

Mapping smooth profile H -plane rectangular waveguide structures to substrate integrated waveguide technology

E. Diaz Caballero, I. Roldan, V. Urrea, M. Chudzik, I. Arregui, I. Arnedo and A. Belenguer

The guidelines for mapping rectangular waveguide structures to substrate integrated waveguide (SIW) technology are well understood for structures with straight walls. However, the mapping of a smooth profile structure from rectangular waveguide to SIW technology is not trivial and it needs to be carefully studied. A general procedure for mapping any smooth profile H -plane rectangular waveguide structure to SIW technology is proposed. A practical example is also provided and experimentally validated.

Introduction: The substrate integrated waveguide (SIW) [1] is a mixed technology between waveguide and printed circuit that inherits the merits from both previous technologies (see Fig. 1). Typical rectangular waveguide devices can also be implemented in SIW, which is not so bulky, has a lower cost and is easier to integrate with planar technologies.

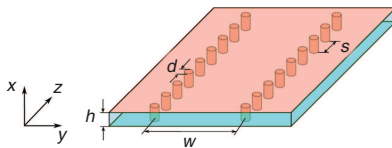


Fig. 1 SIW geometry

The guidelines for mapping rectangular waveguide structures to SIW are well understood for structures whose walls have a straight profile [2, 3]. However, there are several waveguide structures with smooth profile in the H -plane [4], like classical tapers [5] or even recent high-performance filters [6], which would require a general mapping procedure in order to be mapped to SIW technology. Some attempts at transforming a smooth profile designed in waveguide into an SIW structure [7] have been recently done, but a general procedure for implementing such transformation is neither provided nor discussed. Therefore, here we propose a systematic procedure for mapping any type of smooth profile waveguide structure to SIW technology.

Mapping smooth profile structures: In a rectangular waveguide structure with a smooth profile, the width of the waveguide is not constant but varies continuously along the propagation direction z . Assuming symmetry along z , the amplitude of the profile is expressed by $f_{wg}(z)$, so that the waveguide walls are situated at $f_{wg}(z)$ and $-f_{wg}(z)$, respectively. The objective here is to find an equivalent profile in SIW, $f_{SIW}(z)$, and to place the SIW via holes along it so that the performance of the SIW structure is the same as that of the waveguide one.

Let us consider that any smooth profile waveguide is accessed by input and output sections of rectangular waveguides with constant width, a . For the SIW structure, first we choose the values for the via holes diameter, d , and for the pitch between vias, s . Both values must fulfil the design rules for avoiding power leakage between the gaps [2]. Small values for d and s will provide a better mapping from waveguide to SIW. Then, the width between the via hole walls in the accesses, w , can be calculated using the closed expression in (2) of [3].

If we define the ratio

$$\xi = w/a \quad (1)$$

we must note that, for the input and output accesses, the width between via hole walls in SIW, $w = \xi \cdot a$, has a constant value. In the smooth profile, however, the width of the waveguide varies with the propagation direction as $2f_{wg}(z)$, and so the separation in SIW must vary accordingly as $\xi \cdot 2f_{wg}(z)$. Therefore, the smooth profile in SIW is

$$f_{SIW}(z) = \xi \cdot f_{wg}(z) \quad (2)$$

The next step is to place the via holes of the SIW along this new continuous profile, $f_{SIW}(z)$. To do so, it is convenient to fix certain vias at some critical points, such as the minimums or maximums (maximums and minimums can be obtained by calculating the values of z where

the first derivative of the function $f_{SIW}(z)$ is zero) of $f_{SIW}(z)$ (see example in Fig. 2 (left)), so that the profile can be accurately described by the via holes.

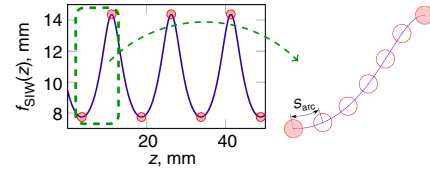


Fig. 2 Placing some vias at critical points of example profile (left), and via holes between two adjacent critical points (right)

Then, the position of the rest of the via holes needs to be determined. Since we are considering a smooth profile for the side walls, a new pitch is going to be defined, s_{arc} , as the arc length between the centres of the via holes along $f_{SIW}(z)$ (see representation of s_{arc} in the example in Fig. 2 (right)). Let L be the arc length along $f_{SIW}(z)$ between two adjacent critical points; we will divide this arc into a whole number, n , of subarcs of length $s_{arc} = L/n$, so that there is no radiation leakage between vias [2]. The position of the each via $i = 1, 2, \dots, n - 1$, $z = z_i$, can be calculated by solving

$$s_{arc} = \int_{z_{i-1}}^{z_i} \sqrt{1 + \left(\frac{\partial f_{SIW}(z)}{\partial z}\right)^2} dz \quad (3)$$

where z_i is the unknown and z_0 and z_n are the respective critical points at each extreme of the arc.

