A NEW VERSION OF THE MICROSTRIP TO WAVEGUIDE TRANSITION

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Abstract

A new version of the microstrip-to-wavetguide transition is described and analyzed. It is the E-plane transition, where the stripe probe is substituted by a rectangular patch. The structure is very simple, easily adjustable, it has a broad band and there is no need to use an impedance transformer. This transition has been analyzed using the method of minimal autonomous blocks and the integral equation method. The obtained results were compared with experimental data. The agreement is good.

Keywords:
microstrip line, rectangular waveguide, transition, solution of electromagnetic field, numerical methods, modelling

Introduction

Millimeter-wave devices are usually designed in microstrip lines. They may be combined with waveguide structures as are diplexers or mixers. Also many sources and detectors have waveguides on output and input. So very often in the practice we meet the problem to use a microstrip-to-waveguide transition.

There are three basic types of microstrip-to-waveguide transitions: a ridged-waveguide taper, a finline taper and an E- plane probe [1]. The ridged waveguide is used either as a smooth taper or as a step-impedance transformer. The later is more suitable for fabrication. Several kinds of finline taper transitions are used. They are simpler than ridged-waveguide transitions.

Only few of information can be found in the literature concerning the E-plane probe transition [2,3] (see Fig.1). This structure is designed as a simple strip probe carried by a dielectric substrate extended into the waveguide through an aperture in the broader wall. The strip on the dielectric substrate can face either the short-cut or the waveguide. The substrate can be either perpendicular or paralel to the waveguide axis. To achieve a broader band a simple impedance transformer in the microstrip line is used. The best performance is adjusted by the proper short-cut position. The measurements and the analysis [4] proved that better results are achieved using a rectangular patch instead of the simple stripe probe. There is no need to use an impedance step transformer in the microstrip line.

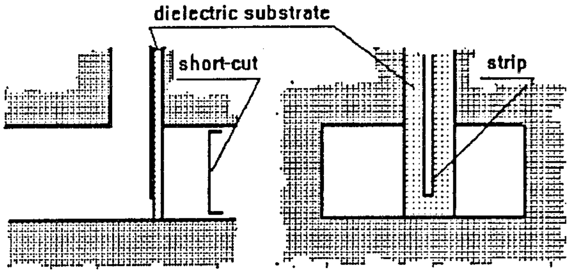

Fig.1
The structure of the E-plane stripe-probe microstrip-to-waveguide transition [1]

The E-plane microstrip-to-waveguide transition was solved in [3] using the spectral-domain technique combined with a residue calculus theorem. The structure with the dielectric substrate paralel to the waveguide axis was solved under the assumption of an infinitesimally narrow probe strip. This method is not suitable for the structure under consideration that has a probe in the shape of a rectangular patch perpendicular to the waveguide axis.

The structure was analyzed using the integral equation method [5] in comparison with the method of minimal autonomous blocks (MAB) [6,7,8]. A set of measurements was performed.

Analysis methods

The solution of the E-plane microstrip-to-waveguide transition was performed using the basis of the integral equation method worked out in [5] where the method is described in details. The method of minimal autonomous blocks was choosen to compare the results. This method was originally worked out in [6] and applied to the solution of various microwave and millimeter-wave structures by the author in [7,8]. We review briefly the substance of bouth methods.

The idea of the integral equation method is based on a necessity to fulfil the boundary condition for electric field on the patch surface [5]. The integral equation has thus a form (the righthand side represents electrical field created by a surface current)

$$\mathbf{n} \times \mathbf{E}_e(\mathbf{r}) = -\mathbf{n} \times \int_S \mathbf{G}_E(\mathbf{r}, \mathbf{r}') \,.\, \mathbf{J}_s(\mathbf{r}')\, dS' \qquad (1)$$

where **n** is the patch normal vector, $\mathbf{E_e(r)}$ is an excitation electric field assumed as the dominant TE_{10} mode at a point **r**, $G_E(\mathbf{r},\mathbf{r}')$ is the Green's function, $\mathbf{J_S}(\mathbf{r}')$ is a surface current created at a point $\mathbf{r}'$ by an incident electromagnetic field. The integration is performed on the patch surface *S*. The unknown cur rent density $\mathbf{J_S}$ is determined from (1) using the method of moments with both basis and test rooftop functions. The Green's function itself is evaluated in the spectral domain. Then it is transformed into the space domain where the integral equation (1) is solved and the current distribution is determined. In the process of the backward Fourier transformation we take the advantage of the solution in the rectangular waveguide to substitute integration by summation.

