Full Band Waveguide-to-Microstrip Probe Transitions

Yoke-Choy Leong[1] and Sander Weinreb[2]

[1]Department of Electrical and Computer Engineering
University of Massachusetts, Amherst, MA 01003
[2]Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109

Abstract- Design data, in the form of dimension tables, is presented for probe transitions for microstrip substrates with 4 dielectric constants (E_r = 2.2, 6.0, 10.1, and 13) in two orientations relative to the waveguide (broadside and longitudinal). These dimensions have been optimized for full waveguide bandwidth with > 20 dB return loss using an electromagnetic CAD procedure. The dimensions can be applied to any size waveguide with a 2:1 width/height aspect ratio. Experimental verification for two of the designs applied to W-band waveguide is presented.

INTRODUCTION

There are many microwave and millimeter-wave receiver and transmitter applications which require broadband, low-loss transitions from rectangular waveguide to microstrip. A literature search of this topic has revealed 30 publications, mostly in the past 10 years, which fall into the following 3 groups:

1. Transitions that are along the propagation direction of the waveguide[1-2];
2. Transitions which couple energy via apertures that are cut in the broadwall or endwall of the waveguide[3];
3. Transitions that utilize probes transverse to the propagation direction of the waveguide[4];

We have selected transitions of the third type for optimization over the full waveguide bandwidth using an electromagnetic CAD procedure. This probe type of transition was selected because of ease of machining and absence of tight- tolerance mechanical joints; it is particularly suitable for millimeter wave use. The transition has two configurations, which are described next and appear to have similar performance; the choice can be made based upon ease of integration with other components and desired orientation of the waveguide. The probe dimensions are dependent upon the dielectric constant of the microstrip and tables of dimensions will be generated for both types for 4 different dielectric constants. Previous publications have described some specific cases or analysis techniques for probe transitions but have not given the complete design data presented in this article.

CONFIGURATIONS

There are two common ways to construct a probe type transition. In both ways, the microstrip will enter the waveguide through a window on the broadwall of the waveguide. In the broadside mounted case, as illustrated in Fig. 1, the substrate extends into the waveguide with the surface of the substrate facing the direction of propagation of the waveguide. In the longitudinal mounted case (which is also commonly referred to as E-plane probe), as illustrated in Fig.2, the surface of the substrate aligns along the direction of propagation of the waveguide. A matching

0-7803-5135-5/99/$10.00 © 1999 IEEE

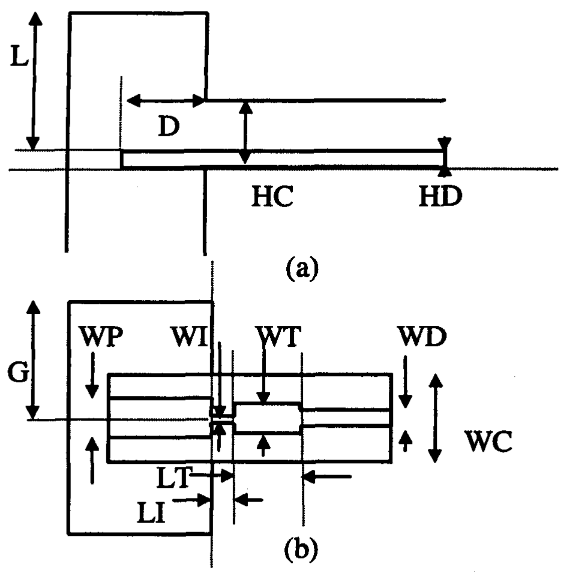

Fig. 1. Configuration for broadside transition. (a) View of WG narrow wall (b) View in direction of propagation away from backshort

