Integrated Transition of Coplanar to Rectangular Waveguides

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Abstract — **Usual transitions between planar circuit and rectangular waveguide make use of 3-D complex mounting structures. Such an integration requires costly high precision mechanical alignment. In this paper, a new planar platform is developed in which a coplanar waveguide (CPW) and a rectangular waveguide are fully integrated on the same substrate, and they are interconnected via a simple transition. They can be built with a standard PCB process. Our experiments at 28 GHz show that an effective bandwidth of 7% at 15 dB return loss can easily be achieved. The CPW-to-waveguide transition allows for a complete integration of waveguide components on substrate with active components such as MMIC.**

I. Introduction

Integration of active and passive components through rectangular waveguide usually requires transitions from planar to non-planar circuits. Various approaches to solving this problem had always led to some complex mounting structures [1,2,3]. High precision mechanical adjustment or tuning mechanism is needed to obtain good performance for a mass production. The microstrip circuit often needs to be cut into a specific shape, hard to achieve in the millimeter-wave range. Furthermore, rectangular waveguide components are long and expensive to manufacture. They make the planar/non-planar integration bulky and costly.

Recently, the idea of an integrated rectangular waveguide was proposed [4]. The waveguide was synthesized with a linear array of metallized via holes on the same substrate used for the planar circuit. The waveguide can also be integrated with metallized wall [5,6]. These techniques allow a very compact integration. However, an efficient transition between both structures is needed. Several solutions have been proposed [5]-[7] to this end. In all these structures, the planar circuits, usually referred to microstrip line circuits, and the rectangular waveguide are built onto the same substrate with a standard PCB process and the transition is formed with a simple matching geometry between both structures. Very good results over a 12% bandwidth have been reported in [4]. Integrating such planar and non-planar circuits can significantly reduce size and cost. To explore a high performance in terms of insertion loss, a low-loss substrate like alumina can be selected. However, with a thin substrate, the conductor loss within the waveguide section cannot be neglected and it may become prohibitive. To reduce it, the substrate thickness must be increased. This leads to an increase of radiation loss in the microstrip components and other problems such as availability of impedance range that may create some complications for active component design and integration. In order to improve the interconnection to the integrated waveguide, a new transition using a planar transmission line compatible with thick dielectric substrate should be considered.

In the millimeter-wave range, the coplanar waveguide (CPW) is a very promising transmission line. Furthermore, increasing dielectric substrate height may not affect too much inherent CPW characteristics. This transmission line is therefore well suitable for the on-substrate hybrid integration with the rectangular waveguide and other uniplanar structures, since the substrate thickness can be increased to reduce conductor loss in the waveguide design without having adverse impact on planar components. This article presents a new planar integrated circuit of CPW-rectangular waveguide, as shown in Figure 1. All the structures are realized on a single PCB using a standard process. Integrating both structures on single PCB layer allows the design of transition without tuning or mechanical mounting. The technology is also compatible with LTCC multilayer processes for a low-cost mass production.

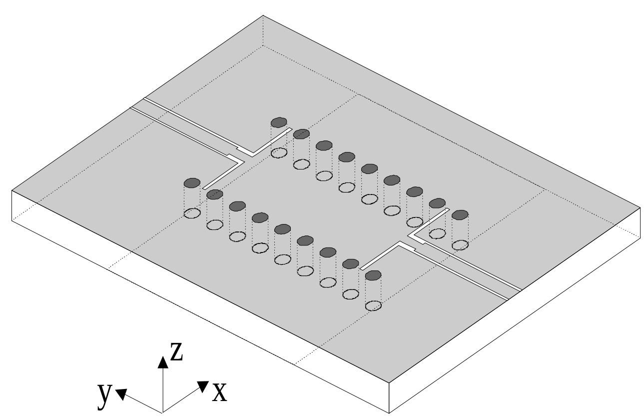

Fig. 1. Schematic view of the proposed transition of coplanar waveguide and rectangular waveguide integrated on the same substrate.

