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External Parasitic Inductance in Microstrip and Stripline Geometries of Finite Size

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Abstract

An external-parasitic ground (return) plane inductance, or a mutual inductance associated with fringing magnetic fields in planar transmission line structures, is the culprit of common-mode voltage (ground plane noise) that leads to parasitic radiation of the corresponding unintentional "antennas" in high-speed electronic equipment. Mutual inductance of this sort in microstrip and stripline structures is studied here using an analytical quasi- magnetostatic approach and FDTD modeling. Closed-form expressions for mutual inductance in symmetrical and asymmetrical microstrip and stripline structures are presented.

Keywords

Mutual inductance, common-mode current loop, differential-mode current loop, microstrip, stripline, ground plane, quasi-magnetostatic approach

INTRODUCTION

Microstrip and stripline structures with comparatively narrow ground (return) planes find various applications in modern high-speed electronic equipment.

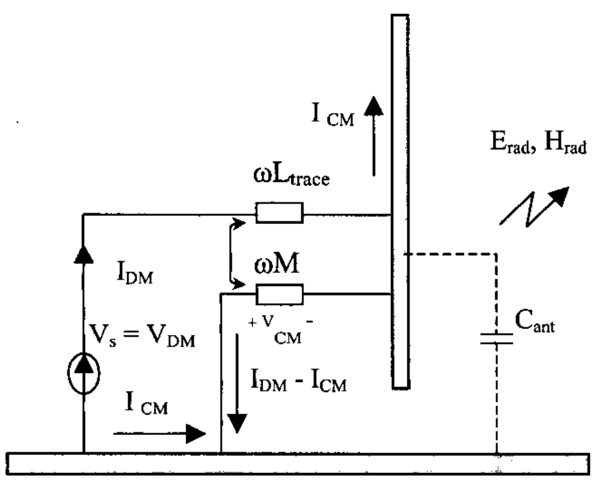

Figure 1. Common-mode "ground noise" that appears in narrow- ground planar transmission line structures due to magnetic field coupling.

There are, for example, narrow planar structures used to increase product assembly density, and also interboard connectors of microstrip or stripline types.

A major problem with such narrow ground (return) plane structures is that a *common-mode voltage* appears due to a fringing magnetic field at the edges of the ground plane, as shown in Figure 1.

This can drive unintentional "antennas" comprised of parts of the electronic equipment – PCB reference planes, cables, and conducting chassis adjacent to the microstrip or stripline structure with narrow ground plane.

To characterize the EMI processes resulting in radiated emissions, an equivalent circuit model including parameters of the parasitic coupling path (capacitance, inductance, resistance) and corresponding noise source must be constructed. Modern analytical and numerical methods of electrodynamics then allow evaluating fields radiated by this "antenna".

Traditionally, the inductance of various circuit board structures has been a very difficult parameter to quantify. At high frequencies, the extraction and quantification of an inductive coupling mechanism is an important, but difficult problem. Recently, there are many publications aimed at this class of problems [1- 11].

There are different ways to study parasitic ground plane inductance. Known conformal mapping approaches using a complex potential is described in [12], where an explicit formula for mutual inductance of two filaments separated by a shield of finite width is obtained. Publication [1] considers mutual inductance of two signal traces shifted from the center, and placed at different sides of a ground plane, using Carson's approach for calculating the return current distribution over the wide ground plane [13]. As for the case of a ground plane of finite size, the closed-form formulas are available only for a microstrip case with either non-shifted strip [1-5], or shifted to the very edge of the ground plane [2]. For a stripline geometry such formulas are not available. Most papers contain numerical or simplified analytical evaluation of ground plane internal impedance of microstrip lines using a quasistatic current density on the ground plane [1,4-8,10-15]. Paper [9] contains a general dual integral approach for the analysis of finite-size ground plane self-inductance of a microstrip, however, there are only implicit expressions for inductance associated with the flux through the loop between the signal trace and ground plane. The resultant value of inductance is frequency-dependent because of the propagation effects, and it cannot be associated with a lumped-element analog in the electrical scheme substituting the distributed inductance.

