A COMPACT MMIC-COMPATIBLE MICROSTRIP TO WAVEGUIDE TRANSITION

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ABSTRACT

A new type of microstrip to waveguide transition is presented, based on slot coupling and a dielectric quarter wave transformer. For a return loss of 20 dB, a relative bandwidth of 16 % was achieved. The structure is compact, MMIC-compatible and can be made hermetic.

INTRODUCTION

In spite of the use of monolithic and hybrid integrated circuits, metal waveguides are still an essential part of most microwave and especially millimeter wave systems. Waveguides are typically needed in antenna feeds, in high-Q components e.g. mm-wave band pass filters and duplexers or in low phase noise oscillators. The transition from a waveguide to a microstrip may often become a critical point especially in the mm-wave frequency range. The most common type of transitions described in literature are the probe type transition [1], the transition via antipodal finline [2], or via a ridged waveguide [3]. They all have shown good results, but they are typically quite complicated and it may be difficult to integrate them with the planar circuits. Due to the disadvantages of the known transition structures, there seems to be need for new, compact, MMIC-packaging compatible microstrip to waveguide transitions.

A slot fed microstrip antenna has been used to couple a cavity resonator to microstrip line [4]. Based on this concept, a microstrip to waveguide transition is presented in [5]. The bandwidth of this kind of a transition is narrow arising from the fact that the region under the patch is basically a resonant cavity with a high quality factor. Typically, a bandwidth of a few percent for a return loss of 20 dB can be achieved when alumina is used. The bandwidth can be improved by placing the patch antenna element on an additional, lower dielectric constant, small substrate in a waveguide so that an air gap remains between the ground plane and the patch antenna element. This transition has been presented in [5,6]. However, the structure may be complicated to manufacture, because of the additional piece of substrate in the waveguide.

NEW TRANSITION

A new type of microstrip to waveguide transition is presented based on the concept of slot coupling and a dielectric quarter wave transformer. The structure is presented in Figure 1 [7].

A slot in the ground plane of a microstrip can be used to couple the microstrip to a waveguide. This kind of structure has been presented e.g. in [8], where a power divider with waveguide and microstrip ports is presented. The slot coupling may, however, become narrow banded due to the high impedance difference between waveguide and microstrip, especially when

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high dielectric constant substrate material is used. The other problem may be the back scattering of the transition.

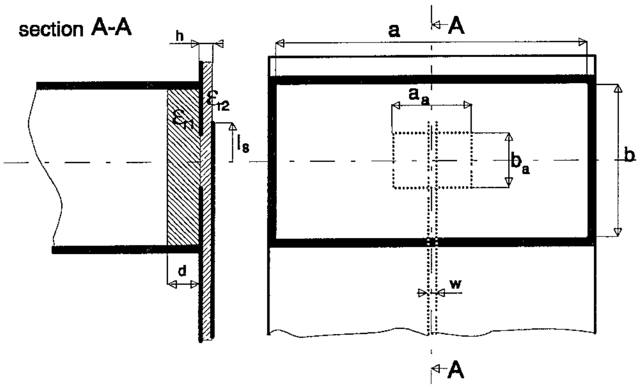

Figure 1. Transition based on a dielectric quarter wave transformer in front of a coupling aperture.

As an improvement, a thick substrate with ε_{r1} is placed in front of the coupling aperture inside the waveguide. The thickness of substrate has been chosen to be a quarter wavelength in substrate material to provide a function of a quarter wave transformer. A quarter wave transformer is based on the well known equation

$$Z_{0wg}(\varepsilon_{r1}) = \sqrt{Z_{0wg} \cdot Z_2} \qquad (1)$$

where Z_{0wg} is the impedance in waveguide, $Z_{0wg}(\varepsilon_{r1})$ is the impedance in a waveguide filled with dielectric material and Z_2 is the impedance seen by the aperture looking into the waveguide accordingly defined as Z_{0wg} and $Z_{0wg}(\varepsilon_{r1})$. The principle is sketched in Figure 2.

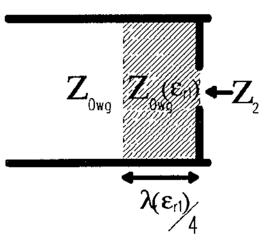

Figure 2. Dielectric quarter wave transformer in waveguide.

