VI. Package Resonance and Field Leakage

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MMIC package performance degrades at millimeter-wave frequencies mainly as the result of ring resonances and cavity resonances. Ring resonances occur when stray electromagnetic fields couple to the ceramic frame of the package [1,2]. Cavity resonances occur when the volume enclosed by the package behaves as a rectangular metal cavity [3]. These resonances are observed as large spikes in the insertion-loss-versus-frequency characteristic of the packaged MMIC. The frame resonances are also responsible for the poor isolation between the input and output RF ports.

Ring resonances can be eliminated by fabricating the frame from metal. However, in general, intricate metal-frame shapes are difficult to fabricate and, therefore, very expensive. A low-cost approach is fabrication from a ceramic material, such as alumina. In this approach, several thin, punched, metallized green-ceramic layers are first stacked to form a frame. Second, the inside and outside vertical walls of the frame, except those areas around the RF signal and dc bias lines, are metallized. Third, the multilayer green frame is co-fired. Fourth, the frame is attached to a metal base and all conductor surfaces are electroplated. This approach is not only cost effective, but ensures that the frame is grounded to the metal base. Grounding the frame significantly reduces the stray coupling between the input and output RF ports. A package with five ceramic layers of this type reportedly has had resonance-free operation with frequencies up to 33 GHz [1]. A schematic of the package is shown in Figure 9-19. However, such packages can support strong cavity resonances if the inside dimensions are not properly chosen. A simple equation to predict cavity resonances is presented at the end of this section.

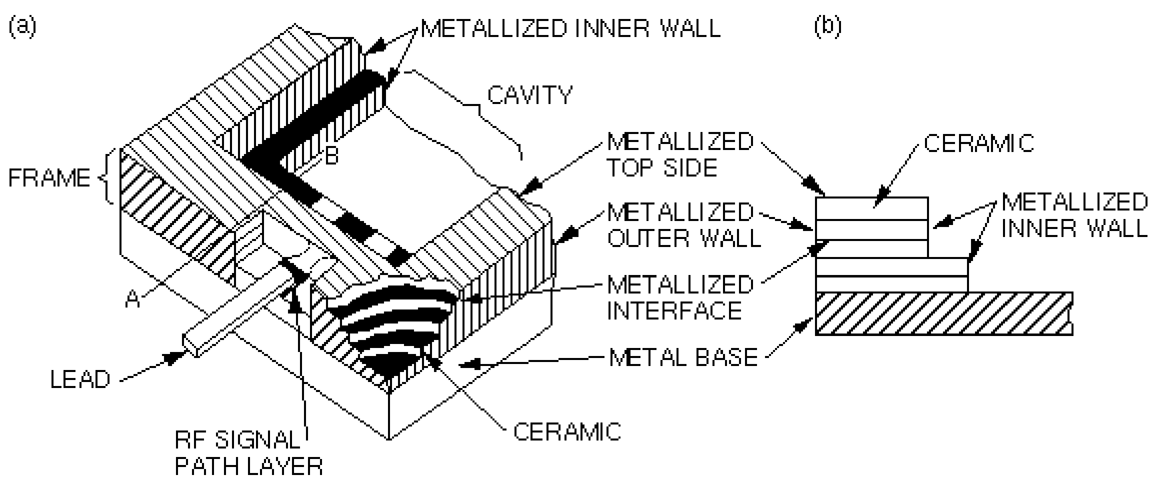

Figure 9-19. Multilayer ceramic package with metallized frame walls: (a) structure around terminal, (b) cross section A–B. (From [1]; ©1988 IEEE.)

An alternate approach in suppressing ceramic frame ring resonances is the periodic placement of metal-filled vias in the frame walls [4]; this replaces metallized surfaces. Figure 9-20 illustrates a Ka-band package with filled metal vias. This package, when experimentally characterized for return loss and insertion loss, shows that the frame resonances are not fully suppressed and they do occur over a narrow frequency band around 20 GHz, this because the metal filled vias are not as effective a shield as the

