Suppression of the Parasitic Modes in CPW Discontinuities Using MCM-D Technology—Application to a Novel 3-dB Power Splitter

Ezzeldin A. Soliman, *Student Member, IEEE*, Philip Pieters, *Student Member, IEEE*, Eric Beyne, and Guy A. E. Vandenbosch, *Member, IEEE*

***Abstract*— In this paper, a new method for the suppression of the parasitic modes in the coplanar waveguide (CPW)-based microwave circuits is presented. The proposed method replaces the costly and mechanically unstable air-bridges. It uses tunnels (bridges) running below (above) the CPW and isolated from it using a thin film layer. This method is convenient for MCM-D technology in which thin films are deposited over the substrate to support the required interconnects. The method is applied to the band reject filter presented in an earlier paper by Rittweger *et al.* and compared with the case of air-bridges. The effects of the tunnel parameters on the filter performance are presented and discussed. The new suppression mechanism is also applied on a novel 3-dB power splitter. Experimental and theoretical results of the new power splitter are presented and compared. The agreement between theory and measurements ensures the efficiency of the proposed suppression mechanism.**

***Index Terms*—Coplanar waveguides, MCM-D, thin-film technology, 3-dB power splitters.**

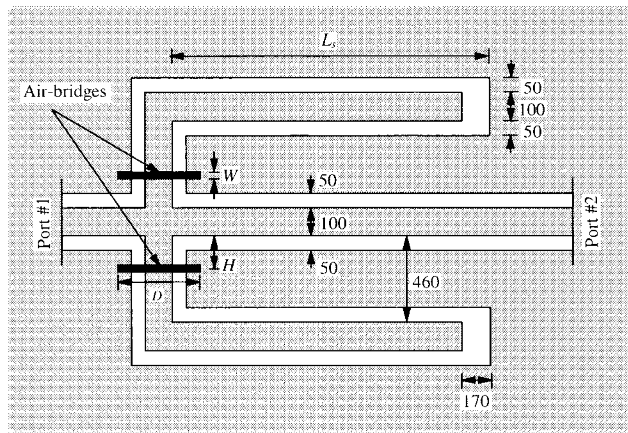

Fig. 1. Rittweger's band reject filter, all dimensions are in μm: $D = 350$ μm, $W = 10$ μm, and $H = 150$ μm.

I. Introduction

Coplanar waveguides (CPW's) become preferable over the conventional microstrip lines for several microwave systems, owing to their low mutual coupling, low dispersion, good control of the characteristic impedance, ease of integration with active devices, and the possibility of connecting shunt lumped elements without the need of via holes through the substrate. However, CPW's suffer from the excitation of the parasitic slotline mode in asymmetric discontinuities. Suppression of the slotline mode in CPW-based microwave circuits may become essential for obtaining an adequate performance. The conventional method for eliminating the unwanted mode is the use of air-bridges [1]–[3]. However, these air-bridges are costly to build and mechanically unstable. Omar and Chow [4] have introduced the use of top and bottom shields instead of air-bridges. The locations of these planes, along the normal to the substrate, are optimized such that the slowly decaying slotline mode is significantly affected and almost eliminated. On the other hand, the coplanar mode which possesses quicker decaying behavior is less affected. The authors applied this method to the band reject filter introduced by Rittweger [1], (see Fig. 1). This filter was designed to have no transmission at 18 GHz and good transmission at 36 GHz. Air-bridges succeed in satisfying the requirements perfectly. The top and bottom shields show very good performance, in comparison with air-bridges, except for small deviation around 18 GHz for S_{11} and around 36 GHz for S_{21} [4]. This deviation was explained as power leakage from the dominant CPW mode into the parallel plate TEM mode.