Finally, the flowchart in Fig. 3 sums up the proposed procedure for obtaining the equivalent SIW structure for a smooth profile rectangular waveguide structure.

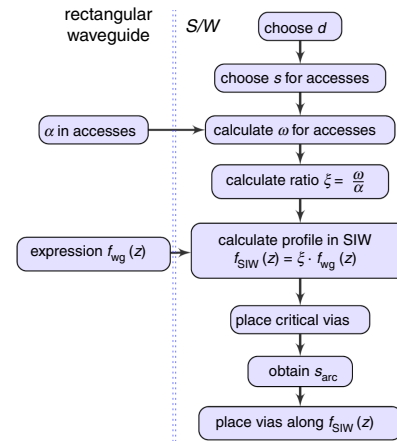


Fig. 3 Procedure for mapping smooth profile structures from rectangular waveguide to SIW technology

Results: In general, the presented procedure can be applied to any H -plane rectangular waveguide structure whose side walls follow a smooth profile. For example, it has been applied to a traditional exponential taper in waveguide, which has been mapped to SIW, comparing both the responses in Fig. 4. However, in this Section, we are going to show also a practical example of its use for a more complex structure. To do so, an H -plane stopband filter centred at 7 GHz, which consists of an electromagnetic bandgap (EBG) structure with a sinusoidal coupling coefficient [8] of amplitude $A_k = 35 \text{ m}^{-1}$ and period $\Lambda = 14.92 \text{ mm}$, is mapped from rectangular waveguide (see layout in Fig. 5) to SIW technology. For the SIW implementation of the filter, we use a Rogers 4003C substrate ($\epsilon_r = 3.55$, $h = 1.524 \text{ mm}$).

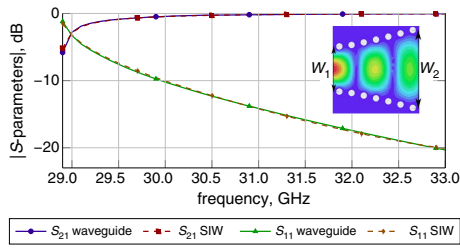


Fig. 4 Waveguide response [5] against SIW response of exponential taper
E-field magnitude inside mapped SIW exponential taper
 Dimensions: $d = 0.5$ mm, $s_{\text{arc}} = 0.96$ mm, $w_1 = 3.455$ mm, $w_2 = 5.956$ mm, $\xi = 1.2$, total length = 6.7 mm

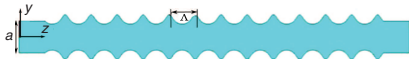


Fig. 5 Layout of waveguide profile to be mapped to SIW technology as a practical example ($a = 18.5$ mm, $\Lambda = 14.92$ mm)

The simulated S-parameters of the mapped SIW structure have been accurately obtained (the SIW structure has been analysed considering all the possible contributions to losses: finite conductivity in the conductor, dielectric losses and potential radiation leakage between via holes) and compared with those of the original rectangular waveguide structure in Fig. 6, showing a very good agreement in an extended bandwidth, which validates the proposed mapping procedure.

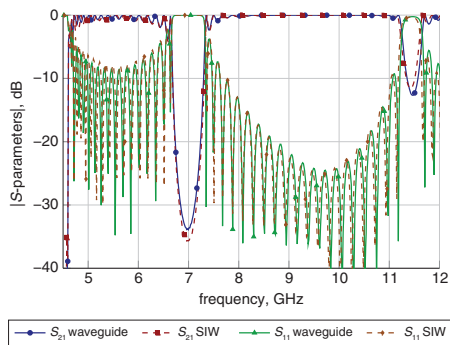


Fig. 6 Waveguide response against SIW response of stopband filter with smooth profile

Then, the SIW structure was fabricated, and the prototype and physical dimensions can be seen in Fig. 7. Its measured S-parameters (using the calkit detailed in [9]) are successfully compared with the simulations including all the contributions to losses in Fig. 8. The insertion loss in measurements is higher than in the simulation with losses, which is due to the fact that the real conductivity of copper is lower than the ideal one considered in simulations; the metal continuity between the via holes and the copper layers in the manufactured prototype is not perfect and the $\tan \delta$ of the dielectric substrate has some tolerance.