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II. ANALYSIS OF INTEGRATED WAVEGUIDE

The integrated waveguide is a good compromise between air filled rectangular waveguide and microstrip line. In the millimeter-wave range, the microstrip is too lossy to design high Q components. For example, a 50 Ω line, designed on an 0.254mm thick dielectric with a permitivity of 2.33 (tanδ=0.001) and 0.0254mm of copper cladding, the unloaded Q factor is 42 at 28 GHz [8]. At the same frequency, the unloaded Q factor of an air-filled rectangular waveguide (WR 28) is 4613 [9]. With the same dielectric material used as in the precedent microstrip example, the unloaded Q factor of the dielectric-filled integrated waveguide (a=5.08 mm) is 342. This allows the design of various kinds of high-quality components such as filter, T-junction, and diplexer.

In [10] a number of components using post-wall waveguide technique combined with metallic layer were analyzed and simulated. Good results were reported for T-junction and isolation performance between waveguides. In order to highlight the potential of the post-wall waveguide in the design of low loss components, a single pole filter was designed, simulated and measured in our work. The resonator was designed using two posts (via hole) in the middle of the integrated waveguide. Filter can be designed using synthesis techniques for inductive post in rectangular waveguide as described in [11]. The circuit was made on 0.254mm thick substrate with ε_r=2.33. The waveguide was synthesized by using two arrays made of 0.76mm via hole (diameter) spaced by 0.76mm (edge to edge). The two post arrays are spaced by 4.42mm. To measure the resonator, the transition described in [4] was used. Results for the single resonator are shown in Figure 2. The simulated results were obtained with a commercial Finite Element Method (FEM) package [12]. Simulated and measured results agree well with each other and this kind of structure is well suited to the design of low loss components such as filter.

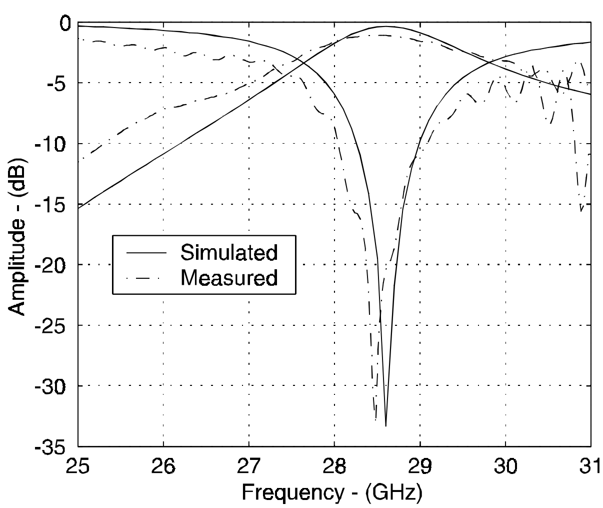

Fig. 2. Simulated and measured results of a resonator design with an integrated waveguide.

The total quality factor (Q_T) in a rectangular waveguide is related to lossy conducting walls (Q_c) and lossy dielectric material (Q_d). Since the lowest Q governs the overall performance, it's important to analyze the effect of the different losses. Q_c is only determined by the metal and the waveguide dimensions for the fundamental mode. Q_d is only affected by dielectric losses. Figure 3 shows that both Q are in the same range of magnitude. In order to obtain a high Q component (~1000), Q_c and Q_d must be around 2000. A very low loss materiel (tanδ=0.0005) and a dielectric thickness over 1.2 mm can meet this expectation. However, with a thick dielectric substrate, microstrip loss is very high, and it is difficult to obtain low impedance