This paper aims at introducing a new method for suppressing the slotline mode, namely the use of thin-film tunnels or thin-film bridges. Microwave components and circuits in MCM-D technology are realized using multiple thin-film layers which are deposited over the substrate [5]. These layers play an important role in isolating the required interconnects of the MCM. The IMEC MCM-D technology [5] uses thin films of BCB, $\varepsilon_r = 2.7$, with 10 μm thickness. The proposed thin-film tunnels (bridges) are running below (above) the CPW and are isolated from it using thin film of BCB. Via holes through the thin BCB film are used to connect the tunnel (bridge) to the required positions of the CPW. Fig. 2 shows a comparison between the air-bridges and the thin-film tunnels. Thin-film technology is found to be more mechanically stable and more economic than the air-bridges.

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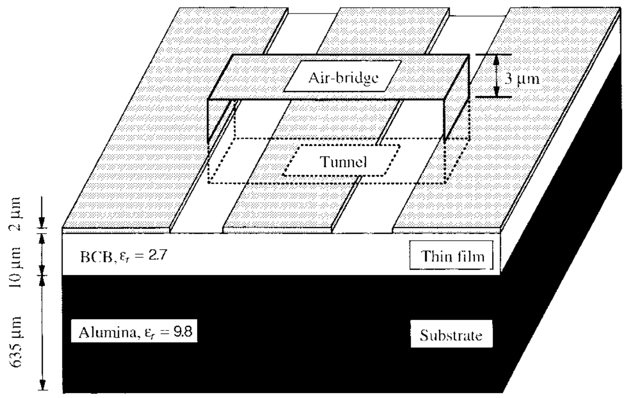

Fig. 2. The proposed thin-film tunnel and the conventional air-bridge.

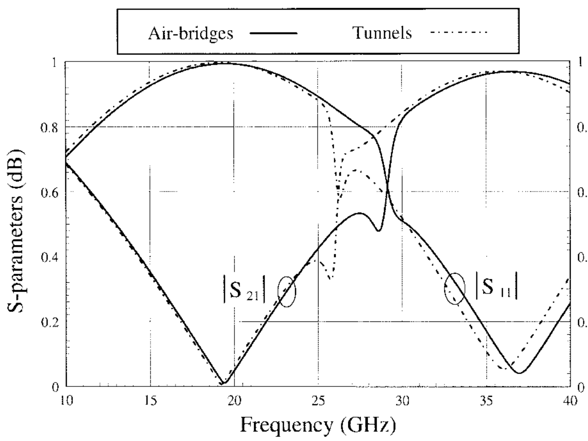

Fig. 3. S-parameters versus frequency: $D = 350$ μm, $W = 10$ μm, and $H = 150$ μm.

Unlike the top and bottom shields, this method offers the possibility of integrating CPW-fed antennas together with the driving electronics and microwave circuits on the same substrate. In Section II, the performance of Rittweger's filter based on both the conventional air-bridges and the proposed thin-film tunnels is investigated theoretically. A novel 3-dB power splitter based on coplanar technology is introduced in Section III. Thin-film bridges are used to suppress the unwanted modes and to meet the required performance for that power splitter. Experimental and theoretical results of the new power splitter are presented and compared.

II. Rittweger's Filter Using Air-Bridges and Thin-Film Tunnels

In order to demonstrate the proposed method, the same Rittweger's band reject filter [1] is studied, as shown in Fig. 1. Thin-film tunnels are used to suppress the slotline mode of the CPW; see Fig. 2. The thin-film layer placed below the CPW tends to slightly reduce the effective dielectric constant. In order to get the same electrical length of the shunt stub, its length is increased from to $L_s = 1420$ to $L_s = 1830$ μm. The filter under investigation is studied rigorously using HP-Momentum which is based on an integral equation formulation. Fig. 3 shows S_{11} and S_{21} versus frequency, using air-bridges or thin-film tunnels. It is clear that the thin-film