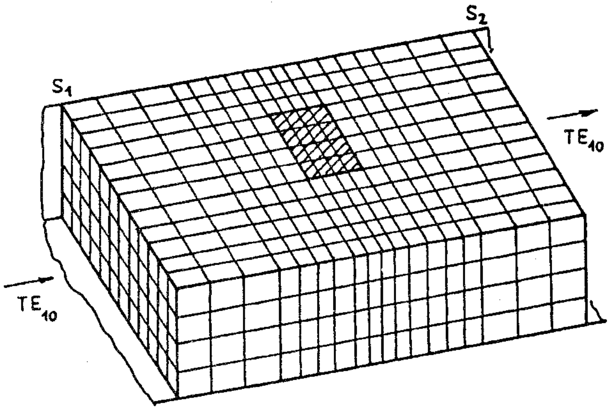

Fig.2a
To the MAB method description
(a) The analyzed volume and its discretization to the minimal autonomous blocks. S and S are the input and output planes respectively.

The MAB method is in fact one from decomposition methods. A volume involving an analyzed discontinuity with neighbouring parts of a waveguide ensuring diminishing of excited higher modes is divided to prisms (see Fig.2a). Each prism (block) is characterised by a scattering matrix determined independently on other blocks solving Maxwell's equations inside it. Under the assumption of constant field on block faces the order of this matrix is minimal and there are only two independent waves on each block face. Every face is assumed as a cross-section of a virtual waveguide with corresponding eigen waves. The scattering matrix describes mutual dependence of these out- and in-going waves. From these the denotation "minimal autonomous block" followes.

Special blocks must be inserted between two adjoining blocks with different media to ensure the proper wave reflection and transmission. Similar blocks are used to fulfil boundary conditions on waveguide walls.

Blocks form an electrical equivalent network that is partially shown in Fig.2b. Each connection between two blocks is in fact created by two lines as there are two independent waves on block faces. The scattering matrix of the whole analyzed wolume is obtained using methods known from the theory of linear n-ports. Order of this matrix is equal to the number of blocks in one transversal layer multiplied by four what is the number of all independent waves on the input and output planes S_1 and S_2.

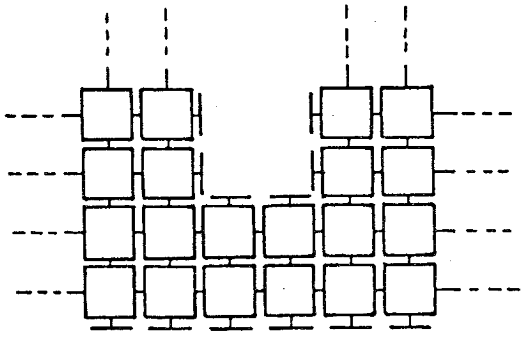

Fig.2b
To the MAB method description
(b) The part of an equivalent electrical network

By the discretization of incident TE_{10} mode to the waves reaching the blocks on the input and output planes we can determine reflectivity and transmissivity of the structure using the resulting scattering matrix.

The structure was analyzed using the version of an universal code for the solution of arbitrary discontinuities in waveguiding structures based on the MAB method [7,8].

Experimental results and data comparison

The common structure of the E-plane microstrip-to-waveguide transition is shown in Fig.1. From the theoretical analysis by MAB method followes that there is practically no difference between structures with the dielectric substrate of the shape from Fig.1 and the dielectric substrate coverring the whole waveguide cross-section. So the latter type (see Fig.4) was used for testing because it can bear the probe in the shape of a patch.