In this paper the parasitic ground plane inductance of microstrip and stripline symmetrical and asymmetrical structures is studied in two ways. The first method uses *direct analytical calculation of magnetic flux* penetrating through the desired loop area. The magnetic field produced by the current in the signal trace as well as induced current in the ground plane of a microstrip line or both ground planes in the stripline case are calculated using a quasi-magnetostatic approach, and, then, magnetic flux through the area under the ground plane is calculated.

According to the general definition of inductance, it is a ratio of the total magnetic flux penetrating through an area (plane loop of area S) to the amplitude of current that produces this flux,

$$M_{gp} = \Psi / I = \oint_S \vec{B} \cdot d\vec{s} / I . \qquad (1)$$

The mutual inductance associated with fringing magnetic field in a microstrip or stripline structure is defined assuming that the ground plane(s) are in the *(xy)*-plane, structure is infinite and homogeneous in x-direction of wave propagation (signal trace is at $y=0$), as shown in Figure 2.

The second approach uses the *numerical FDTD (finite-difference time-domain) method* for calculating voltage induced in a thin wire open loop probe due to a time-varying magnetic flux crossing this loop area. The ground plane inductance is determined as

$$M_{gp} = \left| \frac{V_{loop}}{j\omega \cdot I_{trace}} \right| . \qquad (2)$$

Simple closed-form approximation formulas for ground plane parasitic inductance that allow for the development of engineering design curves for microstrip and stripline structures, both symmetrical and asymmetrical (with offset of a signal trace from the center of the ground plane), are then obtained.

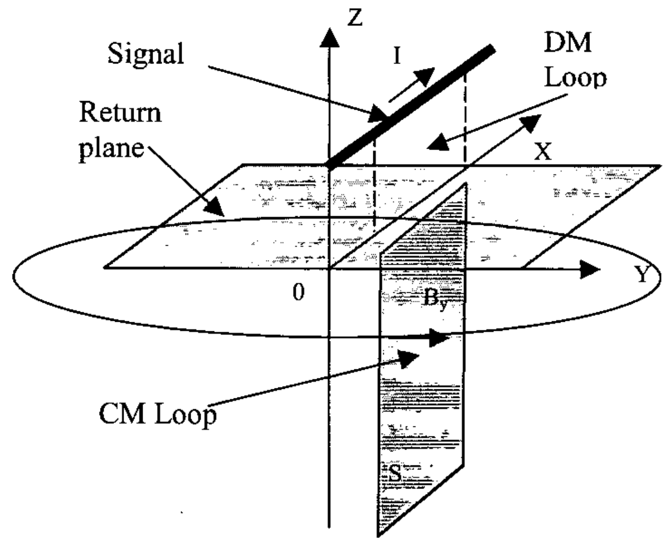

Figure 2. Planar transmission line geometry and definition of ground plane parasitic inductance.

The approximating formulas that can be used for external parasitic ground plane inductance estimation are developed as follows. In the stripline case it coincides with Leferink's formula [2] (at small ratios h/w and without taking into account the width of the signal trace),

$$M^{ms}_{gp\,0} = \frac{\Psi_\Sigma}{I} = \frac{\mu\mu_0}{2}\left(\frac{h}{w}\right), \qquad (3)$$

where h is the distance between the strip and ground plane, and w is the width of a ground plane. In the asymmetrical microstrip case the parasitic ground plane inductance is

$$M^{ms}_{gp} \approx M^{ms}_{gp\,0} + \frac{\mu\mu_0}{2} \cdot \left(\frac{\Delta y}{w}\right)^2 , \qquad (4)$$

where Δy is an offset parameter (the strip is shifted along the horizontal y-axis from the center) .

The results of the radiated E-field computations and measurements presented in [16] also demonstrate that the character of the field variation with the signal trace position respective to the ground plane edge behaves as $\left(\frac{\Delta y}{w}\right)^2$.

