Experimental and Computer-aided Investigation of the Image Guide and its Transition to the Standard Metal Rectangular Waveguide

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***Abstract* — The image guide (IG) has been traditionally considered as a perspective for millimeter wavelengths. The transition between the standard metal rectangular waveguide (SMRW) and the IG usually exists in every experimental set-up involving the IG. Here we have examined experimentally using electric probes the distribution of the electric field components at a double SMRW – IG transition, comprising a dielectric core symmetrically tapered in the H-plane. After that, we have simulated this transition as well as some other transitions using the finite element method (FEM).**

***Keywords* — image guide (IG), millimeter wavelengths, transition to IG.**

I. Introduction

THE image guide (IG) is one of the proposed and intensively investigated structures for millimeter wavelengths [1], [2]. It has been considered not only as a guiding structure with excellent features at millimeter wavelengths, but also as a possible base for design of components, in particular nonreciprocal components (isolators, circulators). The experimental investigations of some nonreciprocal coupled ferrite-dielectric IG structures have been performed in [3], [4]. In order to help the further design of such type of nonreciprocal components, here we have performed experimental and numerical investigation of the IG with an accent on its transition to the standard metal rectangular waveguide (SMRW).

First we have investigated experimentally in the frequency range (30-36) GHz the IG structure, containing two identical transitions between IG and SMRW. The top view of the structure is shown in Fig. 1. Both ends of the IG section made from alumina ($\varepsilon_r = 9.6$, $tg\delta_\varepsilon = 1.10^{-4}$) with a cross section 1.80 mm x 0.97 mm have been symmetrically tapered in H-plane. The length of the tapers (l = 15 mm) has been optimized experimentally during some "cut-and-try" procedure. The entire length of the structure was 80 mm including both transitions.

Following that we have simulated the transitions with lengths from l = 5 mm to l = 25 mm. In addition to the symmetrical configuration (Fig. 2a) we have simulated the asymmetrical one (Fig. 2b) as well.

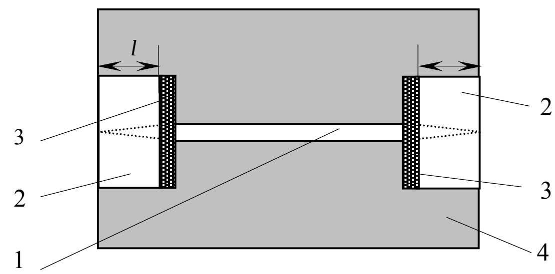
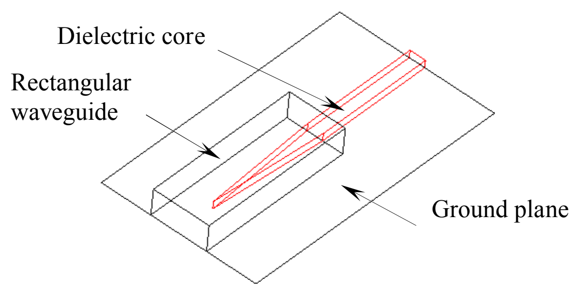
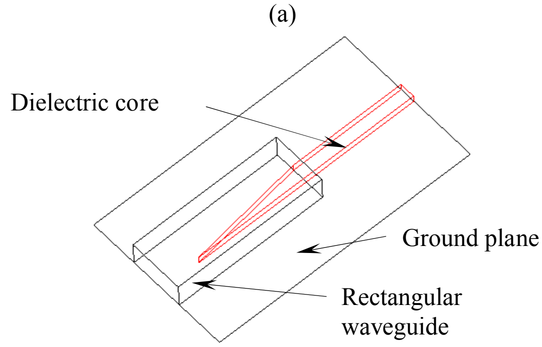


Fig. 1: The top view of the structure under investigation.
1 – IG; 2 – transitions; 3 – absorbing plates; 4 – metal plate; l – transition length.



(a)



(b)

Fig. 2: The symmetrical (a) and asymmetrical (b) transition configurations.