This type of transition is intended to use especially in millimeter-wave bands. For the easier acces the structure was tested on a scaled model in X-band. The waveguide is R100 $a = 22.86$ mm, $b = 10.16$ mm. The microstrip parameters are $\varepsilon = 2.35$ mm, $w = 2.3$ mm and $h = 0.794$ mm. It is shielded in the waveguide with a cross-section 8 × 5 mm.

The simple structure from Fig.1 with a stripe probe without an impedance transformer was measured for various positions of the short-cut and for various probe depths d in the waveguide. The substrate was placed by the probe facing the waveguide (Fig.1). The example of results is in Fig.3. Only the reflectivity (return loss in dB) is plotted in this graph as a function of frequency. The parameter of curves is a short-cut distance from the substrate L. The length of the probe in the waveguide is $d = 9$ mm. This parameter influences only a frequency shift of curves with changes in position of the short cut.

Turning around the substrate with the probe (facing now the short-cut) we obtain similar curves slightly broader and shifted in the position of the short-cut and frequency.

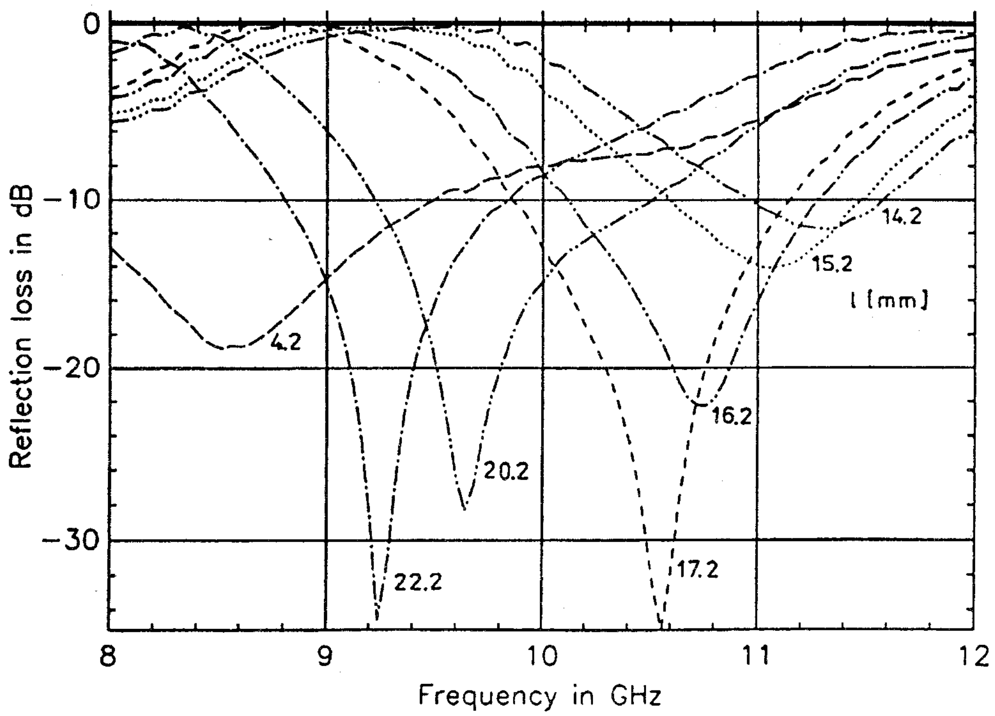

Fig.3

The return loss of the stripe-probe transition. The curves parameter is the short-cut position L

The transition with a broader band was obtained using the probe in the shape of a rectangular patch. Dimensions of the patch are 12 × 6 mm and its distance from the waveguide top wall is 1 mm. This structure is shown in Fig.4. The patch faces the short-cut. Return loss of this structure in dependence on frequency is shown in Fig.5. The parameter of curves is again a short-cut position.

To simlify the analysis the only reflectivity from the waveguide side was determined. This avoids the necessary knowledge of the field distribution in the shielded microstrip.

The convergence of the integral equation method was tested. The computational procedure was repeated using increasing number of modes in both transversal directions and resulting reflectivi ty at 10 GHz is plotted in Fig.6. It is evident that 80 or 100 modes are sufficient for a runtime solution. In a case of maximal number of modes equal to 80 we have in fact the total number of modes $2 \times 80 \times 40 + 80 + 40 = 65200$ (only even modes are assumed in x-direction, we have 40 TE_{m0} modes and 80 TE_{0n} modes).