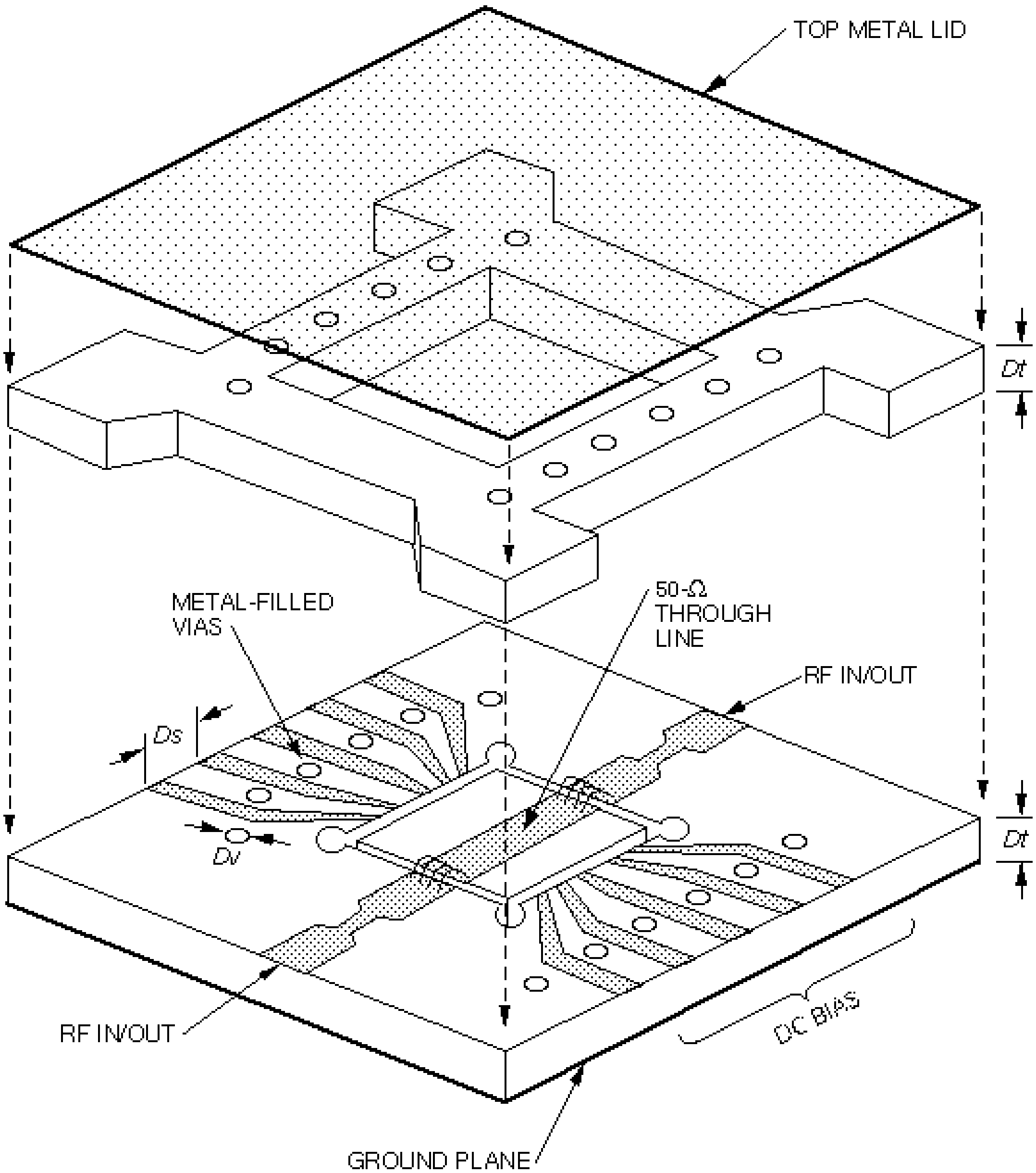

Figure 9-20. Ceramic package with metal-filled vias. (From [5]; ©1996 IEEE.)

metallized wall in the package shown in Figure 9-19. The measured and modeled return loss and insertion loss of the package is shown in Figure 9-21. A full-wave finite-element method (FEM) and numerical simulation of the package shows that a significant amount of RF energy leaks through the walls when the frame resonates [5]. Figure 9-22 shows the computed vertical electric-field distribution at about 20 GHz, as viewed from the top. The plot shows RF energy leaks on all sides through the gaps between the metal-filled vias. It is interesting to note that cavity resonances are not easily supported in this type of package because the side walls are not perfectly conducting—allowing RF energy to leak through the walls. The fields inside the package interact strongly with the ceramic material of the walls, and these fields are attenuated if the dielectric loss tangent is large.