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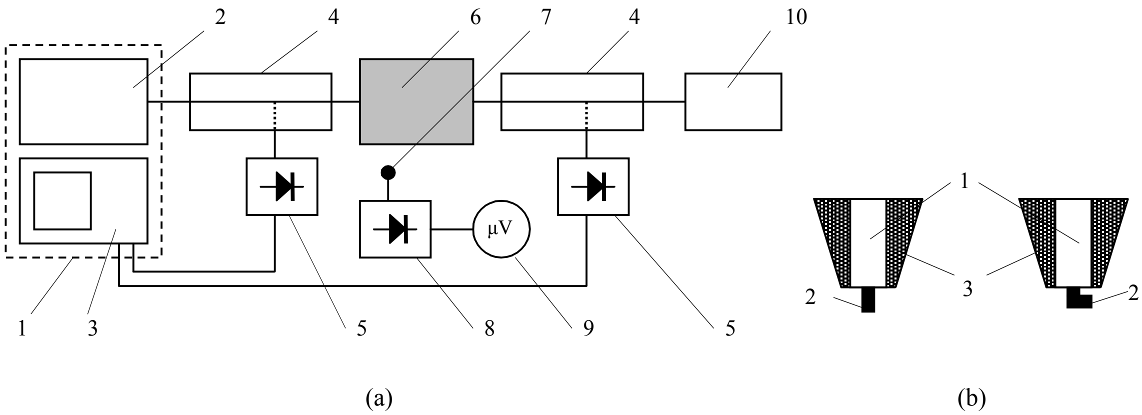


Fig. 3: The experimental setup (a) and the electric probes (b).
(a) 1 – scalar network analyzer; 2 – generator; 3 – indicator; 4 – directional couplers; 5 – detectors; 6 – the structure under investigation; 7 – electric probe; 8 – detector; 9 – microvoltmeter; 10 – matched load.
(b) 1 – semi-rigid coaxial cable; 2 – inner conductor; 3 – absorbing coating.

II. Experimental Investigation

The experimental set-up is shown in Fig. 3a. The scalar network analyzer for frequencies from 26 GHz to 38 GHz includes SMRW components with a cross section of 7.2 mm x 3.4 mm. The structure under investigation has shown losses of about 1 – 2 dB in the entire frequency range.

The coaxial electric probes (Fig. 3b) have been successfully used earlier [4], [5] in the electric field sampling. The electric probe shown in the right (Fig. 3b) is used for both of the E_x and E_z components at the proper orientation, and the electric probe shown in the left – for the E_y component. The electric probes for the E_x and E_z components contain a 90º bend of the inner coaxial conductor and has been assessed as less perfect than the electric probe for the E_y component [5]. The electric probe was mounted on a three axes vernier mechanism that permits positioning of the probe with an accuracy of 0.01 mm along the transverse axes *Ox* and *Oy*, and 0.05 mm along the longitudinal axis *Oz*.

The measured distributions of the electric field components at a frequency of 33 GHz are shown in Fig. 4. The quantity along the vertical axis, which is measured in arbitrary units, is proportional to the squared electric field components due to the square-law characteristic of the detector. The origin of the *x*-axis is at the middle of the dielectric core of the IG. The distribution of the E_y component is omitted here because of its similarity to that of the E_x component, but at a higher level.

As it could be seen from Fig. 4, the distributions are slightly asymmetrical with respect to the plane $x = 0$, which is not in accordance with the geometrical symmetry of the structure and at this stage of the investigation has been explained as due to some imperfections of the real structure. At planes $x = -1$ mm and $x = 1$ mm there are maxima of both of the E_x and E_z components – very slight for the E_x component and strong enough for the E_z component. This could imply, that the non-principal components E_x and E_z seem to be more essential in the vicinity of the dielectric core's side walls. The standing wave pattern observed corresponds to the standing wave ratio SWR of about 1.1 and the guide wavelength λ_g of about 5.7 mm.

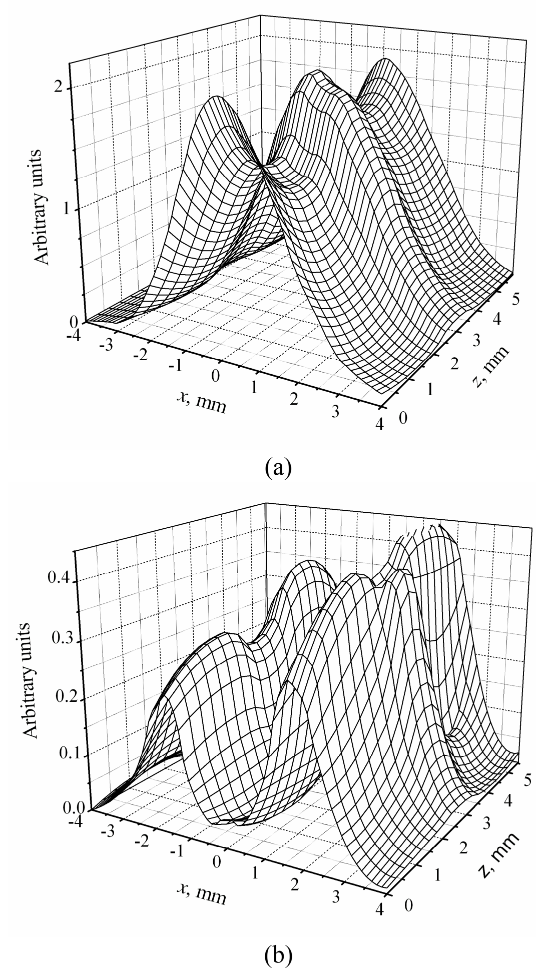


Fig. 4: The measured distributions of the E_x (a) and E_z (b) components.

