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On the Interaction of the MMIC and Its Packaging

Y. L. Chow, G. E. Howard, and M. G. Stubbs

Abstract—**The software WATMIC-EMsim [1] is used to simulate the interaction of an MMIC circuit and its packaging. Specifically in this paper, the circuit is the spiral transformer, and the packaging is the surrounding ground ring used to interface the transformer to its coplanar probes. It is found that the resonant frequencies of the transformer are affected *greatly* with the introduction of the ring but, with its introduction, only slightly by the width of the ring. This paper points out that this finding of interaction mimics the well known phenomenon in electrostatic capacitance. More importantly, this paper points out that in the field theoretic analysis of an MIC/MMIC circuit the influence of the packaging must be considered.**

I. Introduction

It is pointed out by Montgomery [2] that "(MIC) packages in many applications, will remain both a performance and a cost challenge. Yet, current solid state microwave R & D is focused almost entirely on chips, with little attention to package concerns."

As a small first step in the direction of packaging, this paper studies the interaction between a monolithic microwave integrated circuit (MMIC) spiral transformer and its surrounding ground ring as shown in Fig. 1. As recognized there the ring is used as a ground and as an interface between the transformer and the measuring coplanar probes.

The interaction is studied for the same transformer but with a ring of different widths. One special case of interest is that having the width reduced to zero, i.e., the ring is deleted. It is found that there is a great effect in the resonant frequencies of the transformer without and with the ring. However, with the presence of the ring, there is only a small effect with the width of the ring.

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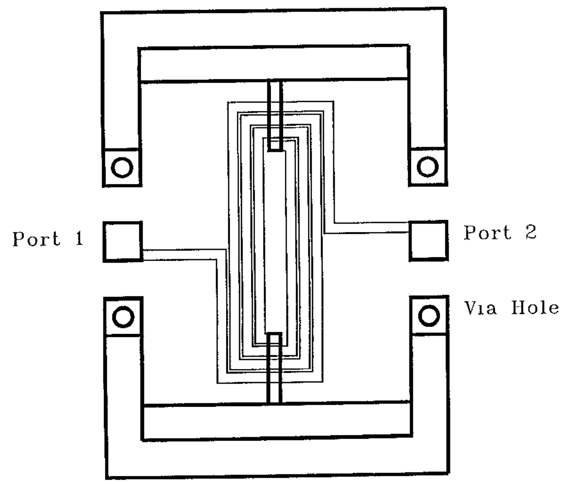

Fig. 1. A spiral transformer with ground ring. The outside dimensions of the ground ring are 1020 μm × 710 μm. Metallization t = 1 μm Gold, substrate h = 250 μm, ϵ_r = 12.9. Dielectric bridge height = 1.3 μm, bridge overlay ϵ_r = 6.8. The width of the spiral metallization is 20 μm and the transformer gap is 6 μm.

Experimentally for MMIC's, changing the ring width is time consuming and expensive. Numerically, on the other hand, electromagnetic simulators such as the software package WATMIC-EMsim [1], the changes can easily be carried out through minor adjustments of the input data. The findings as mentioned in the last paragraph, should be true as numerical technique used has been shown to be quite accurate especially for the MMIC type of MIC circuits [3]–[6].

Despite the above implied accuracy, for a new MMIC structure it is always desirable to have experimental verification and a physical interpretation of the responses of such structures. For the former an experiment on the transformer with a full ground ring, as shown in Fig. 1, is performed and compared with a full numerical simulation. This is given in the next section. For the latter, a numerical experiment on the capacitance to infinity of a metallic box is performed. This is given in Section IV, after the spiral rectangular transformer computations for better interpretation.

II. An Experimental Verification

The transformer with a full ground ring in Fig. 1 is constructed on a GaAs substrate and measured through coplanar probes. The detail of the construction is given in the caption of Fig. 1. Fig. 2 gives the experimental and the computed results of S_{11} and S_{21}. We see very good agreement of the results.

With the experimental verification for the full ground ring case we may proceed with confidence to study the computed results from ground rings of various widths, full, half, and zero width, in the next section.

III. The WATMIC-EMsim Computations and Graphs

Figs. 1, 3, and 4 show the spiral transformer with three different ground rings. Fig. 4 has the width of the ground ring reduced to zero, i.e., Fig. 4 has no ground ring.

