Filled Via Hole Fences For Crosstalk Control of Microstrip Lines in LTCC Packages

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Abstract

Coupling between microstrip lines in dense RF packages is a common problem that degrades the circuit performance. To help alleviate this problem, metal filled via hole fences may be placed on both sides of the microstrip to provide better field confinement. In this paper, a 3D-FEM electromagnetic simulation of the problem is presented and it is shown that a single role of vias provides no reduction in the crosstalk. However, by connecting the tops of the vias with a single metal strip, the crosstalk may be reduced by 8-10 dB.

Key words: microstrip, coupling, LTCC packaging, microwave transmission lines, via holes

Introduction

For the RF systems being built today and planned for the future, a prime design factor is the reduction of the package size. At the same time, the package is now expected to house not only the RF circuits but also the data processing circuits, the bias control circuits, and memory. Even more ambitious systems being developed by NASA add microelectromechanical (MEMS) gyroscopes, active pixel sensors, and other scientific instruments into the package as well. While the size of the package is being reduced and the complexity increased, the cost of the package must also be reduced. There are several packaging technologies that may meet these seemingly contradictory goals, but Low Temperature Co-fired Ceramic (LTCC) packages may be the most developed and therefore the first to be used.

The material system of LTCC packages has a moderate dielectric constant, $4<\varepsilon_r<8$, which permits wider strips and thus lower conductor loss for RF transmission lines than circuits on Si, GaAs, or Alumina while not being so low that the strips become too wide and limit the level of integration. In addition, the loss tangent is on the order of 0.002 at 10 GHz which yields an acceptably low dielectric loss. LTCC packages are comprised of many 0.1-0.25 mm thick ceramic layers with transmission lines on each layer. This increases the level of integration by allowing bias, digital routing, and RF transmission lines and interconnects to be built up in three dimensions.

While the multilayered circuit board lends itself to the use of stripline as the primary RF transmission line, the final connection to the integrated circuits which are usually mounted on the top ceramic surface requires microstrip transmission lines. However, microstrip transmission lines will radiate energy into the substrate and free space at discontinuities [1]. Furthermore, energy will radiate from a uniform microstrip line and couple to identical microstrip lines in its vicinity. Since many circuits are integrated into the package, this coupling between microstrip lines, or crosstalk, must be reduced or the overall packaged system performance will be degraded.

Since filled via holes are inexpensive in LTCC packages, they are commonly used to create via fences and partition areas of a package to reduce coupling between circuits [2-3]. In addition, they may be used to create via fences along striplines to reduce coupling between neighboring striplines [4]. In this paper, we utilize a 3D-Finite Element Method (FEM) [5] to evaluate the use of via fences along microstrip lines for the purpose of reducing the radiation loss of isolated lines and the coupling between adjacent lines. All of the structures that are analyzed use dimensions that are typical for standard LTCC

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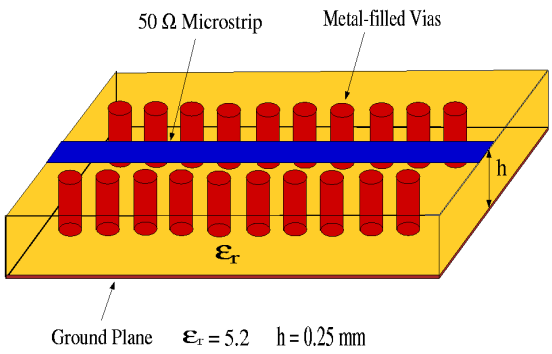
packages and thus relevant for designers, but the problem of coupling between microstrip lines for highly integrated boards is universal. Therefore, the results presented in this paper should find application in other packaging technologies such as surface mount on FR4 and RT/Duriod microwave substrates, MCM-D, and MCM-L packages since filled via holes are practical for these technologies also.

Results

A typical microstrip transmission line with a surrounding metal filled via fence is shown in Figure 1. All of the microstrip lines analyzed in this paper use a relative dielectric constant, ε_r, of 5.2; a substrate thickness, h, of 0.25 mm; a strip width, W, of 0.414 mm to yield a 50 Ω characteristic impedance; and the metal filled via holes are 0.25 mm in diameter. These values and the via hole spacings used throughout the simulations are all standard for LTCC package designs.



