Crosstalk:
Optimum trace spacing

Karthik Raj Guruchandran
www.basebandhub.com

Abstract:

When the frequencies are higher the effect of having a trace next to another becomes more pronounced and the associated losses increase. In this article I have discussed about this particular effect of having traces next to each other. I have presented some background on this phenomenon called Crosstalk and also tried to present some numerical data to show how crosstalk varies with trace spacing.

Background:

Crosstalk can be defined as unintentional coupling of noise from one circuit to another. A typical example of crosstalk would be noise coupling from a trace carrying a clock signal into a Reset signal routed next to it. In this example, when the clock switches from low to high the change in current in the clock trace creates a magnetic field around that trace. This magnetic field is a reactive field that stores energy and not a radiating field that is lossy. The magnetic field associated with the clock trace extends beyond the trace itself (for a few millimeters). Any other trace that is next to this clock trace will see an impact of the magnetic field associated with the trace. This magnetic field induces a flow of current on the trace that lies next to it. This induced current is not intentional instead it is pure noise getting coupled on to it.

A transformer analogy is generally used to explain the crosstalk phenomenon. When alternating voltage is applied on the primary coil, a magnetic field is created around the primary coil due to the flow of current. The Magnetic field induces a current flow on the secondary coil and energy is transferred. In this case, it is not called crosstalk (though the concept is the same) as it is intentional.

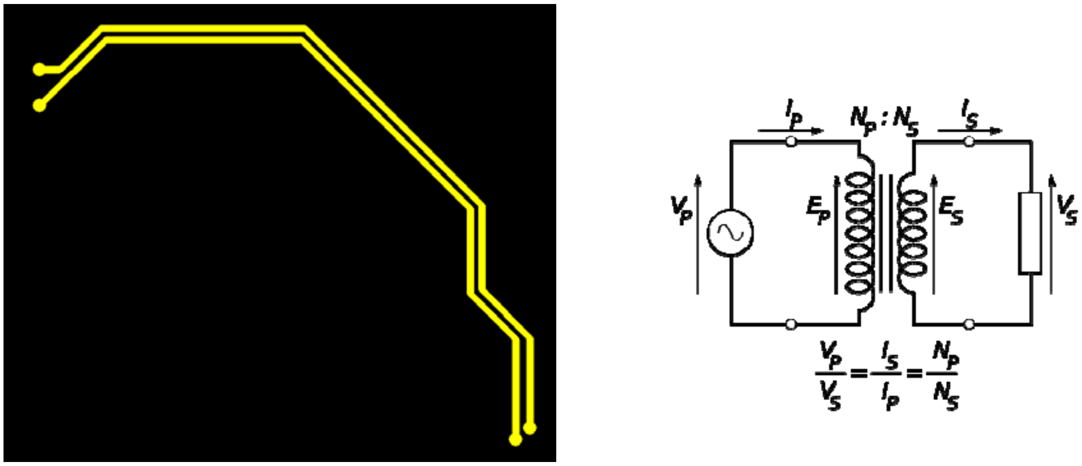

Figure 1: Two traces routed next to each other (left) Ideal Transformer[1] (right)

References:
1) http://en.wikipedia.org/wiki/File:Transformer_under_load.svg

Types of Crosstalk:

Crosstalk can occur because of inductance and also because of capacitance that exist between a trace pair. The terminology used for a trace that carries the actual signal is called the aggressor trace and the trace that lies next to the aggressor trace is called the victim trace.

The capacitive crosstalk happens because of the capacitance associated between the aggressor and the victim traces. To explain in more detail, consider a clock signal traveling on the aggressor line. When the signal switches states, flow of current happens. As current is flow of electrons that are negatively charged particles, the electrons in the victim line get repelled away from their location and that cause current flow. This crosstalk happens due to capacitance that exists between traces and is called capacitive crosstalk.

The inductive crosstalk is different from capacitive crosstalk since it happens because of the magnetic field generated due to the flow of current. The magnetic field then induces current flow on the victim trace thereby causing crosstalk.

Impact of Crosstalk:

There are equations one can use to understand how much crosstalk can occur in real-time on a PCB trace. The simple form of the formula (2) is:

$$\alpha = \frac{1}{1+(D/H)^2}$$

Where,

D is the distance between the two traces
H is the distance from the reference plane

Table 1 shows the calculated crosstalk between two traces that are routed 1mm above the ground plane. To understand the impact on cross talk on trace impedance, I simulated two traces of equal length (50.8mm) running parallel to each other at 1mm distance from the reference plane. In the meantime, I also simulated the crosstalk from one trace to another using the above mentioned parameters to see how closely it relates to the calculated values. One important point to note with the formula is that it is independent on frequency. This is only true to some extent and plotting S-parameters are the right way to understand the variation of crosstalk over frequency.

