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Improved low reflection transition from microstrip line to empty substrate integrated waveguide

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***Abstract*—Substrate integrated waveguides (SIC) maintain the advantages of planar circuits (low loss, low profile, easy manufacturing, integration in a planar circuit board), and improve quality factor in filters. Empty substrate integrated waveguides substantially reduce the insertion losses because waves propagate through air instead of propagating through a lossy dielectric. The first empty substrate integrated waveguide (ESIW) used a simple tapering transition. This transition can not be used for thin substrates. In this work a new transition is presented, which adds another tapering transition. With the double taper, the insertion loss is reduced, the minimum return losses are increased 10 dB, and it can be used for all substrates. The original and the new transition are compared. A back to back of the new transition, as well as a filter with the original and the new transition, have been successfully manufactured and measured.**

***Index Terms*—Substrate integrated waveguide, empty substrate integrated waveguide, planar circuits, transition, tapering structures.**

I. INTRODUCTION

Substrate integrated circuits have attracted much attention in the last years. This is because they maintain the advantages of classical planar circuits (low cost, low profile, easy manufacturing with standard printed circuit board machinery, and integration in a substrate with easy connection to other planar circuits) but they outperform planar circuits since they have higher quality factor for resonators and filters and, in some cases, lower insertion losses. Many devices have been designed and manufactured in all these SIC, but in all of them the synthesized rectangular waveguide is filled with dielectric, and as a consequence the waves propagate through a lossy dielectric medium and the insertion losses are high. In order to solve this problem, a new type of substrate integrated waveguides have appeared where the dielectric is removed, and the losses are decreased. The first one of these waveguides was the empty substrate integrated waveguide (ESIW) [1]. Other empty substrate integrated circuits have appeared since then, such as the hollow substrate integrated waveguide (HSIW) [2], the air filled substrate integrated waveguide [3], the dielectricless substrate integrated waveguide presented in [4], or the empty substrate integrated coaxial line (ESICL) [5].

The ESIW, which was developed in our research group, has already been successfully tested with the design and manufacturing of coupled cavity filters with very high quality factors [1], a horn antenna [7], and a hybrid directional coupler [8]. All these devices are connected to microstrip accessing lines through a microstrip to ESIW transition, presented in [1]. The performance of the transition is crucial for the good connection between the ESIW and other planar circuits. This transition has proved to perform satisfactorily, but its performance can still be improved. Besides, for thin substrates, the optimum values of w_{ti} and l_t (see figure 1(a)) produce a very long and narrow taper than cannot be manufactured, so this taper cannot be used in those cases.

In this work, a novel transition is presented. The original transition had a tapered structure inside the ESIW. The new transition adds another taper in the microstrip, before reaching the beginning of the ESIW. This double tapering improves the performance of the transition, increasing the minimum in band return loss in 10 dB, and allowing the use of arbitrarily thin substrates.

II. DESIGN PROCEDURE

The first time that the ESIW was presented in [1], the connection of the ESIW to the accessing microstrip lines was solved with the transition of figure 1(a). This transition consists on a tapering structure inside the ESIW that decreases the dielectric of the microstrip line exponentially until it disappears. Good initial values for the design parameters (l_t, w_{ti}, w_{ir} and c) are provided in [1] (c controls the exponential curve of the taper). An optimization is next used to fine tune the design parameters, and return losses of around 20 dB are obtained with this transition.

In this work we present an improved transition (see figure 1(b)). The novelty of the new transition is the use of another tapering structure with linear shape at the end of the microstrip line, before entering into the ESIW (controlled by the parameters $l_{t_{ms}}$ and $w_{t_{ms}}$). Another improvement is the mechanization of two holes of diameter d_f. These holes ensure that the size of the opening in the back wall of the ESIW is exactly of width w_{ir}. Otherwise, the width that is obtained with the drill has large tolerances and deviates the measurements from the simulation. Finally, via holes of diameter d_v and pitch s_v are mechanized in order to prevent possible waves traveling through the substrate outside the ESIW to couple with the microstrip and interfere.