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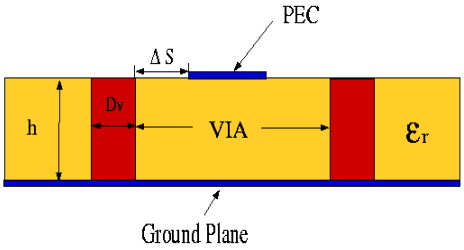
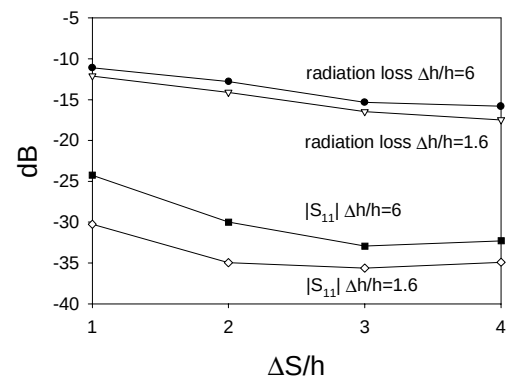


(b)

Figure 1: Microstrip line with surrounding metal filled via hole fence.

The transmission lines are first analyzed using the 3D-FEM over the frequency range of 10 to 40 GHz with the conditions that the dielectric and the conductors are lossless. It is found that the scattering parameters do not vary by more than a few percent over this frequency range if $2\Delta S+W<\lambda_d/2$ where ΔS is the spacing between the strip and the metal filled via hole and λ_d is the wavelength in the dielectric. This condition assures that no dielectric filled box type modes propagate between the two metal fences. Since the S-parameters do not show a strong frequency dependence, an average S-parameter is presented as a function of the geometric parameters to permit design rules to be obtained.



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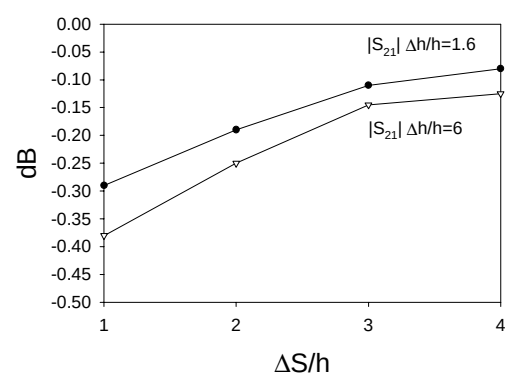
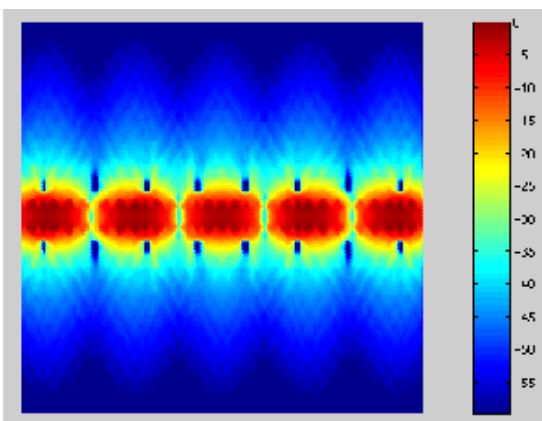


(b)

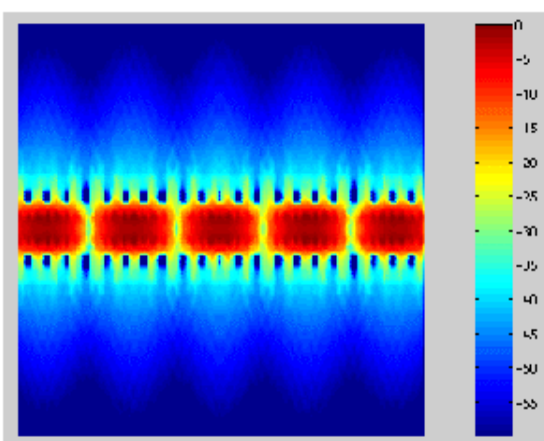
Figure 2: Calculated (a) radiation loss and $|S_{11}|$ and (b) $|S_{21}|$ for microstrip line surrounded by a metal filled via fence.