The moment method software WATMIC-EMsim, version 2, is

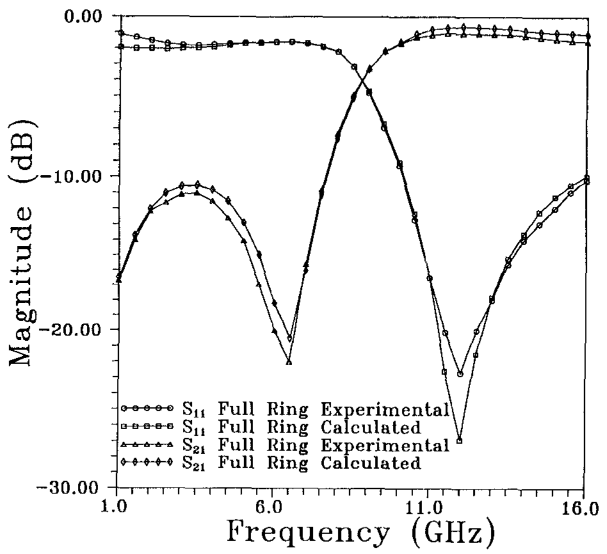

Fig. 2. The experimental and computed $|S_{11}|$ and $|S_{21}|$ of the rectangular spiral transformer with a full ground ring.

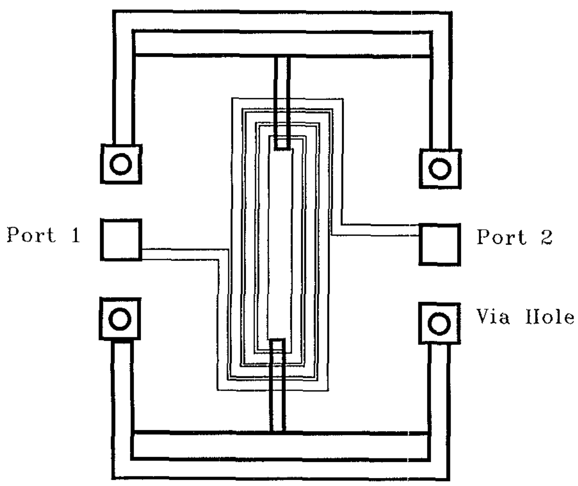

Fig. 3. The spiral transformer with ground ring width reduced to 1/2 of that of Fig. 1.

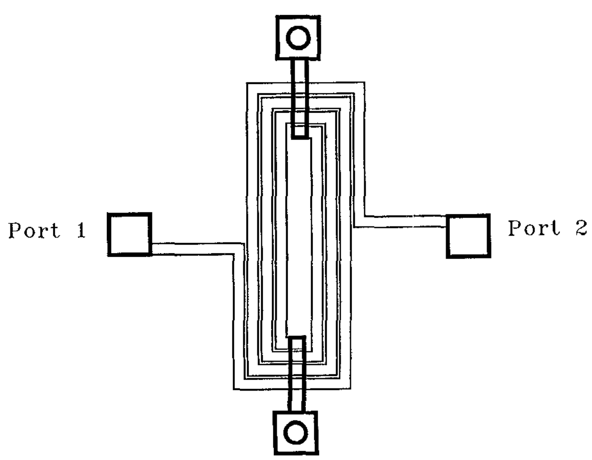

Fig. 4. The spiral transformer with ground ring deleted (i.e. ring width = 0 μm).

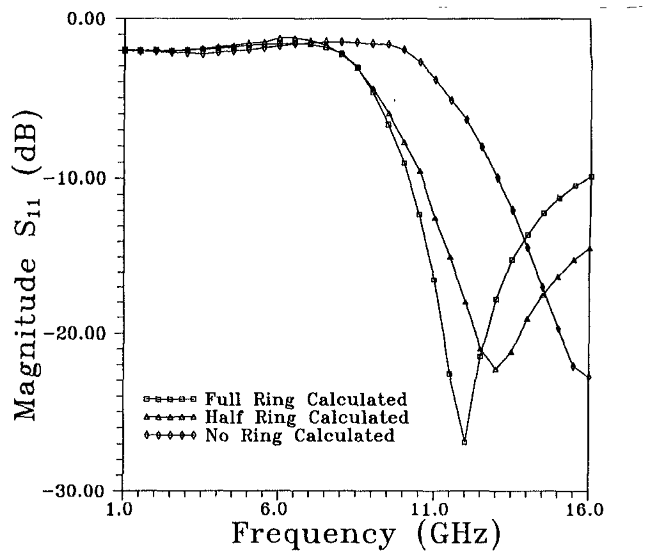

Fig. 5. Rectangular transformer S-parameters (S_{12}).

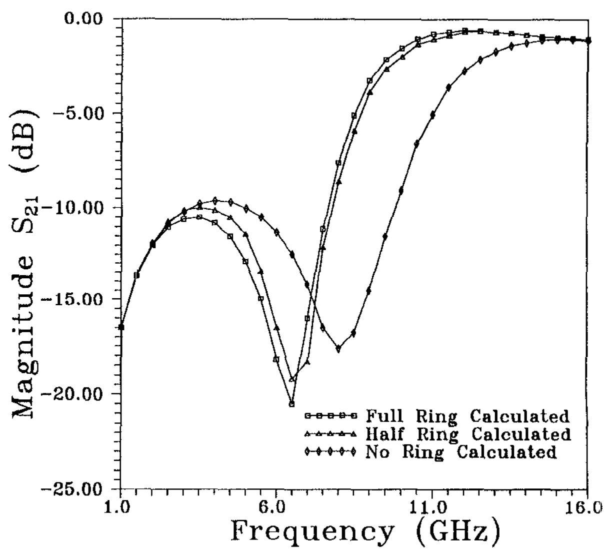

Fig. 6. Rectangular transformer S-parameters (S_{11}).

applied to the transformer and ground ring using nearly square segments over the microstrip lines.

The graphs of $|S_{12}|$ and $|S_{11}|$ of the three configurations are plotted in Fig. 5 and 6.

Comparing the responses of $|S_{11}|$ and $|S_{12}|$ at the minima, it is observed that there are shifts in the resonant frequencies as a function of the width of the ground ring. A surprise is that the function is highly nonlinear. That is: the shift is no more than say 0.5 GHz (7%) when the ring width is reduced to half, but the shift is more than say 3.0 GHz (40%), when the width is reduced from half to zero.

The shifts in frequency are obviously not only with the resonances but with the whole graphs, that is: the graph stretches or compresses with different widths of the ground ring.

It should not be so surprising that the shift in frequency is so nonlinear. A similar shift in capacitance in electrostatics, in fact, has been observed. To gain insight into the shift in frequency, the shift in capacitance is given in the next section.

Before ending this section, however, it may be of interest to point out that in Fig. 1, 3, and 4, the airbridges are above the spiral with

1.3 μm polymide overlay ($\epsilon_r = 6.8$). The resistance of the microstrip is taken to be twice of the ac resistance of the strip in isolation. This increase is taken to account for the edge effect of the strip and the influence of the ground plane [7].

IV. The Capacitance of a Block with Various Surface Areas Deleted

This material is extracted from a report by Chow and Srivastava [8]. Fig. 7 shows (a) an isolated solid conducting block, (b) the block with 47% of the surface area deleted, and (c) the block with 64% of the area deleted. The capacitance to infinity is solved by the moment method using point matching. The changes in capacitances of (b), and (c) from the solid block (a) are listed in Table I. This table also contains the obvious case (d) of 100% deletion.

Fig. 7 and Table I show an interesting phenomenon, that is in (b) with 47% of the flat surface deleted, the change in capacitance is only −5%, but in (c) with the deletion of a little extra of the surface to 64%, the change in capacitance is more than doubled to −12%. This shows that the change in capacitance in electrostatics is similar to that in the shift in resonant frequency. That is, the change can be highly nonlinear with the deletion of surface area. This point is more forcefully demonstrated in (d) of Table I when the surface is completely deleted.

This capacitance phenomenon is well known, and in radar scattering it enables the replacement of a solid scatter by a grid of *thin* (but not zero radius) wires, as long as the edges and the outline of the scatterer are maintained.

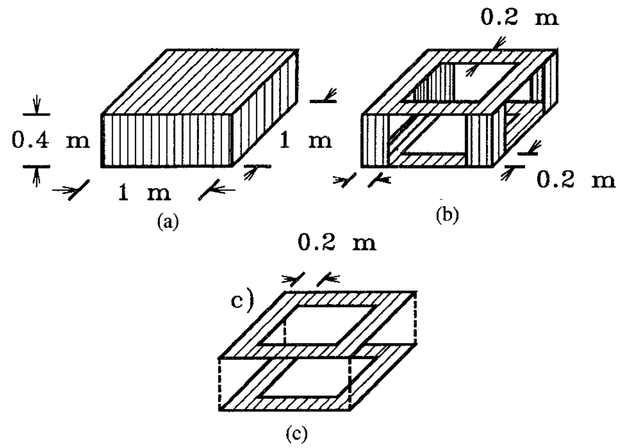

Fig. 7. A conductive block with various surface areas deleted: (a) The full conducting block; (b) The block with 47% of its' surface removed; (c) The block with 64% of its' surface removed.

TABLE I
CAPACITANCE C FROM FIG. 7

Body Shape	C(pf)	%Tage Change of C, from (a)	%Tage of Area Deleted
(a)	56.25	—	0%
(b)	53.62	−5%	−47%
(c)	49.63	−12%	−64%
(d)	0.00	−100%	−100%

V. Discussions and Conclusions

A close inspection of Fig. 7 and Table I indicates that the capacitance of a body remains nearly unchanged with the deletion of surface. However when the deletion of surface involves the deletion of edges (e.g. the dotted line of Fig. 7(c)) so that the structure loses the shape of its outline, the change in capacitance becomes large. This point has actually been analytically proven by Chow et al [8], [9].

The shifts in the resonant frequencies, and the response graphs of Fig. 5 and 6 are similar to the change in the box capacitances as a function of surface deletion. The reason is that the spiral transformer is coupled to the surrounding ground ring. Because of the finite number of via holes and its extended size, the ground ring in fact has a capacitance to ground. The electrostatic example of Fig. 7 indicates that the coupling and the capacitance to ground should remain nearly unchanged when the width of the ground ring is reduced even to half of its original value. The shift of resonant frequency is only 7%.

With the ground ring deleted however in Fig. 4, there is no coupling and no capacitance to ground. This drastic change causes the large change in resonant frequency of 40%.

The ground ring is a planar structure. One may assume that its presence should therefore cause only a small shift in the resonant frequency. However, the shift is large, i.e., 40%, because the ground ring in Fig. 1 is very near the spirals of the transformer and is also large in overall size.

The inductive effects of the ground ring are negligible because of the short length of the ground ring lines from the airbridges to the via hole. In fact at 10 GHz, its electrical length is approximately 15 degrees.

An important point which should not be missed from this analysis, is that characterization of individual components using the coplanar feed with ground ring approach must be performed with care. The final measured performance of a component may not be anywhere near what the in circuit performance is if the effects of the ground ring are not accounted for. When such a measured component is placed in a normal circuit, the grounding ring is usually not present, thus the performance of the component will be drastically altered as indicated in Figs. 5 and 6. Therefore when using this approach to characterize the devices, the size and width of the grounding ring used are not too important, so long as its effects are de-embedded from the desired component response.

Normal packaging, say a box, may be large and not as close to the spirals, however, it is also completely enclosing the spiral transformer or other circuits of interest. Therefore we may speculate that normal packaging can cause a substantial change (eg. 7 to 40%) in an MMIC circuit, both in the resonant frequency and in its other frequency responses. Packaging with boxes and other enclosures cannot be solved by the software used in this analysis, therefore only the planar ground ring packaging is studied here. Despite this inability, this paper serves the purpose of pointing out that in a field theoretic analysis of an MIC/MMIC circuit, it may be good practice to include the packaging structure used in the experimental measurements.

The transformer example is used in this paper because its frequency response is simple and has sharp resonances. This makes the illustration of the packaging effects easy. For this reason, more complicated circuit examples, eg. those in [3]–[6], are not used.

WATMIC-EMSim is quite accurate (error 1–3%), but so are a number of other field theoretic circuit simulators. It is evident therefore some packaging effects can be found using these other simulators.

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Grounding Microstrip Lines With Via Holes

Daniel G. Swanson, Jr.

Abstract—**Grounding microstrip circuits with via holes is an established technology and modeling isolated via holes with analytical models is well known. However, the availability of electromagnetic field solvers provides an opportunity to model via holes and the metalization surrounding them in a more realistic fashion. Calculated equivalent inductances for single and double via hole configurations are presented. A microstrip interdigital filter with grounded resonators provides experimental verification.**

I. Introduction

Most thin film fabrication facilities have a via hole process available to microwave component designers. In most cases the designer will choose the minimum via hole diameter and spacing allowed by the process. Earlier work [1] has focused on analytical models for a single via hole as a function of hole diameter and substrate thickness. But the actual via hole configuration used by the designer is often a more complex combination of several via holes and other microstrip discontinuities. And the significant interactions between several discontinuities in close proximity cannot be accurately described by combining analytical models for isolated elements. In this work, an electromagnetic field solver has been used to compute the equivalent inductance of two different via hole topologies as a function of frequency, substrate thickness and a microstrip discontinuity variable.

II. Single Via Holes

Fig. 1 is the preferred geometry for a single via hole in alumina at Watkins-Johnson. The 13 mil diameter hole is used in both 15 mil thick and 25 mil thick alumina. The surrounding metalization is 24 mils square. A microstrip line of width w could then be connected to one side of square. Because the component designer is most likely to use the minimum via hole diameter and metalization area allowed, the equivalent inductance of this structure can be computed as a function of only line width and frequency. The equivalent inductance is computed at a reference plane defined by the junction of the microstrip line and the square pad around the via hole. For lines other than 24 mils wide it is clear that the model includes a step junction, the inductance of the via hole and the capacitance of the pad surrounding the via.

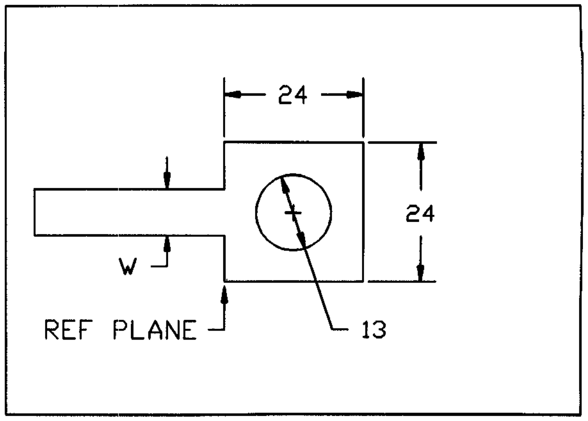

Fig. 1. Microstrip single via hole and microstrip line of width w. All dimensions are mils.

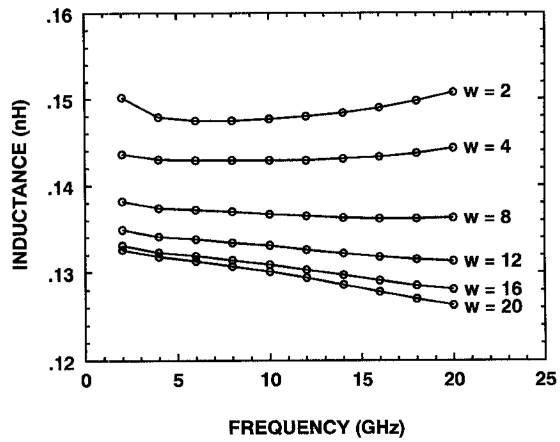

Fig. 2. Equivalent inductance of microstrip single via, alumina substrate, h = 15 mil, ϵ_r = 9.8, w = line width in mils.

The analysis of this structure was carried out on a full wave field solver [2] for several line widths over the 2 to 20 GHz frequency range. The round via hole was approximated by an octagonal hole in the analysis. The results of this analysis for 15 mil thick alumina, ϵ_r = 9.8 are shown in Fig. 2. A similar analysis for 25 mil thick alumina, ϵ_r = 9.8 was also performed with the results shown in Fig. 3. These graphs provide a convenient look-up table for the designer using single via holes.

III. Double Via Holes

Double via holes are often used to decrease the parasitic inductance of the ground connection or to ground a wider microstrip line. Fig. 4 is the preferred geometry for double via holes at Watkins-

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