In order to design the transition, it is convenient to find a good initial point for the design parameters. Table I lists expressions that provide good approximations for the design parameters, and that can be used to obtain good initial points for the transition. These expressions have been obtained experimentally after designing the transitions for different fre-

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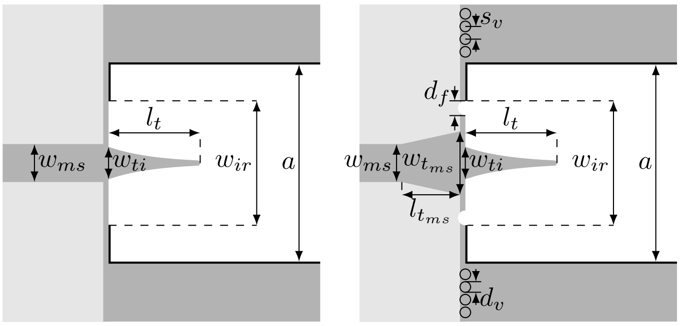
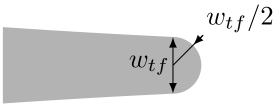


(a) Original transition (b) New transition



(c) Detail of the taper end

Fig. 1. Original and new transitions. Dark gray is dielectric substrate; light gray represents the copper metallization on top layer; black represents the border metallization which has been used to close the ESIW; and white is air.

quency bands and different substrates, with long optimization processes using robust genetic algorithms. The initial point proposed can speed up significantly the optimization process for new designs, regardless of the frequency band, or the specific substrate that has been chosen.

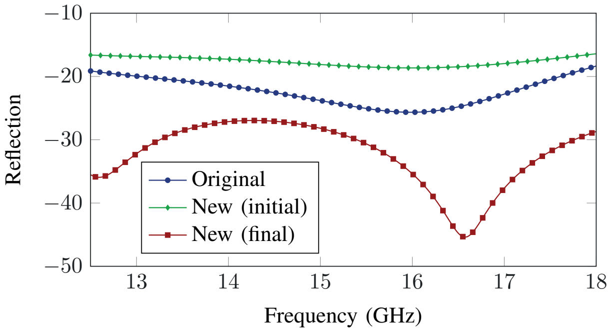
l_t	w_{ti}	w_{ir}	c	$l_{t_{ms}}$	$w_{t_{ms}}$
$\frac{\lambda_g(f_0)}{4}$	$1.2\,w_{t_{ms}}$	$\frac{a+w_{ti}}{2}$	$\frac{2}{l_t}$	$\frac{\lambda_{ms}(f_0)}{4}$	$4\,w_{tf}$

Table I. Initial values for the design parameters of the microstrip to ESIW transition

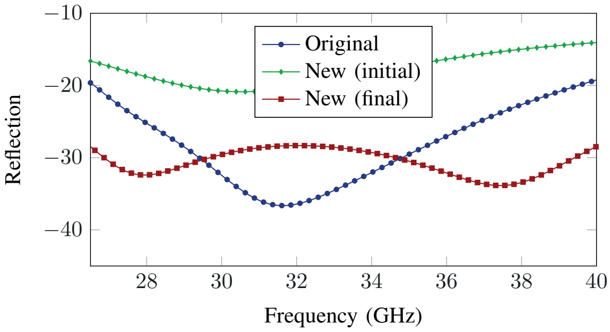
	Fixed values (dimensions in mm)			
	WR-62		WR-28	
a	15.7988		7.1120	
h	0.5080		0.5080	
w_{ms}	1.1071		1.0673	
w_{tf}	0.5000		0.2500	
d_f	1.0000		1.0000	
d_v	0.7000		0.7000	
s_v	1.0000		1.0000	
	Optimization parameters (dimensions in mm)			
	WR-62		WR-28	
	Initial	Final	Initial	Final
l_t	6.4580	6.1568	2.9550	2.7440
w_{ti}	2.4000	2.3693	1.2000	1.5727
w_{ir}	9.0994	7.3651	4.1560	3.6127
$1/c$	3.2290	4.4745	1.4775	1.1324
$l_{t_{ms}}$	3.0000	3.9904	1.2980	1.3203
$w_{t_{ms}}$	2.0000	1.8088	1.0000	1.0331

Table II. Dimensions of the tapers ($\epsilon_r = 3.55$)

The expressions of table I have been used to design two transitions in a Rogers 4003 substrate of height $h = 0.508$ mm, permittivity $\varepsilon_r = 3.55$, and metal thickness $t = 35\,\mu$m. The first transition is for an ESIW with the same width as the standard WR-62 rectangular waveguide. The second transition is for an ESIW with the width of a WR-28 rectangular waveguide. Table II shows the values chosen for the fixed geometrical parameters, and also the initial values (obtained with the expression of table I) and the optimum values of the design parameters. The optimum values have been obtained with an optimization process in which the design goal has been the minimization of $|S_{11}|$ and $|S_{22}|$ in the whole usable frequency band of the corresponding ESIW. The trust region algorithm has been used for the optimization. Thanks to the use of the initial point, the optimization time is significantly reduced.



