Design Tips

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Welcome to Design Tips! In this issue, I would like to share my experience with locating high speed traces on printed circuit boards.

Please send me your most useful design tip for consideration in this section. Ideas should not be limited by anything other than your imagination! Please send these submissions to bruce.arch@ieee.org. I'll look forward to receiving many "Design Tips!" Please also let me know if you have any comments or suggestions for this section, or comments on the Design Tips articles.

High Speed Traces Close to Edge of Reference Plane

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There is a well known EMC rule which cautions never to route a trace too close to the edge of the PCB board and/or reference plane. I have seen rules that state the trace should be no closer than 500 mils, others requiring greater distances. Like most things in EMC rules, there is a grey area, and the good/bad of a particular distance is not black and white.

The reason for this rule is that the return current for the trace is not 100% under the trace; it will spread out a little in order to minimize the overall inductance. If the trace is too close to the edge, then there will be a relatively large amount of current along the edge of the plane, which can radiate and cause EMC problems. Figure 1 shows how this current in the return plane changes as we move further from the microstrip. Note, if the plane is infinite, then the current continues to decrease all the way to infinity. On real-world boards with finite sized planes, the current that would have been in the region beyond the finite sized plane must go 'somewhere', and in fact, the current along the edge will increase slightly to account for this lack of an infinite plane.

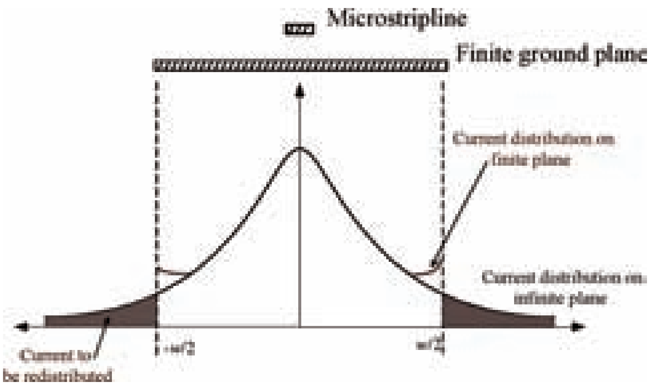

Figure 1. Current Distribution under Microstrip Trace.

Calculating the amount of current along the edge of the plane, given the height of the trace above the plane, and the distance to the edge of the plane, is relatively straightforward. Figure 2 shows a microstrip configuration and equation (1) shows how to calculate the edge current, based on the amplitude of the current on the trace and the physical geometry [1-2].

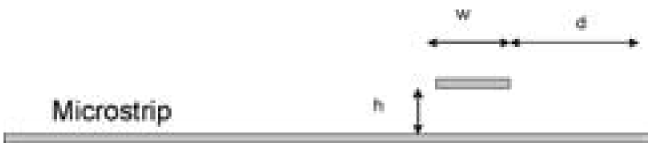

Figure 2. Microstrip Configuration.

$$I_{Edge} = \frac{I_{Signal}}{\pi}\left(\frac{\pi}{2} - \arctan\left(\frac{w_g - 2\left[\left(w_s/2\right) - d\right]}{2h}\right)\right) \quad (1)$$

where:

I_{signal} = the current amplitude (in linear scale) for each harmonic of the current waveform

w_g = the width of the ground-reference plane (set to 1000 always)

d = the distance from the trace to the edge of the ground-reference plane

h = the height between the trace and the ground-reference plane

The calculation for symmetrical and asymmetrical stripline is very similar. Figures 2 and 3 show the configuration for symmetrical and asymmetrical striplines, respectively, and equations (2) and (3) give the formula to calculate the current on the edge of the planes.

Figure 3. Symmetrical Stripline Configuration.

$$I_{Edge} = \frac{I_{Signal}}{2\pi}\left(\frac{\pi}{2} - \arctan\left(\frac{w_g - 2\left[\left(w_s/2\right) - d\right]}{2h}\right)\right) \quad (2)$$

where:

I_{signal} = the current amplitude (in linear scale) for each harmonic of the current waveform

w_g = the width of the ground-reference plane (set to 1000

always)
d = the distance from the trace to the edge of the ground-reference plane
h = the height between the trace and the ground-reference plane

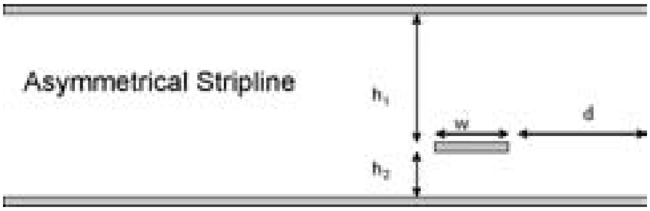

Figure 4. Asymmetrical Stripline Configuration.