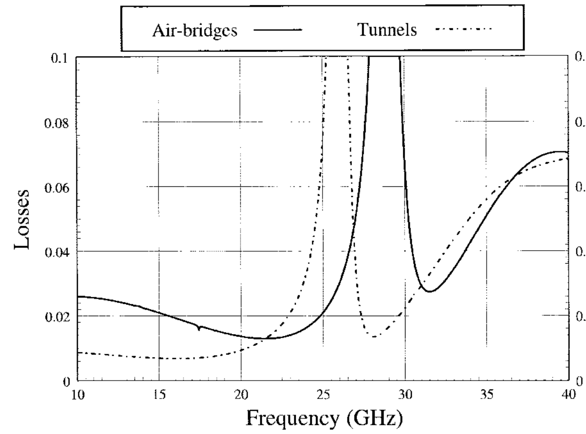

Fig. 4. Total losses versus frequency.

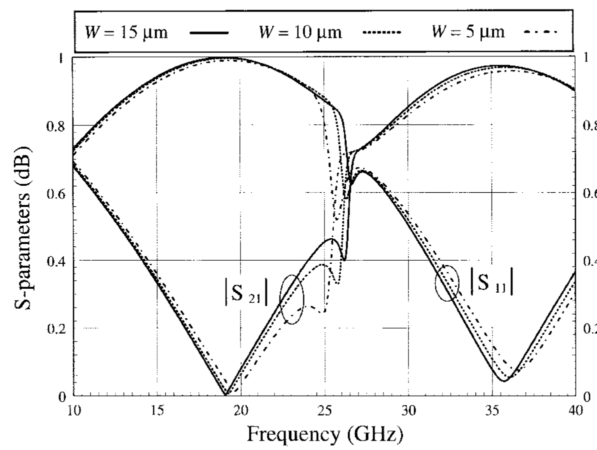

Fig. 5. S-parameters versus frequency for different values of the tunnel width: $D = 350$ μm and $H = 150$ μm.

tunnels succeed in satisfying the requirements. Very good matching between the results of the air-bridges, the thin-film tunnels, and [1] is observed around 18 and 36 GHz. Fig. 4 shows the total loss versus frequency, which is equal to $1 - |S_{11}|^2 - |S_{21}|^2$. The sources of loss are: coupling to slotline mode, radiation, surface waves, and ohmic losses. Normally, the main contribution to the losses is due to leaking power to the slotline mode. Consequently, the losses can be considered as an indication of the efficiency of the slotline mode suppression mechanism. The losses for both cases are small; however, for the case of thin-film tunnels, the losses are even smaller especially at low frequencies. This indicates the efficiency of the new mechanism.

The effects of varying the tunnel parameters (W, D, and H), see Fig. 1, on the filter performance are investigated. Fig. 5 shows the effect of varying the tunnel width W. The capacitance between the tunnel and the center strip increases as the tunnel width increases. Consequently, the effective length of the stubs increases and shifts down the resonance frequencies. The same behavior is reported in [2]. The effect of varying the tunnel length D is shown in Fig. 6. It is clear that this effect is almost negligible. Fig. 7 shows the effect of the tunnel location H on the filter performance. The higher the separation between the tunnel and the discontinuity, the

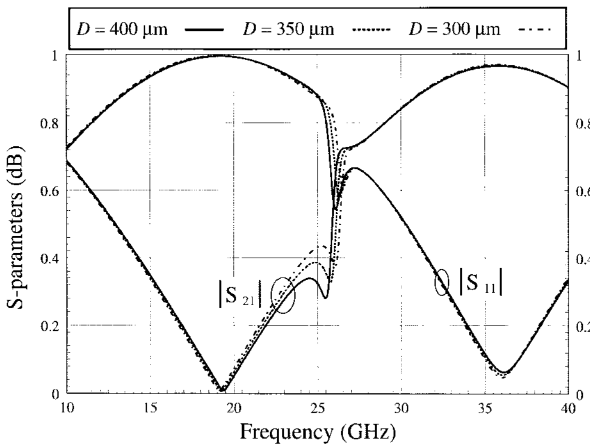

Fig. 6. S-parameters versus frequency for different values of the tunnel length: $W = 15$ μm and $H = 150$ μm.

