[Total inductance in the return path: Rule of Thumb #7](#)

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This rule of thumb estimates the total inductance in the return path of a flat, wide conductor.

$L_{total} \sim 10$ nH/inch x Len

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

Previous [Rule of Thumb #6: Inductance per length in all 50 Ohm transmission lines in FR4.](#)

Inductance is probably the most confusing and incorrectly applied concept in signal integrity. (If you are looking to get a firm understanding of inductance, see chapter 6 in my [textbook](#), *Signal and Power Integrity- Simplified*.)

There are two schools of thought about inductance: those who will only talk about a loop inductance and those who are brave enough to look under the hood and leverage the powerful, and dangerous, principles of partial inductance. It's dangerous because there are a lot more ways of making mistakes using partial inductance. It's powerful because if you really know how to use it, partial inductance can often help guide you in design decisions, especially about ground bounce.

Ground bounce is the voltage noise generated across the return path of an interconnect as a dI/dt of switching return current passes through its total inductance.

The next rule of thumb covers how to estimate the amount of ground bounce in a connector. But, before we can estimate the ground bounce expected, we have to be able to estimate the total inductance in the return path. The problem is this is generally really hard.

The total inductance of a return path depends not only on the geometry of the return path, but also on the geometry and location of the signal path. Change the location of the signal path, and the total inductance in the return path changes.

We are faced with the fundamental tradeoff of simplifying the problem enough to make the calculation easy, and at the same time keeping it close enough to real situations to be useful.

There are two geometries where the total inductance in the return path has a simple form and for which we can develop a simple estimate: when the two conductors are two parallel round rods, like a

pair of wire bonds, or a pair of vias, and when the conductors are two wide, parallel, flat leads, side by side. Surprisingly, the result is just about the same.

In this rule of thumb, we will consider the very special geometry of two flat conductors, like adjacent leads in a lead frame package. An example of the geometry we analyze is shown in Figure 1.
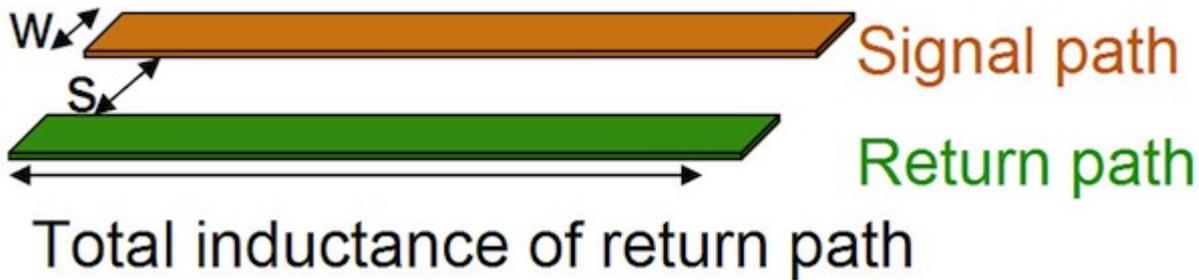
*Figure 1 Geometry considered in this rule of thumb*

There are no good analytical approximations for the total inductance in one leg of these conductors, but we can use a 2D field solver to calculate it. We take two long conductors, send current down one, let it return down the other and calculate the total inductance in each leg. If the two conductors are symmetrical, the total inductance in either leg is just half the loop inductance.

If they are long, the loop inductance, and the total inductance of the return path, scales with length. This means we can consider the total inductance per length of the return path.

Remember another one of my rules: never do a measurement or simulation without first anticipating the result.

We would expect that as the line width of each line increases, keeping the spacing between them fixed, the total inductance of the return path will decrease, a little bit. In addition, if we keep the line width fixed, and pull the conductors farther apart, the total inductance of the return path should increase.