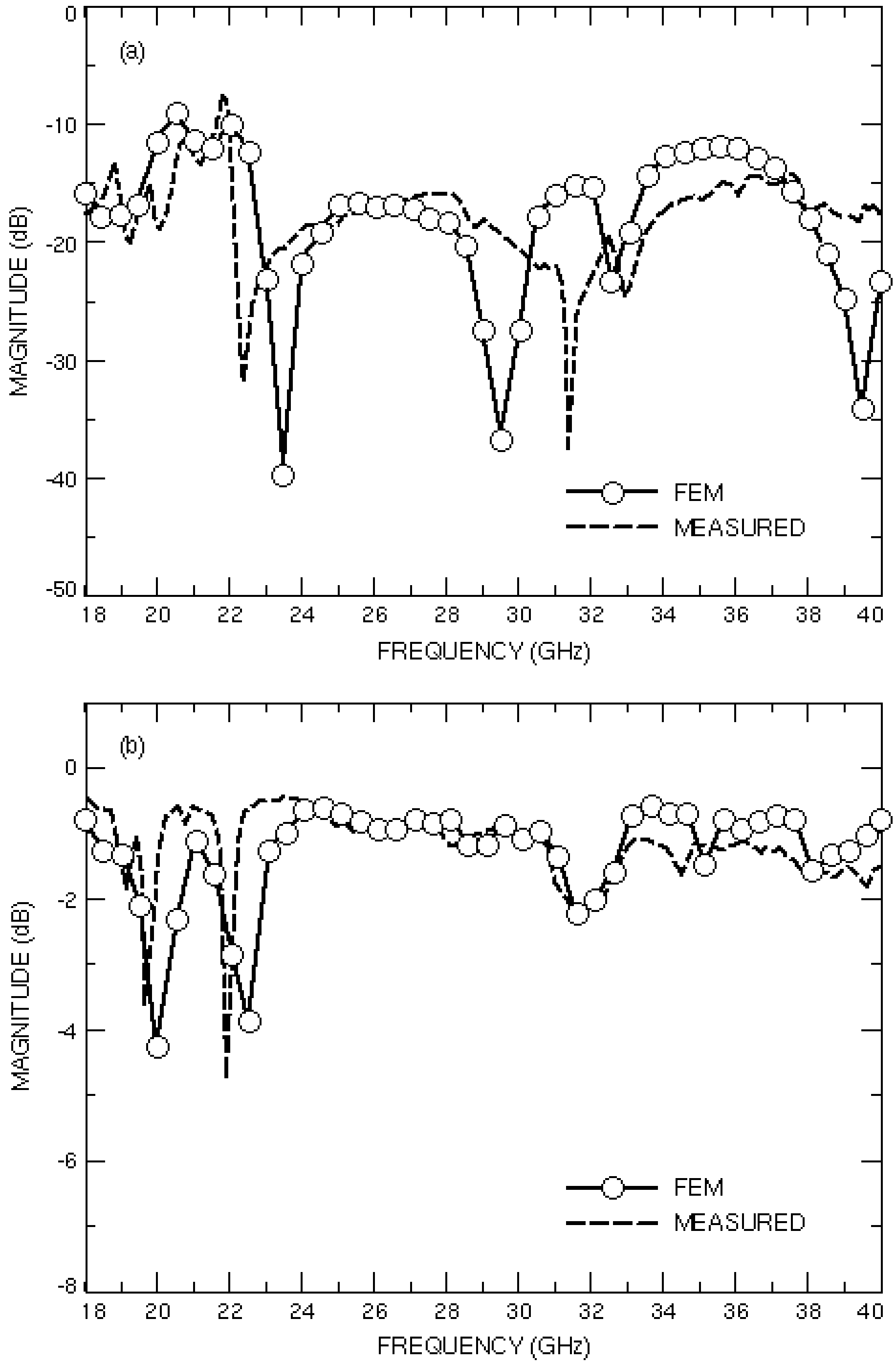

Figure 9-21. Measured and modeled *S*-parameters: (a) S11, (b) S21. (From [5]; ©1996 IEEE.)

