Efficient full-wave analysis of coplanar waveguide to slotline interconnections with finite metallization thickness accounting for air bridge effects

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Abstract

The Coplanar Waveguide (CPW) to slot line transition is a key component of uniplanar circuit configuration for monolithic microwave integrated circuits (MMIC's). In this paper we introduce a new, efficient, full-wave model, based on the 3-D mode-matching technique. The model describes the transition taking into account the finite metallization thickness of the CPW as well as the effects of the air bridge. Theoretical simulations are compared with experimental results showing a good agreement.

Introduction

The growing demand for densely packed Monolithic Microwave Integrated Circuits (MMICs) has pushed toward the use of coplanar-waveguide (CPW) as the leading transmission line. Unlike microstrip line, the CPW avoids via holes, excessively thin substrates and backside metallization; moreover, it can easily integrate shunt lumped elements as well as solid-state devices on a single surface.

The advantages of the use of CPW and slotline have been recognized long ago [1-3], but only in recent times several new applications have appeared. By using the so-called "uniplanar approach" [4,5], complex circuits such as switchable and tunable band-pass filters [6], broad-band branch-line couplers [7], low-noise amplfiers, mixers, etc. [8], have been realized. In many of the above circuits the CPW-slotline transition represents a fundamental building block.

A CPW-to-slotline balun is also necessary to provide the slotline balanced feed to several types of antennas [9]. This transition can be realized in a variety of ways: by using an open circuit transition as in [5], or a 4-port balun as in [10], and a 6-port balun [11]. The CPW-slotline transition has been used in reference [12] where a structure similar to that in Fig. 1a has been realized and measured. To achieve wider bandwidths, the structure of Fig. 1c has been proposed in [13]. Recently, an experimental investigation [13] has been carried out to investigate the insertion loss characteristics of eight different types of transitions.

Common to the above designs is their experimental nature. The lack of accurate simulation tools is particularly felt by designers. Nowadays, models for the coplanar strip and slotline are not available in current versions of commercial simulation tools such as Libra or Touchstone [14]. While this drawback can be easily overcome by simply adding equations describing the electrical properties of the line in terms of its geometry, it is difficult to consider junction parasitics. Therefore, full-wave numerical simulations are needed to fully exploit the electrical behavior of this type of transition, as well as to provide efficient CAD tools.

We consider a model for the CPW-slotline transition which allows the efficient full-wave analysis of this type of structure. This model, based on 3-D mode matching technique, also allows one to account for the finite metallization thickness of the CPW, as well as for the presence of the air bridge. The importance of the metallization thickness has been already pointed out in [15, 16].

Electromagnetic analysis and parameter extraction

Interconnections between CPWs and slot lines can be realized in a variety of ways, some of which are shown in Fig. 1. Although the electrical characteristics of the various interconnections are sensibly different, the analysis of most of them can be done following the same approach. Let us refer to the interconnection of Fig. 1b. This discontinuity is separated into three different building blocks:

i) a short-circuited section of slot-line;
ii) a slot line;
iii) the junction between the slot lines and the CPW (including the air bridge)

The slot-line sections are analyzed separately by full-wave simulators in a standard fashion. On the other hand, the CPW-slot line junction must be analyzed by using a full-wave electromagnetic (EM) simulator. To this end the

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junction is enclosed in a metallic box of suitable dimensions, possibly representing also the actual package of the final circuit. The EM field distributions for the boxed junctions are obtained by using the 3-D Mode Matching technique presented in [16] along with the impressed source technique. Note that in the full-wave analysis the thickness of the metallization is taken into account. The procedure is described in [16].

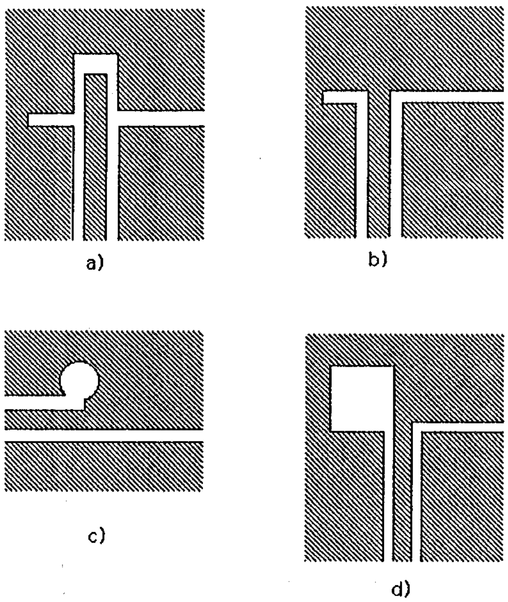

Figure 1. CPW-Slotline transitions. a) $\lambda_g/4$ cross-junction; b) slotline shorts and CPW shorts; c) slotline circular opens and CPW shorts; d) slotline rectangular opens and CPW shorts.

