# A Novel Microstrip Mode To Waveguide Mode Transformer And Its Applications

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***Abstract* — A microstrip-to-rectangular waveguide mode transformer that can be implemented using PCB technology is presented. The RT/Duroid based transformer has a wide simulated frequency response extending from 55 GHz to 140 GHz with about 0.15 dB radiation losses. Many important applications that are easy-to-manufacture are possible. Measurement results of a typical configuration are presented.**

## I. INTRODUCTION

Numerous commercial mm-wave systems require microstrip-to-rectangular waveguide transitions [1-2]. The key requirements of such a transition are compact size, easy-to-manufacture, low radiation loss, and process-tolerant for PCB compatible fabrication. Additionally, good electrical isolation is desired when multiple transitions from a substrate for multi-beam system are required. Autonomous cruise control (ACC) radar system is an example to such systems.

A number of such transitions have been proposed in the literature [3-10]. The well-known transitions from microstrip to rectangular mode are the E-field probe method [3] and ridge waveguide transition [4]. Both of them require modification to the waveguide and puts restriction on the planar circuit design [8]. Recently a number of transitions, compatible with MMIC and MIC processing, have been proposed [5-9]. While these new transitions provide a suitable technology for large-scale low-cost manufacturing, the performance of the printed transition has been unsatisfactory. Firstly, they have excessive loss (up to 2 dB [8]), and/or relatively a narrow-bandwidth. Secondly, the transitions are prone to cross talk; and are sensitive to manufacturing tolerances and operating environment. Thus there is a need for a broadband microstrip-to-rectangular waveguide transformer for high frequency modules that is easy to manufacture, low loss, and insensitive to manufacturing tolerances.

In this paper we present the design and measurements of a novel microstrip-to-rectangular waveguide (MS-to-RW) transition [10]. This transition is relatively insensitive to manufacturing tolerances and provides excellent broadband performance. This is because it does not rely on resonance phenomenon for coupling. It also provides excellent isolation between two adjacent transitions.

Measurements are presented to validate the simulation results for a back-to-back transition. Finally some application areas are cited where this transition can be used.

## II. THEORY AND PERFORMANCE

Figure 1 shows the novel MS-to-RW transition that is described in this paper. The energy carried by the microstrip line (MS) is transferred to the rectangular waveguide (RW) formed in the dielectric. The dielectric waveguide is made by using plated rectangular via-trenches at the sides, and metallic patch on the top as shown in Figure 1. After transferring to the waveguide medium in the dielectric, the energy can be carried with low-loss or transferred to the other side of the PCB through another waveguide section [1]. To explain the transition performance, one needs to consider a representation of rectangular waveguide shown in [13] when the waveguide is above cut-off.

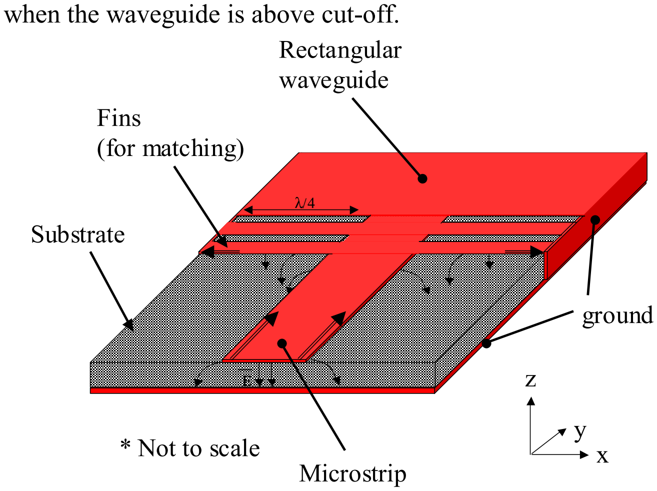


Figure 1: The novel microstrip-to-rectangular waveguide transition.

The rectangular waveguide can be thought of many quarter wavelength strips (fins) extending from the center region and shorted at the far end (rectangular waveguide wall). The central region of the rectangular waveguide can be approximated by a parallel-plate waveguide provided it is above cut-off. To gradually transfer the microstrip to parallel-plate waveguide one needs fins, shown in Figure 1, which help restrict the E-field within the substrate when the microstrip ends. Because RW can also be equated to fins closely spaced, even under no fin conditions the transfer of E-fields into the substrate is very good. Therefore, broadband match for the transition shown in Figure 1 is achieved when the impedance of the resulting parallel-plate line is approximately matched to the microstrip transmission line at the frequency of interest.

