Reduction in Reflections and Ground Bounce for Signal Line through a Split Power Plane by Using Differential Coupled Microstrip Lines

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Abstract

The signal propagating along a microstrip line over a slot on the power plane will suffer from composite effects of reflected noise by a discontinuity in signal return path and ground bounce between power/ground planes. The paper investigates the noise reduction by using differential signaling. A efficient 2D FDTD method together with equivalent circuits for the differential line and the slot is established and simulations are performed for a three-layer structure to characterize ground bounce coupling.

1 Introduction

It is a common practice in a multi-layer printed circuit board (PCB) or multi-chip module (MCM) to cut a slot in ground or power plane. For example, cutting a power plane into several areas provides multiple power distribution and making isolated power or ground plane area, called island, to isolate a noisy or sensitive circuit from other circuits. However, signal lines have to cross the slots in order to communicate between different areas. Thus incurred are signal integrity concerns due to the reflection by the discontinuity in signal return path[1] and if the multilayer environment, compound effects with the ground bounce due to the voltage fluctuations between power and ground planes[2].

One efficient way proposed for better signal integrity is to employ coupled line and propagate the signal in odd mode excitation, or differential signalling[3]. The electric field in odd mode is anti-symmetric to the center plane and there exhibits a voltage null which can be named as virtual ground to the signal. The virtual ground provides an alternative reference to the signals so that the impact of return path discontinuity to the signal quality can be reduced to a lesser degree. Differential signaling also offers the benefit in EMI reduction due to the cancellation of the magnetic fields resulting from the opposing current flows[4].

This paper presents an efficient scheme to investigate the signal integrity due to differential signal lines through a split power plane. The analysis scheme which consists of the two-dimensional FDTD method for the propagation of ground bounce, the transmission line theory for the signal propagation along differential microstrip lines and slot line, and an equivalent circuit for the mode coupling between signal lines, slot line, and radial mode in parallel plates. The effects of differential signaling on the coupling between ground bounce and signal propagation along the slot are thus characterized.

2 Theory and Circuit Modelling

Consider a multi-layer structure shown in Fig. in which the power plane is cut with a finite slot. The whole structure can be divided into two regions, one between the coupled microstrip lines and power plane, and the other between parallel metal plates with a split on one plane. Without loss of generosity, assume that the slotline is along $x = x_0 \equiv (i_0 + \frac{1}{2})\Delta x$ while the coupled microstrip lines are along $y = y_1 \equiv j_1 \Delta y$, $y = y_2 \equiv j_2 \Delta y$.

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The coupled microstrip lines can be modelled as transmission lines governed by the telegrapher's equation using central difference discretization. Base on the equivalent LC ladder circuits show in Fig. 2 , the signal propagation can be simulated by

$$\Delta x \frac{d}{dt}\begin{bmatrix} V_{\mu\text{strip},1} \\ V_{\mu\text{strip},2} \end{bmatrix}_{(i\Delta x,t)} = \frac{1}{C_s^2 + 2C_s C_m}\begin{bmatrix} C_m + C_s & C_m \\ C_m & C_m + C_s \end{bmatrix} \cdot \left\{ \begin{bmatrix} I_{\mu\text{strip},1} \\ I_{\mu\text{strip},2} \end{bmatrix}_{((i-1/2)\Delta x,t)} - \begin{bmatrix} I_{\mu\text{strip},1} \\ I_{\mu\text{strip},2} \end{bmatrix}_{((i+1/2)\Delta x,t)} \right\} \quad (1a)$$

$$\Delta x \frac{d}{dt}\begin{bmatrix} I_{\mu\text{strip},1} \\ I_{\mu\text{strip},2} \end{bmatrix}_{((i+1/2)\Delta x,t)} = \frac{1}{L_s^2 - L_m}\begin{bmatrix} L_s & -L_m \\ -L_m & L_s \end{bmatrix} \cdot \left\{ \begin{bmatrix} V_{\mu\text{strip},1} \\ V_{\mu\text{strip},2} \end{bmatrix}_{(i\Delta x,t)} - \begin{bmatrix} V_{\mu\text{strip},1} \\ V_{\mu\text{strip},2} \end{bmatrix}_{((i+1)\Delta x,t)} - \begin{bmatrix} V_{\text{slot}}(j_1\Delta y,t) \\ V_{\text{slot}}(j_2\Delta y,t) \end{bmatrix}\delta_{i,i_0} \right\} \quad (2a)$$