How much will it be affected by the geometry? That's where we need to use the field solver to tell us. Figure 2 is the result, using in this case, the 2D field solver built into Agilent's ADS.
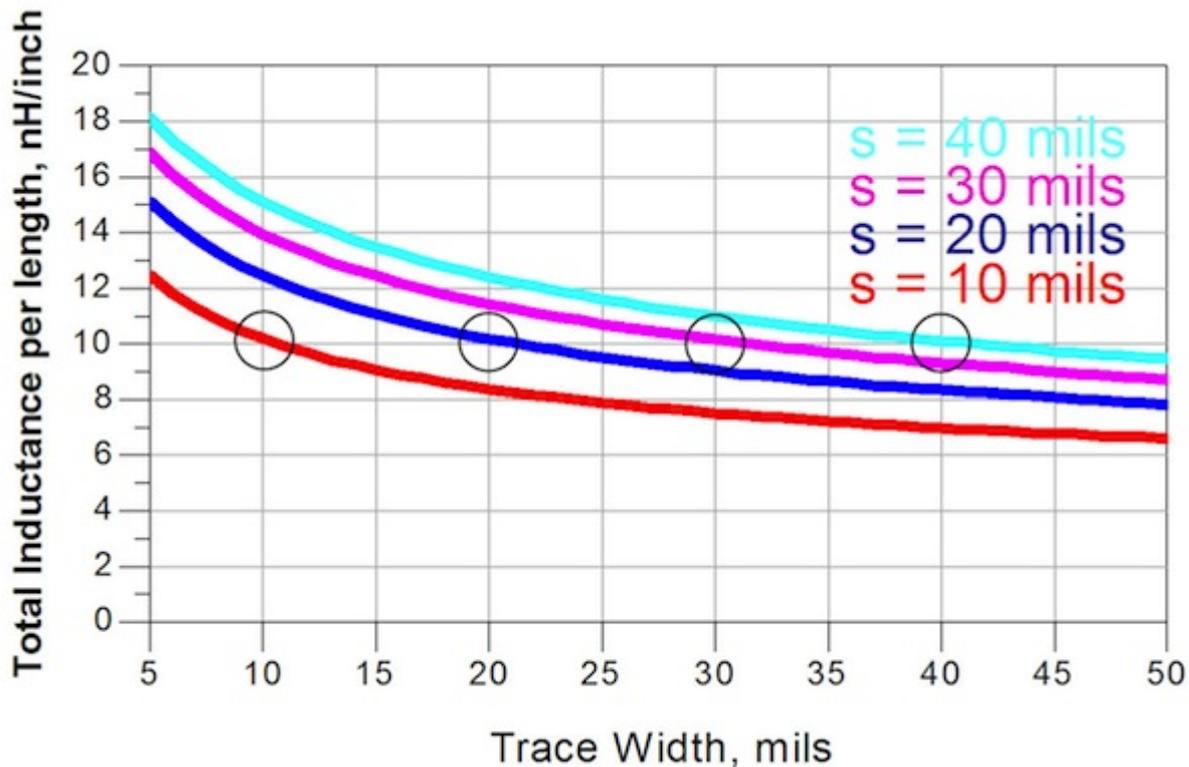
Figure 2. Simulated total inductance of the return path per length, as the trace width increases, for different separations.

The behaviors we see from the field solver predictions are exactly what we expected. What is surprising is that if we look at the special case of the line width equal to the separation, for each of the four different separations simulated, we find the total inductance in the return path is the same, 10 nH/inch.

This is the origin of the simple rule of thumb.

Rule of Thumb # 7: In the special case of two flat, wide conductors, adjacent to each other, with a spacing comparable to their line width, the total inductance of either one is just 10 nH/inch.

This rule of thumb helps us estimate the total inductance in the return path of a connector or package lead. Of course, if there is a conducting plane nearby, like a pair of microstrip leads, the plane can distort the inductances and this rule of thumb does not apply.

For example, in a lead frame of a package where adjacent conductors are wide, flat and spaced comparable to their width, the total inductance in the return path would be about 10 nH/inch. If the lead is 0.3 inches long, the total inductance would be 10 nH/inch x 0.3 inch = 3 nH.

Now you try it:

1. What is the total inductance in a connector pin that is 0.5 inches long, like a pin-in-box connector?
2. What is the total inductance in the return path of a 2 layer BGA lead that is 0.4 inches long?

Next rule of thumb: RoT #8: Estimating ground bounce in a connector

Also See: