Full-Wave Investigation on the Curved Bonding Wire Interconnection by using a Suitable FDTD Code

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Abstract— **The scattering parameters of the curved bonding wire interconnection, accounting for its curvature, have been computed by using a proper discretization technique along with the Finite Difference Time Domain (FDTD) method. The curvature has been modeled assuming a polygonal approximation. The obtained results have been compared against vector network analyzer measurements showing a satisfactory agreement. In order to investigate the curvature effect, the proposed approach has been compared with a rectangular approximation of the bonding wire demonstrating that this approximation provides a useful modeling of the interconnection.**

I. Introduction

The microstrip bonding wire is widely used in the hybrid microwave circuits to provide reliable and low-cost interconnections. Although this technology is well established, at high frequency the electrical performances of the bonding wire become fairly poor. The response of the bonded circuit may be seriously altered mainly because of the parasitic inductance of the bonding wire [1].

An early study of the bonding wire, based on the frequency domain transmission line matrix method, was published by Jin *et al.* [2] in 1993. In 1994, Horng *et al.* [3] used the spectral domain method to extract the parameters of a π-network equivalent to the bonding wire. In the same year an equivalent circuit was derived using a conformal mapping method, [4], [5]. In 1995 Vahldieck *et al.* [6] compared the performances of the bonding wire with those of the flip-chip interconnection by adopting the same method as [2]. Recently Sercu *et al.* [7] used a suitable mixed potential formulation to compute the impedance of the bonding wire and Krems *et al.* [8] derived experimentally an equivalent circuit of a multiple wire interconnection between two coplanar waveguides.

Unlike the cited works, where a rectangular shape has been assumed for the interconnection, in[9] and [10] there is a first attempt to model the curvature of the bonding wire along with a moment method formulation.

In the present paper the bonding wire has been analyzed with the FDTD method. The curvature of the interconnection has been considered by combining a multiple staircase approximation with a mesh grading [11] and with the slanted wall modeling in orthogonal coordinate systems [12], [13]. The computed performance of the bonding wire has been compared against vector network analyzer measurements up to millimeter-wave frequencies showing a satisfactory agreement. The capability to consider the curvature of the bonding wire has then been adopted to evaluate the accuracy of coarse straight approximations of the same structure that are extensively adopted for the derivation of high frequency equivalent circuits suitable for CAD implementation.

II. Method of Discretization

In [4] bonding experiments have been carried out using a 17 μm diameter gold wire and a 254 μm alumina substrate, this structure is shown in Fig. 1. The shape of the microstrip bonding wire has been approximated, in this work, by an arc of a circle with a radius of 352 μm that has

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been derived from the optical measurement of the height and the length of the interconnection. The geometrical parameters are quoted in Table I.

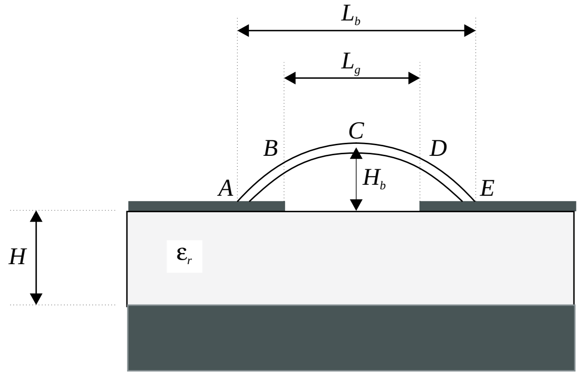

Fig. 1. Microstrip bonding wire interconnection.

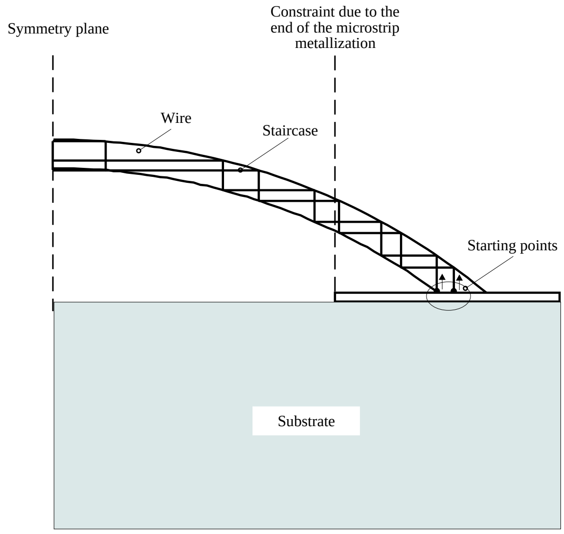

Fig. 2. Discretization strategy.

TABLE I

Substrate		
ϵ_r	9.86	
H	254	μm
Microstrip		
Impedance (5 GHz)	50	Ω
ϵ_{eff} (5 GHz)	6.53	
Width	238	μm
Metalization Thick.	5	μm
Interconnection		
Max. frequency	40	GHz
Wire diameter	17	μm
L_b	470	μm
L_g	310	μm
H_b	90	μm

The discretization strategy used to describe the curvature of the interconnection is illustrated in Fig. 2. This technique is based on the definition of a graded mesh [11] capable to fit the boundaries of the curved wire; it means that a number of nodes, sufficient to provide the required spatial accuracy, must be located on the wire contour. To obtain such a mesh we adopt the following procedure: a path, referred to as staircase, has been defined by alternating vertical and horizontal segments with the constraint that each segment must extend from one boundary of the wire to the other.

Each step of the previous staircase yields the definition of two horizontal and two vertical gridlines, the intersection of which produces four gridnodes. Three of them belong to the step and stand, by construction, on the boundary of the curved wire.

To define unequivocally the staircase a specific starting point, for the first segment, has to be chosen. If we assume that the first segment is vertical, the starting point must be located within the wire at the intersection with the microstrip (see Fig. 2).

The adoption of only one staircase has two limitations: first, it allows only the geometrical constraints stated by the wire contour to be satisfied; second, the resulting mesh is often too coarse. To overcome these problems some staircases, with different starting points, have to be defined with the same strategy. For example Fig. 2 shows how the boundaries of the curved wire are fit, together with the constraint due to the open end of the microstrip, by two staircases. Fig. 3 shows the resulting graded mesh. Note that, outside the region where the mesh is determined by the staircases, an optimum grading has been adopted according to [14].

By locating metallic walls at the segments forming each staircase, a “multiple staircase” approx-

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imation of the wire contour is obtained.

To improve the accuracy of such approximation, the triangular cell field updating described in [13] has been adopted. The electromagnetic field is mapped according to the inset of Fig. 3. In this way a polygonal description of the wire contour is attained.

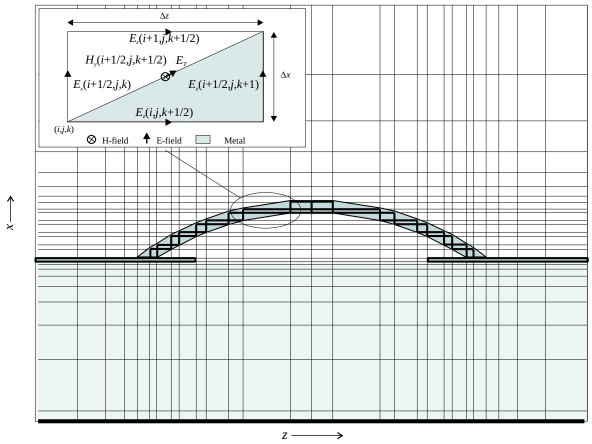

Fig. 3. Graded mesh and polygonal approximation of the bonding wire.

III. Results

Fig. 4 shows the comparison between the experiments and the FDTD analyses performed. In particular: the curve (a) is the experimental result [4], [15]. The curve (b) is the response obtained by neglecting the curvature and by modeling the interconnection with a straight wire (rectangular shape), the height of which is equal to the maximum height of the bonding wire ($H = H_b = 90\ \mu m$). The curve (c) has been obtained under the same assumption with the height set to an intermediate value ($H = 72\ \mu m$). The curve (d) is the response obtained with the polygonal approximation described previously.

All the curves exhibit a fairly good agreement with experiment. This demonstrates that, to a certain extent, the response of the bonding wire is not very sensitive to the shape of the curvature. In particular the approximation of the curved bonding wire with a straight one, with a proper height, provides an acceptable accuracy even up to millimeter-wave frequencies.

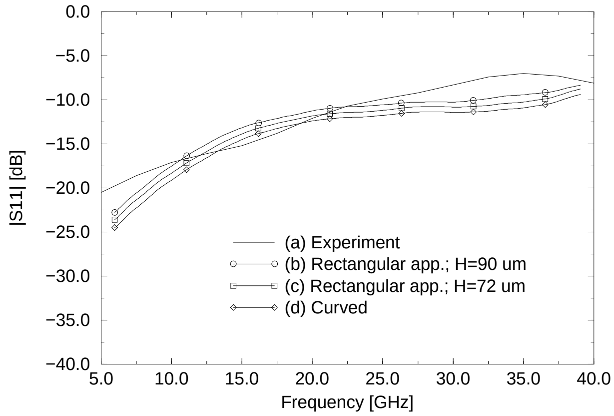

Fig. 4. Comparison between experiment and different approximations of the bonding wire interconnection.

It is worth noting that the described way to discretize curved bonding wires has been applied here to the fairly simple geometry consisting of an interconnection between two microstrips laying on the same substrate (for this structure experimental results were available), but this method can be straightforwardly applied to different and more complicated geometries thus providing an interesting tool for the investigation of a huge number of bonding wire interconnections and for the definition of the related equivalent circuits.

IV. Conclusions

In this paper, the Yee's discretization scheme has been simply suited to the analysis of curved bonding wire interconnections. To this purpose, a code combining the mesh grading, the electromagnetic field updating over cells crossed along the diagonal by an electric wall, and the multiple staircase discretization of the curvature, has been adopted. Some simulations have been performed to compare the accuracy of different approximations of the curvature. This comparison demonstrates that a satisfactory modeling of the curved bonding wire can be attained, even up to millimeter-wave frequencies, by replacing the curved wire with a straight one with a proper height. The proposed technique allows complex structures to be characterized thus providing an useful tool for the definition and optimization of interconnection models for CAD libraries.

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