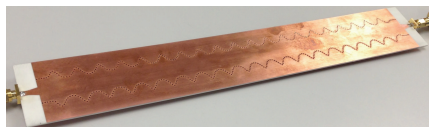


Fig. 7 Manufactured stopband SIW filter with smooth profile mapped from rectangular waveguide design

Dimensions: $d = 1$ mm, $w = 19.26$ mm, $s = 1.5$ mm, $s_{\text{arc}} = 1.75$ mm, $\xi = 1.04$, total length = 31.1 cm

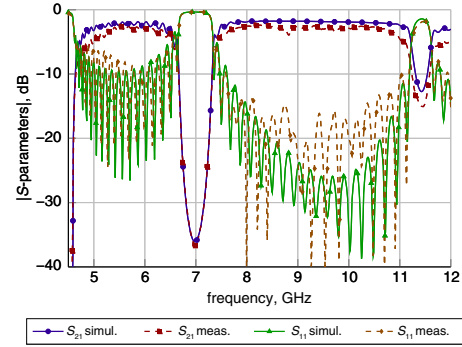


Fig. 8 Simulation with losses against measurements for fabricated stopband filter with smooth profile in SIW

Conclusions: A general and systematic procedure for mapping any smooth profile *H*-plane rectangular waveguide structure to SIW technology has been presented and successfully tested with a practical example. In particular, a stopband waveguide filter based on an EBG rectangular waveguide structure has been mapped to SIW technology, and a prototype has been fabricated and measured.

© The Institution of Engineering and Technology 2014

30 April 2014

doi: 10.1049/el.2014.1581

One or more of the Figures in this Letter are available in colour online.

E. Diaz Caballero and I. Roldan (*Instituto de Telecomunicaciones y Aplicaciones Multimedia, Universitat Politècnica de València, Valencia, Spain*)

E-mail: eldiaca@iteam.upv.es

V. Urrea, M. Chudzik, I. Arregui and I. Arnedo (*Departamento de Ingeniería Eléctrica y Electrónica, Universidad Pública de Navarra, Pamplona, Spain*)

A. Belenguier (*Departamento de Ingeniería Eléctrica, Electrónica, Automática y Comunicaciones, Universidad de Castilla-La Mancha, Cuenca, Spain*)

References

- Deslandes, D., and Wu, K.: 'Integrated microstrip and rectangular waveguide in planar form', *IEEE Microw. Wirel. Compon. Lett.*, 2001, **11**, (2), pp. 68–70
- Deslandes, D., and Wu, K.: 'Accurate modeling, wave mechanisms, and design considerations of a substrate integrated waveguide', *IEEE Trans. Microw. Theory Tech.*, 2006, **54**, (6), pp. 2516–2526
- Diaz Caballero, E., Esteban, H., Belenguier, A., Boria, V., Morro, J., and Cascon, J.: 'Efficient design of substrate integrated waveguide filters using a hybrid MoM/MM analysis method and efficient rectangular waveguide design tools'. *Int. Conf. Electromagnetics in Advanced Applications*, Turin, Italy, September 2011, pp. 456–459
- Mallik, A., and Sanyal, G.: 'Electromagnetic wave propagation in a rectangular waveguide with sinusoidally varying width', *IEEE Trans. Microw. Theory Tech.*, 1978, **26**, (4), pp. 243–249
- Sporleder, F., and Unger, H.: 'Waveguide tapers, transitions and couplers' (Peter Peregrinus Ltd., 1979)
- Lorente, J.A., Ernst, C., and Melcon, A.A.: 'Rigorous derivation of lossy equivalent circuit for narrowband waveguide direct-coupled-cavity filters', *IET Microw. Antennas Propag.*, 2013, **7**, (4), pp. 251–258
- Schwartz, J., Abhari, R., Plant, D., and Azana, J.: 'Design and analysis of 1-d uniform and chirped electromagnetic bandgap structures in substrate integrated waveguides', *IEEE Trans. Microw. Theory Tech.*, 2010, **58**, (7), pp. 1858–1866
- Arnedo, I., Arregui, I., Lujambio, A., Chudzik, M., Laso, M., and Lopetegui, T.: 'Synthesis of microwave filters by inverse scattering using a closed-form expression valid for rational frequency responses', *IEEE Trans. Microw. Theory Tech.*, 2012, **60**, (5), pp. 1244–1257
- Diaz Caballero, E., Belenguier, A., Esteban, H., and Boria, V.: 'Thru-reflection calibration for substrate integrated waveguide devices with tapered microstrip transitions', *Electron. Lett.*, 2013, **49**, (2), pp. 132–133