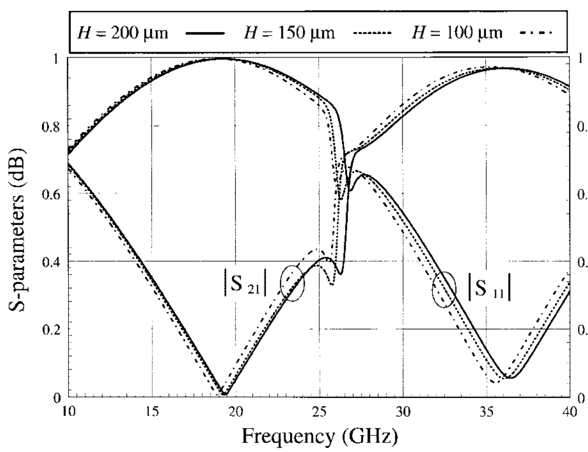

Fig. 7. S-parameters versus frequency for different values of the tunnel location: $W = 15$ μm and $D = 350$ μm.

higher the resonance frequencies will be. This is explained in [2] as a result of the decrease of the effective length of the stubs due to the propagation of the high-speed slotline mode.

III. Novel 3-dB Power Splitter Using Thin-Film Bridges

The power splitter is an important component in several microwave circuits [6]. In this section, a novel 3-dB power splitter is introduced (see Fig. 8). The CPW lines connected to the three ports are identical to each other. The characteristic impedance of the feeding CPW, port #1, is matched to the characteristic impedance of the "coplanar-like" mode of the triple slot transmission line. The modal distribution of the equivalent magnetic current of the "coplanar-like" mode has the following properties: 1) the equivalent magnetic currents in the outer slots are equal in magnitude but opposite in phase and 2) the equivalent magnetic current in the central slot is very small compared to the currents of the outer slots. These properties of the modal current distribution of the "coplanar-like" mode provide the required power splitting, as the potential levels of the central strips are almost the same.

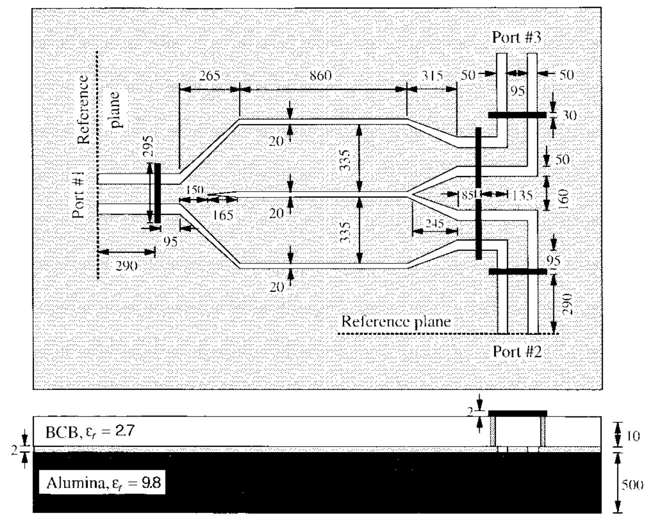

Fig. 8. Geometry of the proposed 3-dB power splitter with thin-film bridges (all dimensions are in micrometers).

In order to suppress the other two unwanted modes, thin-film bridges are placed just before and after the triple slot section. The choice of bridges over the thin film, instead of tunnels, in this case is based on the sensitivity to manufacturing tolerances. Placing the thin-film layer below the triple slot line results in a significant decrease of the equivalent shunt capacitance of the line and, consequently, a significant increase in the characteristic impedance of the "coplanar-like" mode. In order to keep it matched to the feeding 50-Ω CPW, the slot width must significantly decrease and may become sensitive to the manufacturing tolerances. On the other hand, placing the thin film on the top of the triple slot line makes it possible to obtain the required characteristic impedance with reasonable slot width. The central slot is split into two slots which are grouped together with the outer slots to feed the CPW lines in ports #2 and #3 through 90° bends. Additional bridges are placed after the bends in order to suppress the slotline mode of the CPW lines.