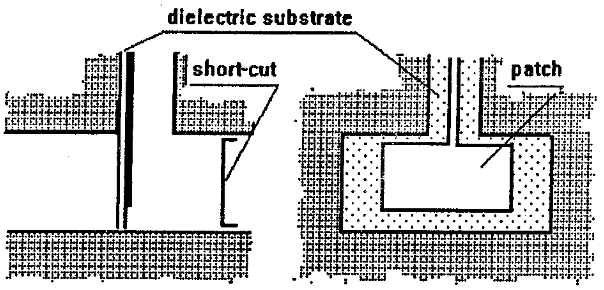

Fig.4

The E-plane microstrip-to-waveguide transition with the rectangular patch probe facing the short-cut

Results for the structure from Fig.4 having the optimized tansition band by the short-cut position are in Fig.7. The short-cut distance from the substrate is 5.2 mm. The theoretical data are compared with results of an experiment [8]. There are several problems both in a computational procedure and in an experiment. The main problem of the solution using the MAB method lies in edge effects and the needed density of blocks. The electromagnetic field on block faces should be constant so the density of blocks must be high particularly in the vicinity of patch edges [6]. The number of blocks determining storage demands and CPU time consumed by the code must be on the contrary limitted. The used net of blocks is therefore constructed as a result of a compromise. This is the reason of a frequency shift of theoretical and experimental curves from Fig.7 [7]. Results of the integral equation method fit better experimental data except the low frequency part. The bahaviour here is not clear yet. Moreover the CPU time consumed is hundred times shorter then in the case of program using MAB method. So this method is more convenient to a next structure optimization process.

The uncertainty of experimental data is caused by a measurement setup. The used network analyser has input and output on coax lines. So two more transitions were added to the measured structure, transition between coax and waveguide and between microstrip and coax. The shape of the experimental curve is strongly influenced by mismatches of these transitions. The groove made in the waveguide walls for clamping the substrate has also the negative influence to the shape of the measured characteristic probably especially in the high frequency side. So the experimental data are not reliable under −20 dB. In spite of this the agreement for reflection loss higher then −10 or −15 dB is quite well.

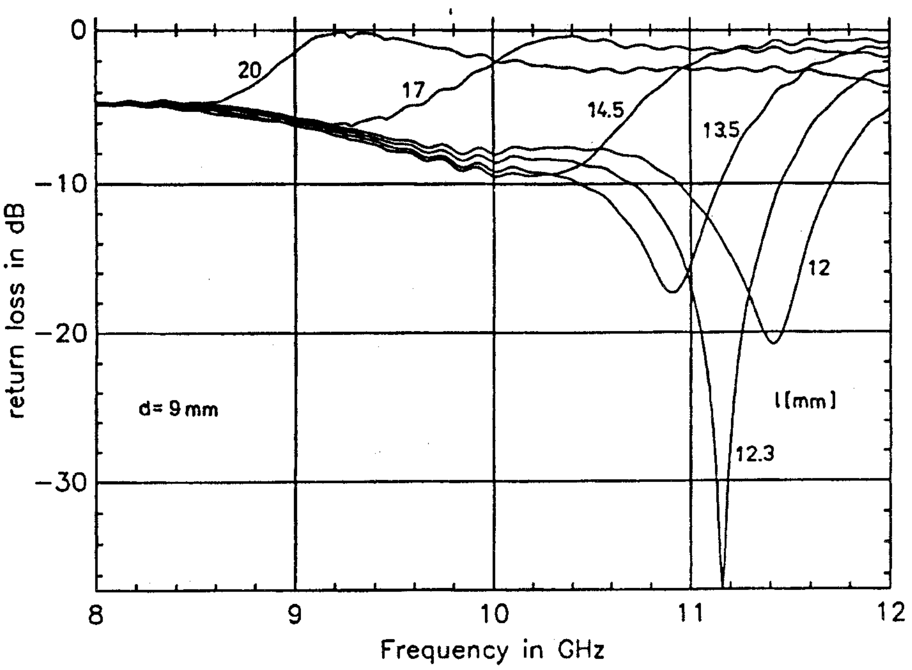

Fig.5
The return loss of the rectangular-patch-probe transition. Thecurves parameter is the short-cut position