Figure 6 shows the study of the transition shown in Figure 1 with respect to different number of fins. The MS line is nominally 50-Ohms and is 380-µm wide while the rectangular waveguide width is 2020 µm. The *S*-parameters are in the natural impedance of the transmission lines and, thus, reflect the characteristics of the mode transformer. Simulations show that the radiation loss at the transition is about 0.15 dB per transition and the operating bandwidth is from 65-90 GHz. Also shown in the figure is the result of reducing the number fingers. It is clearly seen that the number of fins can change the frequency where optimum match is achieved. For the no fin case, introducing a slight capacitance at the junction can optimize the performance. Figure 7 shows the optimized performance for the no-fin case using full-wave electromagnetic (EM) simulations with the *S*-parameter referred to the natural impedances of the transmission lines. Clearly a return loss better than 15-dB is obtained for 60-140 GHz bandwidth showing the broadband nature of the transition. The matching patch at the junction (capacitance) measures 342-µm long and 655-µm wide.

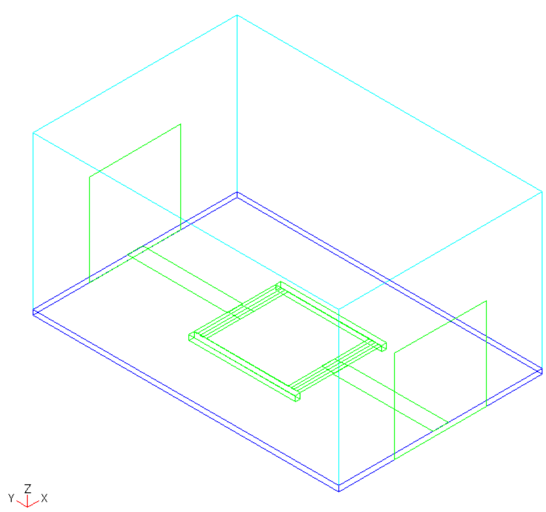


Figure 2: Agilent HFSS™ geometry of the back-to-back transition.

In order to test the idea, we have constructed a back-to-back transition structure with two fins as shown in Figure 2 and Figure 3. In this topology, the mm-wave energy is first transferred from microstrip to the rectangular waveguide formed in the dielectric, and then using a second transformer, it is transferred back to the microstrip.

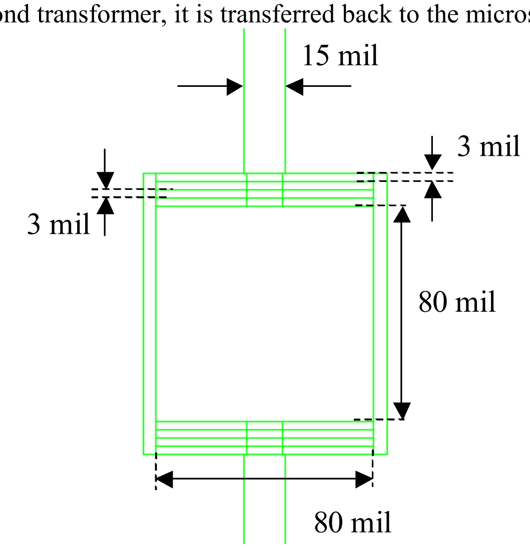


Figure 3: Agilent HFSS™ geometry (top view) of the back-to-back transition and typical dimensions for the 127-µm Duroid 5880.

Figure 4 and Figure 5 shows the manufactured MS-to-RW transition implemented in 127-µm thick RT/Duroid 5880. The measurement results of the back-to-back transition in 50-Ohm environment are shown in Figure 8 and Figure 9 (in dB). A TRL calibration scheme that uses multiple transmission lines (Multiline™) was employed for accurate calibration.

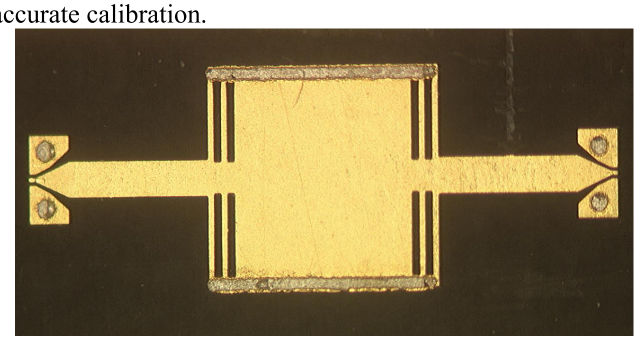

Figure 4: The manufactured back-to-back microstrip-to-rectangular waveguide transitions on RT/Duroid 5880.