The impedance Z_2 seen by the aperture looking into the waveguide can now be solved (2). In this case, we use the power-voltage definition of the waveguide impedance [9].

$$Z_2 = \frac{\frac{2b}{a}\cdot\eta_0\cdot\sqrt{1-(\frac{f_c}{f})^2}}{\varepsilon_{r1}-\left(\frac{f_c}{f}\right)^2} \qquad (2)$$

To illustrate the dielectric quarter wave transformer, example values, a frequency 1.8 times the cutoff frequency and the dielectric constant $\varepsilon_{r1} = 9.8$ (alumina) are chosen. A standard waveguide with the cross section $a = 2b$ is assumed. Now the impedance of an air filled waveguide $Z_{0wg} = 453\Omega$ is transformed down to $Z_2 = 33\Omega$ according to the power-voltage definition of the waveguide impedance. The lowering of the impedance level of the waveguide by the dielectric quarter wave transformer, helps to realize the broadband aperture coupling to the microstrip. It is notable that in order to achieve a high impedance transform ratio, a relatively high dielectric constant is needed.

Usually slot fed patch antennas are designed to work at considerably lower frequencies than the resonant frequency of the coupling aperture to avoid the property of a resonating slot to radiate also backwards. The thicker the substrate between the patch and the slot is, the larger a coupling aperture is needed and the resonant frequency of the aperture is decreased. This leads to a situation where the aperture starts resonating and back scattering is increased. In this transition, the best size of the aperture is found to be larger than the size of a resonating aperture. The transition works now above the resonant frequency of the aperture and no back scattering is detected. When a waveguide is filled with high dielectric constant material, higher modes are able to propagate. The aperture can excite all the modes with the same symmetry as the field distribution at the aperture has. These modes are evanescent in an air filled waveguide and they remain in the region of a dielectric filled waveguide. The excited higher order modes can be understood as parallel reactances, and they may have resonances.

When the thickness of the substrate and the width and the height of the aperture are chosen appropriately, some modes have resonances on the pass band of the transition. These resonances can be used to match the transition even more wideband.

In Figure 3, the measured frequency response of a realized transition is presented. Waveguide R58 (recommended frequency range from 4.9 to 7.0 GHz) has been used. Rogers RT6010 was chosen for the dielectric material, because of its ease of machining and because its dielectric constant ($\varepsilon_{r1} = 10.2$) is close to that of alumina which is intended to be used in future MMIC housings. For a return loss of 15 dB, a relative bandwidth of 14.5 % was achieved.

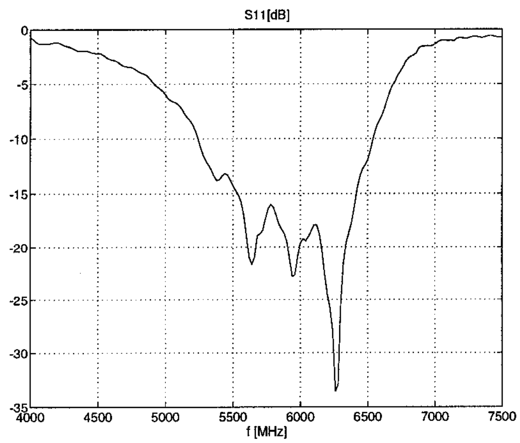

Figure 3. Measured reflection coefficient of the transition in Figure 1.

f_0	BW ($S_{11} \leq$ -15 dB)	BW % ($S_{11} \leq$ -15 dB)
5.9 GHz	~ 860 MHz	~ 14.5 %

d = 3.81 mm h = 1.27 mm w = 1.26 mm	$\varepsilon_{r1} = 10.2$ $\varepsilon_{r2} = 10.2$	$a_a = 10.2$ mm $b_a = 4.0$ mm

Table 1. Bandwidths and dimensions of the transition in Figure 1.

To further improve the performance of the transition, an additional resonating patch element was added onto the substrate. The structure is presented in Figure 4. The best performance is achieved when the patch element is wide. A wide but low patch element is more broadbanded than a narrow but tall patch. In the realized transition, the resonance of the patch element was located at the lower part of the pass band. The good matching at the higher pass band is due to the resonances in the dielectric quarter wave transformer.