Figures 2a and 2b show the magnitude of the return loss and the insertion loss, $|S_{11}|$ and $|S_{21}|$ respectively, as a function of the distance between the strip and the via holes, ΔS, and the distance between the via holes, Δh. Since no conductor or dielectric loss exists in the simulations, $1-|S_{11}|^2-|S_{21}|^2$ yields the radiation loss of the microstrip line and is also shown in Figure 2a. It is seen that the reflection coefficient, the insertion loss, and the radiation loss all increase as ΔS/h decreases or Δh/h increases. Figure 2 also indicates that ΔS/h>3 is required for good microstrip propagation characteristics which agrees with the

microstrip design rule of maintaining 3h separation between elements [1]. When ΔS/h is small, significant fields terminate either on the via fence itself or on the other side of the fence. Although these fields appear to propagate along with the microstrip mode, they contribute to the radiation loss. This is seen in Figures 3a and 3b which show the electric field distribution along the microstrip line for ΔS/h=1 and Δh/h of 6 and 1.6 respectively. Even with a very small via hole spacing of Δh/h=1.6 or $\Delta h=\lambda_g/9$ where λ_g is the wavelength of the microstrip mode, there are significant fields outside of the via fence.



(a)



(b)

Figure 3: Electric field distribution of microstrip line with a continuous metal filled via fence at 25 GHz, ΔS/h=1, (a) Δh/h=6, (b) Δh/h=1.6

Since the main electric field component close to the microstrip is in the plane of the substrate, a metal strip connecting the top of each metal filled via hole in the fence should provide better field confinement. A schematic of this new structure is shown in Figure 4, and Figures 5a and 5b show the insertion loss, reflection coefficient, and radiation loss for this microstrip. The better field confinement is evidenced by the 3 dB reduction in radiation loss with a connecting strip, Figure 5a, compared to the via fence without a connecting strip Figure 2a.

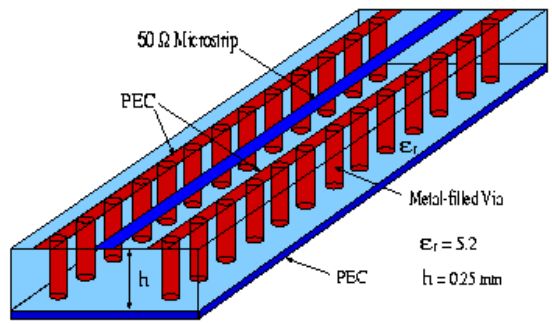
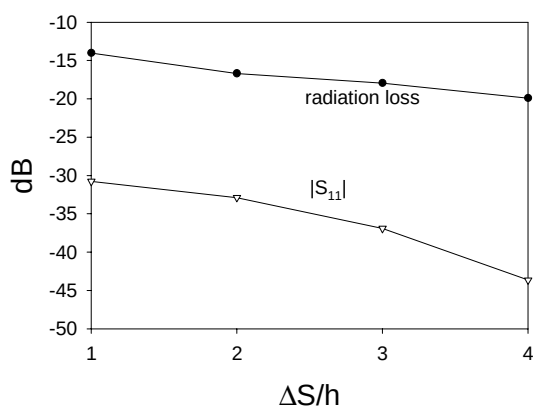


Figure 4: Schematic of microstrip line surrounded by a continuous metal filled via fence which is connected by a metal strip on the substrate surface.



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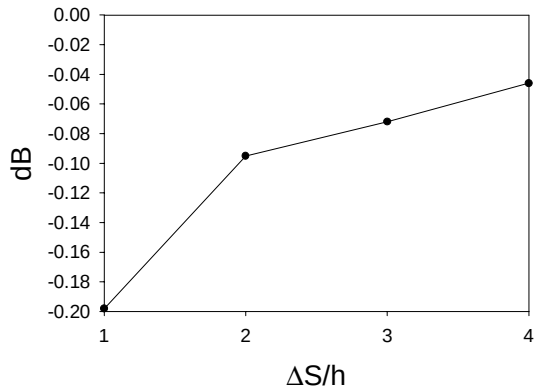

(b)

Figure 5: Calculated (a) radiation loss and $|S_{11}|$ and (b) $|S_{21}|$ for microstrip line surrounded by a metal filled via fence connected on the substrate surface by a metal strip, Δh/h=1.6.

While radiation loss is an important parameter for evaluating the efficiency of transmission lines, it also indicates the amount of coupling that will occur in a microwave package. This may be shown by using the 3D-FEM to evaluate the coupling between two microstrip lines separated by a metal filled via hole fence as shown in Figure 6. The lower left microstrip port is excited with a microstrip mode and the magnitude of the resulting electric field is compared at each port. Similar structures without the via fence and with a via fence connected by a metal strip as shown in Figure 4 are also evaluated in the same way. In each case, the separation between the lines is 3h and Δh/h=1.6 for the two cases with the via fence.