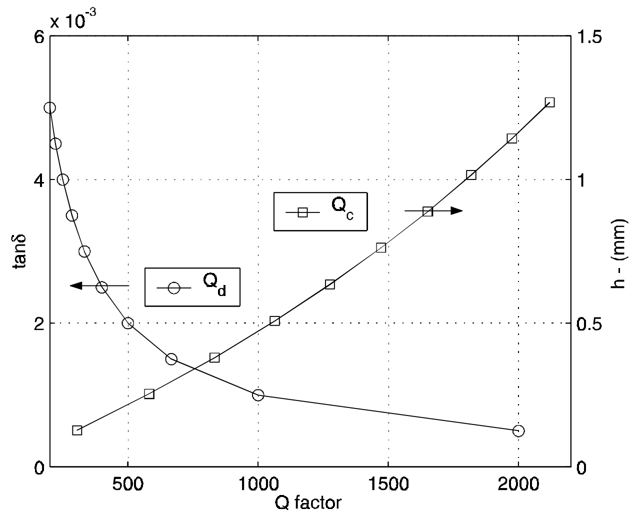

Fig. 3. Effect of dielectric loss tangent and dielectric thickness on Q_C and Q_d.

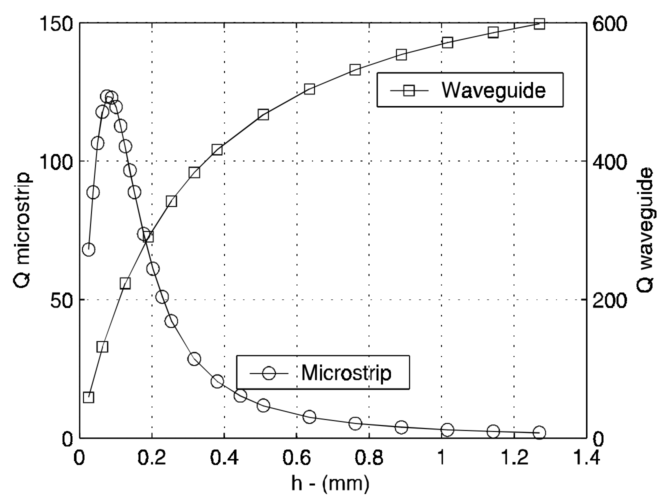

Fig. 4. Quality factors of microstrip line and integrated waveguide as a function of the dielectric thickness.

without high radiation loss. Figure 4 shows that there is no cross-point of the minimum loss points between microstrip line and integrated waveguide in the same region.

III. Design of the Proposed Transition

Figure 1 shows the proposed back-to-back transition structure from CPW to rectangular waveguide integrated on the same substrate layer. It consists of a coplanar waveguide with 90° bend on each slot. A stub is added on the CPW line to match the transition and the rectangular waveguide is constructed with the via hole arrays. The back metallic plane is added only under the transition and the rectangular waveguide. Two via holes, one for each side of the stub, are added to remove a potential parallel plate mode that can propagate between the CPW and the back plane before the rectangular waveguide. The stub length (l), the stub width (s), the slot length (L) and the slot width (d), with reference to Figure 5, must be optimized in this structure to minimize the insertion loss and match the transition over a wide bandwidth.

The design of this transition is very simple. The length of each bend slot (L) on the CPW is approximately λ/4 and ended with a short circuit. The electric fields on these slots, minimum at the end and maximum at the other end of the quarter wavelength line, very well match the TE_{10} field distribution in the waveguide except that for the slot, the electric field is in the x-y plane and in the x-z plane for the rectangular waveguide. Since the CPW is a uniplanar transmission line and rectangular waveguide is a planar 3D structure in this case, a back plane must be added in the transition. This allows having a non-ambiguity match along the transition for the electric fields. With this discontinuity, however, it is hard to achieve a good matching. Therefore, a stub has to be added to obtain a good insertion loss. Designed between the CPW and the bend slot, the λ/4 grounded-CPW stub allows a good matching over a relatively large bandwidth.