(a) WR-62 ESIW



(b) WR-28 ESIW

Fig. 2. Reflection of the microstrip to ESIW transition. Comparison between original and new transitions (initial and optimum designs)

Figure II shows the reflection of the original and new transitions (both initial and optimum design). These results correspond to simulations made with the Computer Simulation Technology (CST) commercial software. No losses have been considered. It can be observed that the initial point provides a good approximation to the optimum values, with return losses above 15 dB. After optimization the transitions (both for WR-28 and for WR-62) provide return losses over 28 dB and insertion losses (not shown in the figure) lower than 0.13 dB in all the usable frequency band of the ESIW. It can also be observed that the new transition increases in 10 dB the minimum return losses when compared to the original transition. The insertion losses (not shown) are also significantly reduced.

III. BACK-TO-BACK PROTOTYPE

In order to test the validity of the new transition, a back-to-back transition has been designed and manufactured. A Rogers 4003 substrate with height $h = 0.813$ mm and $\varepsilon_r = 3,55$

Fixed values (dimensions in mm)		Optimization parameters (dimensions in mm)	
a	15.7988	l_t	5.9917
h	0.8130	w_{ti}	2.9469
w_{ms}	1.8519	w_{ir}	6.8070
w_{tf}	0.5000	$1/c$	3.8945
d_f	1.0000	l_{tms}	2.1756
d_v	0.7000	w_{tms}	2.4486
s_v	1.0000		

Table III. Dimensions of the manufactured taper ($\epsilon_r = 3.55$)

has been chosen. The ESIW used in this transition has the same width as the WR-62 waveguide. The design procedure described in the previous section has been used in order to design the microstrip to ESIW transition. The optimum geometrical values of the transition are shown in table III.

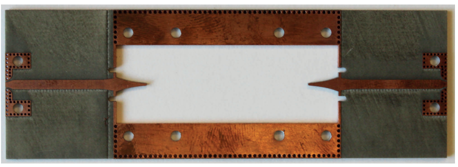


Fig. 3. Manufactured back-to-back transition without top and bottom covers

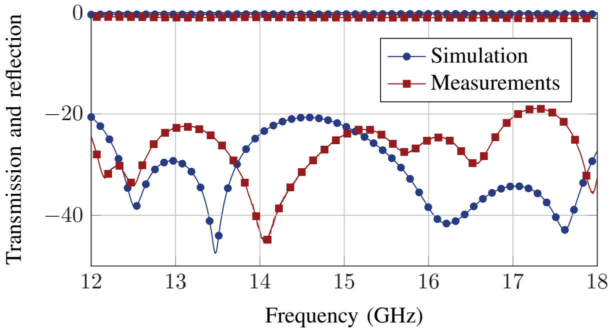


Fig. 4. Comparison between simulation and measurement for the back-to-back transition from microstrip to ESIW

Figure 3 shows the manufactured prototype of the back-to-back transition without the top and bottom covers. After measuring with a TRL calibration kit, the measured transmission and reflection are depicted in figure 4, and compared with simulation. The simulated results have been obtained with CST, considering losses both in the metallic parts and in the dielectric body. As it can be observed, simulation and measurements are in good agreement. The measured return loss is greater than 20 dB and the insertion loss is smaller than 1.2 dB in the whole usable frequency band of the ESIW.

A two pole filter in ESIW has been manufactured with the original transition, and with the new one, with a Rogers 4003 substrate with height $h = 0.813$ mm and $\varepsilon_r = 3,55$. The width of the ESIW in this case is the same as the WR-90. Figure 5 compares the responses of the two prototypes. It can be observed that the prototype with the new transition has higher return losses and lower insertion losses.

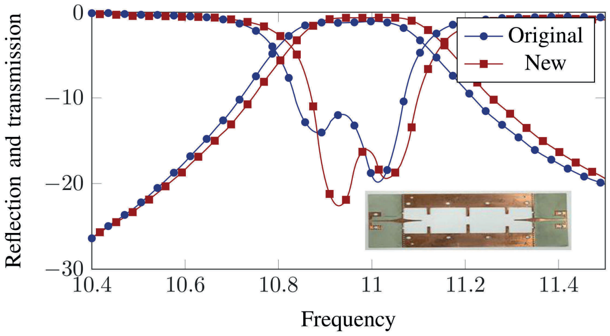


Fig. 5. Reflection and transmission of a two pole filter in ESIW with the original and the new transition

IV. CONCLUSIONS

In this work a novel transition from microstrip to ESIW has been presented that increases return losses 10 dB with respect to the original transition, and it is usable for all substrate heights. A back-to-back transition and a two pole filter have been successfully manufactured and measured.

V. ACKNOWLEDGEMENT

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