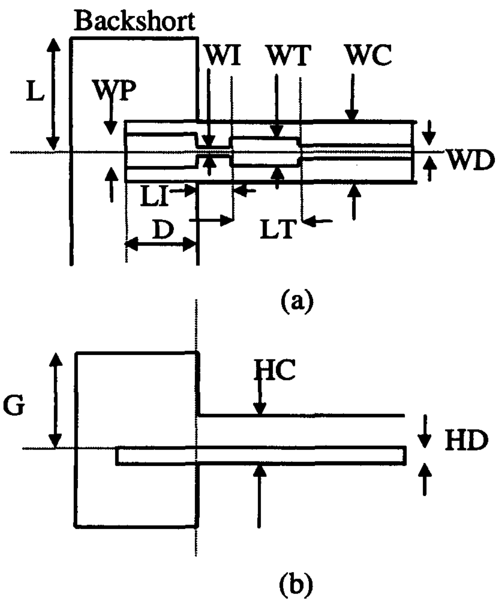

Fig. 2. Configuration for longitudinal transition. (a) View of WG narrow wall (b) View in direction of propagation towards backshort.

network which consists of a high impedance microstrip line and a quarter-wave impedance transformer is used to achieve broadband matching of the probe impedance in both cases. All critical dimensions are defined in the illustrations.

DESIGN APPROACH

The width and height of the window opening at the broadwall of the waveguide were first fixed based on easy assembly requirements and to ensure that the waveguide modes are in cut-off condition along the direction of propagation towards the microstrip line. A parametric study was then carried out to investigate on how the probe width, probe length and back-short distance will affect the impedance vs frequency of the probe as seen at the plane of the broadwall window. This was done for substrates with four different relative dielectric constants and mounted in 2 orientations. The analysis were performed using Ansoft's Maxwell 3D electromagnetic simulator.

It was observed that for all cases, there exists a combination of probe width, probe length and backshort distance where the probe impedance varies little with frequency, i.e. the rate of change of both the real part and imaginary part of impedance with frequency is small. In the case where the relative dielectric constant of the substrate is 2.2, this impedance has a real part of 50 ohms and a capacitive series reactance. To match it to 50 ohms system, a high impedance inductive line is used in series with the probe to resonate out the capacitive reactance. In all other cases, the impedance has a real part of less than 50 ohms and a capacitive series reactance. A high impedance inductive line is first used in series to resonate out the capacitive reactance and followed by a quarter-wave impedance transformer to match the real part of the probe impedance to 50 ohms.

Based on the described approach, 9 designs of broadside and longitudinal probes using substrates with relative dielectric constants of 2.2, 6, 10.1 and 13 are analyzed across 75-110 GHz. The detail design parameters of the 9 designs are listed in Table 1 and 2. These probe designs can be applied to any size waveguide with a 2:1 width/height aspect ratio by multiplying the dimensions listed in the tables by a scaling factor equal to (width of the target waveguide in um)/2540. All probes exhibit greater than 20 dB of return loss across the entire W band in HFSS simulation.

EXPERIMENTAL VERIFICATION

Two designs, probes no. 2 and no. 4 as listed in Table 2, were fabricated and assembled in separate WR-10 modules. For each design, the probes are arranged in back-to-back configuration for convenient testing and interpretation of results. Fig. 3 shows the transmission and return loss of the Teflon probe measured with the WR-10 module. It can be

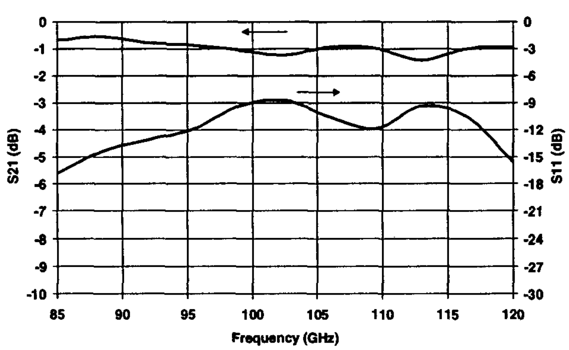

Fig. 3. Measured insertion and return loss for 2 Longitudinal Teflon probes(back to back)

seen that the maximum transmission loss is 1.5 dB across 85 to 120 GHz and the minimum return loss is 8.5 dB. Fig 4. shows the transmission and return loss of the alumina probe measured with the WR-10 module. The maximum transmission loss is 2 dB across 85 to 120 GHz and the minimum return loss is about 10 dB for two probes back-to-back.