Under the consideration of ground bounce coupling, the telegrapher's equation for slotline becomes[2]

$$\begin{cases} C_{\text{slot}}\Delta y \frac{\partial}{\partial t} V_{\text{slot, k}}(j\Delta y,t) \cong -H_y((i_0+\tfrac{1}{2})\Delta x, j\Delta y, t)\Delta y - I_{\text{slot}}((j+\tfrac{1}{2})\Delta y,t) + I_{\text{slot}}((j-\tfrac{1}{2})\Delta y,t) \\ \qquad + I_{\mu\text{strip},1}(i_0\Delta x,t)\delta_{j,j_1} + I_{\mu\text{strip},2}(i_0\Delta x,t)\delta_{j,j_2} \quad (2a) \\ L_{\text{slot}}\Delta y \frac{\partial}{\partial t} I_{\text{slot, k}}((j+\tfrac{1}{2})\Delta y,t) = V_{\text{slot}}(j\Delta y,t) - V_{\text{slot}}((j+1)\Delta y,t) \quad (2b) \end{cases}$$

Here, L_{slot} and C_{slot} are the per-unit-length inductance and capacitance of slotline in the presence of power/ground planes, and H_y is the magnetic field in y direction under slotline inside the power/ground planes. In the region between two metal planes, the conventional 2-D FDTD is employed to simulate electromagnetic fields E_z, H_x and H_y. It is worthy mentioning that, due to the presence of the voltage on slotline , H_y is updated by [2]

$$\mu\frac{\partial}{\partial t}H_y((i+\tfrac{1}{2})\Delta x, j\Delta y,t)\Delta x\cdot d = [E_z((i+1)\Delta x, j\Delta y,t) - E_z(i\Delta x, j\Delta y,t)]d + \delta_{i,i_0}[V_{\text{slot}}(j_1\Delta y,t)\delta_{j,j_1} + V_{\text{slot}}(j_2\Delta y,t)\delta_{j,j_2}] \quad (3)$$

The time marching is the same as [2] and is omitted here .

3 Simulation Results

Consider the structures of 10cm x 10cm PCBs in Fig.1, in which the power plane is cut with a finite slotline. The length and width of the slot are 4cm and 0.05mm. The heights of signal layer and power/ground planes are 635 μm and 150 μm , respectively, and the material is of dielectric constant 9.7. The dimensions of this structure are the same as those in [2], but the signal trace is the differential coupled microstrip lines with both the width and separation being 0.25mm. The coupled microstrip lines are subject to an imposed differential Gaussian signal in Fig.3(a). Each voltage source is in series with an internal odd mode resistance of 50ohm, while onthe other end of the signal lines are connected with matched loads.

The voltages at points A and B are monitored and the waveforms are shown in Fig. 4(a), while the voltages at points a, b, and c in Fig 4(b) and the ground bounce beneath slotline in Fig. 4(c). As shown in Fig. 4(b),the voltage propagating along the slot decays continually due to the energy coupling onto power/ground planes. Due to the odd mode excitation, the voltage propagating along the slot above and below the differential coupled microstrip lines is nearly out of phase. The ground bounce that is reflected by the edge couples into slotline and then causes small noise on differential coupled microstrip lines as shown in Fig. 4(a). As a result, the late time noise on differential coupled microstrip lines is found to be much smaller than on single microstrip line[2].

A simple model in Fig.5 can be used to characterize how the differential coupled microstrip lines can help minimize the ground bounce. As the differential signal propagates across the slot, the induced voltage can be modelled as $f(t)$ and $-f(t-\tau)$ where τ is the time delay between the two traces. The resultant slot voltage can be written as

$$g(t) = f(t) - f(t-\tau) \approx \tau \cdot f'(t)$$

Hence, the amount of ground bounce is proportional to the separation between the coupled microstrip lines.

For the same structure in Fig 1, we choose several combinations of the width w and separation s of the differential coupled microstrip lines but with fixed differential impedance of $100\,\Omega$. Table 1 gives the peak-to-peak amplitude of the ground bounce V_{gb} normalized to amplitude of the input signal V_{in} with s and w as the parameters. It is evident from the table that the closer the differential lines are, the stronger the coupling factor and the smaller the ground bounce is. As compared with the slot induced ground bounce for a single microstrip line, the value can be reduced by an order of magnitude for differential lines. The peak-to-peak noise voltage in [2] is about 5%, while that is deduced to about 0.89% by using differential lines with coupling of 0.305.

4 Conclusions

In this paper, an efficient scheme is proposed to deal with signal propagation flowing on differential coupled microstrip lines above a split power or ground plane. Simulation results from the slot-induced ground bounce are presented to characterize the noise reduction by the employment of differential signalling. Using differential coupled microstrip lines flowing above a split power or ground plane can significantly reduce the effects of slot induced ground bounce and the reduction factor depends on the coupling factor.