The length of the triple slot transmission line must be slightly higher than $\lambda_g/4$ of the "coplanar-like" mode at the minimum frequency of the design band, in order to ensure the attenuation of the higher order modes which may be excited at the ends of the triple slot transmission line. The wide band nature of the presented power splitter is a consequence of its independence on any specific electrical lengths. Instead, the criteria for obtaining an adequate performance is that the characteristic impedance of the CPW's connected to the three ports are close to the characteristic impedance of the "coplanar-like" mode of the triple slot transmission line. This criteria is easy to be meet since the coplanar mode and the "coplanar-like" mode of the CPW and the triple slot transmission line, respectively, possess low dispersion characteristics. Moreover, reasonable degree of dispersion over the entire band is acceptable as long as the characteristic impedances of the coplanar and the "coplanar-like" modes are still close to each other.

The proposed power splitter is studied both theoretically and experimentally. Experiments are performed using an HP-

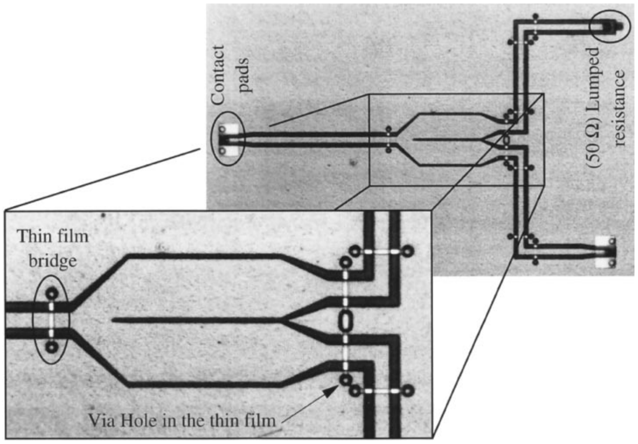

Fig. 9. Picture of the realized 3-dB power splitter.

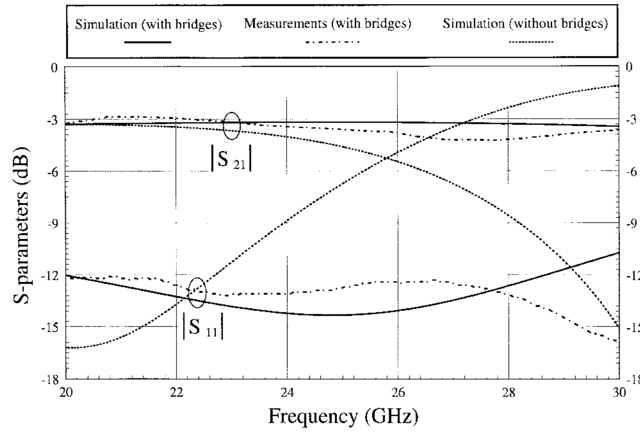

Fig. 10. Measured and calculated magnitude of the S-parameters of the power splitter versus frequency.

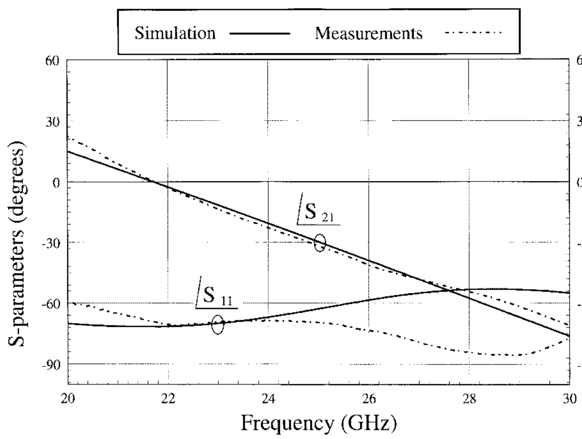

Fig. 11. Measured and calculated phase of the S-parameters of the power splitter versus frequency.