Trace Spacing (mm) (centre-centre)	**Coupling co-efficient (α)**	**Computed Crosstalk (dB)**
2	0.2	-13.97940009
2.25	0.164948454	-15.65303503
2.5	0.137931034	-17.20676013
3	0.1	-20
4	0.058823529	-24.60897843
5	0.038461538	-28.29946696

Table 1: Calculated Crosstalk

First, I started of by simulating crosstalk with the 3D models to plot S-parameters at various trace spacing. From the results I computed trace impedance using TDR method. The designed trace impedance and the source and termination ports were all 50 ohms. But it was interesting to see the variation in impedance due to coupling between the traces. The trace impedance reduces because the L and C values that are associated with the trace get affected by having another trace next to it.

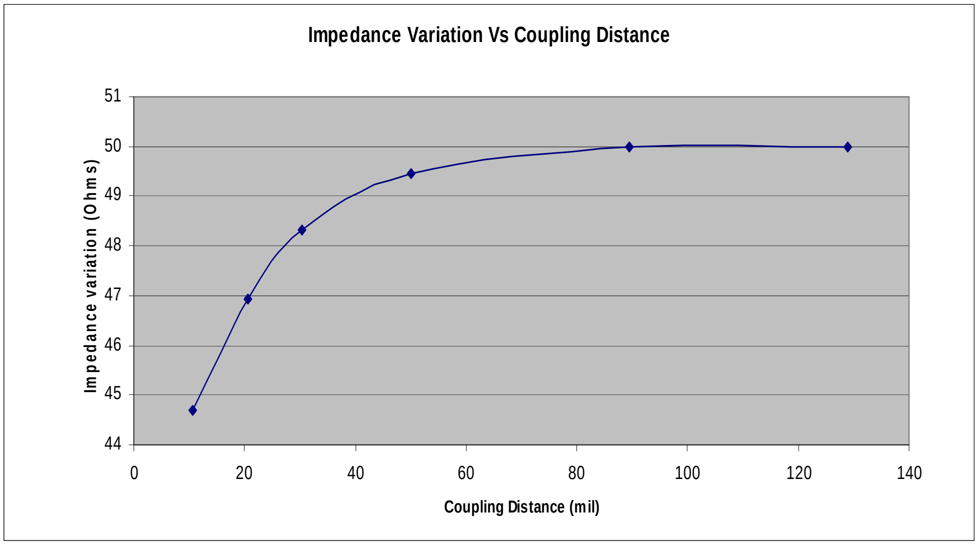

Figure 2: Simulated Impedance Variation Vs Coupling Distance

Due to the impedance mismatch, the S11 increased significantly when the traces were close to each other and reduced as the traces were moved apart. This re-iterates maximum power transfer theory – as line impedance gets closer to source and termination impedance the reflection gets lower and maximum energy gets transferred. Below is a plot of S11 at various trace spacing at 750MHz.