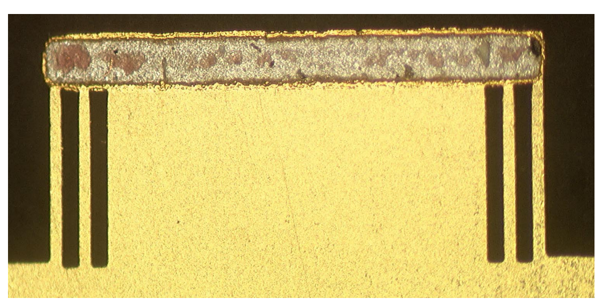

Figure 5: Close-up picture of the plated rectangular via trenches shown in Figure 4.

The simulated and measured responses of the back-to-back transitions shown in Figure 8 and Figure 9 clearly indicate excellent correlation between measurements and simulations. The measured loss due to the transition ($|S_{11}|^2+|S_{21}|^2$) is calculated using differential measurements techniques of two back-to-back transitions that have different lengthes and is given in Figure 10. The figure shows that from 65-85 GHz the loss in transition is less than 0.2 dB per transition, which is very close to the results predicted by the simulations. The slight mismatch in the loss numbers between the simulations and the measurements towards end of the band in Figure 6 is most probably due to the inaccuracy of the loss tangent of the materials. In the simulations the loss tangent and dielectric constant of the Duroid board are taken as 0.003 and 2.2, respectively. The conductivity of the metals are taken as $4.5x10^7$. It is also possible that the radiation losses are slightly higher in the simulation because of the fact that it is necessary to enclose the structure completely in FEM and apply proper radiation boundary conditions.

## III. DISCUSSION

The novel transition can be used for many differing applications. An important application is to transfer the mm-wave energy to a RW perpendicular to the MS plane in an mm-wave package. In [1], it is shown that the base plate of the mm-wave package can have a multi-section RW implemented sections that can transform the waveguide impedance into free-space impedance and in the process turn it 90-degrees as well. The resultant MS-to-RW transition is process insensitive [1]. Moreover, with this interconnect it would be feasible to mount MMICs on top of Duroid substrate for mm-wave application even when line lithography may not be very well controlled [13].

In addition, the transition is usable for broadband packages, couplers, power splitters and combiners, and transitions. Moreover for ease of manufacturing, the edge wall can be replaced by continuous via-holes mimicking the continuous ground wall. Finally as this transition allows easy PCB based MS-to-RW transition, waveguide filters in the substrate can now be built where via-hole could be used as inductive and/or capacitive elements.

## IV. CONCLUSIONS

In conclusion, a novel broadband microstrip to rectangular-waveguide transition that is compatible with PCB technology is presented. The transition has been used in mm-wave packages and has shown radiation loss less than 0.2 dB with excellent adjacent transition isolation. The novel transition is relatively insensitive to manufacturing tolerances.

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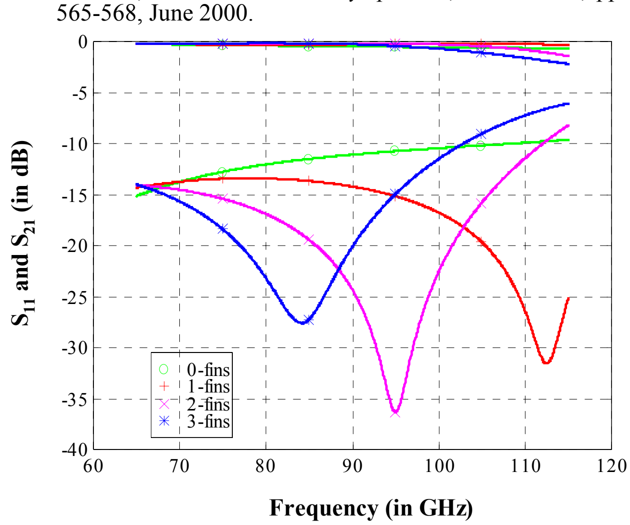


Figure 6: HFSS™ simulated *S*-parameters for the transition with varying number of fins. Note that adding fins improves the return loss performance.