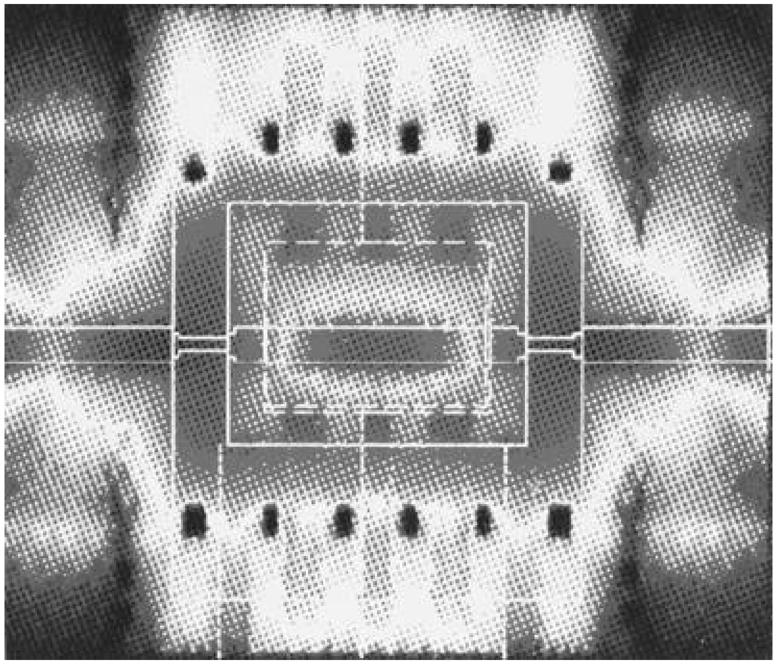

Figure 9-22. Computed vertical electric-field distribution.

The cavity resonances are predicted from a model [3] that considers the package as a rectangular metal cavity loaded with a H-plane dielectric slab, as shown in Figure 9-23. In this model, the length, width, and height of the cavity are represented as *L*, *W*, and *H*, respectively. The dielectric slab is of thickness *d* and relative permittivity ε_r. The cavity is excited by a microstrip line at the input and output ports. The resonance frequency f_r is approximately given by

$$f_r = f_c\sqrt{1 - \left(\frac{d}{H}\right)*\left(\frac{\varepsilon_r - 1}{\varepsilon_r}\right)}$$

where f_c is the cut-off frequency of the TE_{101} mode in the empty cavity. As an example, if ε_r = 13, *d* = 0.01016 cm (0.004 in.), *L* = 0.4064 cm (0.16 in.), *W* = 0.254 cm (0.1 in.), and *H* = 0.04826 cm (0.019 in.), then f_c and f_r are 69.641 GHz and 62.508 GHz, respectively.

Even when the package is designed to avoid in-band resonances and to suppress field leakage, electromagnetic effects may still degrade the circuit performance. To understand this MMIC performance degradation, first recall that microwave transmission lines such as microstrip and coplanar waveguide (CPW) do not confine the electromagnetic energy to a finite volume, but simply guide it along the path of the line. The amount of energy that spreads beyond the microstrip or slots of the CPW is dependent on the substrate thickness, permittivity, and the geometry of the transmission line. When a MMIC is tested on a wafer probe station, this energy that is not well confined to the guide tends to radiate outward from the line and dissipate, but if that same MMIC is placed in a package, the unconfined energy reflects off of the package walls and

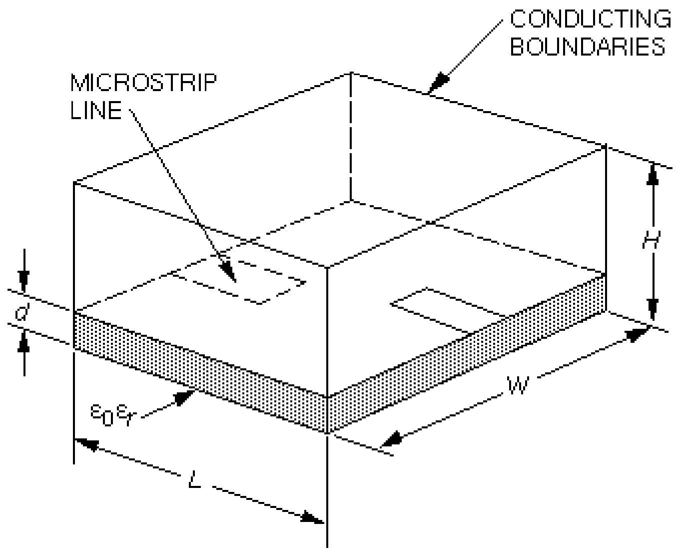

Figure 9-23. Partially filled metal cavity with microstrip input/output ports.

recombines with the energy traveling down the transmission line. The result is a distortion of the transmitted signal [6]. Therefore, it is recommended that MMICs be tested in their package as well as subjected to the on-wafer RF characterization.

References

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Additional Reading

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