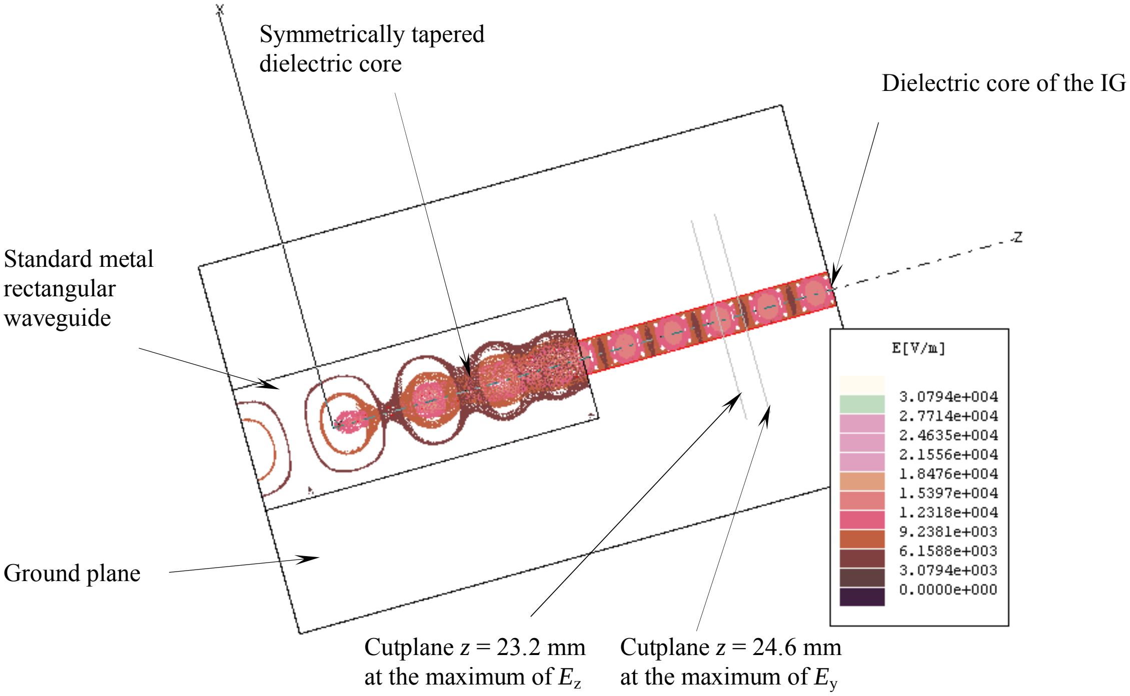


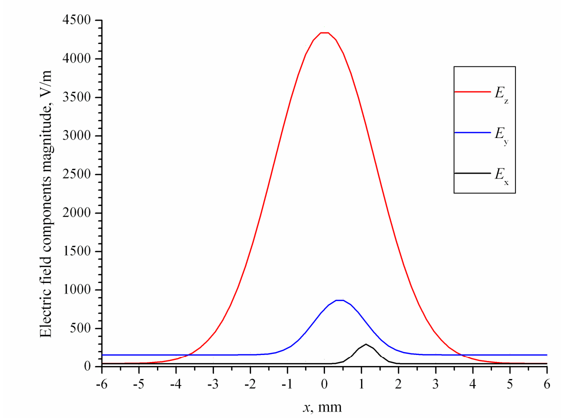
Fig. 5: The simulated distribution of the electric field magnitude in the symmetrical transition with length l = 15 mm.

III. Simulation Results

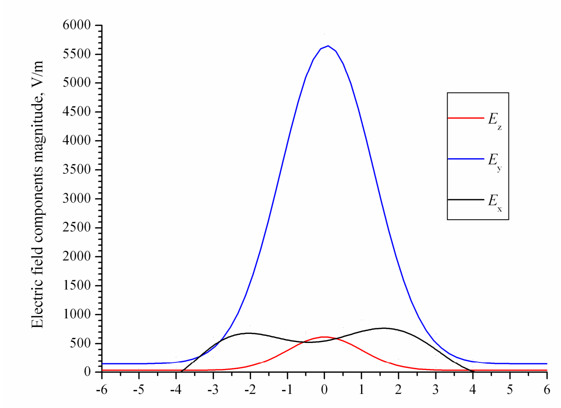
The simulated distribution of the electric field magnitude in the symmetrical transition with length l = 15 mm is shown in the Fig. 5. It is evident the gradual transformation of the dominant mode H_{10} in the SMRW to the dominant mode in the IG. The field outside the dielectric core of the IG is not shown in Fig. 5 in order to visualize better the distribution inside.