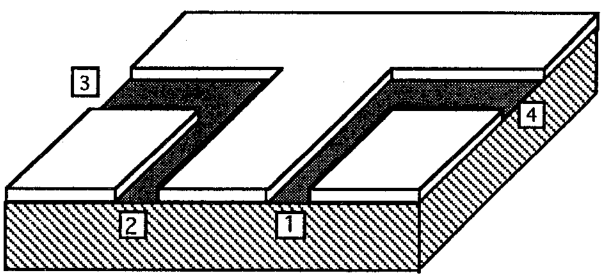

Figure 2. Geometry of the CPW to slotline junction. The numbers refer to the electrical ports which are labeled by considering each slot corresponding to a port.

Once the EM fields have been computed we can describe the junction using a circuit description at its terminals. Let us first look at the CPW as two slotlines. The transition is represented by a four port network, each port corresponding to one slotline. At each port voltages and currents are computed from the EM simulation at such a distance from the junction so that higher order modes excited at the discontinuity have died out.

Accordingly, once symmetry is accounted for, we obtain for the four port an admittance matrix description of the form

$$\begin{pmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} & y_{13} & y_{14} \\ y_{12} & y_{11} & y_{14} & y_{13} \\ y_{13} & y_{14} & y_{33} & y_{34} \\ y_{14} & y_{13} & y_{34} & y_{33} \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{pmatrix} \quad (1)$$

In (1) only six independent parameters are present. They can be determined by exciting the structure from one port, say port 1, and looking at the currents at ports 1, 2, 3 and 4. In this way we obtain y_{11}, y_{12}, y_{13}, y_{14} ; now, by exciting from port 3, we can also determine the values of y_{33}, y_{34}. For nonsymmetrical structures, the same procedure can be applied using more excitations to obtain all the relevant admittances.

Rather than describing the CPW as two slots, it is more convenient to refer to the dominant even and odd CPW modes. The network representation of this transformation is depicted in Fig 3b, and is obtained by considering that

$$v_c = \frac{v_1 + v_2}{2} \qquad i_c = \frac{i_1 + i_2}{2}$$
$$v'_c = \frac{v_1 - v_2}{2} \qquad i'_c = \frac{i_1 - i_2}{2} \quad (2)$$

where v_c, i_c, represent the even CPW mode while v'_c, i'_c are the voltages and currents of the odd (unwanted) CPW mode.

We can now take into account the air bridge effect by short-circuiting the odd mode (Fig. 3a, b). In other words, at the position of the air bridge we impose that

$$v'_c = 0 \quad (3)$$

Two approximations are involved by the above condition. On the one hand, no account is taken of possible interaction of the air bridge with the junction through higher order modes. Such an interaction may produce reactive coupling effects but is supposed to be negligible, because the distance from the junction is long enough to neglect higher order modes. The second approximation neglects the inductance associated with the current flowing on the bridge. This can be taken into account by replacing (3) with

$$v'_c = j\omega L_b i'_c \quad (4)$$

L_b being the inductance of the bridge.

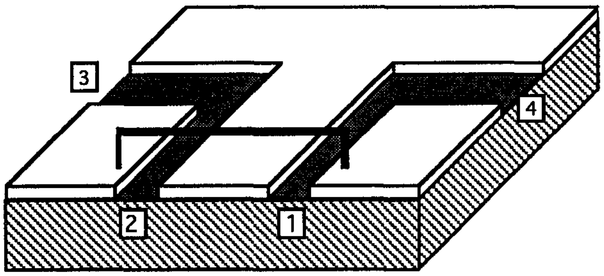

Fig. 3a The CPW odd mode is eliminated by placing the air-bridge at a certain distance from the transition

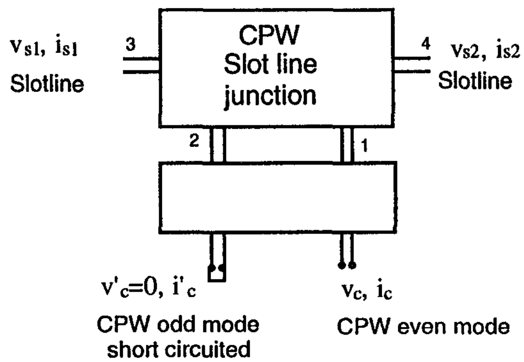

Fig. 3 b Equivalent network of the CPW slot line transition, when taking into account the air bridge effect on the odd mode

After using the procedure described and defining

$$v_{s1}=v_3,\ v_{s2}=v_4$$
$$i_{s1}=i_3,\ i_{s2}=i_4$$

we obtain the following 3-port representation of the junction between the CPW and the two slotlines

$$\begin{pmatrix} i_c \\ i_{s1} \\ i_{s2} \end{pmatrix} = \begin{pmatrix} y_{cc} & y_{cs} & y_{cs} \\ y_{cs} & y_{s1s1} & y_{s1s2} \\ y_{cs} & y_{s1s2} & y_{s2s2} \end{pmatrix} \begin{pmatrix} v_c \\ v_{s1} \\ v_{s2} \end{pmatrix} =$$

$$= \begin{pmatrix} y_{11}+y_{12} & (y_{13}+y_{14})/2 & (y_{13}+y_{14})/2 \\ (y_{13}+y_{14})/2 & y_{33} & y_{34} \\ (y_{13}+y_{14})/2 & y_{34} & y_{33} \end{pmatrix} \begin{pmatrix} v_c \\ v_{s1} \\ v_{s2} \end{pmatrix} \tag{5}$$

with obvious meaning of the symbols.