The numerical results in the stripline symmetrical case behave as a square-law function,

$$M^{sl}_{gp_0} = \frac{\mu_0}{\pi \cdot k} \cdot \left(\frac{h}{w}\right)^2, \tag{5}$$

where k is a correction coefficient approximated by the "empirical" dependence that fits both MAPLE 6.0 integration for the analytical results, and FDTD modeling, and can be used as a "design curve",

$$k = \begin{cases} 0.55 \cdot \left(\frac{w}{h}\right) + 1.05, & \frac{w}{h} \geq 5 \\ 2.49 + 0.054 \cdot \left(\frac{w}{h}\right)^2, & \frac{w}{h} < 5 \end{cases} . \tag{6}$$

In the asymmetrical stripline case, where the strip is shifted in the horizontal direction, an approximation with a quartic dependence results from the analytical formulation,

$$M^{sl}_{gp} \approx M^{sl}_{gp0} + \frac{\mu\mu_0}{2\pi} \cdot \left(\frac{\Delta y}{w}\right)^4 . \tag{7}$$

As for the vertical shift of a strip from the central position between two ground planes, the dependence is linear,

$$M^{sl}_{gp}(r) = K \cdot |r| + M^{sl}_{gp}|_{r=0}, \tag{8}$$

where

$$r = (h_1 - h_2)/(2w) \tag{9}$$

is the parameter describing the offset from the centered vertical position (at $h_1 = h_2$ parameter $r = 0$). The coefficient K is

$$K = \frac{(M_{max} - M_{min})}{h} \cdot w, \tag{10}$$

where

$$M_{max} \approx 1.96\mu\mu_0\left(\frac{h}{w}\right) \tag{11}$$

and

$$M_{min} = M^{sl}_{gp}|_{r=0} \tag{12}$$

In the general case of an arbitrary offset of the trace from the central position, the parasitic mutual inductance depends on the combination of the signal trace shift in both horizontal and vertical directions.

The results of direct analytical integration (using MAPLE 6.0) and FDTD, as well as approximating curves are presented in the figures below, correspondingly, for symmetric microstrip line (Figure 3), microstrip with offset of a signal trace from the center (Figure 4), symmetric stripline (Figure 5), and stripline with offset of a strip from the center (Figure 6).

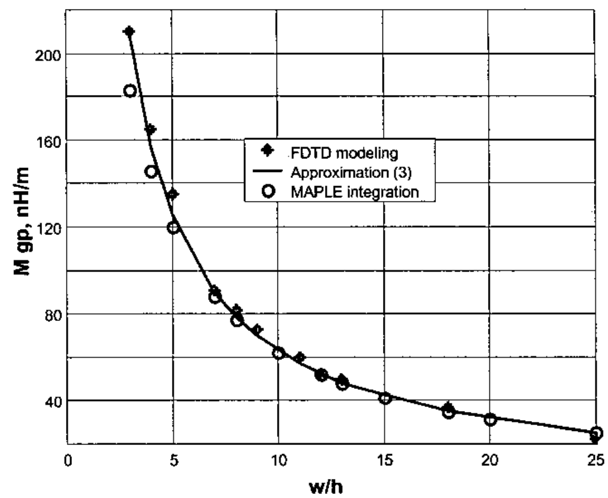

Figure 3. Parasitic mutual inductance for microstrip geometry versus the ratio of a ground plane width (w) and distance from the ground plane to the trace (h).

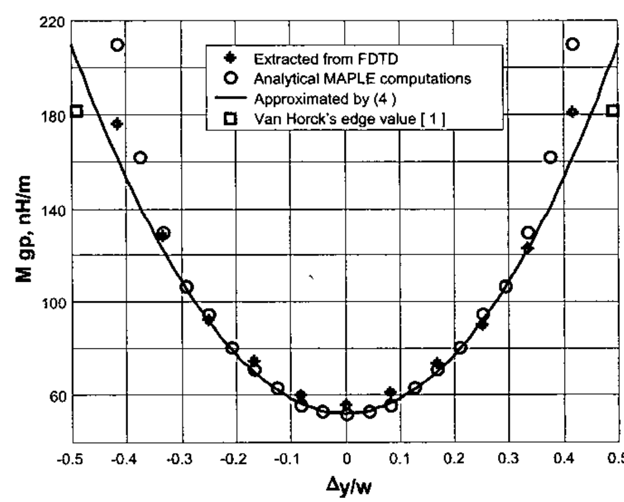

Figure 4. Parasitic mutual inductance of a microstrip ground plane versus an offset of a signal trace from the center.