The simulated results for the electric field components at the two cutplanes (Fig. 5), z = 23.2 mm and z = 24.6 mm, are shown in Fig. 6. The former cutplane corresponds to the maximum of both the E_z component and the magnitude of the electric field, and the latter – to the maximum of the E_y component. It is evident the asymmetry in the distributions for the E_x and E_y components in Fig. 6a, and also in the distribution for the E_x component in Fig. 6b. This lack of symmetry of the simulated distributions is in agreement with the aforementioned asymmetry in the measured distributions in Fig. 4.

In an attempt to optimize the transition geometry with the help of a 3D electromagnetic simulator [6], [7], we have used the Ansoft HFSS for both the symmetrical and asymmetrical transitions with several taper lengths – l = 0, 5, 10, 15, 20 and 25 mm. The results for the scattering parameters S_{11} and S_{21} at a frequency of 33 GHz are shown in Table 1. It could be seen, that the symmetrical transitions don't possess better S_{11} than the asymmetrical ones at every frequency. As a rule, the symmetrical transitions have better S_{11} at shorter taper lengths, and the asymmetrical transitions – at greater taper lengths. The parameter S_{21} was better for the symmetrical transitions

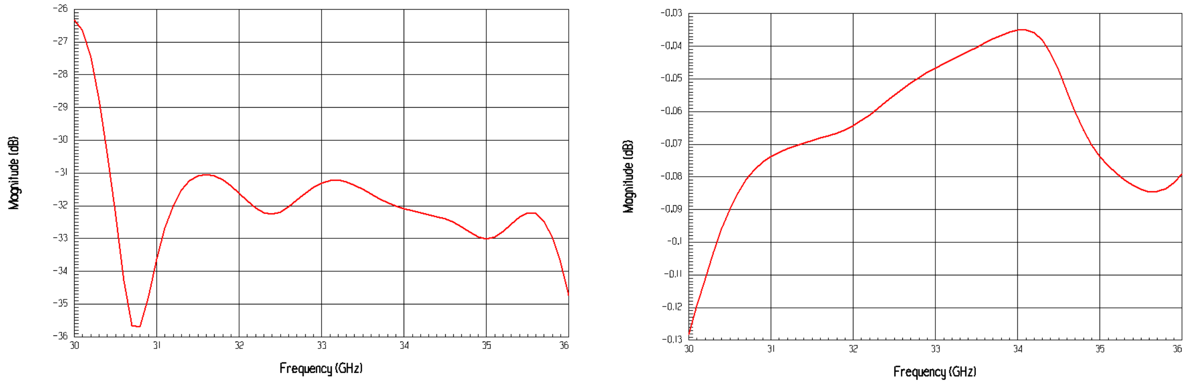


(a)



(b)

Fig. 6: The simulated results for the electric field components at (a) z = 23.2 mm (b) z = 24.6 mm.



(a) (b)

Fig. 7: The simulated results for the scattering parameters S_{11} (a) and S_{21} (b) in the frequency range (30 – 36) GHz.

compared to the asymmetrical ones at every taper length.

The frequency dependence of the parameters S_{11} and S_{21} in the frequency range (33 – 36) GHz for the symmetrical transition with length l = 15 mm are presented in Fig. 7. The parameter S_{11} varies between (–0.13 dB) to (–0.035 dB), and the parameter S_{21} – between (–36 dB) to (–26 dB), which is a rather good performance.

TABLE 1: SIMULATION RESULTS FOR SCATTERING PARAMETEWRS AT DIFFERENT TRANSITION LENGTHS.

Transition configuration	l, mm	S_{11}, dB	S_{21}, dB
	0	- 10.00	- 1.34
Symmetrical	5	- 32.69	- 0.25
	10	- 32.55	- 0.08
	15	- 31.34	- 0.05
	20	- 35.54	- 0.03
	25	- 35.00	- 0.03
Asymmetrical	5	- 30.04	- 0.38
	10	- 33.65	- 0.11
	15	- 32.23	- 0.06
	20	- 35.80	- 0.04
	25	- 37.08	- 0.04

IV. CONCLUSION

It could be concluded, that the transitions with lengths equal to two-three guide wavelengths are quite a reasonable choice. The symmetrical tapers perform better than the asymmetrical ones at middle taper lengths.

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