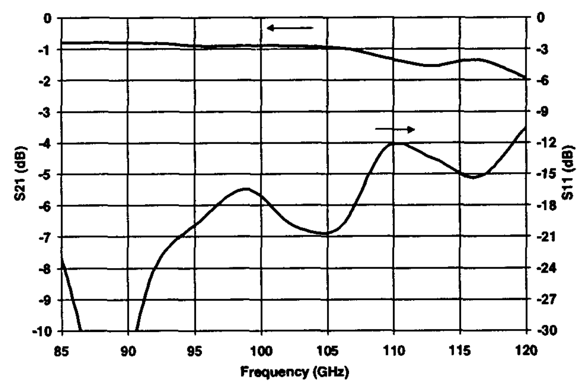

Fig. 4. Measured insertion and return loss for 2 Longitudinal alumina probes(back to back)

The total transmission loss in WR-10 waveguides within the module is estimated to be around 0.04 dB and the estimated transmission loss in the Teflon and alumina microstrip within the module is 0.1 dB and 0.24 dB respectively.

After accounting for these losses, the maximum net transmission loss per transition is 0.68 dB for the Teflon probe and 0.86 dB for the alumina probe across 85 to 110 GHz. The alumina probe is further used in the construction of a very low noise module in W-band[5] and the module has achieved excellent noise performance across the entire band.

CONCLUSION

An electromagnetic CAD procedure has been outlined for the design of broadband waveguide-to-microstrip transition. Design data for 9 broadband probes of two different configurations and four different dielectric mediums has been presented. Experimental verification on two of the probes shows good performance over the entire W band.

ACKNOWLEDGEMENT

The authors would like to thank Todd Gaier from JPL for construction, assembly and testing of the transitions.

REFERENCES

[1] J.H.C. van Heuven, "A New Integrated Waveguide-Microstrip Transition," IEEE Trans. Microwave Theory Tech., vol. MTT-24, pp. 144-147, March 1976.

[2] Hui-Wen Yao, Amr Abdelmonem, Ji-Fuh Liang, and Kawthar A. Zaki, "Analysis and design of microstrip-to-waveguide transitions," IEEE Trans. Microwave Theory Tech., vol. MTT-42, pp. 2371-2380, Dec. 1994.

[3] Amjad A. Omar and Nihad I. Dib, "Analysis of slot-coupled transitions from microstrip-to-microstrip and microstrip-to-waveguides," IEEE Trans. Microwave Theory Tech., vol. MTT-45, pp. 1127-1132, Jul. 1997.

[4] Yi-Chi Shih, Thuy-Nhung Ton, and Long Q. Bui, "Waveguide-to-microstrip transitions for millimeter-wave applications," in 1988 IEEE MTT-S Int. Microwave Symp. Dig., pp. 473-475.

[5] S. Weinreb, R. Lai , N. Erickson , T. Gaier , and J. Wielgus, "W-Band InP Wideband MMIC LNA with 30K Noise Temperature," in 1999 IEEE MTT-S Int. Microwave Symp. Dig.

Table 1: Broadside probe dimensions for substrates of 4 different dielectric constants. All units are in um and are for WR-10 waveguide

#	Probe	Er	L	HC	HD	WC	WP	D	WI	LI	WT	LT	G	WD
1	Teflon-127	2.2	778	259	127	973	422	681	60	90	-	-	1270	230
2	Diel6-127	6.0	811	259	127	740	291	600	100	110	200	400	1270	140
3	Alumina-100	10.1	843	259	100	508	200	584	50	90	130	350	1270	80
4	GaAs-100	13.0	843	259	100	740	259	560	50	60	120	310	1270	70

Table 2: Longitudinal probe dimensions for substrates of 4 different dielectric constants. All units are in um and are for WR-10 waveguide

#	Probe	Er	L	HC	HD	WC	WP	D	WI	LI	WT	LT	G	WD
1	Teflon-127	2.2	838	259	127	973	324	635	80	100	-	-	1270	230
2	Teflon-76	2.1	838	254	76	508	230	660	120	260	-	-	1270	210
3	Diel6-127	6.0	876	259	127	740	291	600	80	100	180	420	1270	140
4	Alumina-100	10.1	876	259	100	508	200	600	50	100	130	350	1270	80
5	GaAs-100	13.0	908	259	100	740	259	560	40	60	130	320	1270	70