There is a good agreement between the analytically integrated and numerical (FDTD) results at lower frequencies where the quasistatic approximation is valid. Figure 7 shows the dependence of a parasitic mutual inductance on the vertical offset from the center in the stripline structure.

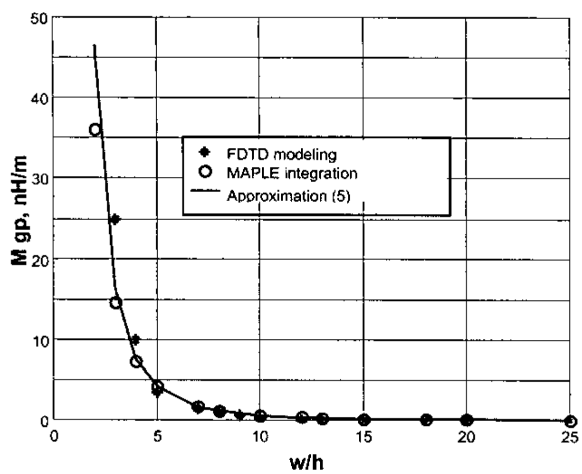

Figure 5. Parasitic mutual inductance of a ground plane versus ratio of the ground plane width to the distance between strip and any ground plane in symmetrical stripline structure.

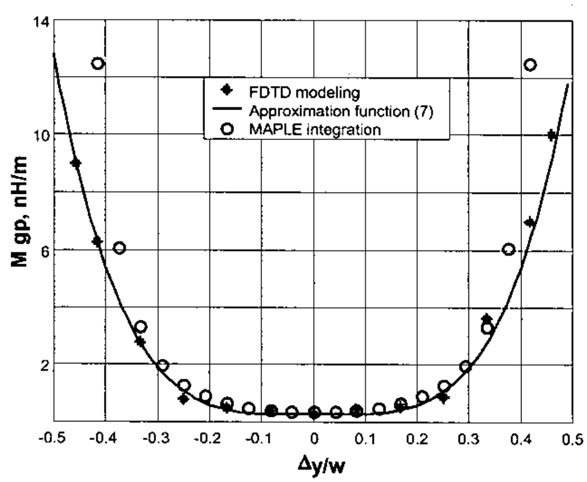

Figure 6. Behavior of parasitic inductance of a ground plane if there is an offset of a signal trace from the center.

CONCLUSIONS

Mutual inductance associated with fringing fields in planar microstrip and stripline structures is analyzed using a direct integration quasi- magnetostatic approach and a full-wave FDTD modeling approach. Simple closed-form approximate expressions for mutual inductance provide engineering design curves for symmetrical and asymmetrical microstrip and stripline structures. There is good coincidence of analytically integrated and numerical (FDTD) results at lower frequencies where the quasistatic approximation is valid.

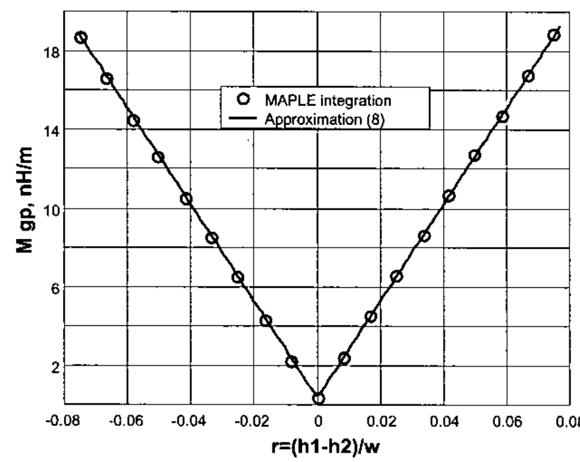

Figure 7. Dependence of ground plane inductance on the vertical offset of the strip from the equidistant position from ground planes. Strip is in the center in horizontal plane.

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