Conclusions

Several variations of the E-plane microstrip-to-waveguide transition were tested both experimentally and theoretically. The transmission band can be adjusted by the short-cut position. The simplest structure has a stripe probe facing either the waveguide or the short-cut. The version with the probe on the dielectric substrate facing the short-cut has slightly broader band.

Better results with a broader transmission band were obtained with the new type of this transition having the probe in the shape of a rectangular patch facing the short-cut, again with a possibility to adjust the trasmission band by the short-cut position. It is not necessary to include an impedance transformer into the structure.

As the result of the proper short-cut positionning we obtained relatively brodad-band transition ensuring in the band of 3.2 GHz insertion loss better than −0.45 dB that relates to the reflection loss lower than −10 dB .

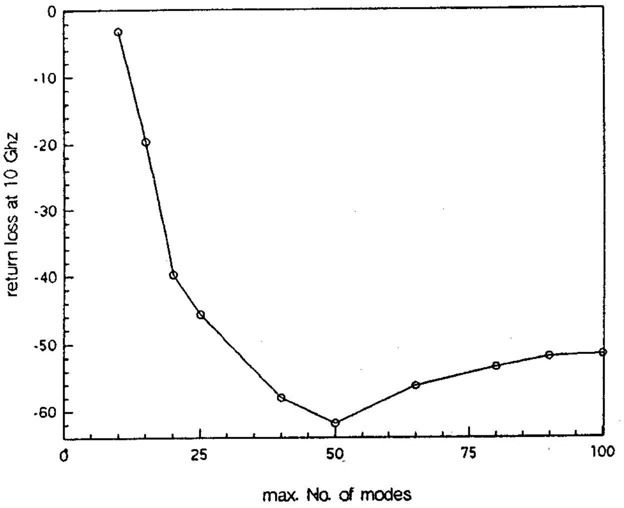

Fig.6
Convergence of the integral equation method

This rather complicated structure was quite precisely analyzed using the integral equation method and the three dimensional MAB method.

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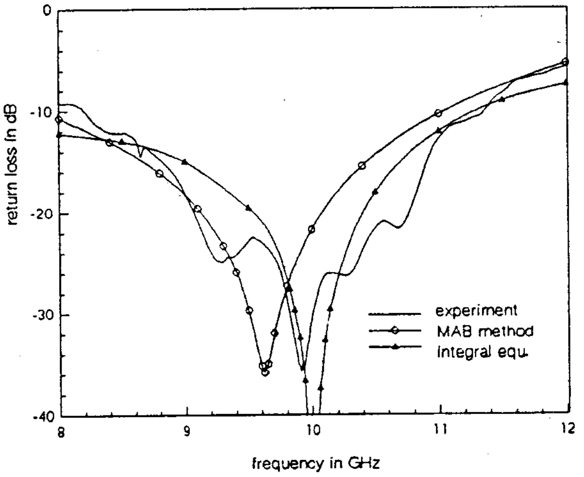

Fig.7
Comparison of the experimantal data with results of analysis for the structure from Fig.4 with the optimized short-cut position L = 5.2 mm

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Jan Macháč, was born in Czechoslovakia on April 1, 1953. He graduated at the Faculty of Electrical Engineering, Czech Technical University of Prague in 1977 and obtained the Ph.D degree from the Institute of Radioengineering and Electronics, Czechoslovak Academy of Sciencies in Prague in 1982. He was active at research in the field of light emitting semiconductor devices and semiconductor photodetectors. He was appointed to a lecturing post at the Department of Electromagnetic Field Faculty of Electrical Engineering, Czech Technical University of Prague in 1984 as a senior lecturer and as associate professor since 1991. His field of interests includes solution of electromagnetic fields by numerical methods in passive elements of microwave and millimetrer wave systems.