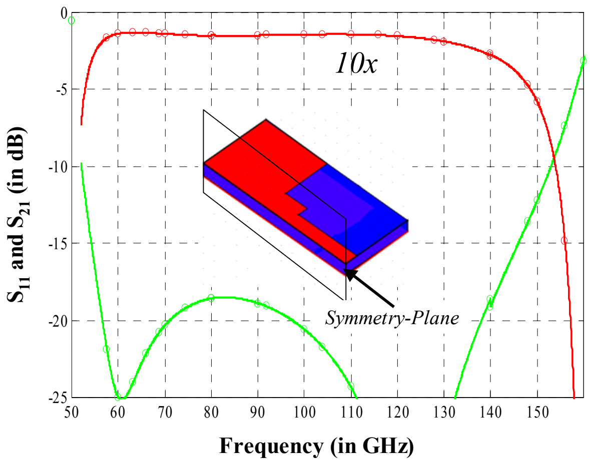


Figure 7: Optimized performance of the MS-to-RW transition without fins (*Patent pending*). The inset shows the optimized structure.

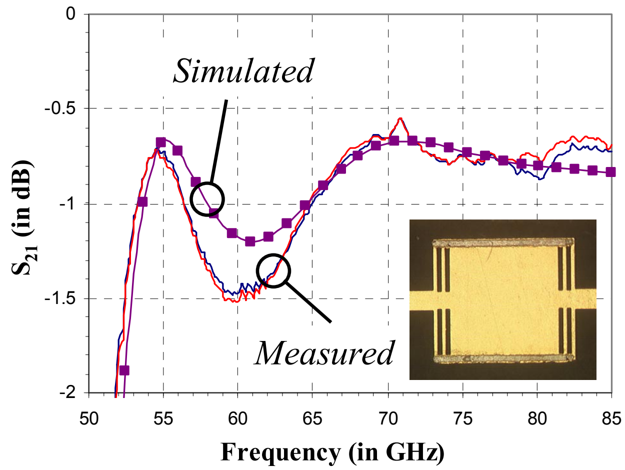


Figure 9: Measured and simulated $S_{12}$ (in dB) of the back-to-back transition (see Figure 4).

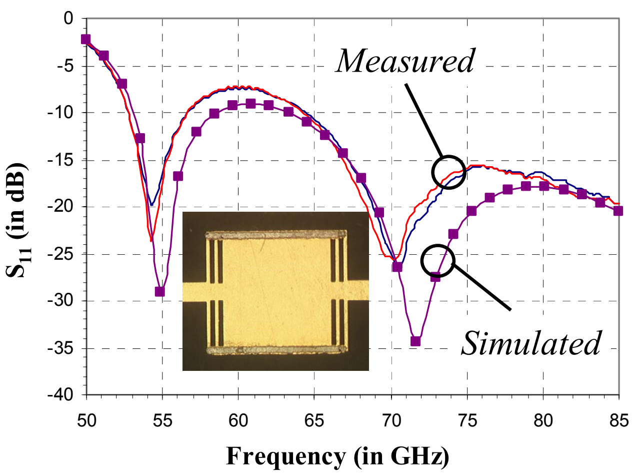


Figure 8: Measured and simulated $S_{11}$ (in dB) of the back-to-back transition (see Figure 4).

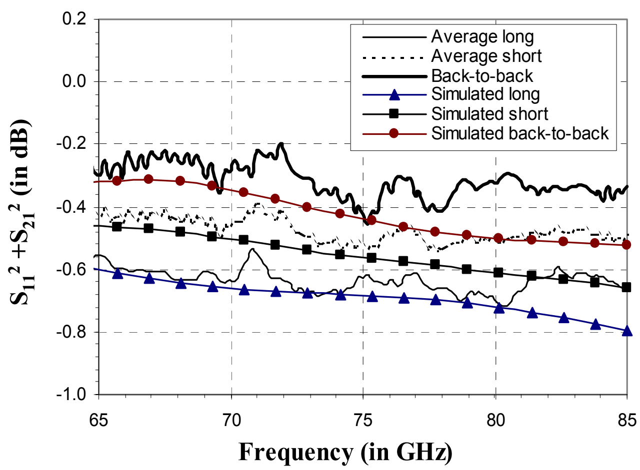


Figure 10: Measured loss of a back-to-back transition obtained by multi-line calibration. The long transition was twice the length of the short.