$$I_{Edge-Nearest} = \frac{I_{Signal}}{\pi}\left(\frac{h_2}{h_1}\right)\left(\frac{\pi}{2} - \arctan\left(\frac{w_g - 2\left[\left(w_g/2\right) - d\right]}{2h_2}\right)\right) \quad (3a)$$

$$I_{Edge-Furthest} = \frac{I_{Signal}}{\pi}\left(\frac{h_1}{h_2}\right)\left(\frac{\pi}{2} - \arctan\left(\frac{w_g - 2\left[\left(w_g/2\right) - d\right]}{2h_1}\right)\right) \quad (3b)$$

where:
I_{signal} = the current amplitude (in linear scale) for each harmonic of the current waveform
w_g = the width of the ground-reference plane (set to 1000 always)
d = the distance from the trace to the edge of the ground-reference plane
h_1 and h_2 = the height between the trace and the ground-reference plane

Figure 5 shows a plot of the current on the edge for the microstrip and symmetrical stripline normalized to the current on the trace.

How Much is Too Much?

This is a difficult question to answer without a lot of detailed analysis of the PCB configuration. However, we can get an order of magnitude using some simple analysis. If we consider the edge of the reference plane as a thin wire antenna when looking at the edge view (similar to a dipole antenna), and looking at the most efficient radiation model, we can use a half-wave dipole model. The far field for a half-wave dipole is given in equation (4).

$$E_\phi = \frac{120\pi I \sin\theta}{r} \quad (4)$$

where:
E_ϕ = Electric Field (V/m)
I = current amplitude (A)
r = distance to observation point (meters)
θ = angle from dipole to observation point

Let's take an example where the fundamental harmonic frequency has an amplitude of 10 ma and the microstrip trace is 10 mils above the plane, and 300 mils from the edge of the plane (distance/height = 30). From Figure 5 we see the normalized edge current will be 40 dB less than the trace current, giving us 100 μa of current along the edge of the plane. Using this value of current, and maximizing the angle, we will have ~ 71.5 dBμV/m at 10 meters from the edge of the plane. We can use this very approximate value to very roughly determine the amount of shielding that may be required to meet emissions standards. We can also see that if we are able to move the trace further from the edge to 3000 mils (ratio of 300), we can see that we will reduce the current along the edge (and the radiated emissions) by 20 dB for this potential issue.

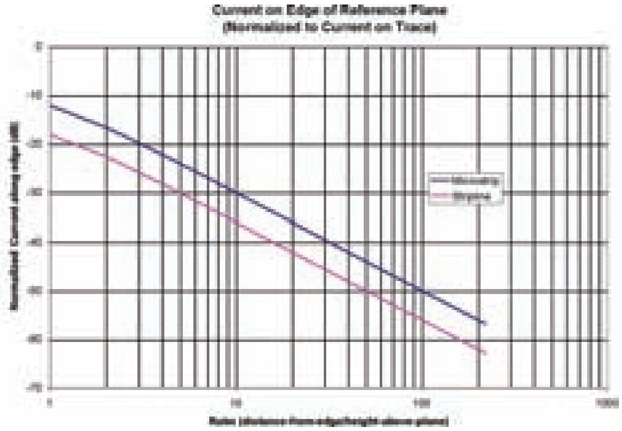

Figure 5. Normalized Current on Edge of Reference Plane.

Summary

This article shows how to do some rough calculations to determine the effect of a trace's distance to the edge of the reference plane. The emissions calculation is very rough, and should only be used with extreme care. For example, if the length of the board is much smaller than a half-wave length, the dipole equation is not appropriate (but will provide a worst case result). The emissions will be directly proportional to the amplitude of the current along the edge of the plane, so reducing the current will have a corresponding reduction in the emissions for this potential issue.

References:

[1] M.Y. Koledintseva, J.L. Drewniak, T.P. Van Doren, D.J. Pommerenke, M. Cocchini, and D.M. Hockanson, "Method of edge currents for calculating mutual external inductance in a microstrip structure," Progress in Electromagnetic Research (PIER), Vol. 80, Jan. 2008, pp. 197-224.

[2] M.Y. Koledintseva, J.L. Drewniak, T.P. Van Doren, D.J. Pommerenke, M. Cocchini, and D.M. Hockanson, "Mutual external inductance in stripline structures," Progress in Electromagnetic Research (PIER), Vol. 80, Jan. 2008, pp. 349-368.

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