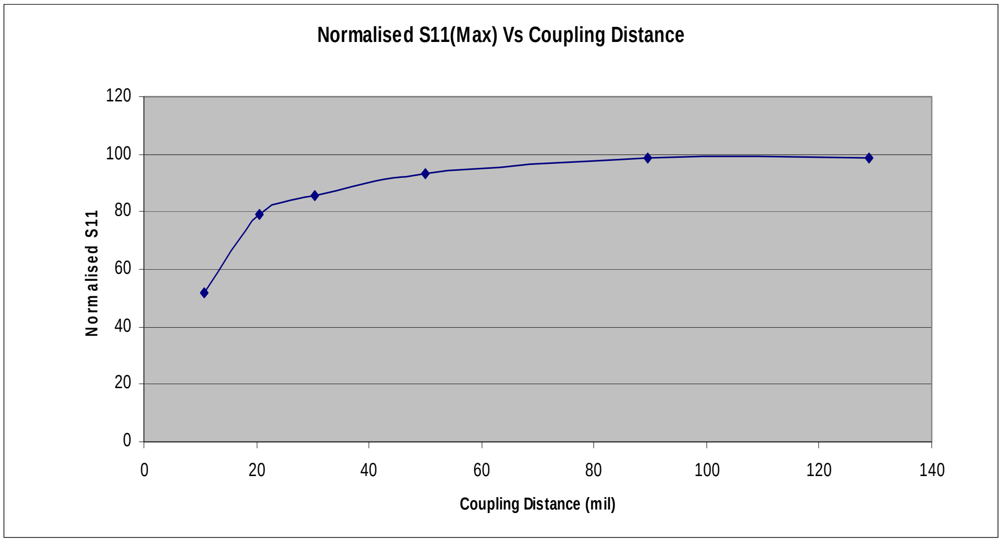

Figure 3: Normalized S11 Vs Coupling Distance

Note: The values shown in Figure3 are normalized to maximum value of S11 simulated on a single trace.

As we can see, the return loss is almost double at a trace spacing of 10mils when compared to a trace spacing of 50mils and is 30% more at 10mils spacing when compared to 20mils spacing. The S3,1 value that represents the crosstalk showed a nice and linear response as trace spacing increased. This is the absolute measure to understand near end crosstalk between two traces. The simulated S3,1 results match very closely the calculated crosstalk as shown in Table 2.

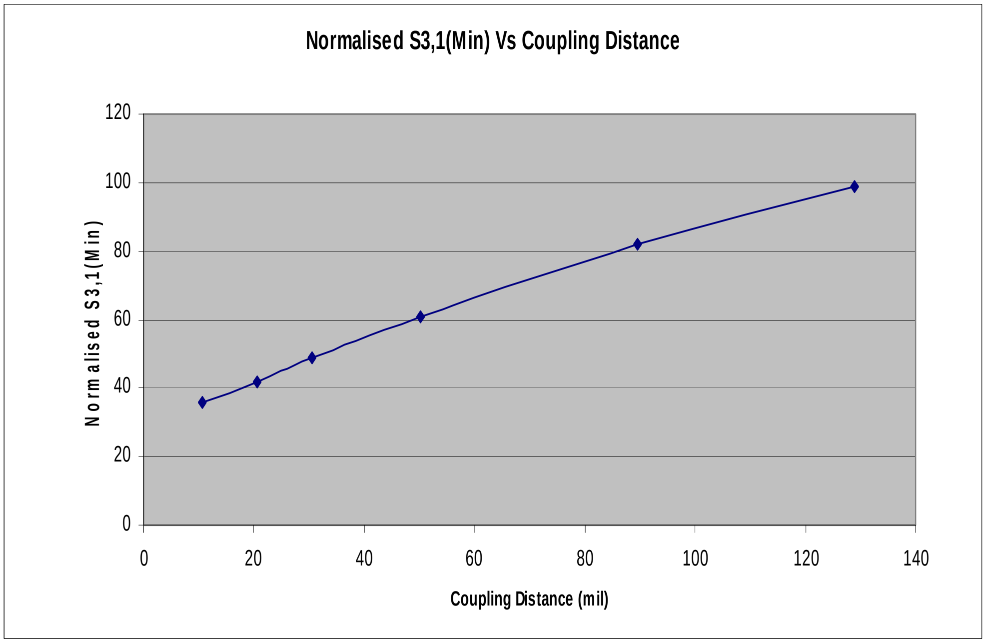

Figure 4: Normalized S31 Vs Coupling Distance

Note: The values shown in Figure 4 are normalized to maximum value of S31 simulated with a spacing of 130mils (edge to edge).

Trace Spacing(mils) (edge-edge)	Coupling co-efficient (α)	Computed Crosstalk (dB)	S3,1@750MHz (dB)	Computed – simulated (dB)
10.740136	0.2	-13.97940009	-9.94	-4.039400087
20.582636	0.164948454	-15.65303503	-11.61	-4.043035032
30.425136	0.137931034	-17.20676013	-13.5	-3.706760131
50.110136	0.1	-20	-16.91	-3.09
89.480136	0.058823529	-24.60897843	-22.76	-1.848978428
128.850136	0.038461538	-28.29946696	-27.46	-0.839466959

Table 2: Simulated Vs Computed Crosstalk

Conclusion:

Traces that are separated by more than 2mm (80mils) have very less impact because of crosstalk. The effect of crosstalk on nearby traces reduces significantly as spacing increases. The relation between trace spacing and near end crosstalk looks linear (in dB scale). A benefit of around 1.5 - 2dB can be achieved by spacing the traces 10mil further apart. This could be used as a good rule of thumb by any designer working on high speed signal.