's about the geometry. Every geometry has a different connection between the structural features and its inductance.

One of the reasons why inductance is so confusing and hard to estimate is that it often involves two triple-integrals. One triple-integral calculates the magnetic field density at each point in space from a 3D collection of currents, and the second triple-integral calculates all the number of rings of magnetic field lines around the 3D conductor.

In this rule of thumb, we will look at the specific case of loop self-inductance of a circular loop of round wire. The loop self-inductance of a circular loop is really the number of rings of magnetic field lines surrounding the wire – which also happen to pass through the center of the loop – per amp of current in the loop. **Figure 1** shows the shape of the magnetic field lines with 1 amp through the wire.

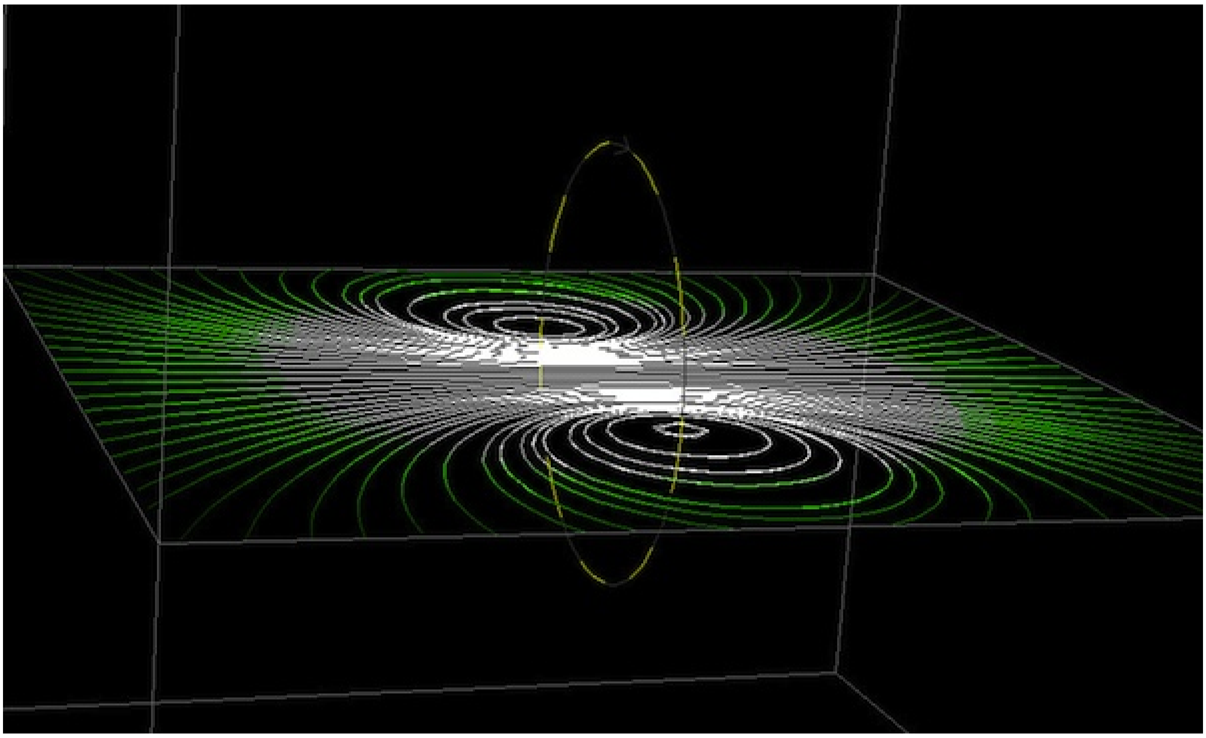

Figure 1 Magnetic field lines around a circular loop of wire with 1A of current. The dashed line is the loop with the current.

When the two triple integrals to calculate the number of rings of magnetic field lines completely surrounding the closed loop of wire are evaluated, we get a very complicated expression. In the extreme case – of a loop of large diameter compared to the wire diameter, we can approximate this complex relationship with a simple analytical expression:

$$L_{loop} = \mu_0 a \left(\ln\left(\frac{8a}{WR} \right) - 2 \right)$$

Where:

L_{loop} is the loop inductance in nH

a is the loop radius in inches

WR is the wire radius in inches

μ_0 = permeability of free space, 32 nH/inch

Notice that for a round loop, the loop inductance is *not* proportional to the area of the loop (a^2). Nor is it proportional to the circumference (a). It is proportional to a × ln(a). This makes loop self-inductance just that much more complicated.

Let's look at a simple example. With the tips of your index finger and thumb together, you can make a loop with a radius of about 1 inch. If this loop was composed of 24 gauge wire, with a radius of 10 mils, its loop self-inductance would be about:

$$L_{loop} = \mu_0 a \left(\ln\left(\frac{8a}{WR} \right) - 2 \right) = 32 \frac{nH}{in} \times 1in \times \left(\ln\left(\frac{8 \times 1in}{0.01in} \right) - 2 \right) = 150nH$$

Notice that the wire radius and the second term for the loop radius are in the ln function. They are only very slowly varying. As a rough rule of thumb, to create a simple way of estimating loop self-inductance, we can say that this 150nH of loop inductance is distributed around the circumference of the loop. The circumference of a loop with a radius of 1 inch is about 6 inches.

> *The loop self inductance, distributed per inch of circumference, is roughly 150nH / 6 inches, or 25nH per inch of circumference. This is the origin of the rule of thumb that the total inductance of a wire is about 25 nH/inch. The hidden assumption is that the wire is really part of a loop!*

For example, take an axial lead resistor, mounted to a board, and therefore like part of a complete loop. If it's 0.25 inches long, its total inductance is about 0.25" × 25nH = 6nH.

Now you try it:

1. What is the total inductance of a via?
2. What is the loop inductance of two wires from a power supply that are 4 inches apart and 4 inches long?

Next rule of thumb #16: Estimating sheet inductance of a cavity.

Additional information on this and other signal integrity topics can be found at the Signal Integrity Academy, www.beTheSignal.com.

Also see:

- Resistors aren't resistors
- Designing high-current chokes is easy