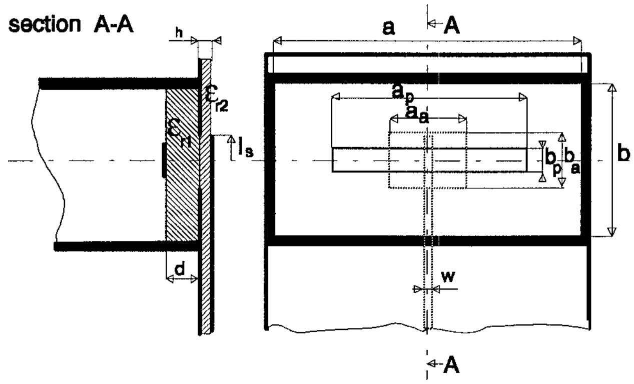

Figure 4. Transition based on a dielectric quarter wave transformer in front of a coupling aperture with a patch added onto the transformer.

In Figure 5, the measured return loss and insertion loss of a realized transition are presented. For a return loss of 20 dB, a relative bandwidth of 16 % was achieved. The insertion loss on the pass band was found to be less than 0.7 dB not including the loss of the microstrip used in the measurement setup. This can be predicted to be even less, when alumina instead of Duroid is used due to smaller dielectric loss of alumina.

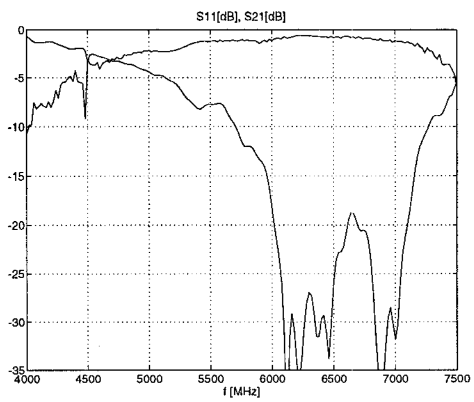

Figure 5. Measured reflection and transmission coefficients of the transition with a patch element shown in Figure 4.

f_0	BW ($S_{11} \leq$ -20dB)	BW % ($S_{11} \leq$ -20dB)
6.6 GHz	1.1 GHz	~ 16 %

d = 3.21 mm	h = 1.27 mm	w = 1.26 mm
a_a = 7.95 mm	b_a = 5.77 mm	ε_{r1} = 10.5
a_p = 23.05 mm	b_p = 3.05 mm	ε_{r2} = 10.2
l_s = 2.7 mm		

Table 2. Bandwidths and dimensions of the transition in Figure 4.

The structures were simulated with an electromagnetic field simulator HFSS (High Frequency Structure Simulator, Hewlett-Packard). The simulator predicts the basic characteristics of the transition well, but seemingly cannot find the resonances responsible for the wide band matching. The simulator might find these resonances if a very dense solution matrix could be defined in the volume of the dielectric quarter wave transformer. For the time being, this is restricted by the available computer resources.

The realized prototype can be scaled to higher frequencies. It can be manufactured easily, because the planar structure can be processed as one piece on the bottom of a mm-wave circuitry housing. As a very compact structure the bandwidth of this transition is relatively wide, taking into account the difficulties achieving broadband performance with high dielectric constant materials.

CONCLUSIONS

A novel transition from microstrip to waveguide has been described. The transition is based on the principle of a dielectric quarter wave transformer in a waveguide and on the coupling from a waveguide to a microstrip via a slot which is on the ground plane of a microstrip. Resonances associated with higher modes existing in a dielectric material filled waveguide are utilized to achieve a very broadband matching of the transition. Best results were obtained with a structure including a patch element on the dielectric quarter wave transformer. For a return loss of 20 dB, a relative bandwidth of 16 % was achieved. The structure is very compact, and it creates a hermetic seal without any additional piece in a waveguide. The transition is compatible with MMIC technology, because it can be integrated easily in the bottom of a MMIC housing. By using high dielectric constant material, the quarter wave transformer effect can be utilized. The transition is ideally suited for future mm-wave applications using alumina for MMIC substrate and circuitry housing.

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