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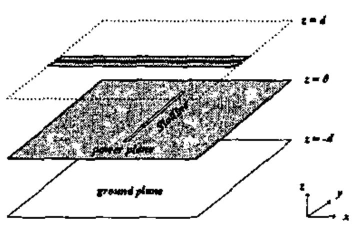


Fig. 1 A simple multi-layer structure with differential lines over split power plane

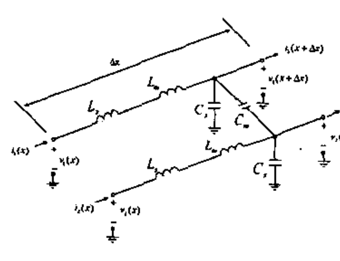
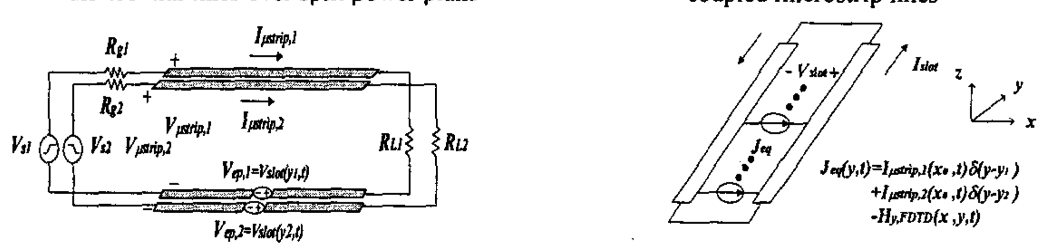


Fig. 2 Lumped equivalent circuit for coupled microstrip lines



(a) (b)

Fig. 3 Equivalent circuit (a) coupled microstrip lines (b) slotline

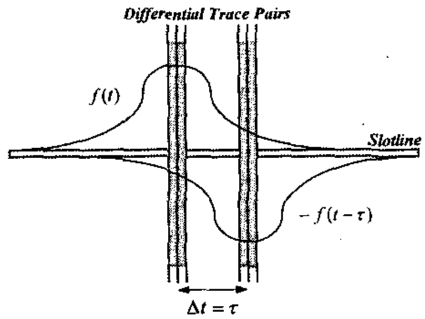
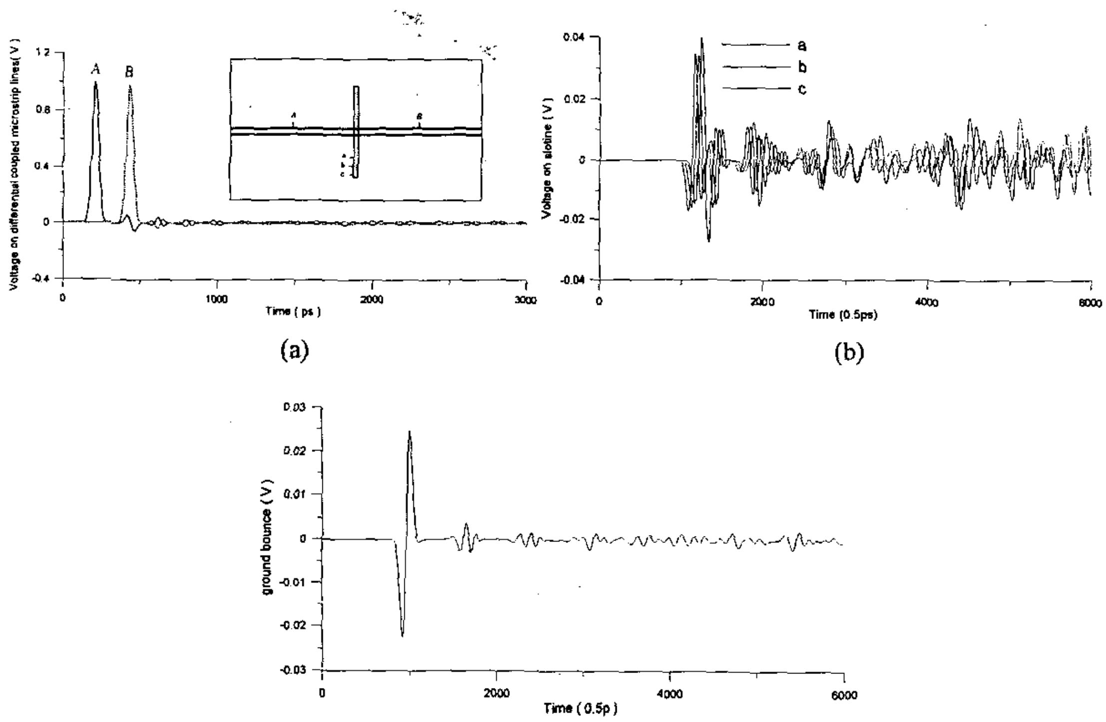


Fig. 5 The resultant slot voltage

w(mm)	s(mm)	coupling factor	V_{gb}/V_{in} (%)
0.25	0.25	0.305	0.89%
0.38	0.50	0.180	1.71%
0.50	1.00	0.082	2.48%

Table 1 Ground bounce voltage to input voltage ratio with width and separation of the differential lines as the parameters induced by differential trace pairs



(a) (b) (c)

Fig. 4(a) Voltages at A, B, (b) voltages at a ,b, c, and (c) ground bounce near slotline. The point A, B, a, b, and c are defined in the inset of (a).