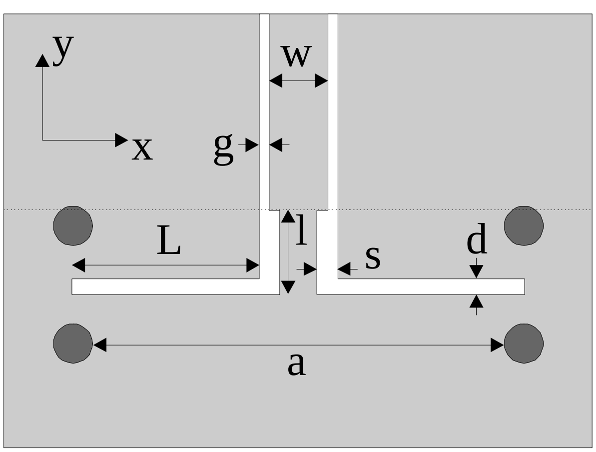

Fig. 5. Geometry of the CPW-to-rectangular waveguide transition.

A commercial package using a finite element method (FEM) is used to simulate and optimize the structure [12]. Since the simulation time is very long for this kind of structure, due to the small gap detail involved in the CPW design, a set of good initial values for various parameters should be considered. We start the optimization with a 50 Ω CPW line, a rectangular waveguide working from 19 to 38 GHz, two pre-designated λ/4 slots (L) and λ/4 stubs (l). The stub width (s) is selected arbitrarily up to a half of the CPW line width and the slot width (d) is chosen with the same value as the slot over the stub of the CPW. These values yield a good starting point and the convergence to the optimum point is relatively fast. In order to reduce our simulation time, the via-holes are defined as a set of hexagons. The structure is then optimized to obtain the better reflection and insertion losses around 28 GHz.

IV. Experimental Results

To verify the proposed concept, a transition working in the LMDS frequency range is designed, optimized and measured. The structure consists of two back-to-back transitions and an integrated waveguide with a length of 10 mm. The whole circuit is constructed on a 0.508 mm thick dielectric substrate with $\varepsilon_r = 2.33$. The final dimensions, referring to Figure 5, are: w=0.762 mm, g=0.254 mm, l=1.092 mm, s= 0.279, L=2.413 mm, d=0.191 mm and a=5.08 mm. This leads to a 54 Ω CPW line and a waveguide operating from 19 to 38 GHz. The diameter of each via-hole for synthesizing the waveguide is 0.76 mm and spacing between two adjacent vias is also 0.76 mm, which is the same as the previous structure. An HP8510 network analyzer and a Wiltron test fixture are used to measure the circuit. A standard TRL calibration is carried out before the measurement.

Figure 6 shows our simulated and measured results, which involve two transitions and 10 mm synthesized rectangular waveguide. A bandwidth of more than 7 % is obtained here for 15dB return loss from 27.5 to 29.5 GHz. The measured insertion loss is better than 3.2 dB in the entire band. Since the materiel loss is expected to be very small and the reflection loss is relatively good, the major part of the insertion loss may be caused by radiation.

V. Conclusions

A new integrated transition of CPW line to rectangular waveguide has been proposed and studied. It allows the design of a completely integrated planar circuit and waveguide on the same substrate without any additional mechanical assembling or tuning. Uniplanar characteristics of CPW line make the integration easier with active circuits. The dielectric thickness can be increased to reduce conductor loss related to the design of the rectangular waveguide. Measured results agree well with the simulated ones for our fabricated sample of the transition. With its direct integration, small size and low loss features, this new scheme is well suited for circuit design at millimeter-wave frequencies. It can be used to integrate passive waveguide components with MIC and MMIC active circuits for mass production.