8510C network analyzer. A picture of the realized power splitter is shown in Fig. 9. On-wafer probes are used to feed the power splitter under test through tapers which accommodate the probe pitch to the pitch of the feeding CPW (see Fig. 9). In order to overcome the limitation of the two-port measurements of the network analyzer, the third port is terminated by a lumped 50-Ω resistance. The lumped resistance is implemented using the multilayer thin-film technology (see Fig. 9). The 90° bends connected to the feeding CPW's of ports #2 and #3 are due to the limitation of the probe station which allow only parallel trajectories for the on-wafer probes. The metal pads at the feeding ports are used to provide electrical contact, through via holes in the thin film, to the CPW lines which are placed below the thin film and above the substrate. In order to set the reference planes for the phase measurements and to de-embed the taper from the measurements, full two-port thru-reflect-line (TRL) calibration is performed. The location of the reference planes are set 290 μm away from the discontinuities (see Fig. 8). The length of the bent CPW's placed between the reference planes and the feeding points of ports #2 and #3 is identical to the length of that piece of CPW placed between the reference plane and the feeding point of port #1. This common piece of CPW is de-embedded out from the measurements, using appropriate calibration standards, which allow correct phase measurements without the need for rotation of the reference planes.

The measured and calculated magnitude and phase of the S-parameters are shown in Figs. 10 and 11, respectively. Very good agreement between theory and measurements is observed for S_{21}, while reasonable agreement is observed for S_{11}. It is clear from Fig. 10 that the proposed power splitter satisfies the required 3-dB coupling to port #2 over the entire frequency band of interest. The measured and calculated return loss is below 10 dB over the entire band which corresponds to SWR < 2. For the return loss, the deviation between theory and measurements is likely due to the uncertainty in the value of the termination lumped resistance at port #3. The calculated S-parameter magnitudes of the power splitter without the thin-film bridges are presented in Fig. 10. It is clear that without the thin-film bridges, the power splitter fails to satisfy the requirements above 24 GHz.

IV. Conclusion

A new method for suppressing the parasitic modes in coplanar waveguide discontinuities has been presented. It replaces the conventional air-bridges by thin-film tunnels (bridges) running below (above) the CPW. This method is convenient for the microwave circuits built in MCM-D, which uses thin films to support the required interconnects. The proposed method is applied on a band reject filter and studied rigorously using a full wave simulation program. The results show that the thin-film tunnels are able to suppress the slotline mode of the CPW and satisfying the requirements of the Rittweger's band reject filter to a high degree of accuracy. The effect of varying the tunnel parameters on the filter performance is also studied. The results show that the variation of the tunnel width, which is likely to be affected by the manufacture tolerance, has more significant effect than the variation of the tunnel length and location. The smaller the width, the much closer the resonance frequencies to the designed values. The suppression mechanism is also applied on a novel 3-dB power splitter. The proposed power splitter is studied both theoretically and experimentally. The results show that thin-film bridges are essential for the power splitter to satisfy the required 3-dB coupling over the investigated frequency band. The proposed 3-dB power splitter can be used as a building block of a wide band feeding network for an antenna phased array. From the technology point of view, the thin-film tunnels (bridges) are much more stable than the conventional air-bridges. Moreover, they are more economic than the air-bridges. Unlike the top and bottom shields suppression mechanism, thin-film tunnels (bridges) are suitable for microwave circuits driving planar antennas.

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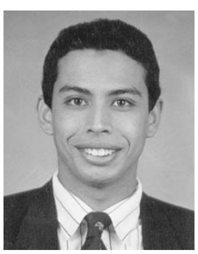

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