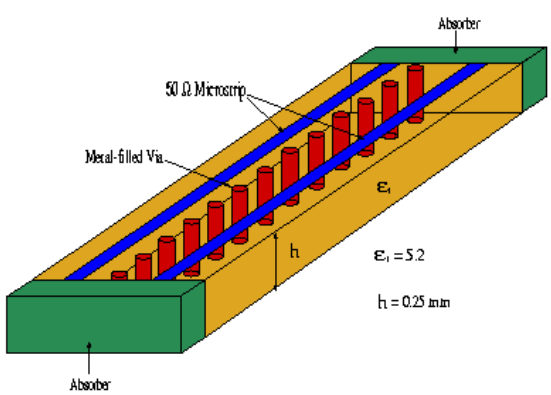

Figure 6: Schematic of two microstrip lines separated by a metal filled via fence.

The coupling is primarily in the forward direction, or out of the upper right hand microstrip port for the three microstrip structures. This is illustrated in Figure 7 which shows the electric field distribution for the structure shown in Figure 6. The metal filled via posts between the two microstrip lines are clearly visible as is the strong coupling. The forward coupling for the three different structures is summarized in Figure 8. It is interesting to note that the via fence without the metal connecting strip does not provide any improvement in coupling compared to the case of two microstrip lines without the via fence, and in fact, the coupling is 1-2 dB worse over the entire frequency range with the via fence. However, by connecting the via fence with the metal connecting strip, the coupling is reduced by approximately 8 dB over the entire frequency range. This agrees with the radiation loss results for a single microstrip line in the vicinity of the via fences presented earlier.

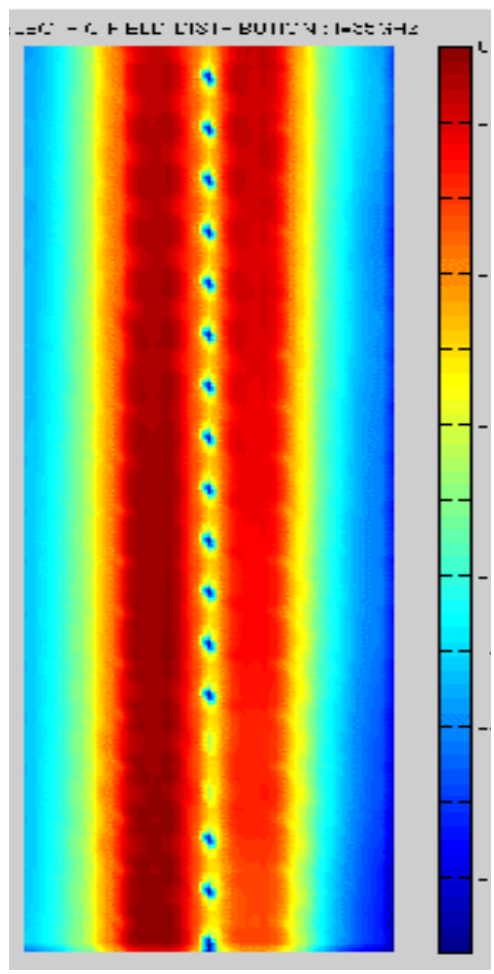

Figure 7: Electric field distribution of two microstrip lines separated by a continuous metal filled via fence, f=35 GHz, Δh/h=1.6, ΔS/h=1.

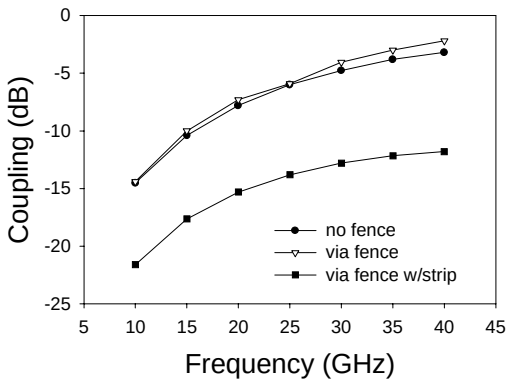

Figure 8: Calculated coupling between two microstrip lines separated by 3h as a function of frequency.

Conclusions

It has been shown that metal filled via fences placed on either side of a microstrip line do not reduce the radiation loss of the line or the coupling between lines. However, by connecting the tops of the via posts with a continuous metal strip, the radiation loss of the microstrip line is reduced, and the coupling between two microstrip lines is reduced by 8 dB. This method may be used to permit closer spacing between microstrip lines without increasing the crosstalk in the circuit.

References

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