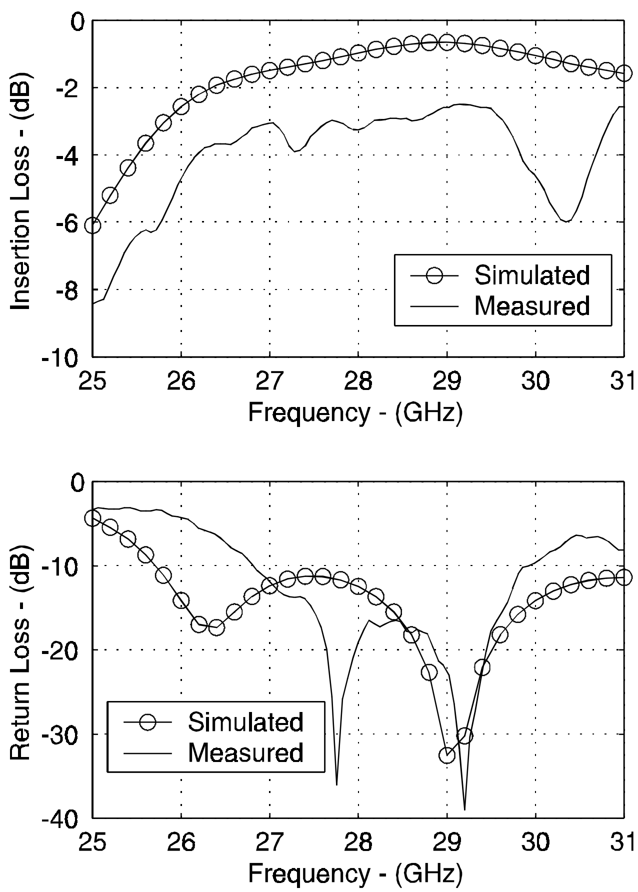

Fig. 6. Simulated and measured results for two back-to-back transitions separated by 10 mm integrated waveguide.

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REFERENCES

[1] B. N. Das, K. V. S. V. R. Prasad, and K. V. Seshagiri Rao, "Excitation of waveguide by stripline and microstrip-line-fed slots," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-34, no. 3, pp. 321-327, March 1986.

[2] W. Grabherr, B. Huder, and W. Menzel, "Microstrip to waveguide transition compatible with mm-wave integrated circuits," *IEEE Trans. Microwave Theory and Tech.*, vol. 42, no. 9, pp. 1842-1843, September 1994.

[3] G. E. Ponchak, and R. N. Simons, "New rectangular waveguide to coplanar waveguide transition," *1990 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 491-492, May 1990.

[4] J. Hirokawa, and M. Ando, "Single-layer Feed Waveguide Consisting of Posts for Plane TEM Wave Excitation in Parallel Plates,"*IEEE Trans. Antennas Propagat.*, vol. 46, no. 5, pp. 625-630, May 1998.

[5] D. Deslandes, and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *to be published in IEEE Microwave and Guided Wave Letters*, 2001.

[6] C.-K. C. Tzuang, K.-C. Chen, C.-J. Lee, C.-C. Ho, and H.-S. Wu, "H-Plane mode conversion and application in printed microwave integrated circuit," *2000 European Microwave Conference Proceedings*, vol. 2, pp. 37-40, October 2000.

[7] N. Jain, "Transverse Electric or Quasi-Transverse Electric Mode to Waveguide Mode Transformer," *US Patent*, no 6087907, July 11, 2000.

[8] K. C. Gupta, *Microstrip lines and Slotlines*, Dedham: Artech House, 1996.

[9] D.M. Pozar, *Microwave Engineering*, New York: Wiley, 1998.

[10] H. Uchimura, and T. Takenoshita, "Development of a Laminated Waveguide," *IEEE Trans. Microwave Theory and Tech.*, vol. 46, no. 12, pp. 2438-2443, December 1998.

[11] R G.L. Matthaei, L. Young, and E.M.T. Jones, *Microwave Filters, Impedance-Matching Networks and coupling Structures*, New York: McGraw-Hill, 1964.

[12] Agilent HFSS Version 5.6, Agilent Technologies, Inc., Palo Alto, CA.