To compute the description of the CPW-slotline transition we have now to terminate one of the two slotines (say the slotline No.2) with a short circuited section. This step is also performed using the same 3D mode matching method. The computed input admittance of the shorted slotline is then used in (5) to eliminate the corresponding quantities v_{s2}, i_{s2} so as to obtain the 2x2 admittance matrix description of the transition.

Experimental and numerical results.

A typical CPW slot line transition, with the dimensions shown in Fig. 4, has been realized and measured. For the measurements to be performed, a double transition (i.e. a CPW to slot line to CPW) has been used. The same discontinuities have also been simulated by using the 3-D mode matching code and the results are shown in Fig. 5. The agreement is satisfactory, also considering that experiments are affected by coaxial to CPW connectors. As noted above, another possible source of disagreement can be due to the inductance associated to the air bridge. In addition, the location of the air bridge itself in the experiment was not perfectly defined.

We have therefore investigated the effects of the location of the air bridge position. In Fig. 6 the insertion loss for three different positions of the air bridge hase been plotted. It is seen that the position of the air bridge affects significantly the electrical response. By comparison with Fig.5 it is also noted that a better agreement with the experiments is obtained by shifting the location of the short circuit of about 2.5 mm. This shows that the main effect of the air bridge can be effectively modeled by an inductance loading the unwanted odd mode of the CPW.

Conclusions

We have introduced a new full-wave model to characterize the transition between the Coplanar Waveguide (CPW) and the slot line. The model is based on the 3-D mode-matching technique and takes into account the finite metallization thickness of the CPW as well as the effects of the air bridge. The effect of the air bridge is shown to that of an inductance loading the odd CPW mode. Theoretical simulations are compared with experimental results showing a good agreement.

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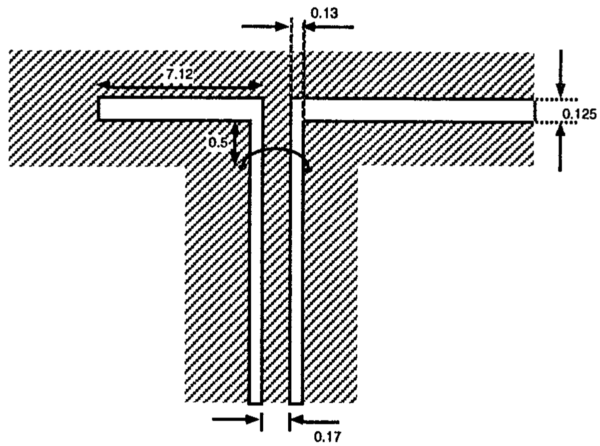

Fig. 4 Geometry and dimensions (in mm) of the CPW Slot line transition. The substrate thickness is 1.27 mm, the metallization thickness is 17 μm and ε_r=11

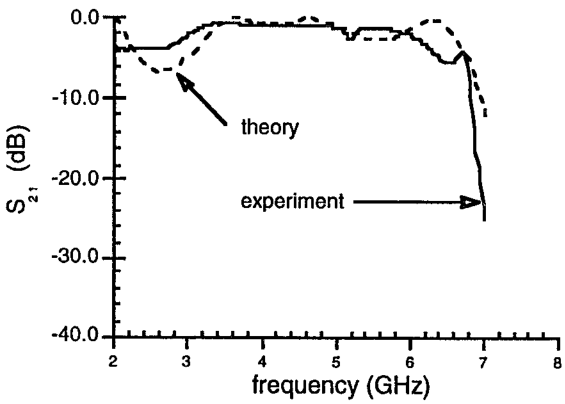

Fig. 5 Theoretical and experimental results for the CPW slot line transition of Fig. 4.

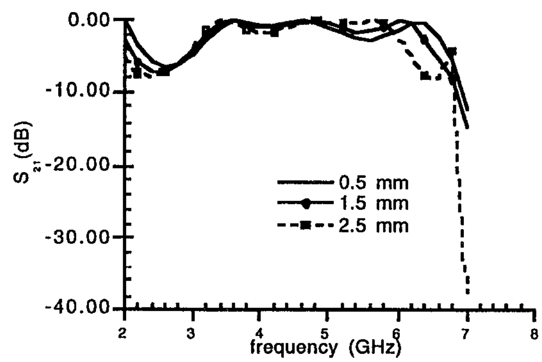

Fig. 6 Theoretical results for different airbridge positions (reported in the inset) for the CPW slot line transition of Fig. 4.