How to engineer acceptable far-end crosstalk: Rule of Thumb #21

Eric Bogatin - December 10, 2014

Far-end crosstalk can often cause a product to fail. Unless you select the transmission line features carefully, FEXT will likely be an issue. Here is a simple way to make sure you have a robust design.

Spoiler summary: Far-end crosstalk (or FEXT) in microstrips scales with the coupled length and inversely with rise time. In single-ended, tightly spaced, 50Ω microstrips in FR4, the amount of far-end crosstalk is 0.5% × Len[in]/RT[ns].

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

Previous: How far is far enough? Signal line spacing for acceptable near end crosstalk: Rule of Thumb #20

Far-end crosstalk is the noise on the quiet line which propagates in the direction of the signal on the aggressor line. It is one of the most subtle sources of noise. If you really want to understand the principles and root cause of all three of the noise sources, check out Chapter 10 in Signal and Power Integrity- Simplified, or the EPSI course on the Signal Integrity Academy.

We can describe the origin of far-end crosstalk in two very different, seemingly unconnected explanations:

> In one explanation, we describe the two transmission lines as single-ended lines with coupling. Then far-end crosstalk is due to the difference between the capacitive coupling and the inductive coupling between the two adjacent lines. These coupled noises subtract in the forward direction. When they are equal, they cancel out and there is no far-end crosstalk. This is the case in any stripline geometry, where the dielectric is uniform. There is no far-end crosstalk in stripline.
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> We can also describe these two single-ended transmission lines with coupling as one differential pair. In this explanation, far-end crosstalk arises from the difference in speed of a differential and common signal. In microstrip, the differential signal travels a little faster than the common signal. What we call far-end crosstalk is really the leading edge of the differential signal component reaching the far-end of the victim line before the common signal component.

Both explanations are correct and they both highlight the features in the transmission lines which contribute to far-end crosstalk. The best way of reducing far-end crosstalk is to route the traces in stripline. But, since the surface traces are “free”, everyone uses them. You just have to watch out for a potential far-end noise problem.

The peak far-end noise scales with the coupling length. The longer the coupling path, the more opportunity there is for the noise to couple over and build on the quiet line. This means long busses on the surface will have more far-end crosstalk.

The peak amount of far-end noise also scales inversely with rise time (RT). The shorter the rise time, the larger the coupled noise that builds up as it propagates. This means that a design that did not have a far-end crosstalk problem suddenly has one when the rise time is reduced, like in a die shrink.

The relative amount of far-end noise is proportional to Len/RT.

The third element which determines just how much far-end crosstalk is created is the spacing between the two lines. The closer the spacing, the more the far-end crosstalk.

The recipe for a far-end crosstalk disaster is long, tightly spaced busses carrying short rise time signals. If you have this combination on your board, you’d better check the numbers to see how bad the far-end crosstalk could be.

Unfortunately, there are no good analytical approximations to estimate the amount of far-end crosstalk in microstrip. The only way of calculating it is with a 2D field solver.

Figure 1 is the scaled amount of far-end crosstalk for a 1 inch line with a 1 ns rise time, for a pair of 50Ω lines in FR4. We calculate the coupling coefficient, k, in the expression FEXT = k × Len/RT. From this curve, we can estimate the FEXT for any spacing, length, and rise time for 50Ω lines in FR4.

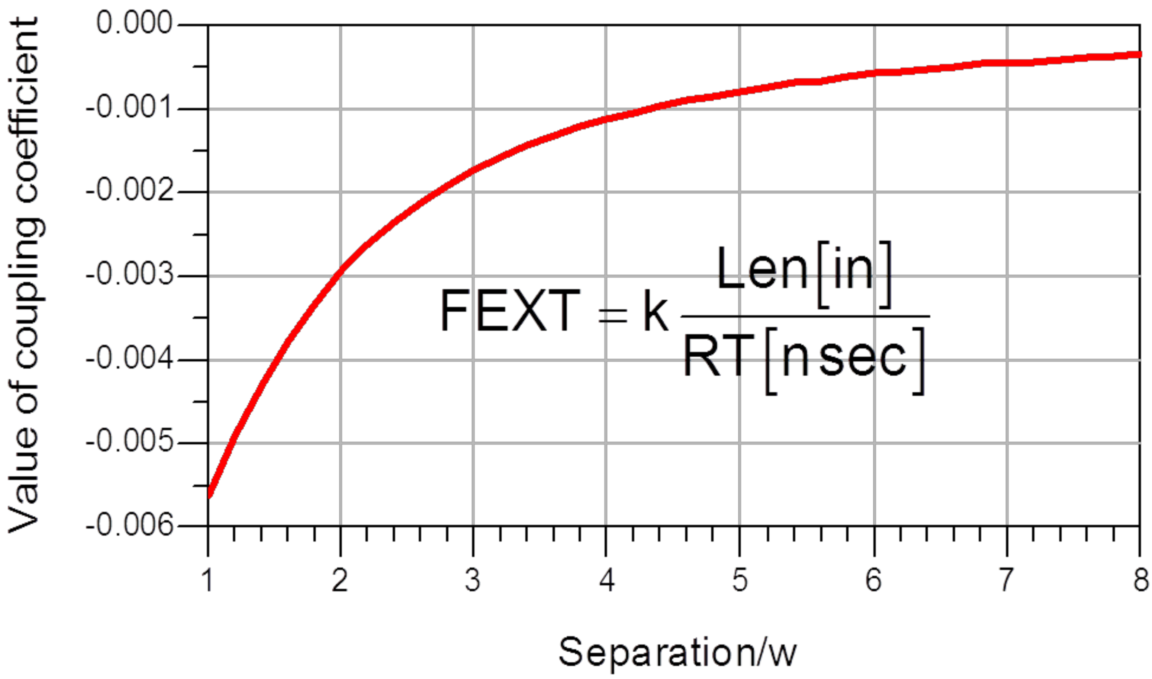

Figure 1

For example, with a spacing equal to the line width, the coupling coefficient, k, read off the graph, is about 0.0055, or 0.5%. In this case, the far-end noise would be:

$$FEXT = 0.5\% \frac{Len[in]}{RT[nsec]}$$

If the coupling length is 10 inches, and the rise time is 1 ns, the FEXT = 0.5% × 10”/1ns = 5%.

As we showed in Rule of Thumb #19, 5% crosstalk is probably acceptable. But if the victim line has an aggressor on both sides, and they have the same bit signature, the far-end noise on the victim line would be 10%. And if there were a die shrink and the rise time dropped to 0.5 ns, then the far-end noise would be 20%. Now we’re talking a lot of noise.

Now you try it:

1. In a DDR bus, the spacing equals the line width, the rise time is 0.3 ns, and the coupled length is 5 inches. Should we worry about FEXT?
2. Suppose the line impedance in the example above were not 50Ω, but 60Ω. Would the far-end crosstalk increase or decrease?

Next rule of thumb #22: At what frequency will there be a dip in the insertion loss for adjacent microstrip transmission lines?

Also see:

- Bogatin's Rules of Thumb
- Measuring crosstalk in differential signals
- Minimize crosstalk with optimized PCB routing technique
- Getting EMC design right – First time, Part 7: Crosstalk
- Guard traces - use 'em, or not?

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