A low-loss Ka-band Waveguide to Substrate Integrated Waveguide Transition Based on Ridged Stepped-Impedance Transformer

Citation for published version:
Garcia Perez, J, Goussetis, G, Fan, H & Ding, Y 2021, 'A low-loss Ka-band Waveguide to Substrate Integrated Waveguide Transition Based on Ridged Stepped-Impedance Transformer', *Electronics Letters*.

Published In:
Electronics Letters

A low-loss Ka-band Waveguide to Substrate Integrated Waveguide Transition Based on Ridged Stepped-Impedance Transformer

J. A. García Pérez, G. Goussetis, H. Fan, Y. Ding

In this paper, a low-loss Ka-band transition from waveguide to substrate integrated waveguide (SIW) is presented based on ridge waveguide stepped-impedance transformer. This novel transition can operate across full Ka-band (26.5 GHz to 40 GHz) with insertion loss lower than 0.59 dB and return loss over 14.2 dB. Furthermore, compared to existing transitions the introduction of ridges reduces the metal usage, resulting in a weight reduction and offering an encouraging application for weight sensitive satellite communications (SatComs).

Introduction: In recent years, mm-wave applications above 20 GHz have been increasingly playing a prominent role in the commercial development of Ka-band satellite communications (SatComs) and the fifth generation of mobile communications (5G). This has created an inexorable demand for components to meet stringent performance specifications at Ka band and beyond. At these high frequencies, the losses related to planar/microstrip transmission lines are significantly higher than those at lower frequencies, and therefore air-filled waveguides are preferred solutions to reduce losses. However, most of the commercially available components are in form of surface mount technology (SMT) or monolithic microwave integrated circuit (MMIC) technologies, requiring to be surface mounted, or wire bonded to a planar structure. To this end, efficient transitions from waveguide to planar technologies are desired to avoid unnecessary losses, especially in cost sensitive applications such as SatComs, where just a few tenths of dB could result in a significant cost increase or even a system power shortage.

Substrate integrated waveguide (SIW) has provided a good solution at higher frequencies due to its low loss and easy integration with planar circuits, SMT components and MMIC chips. It also benefits from cheap fabrication costs and low profile. To synergise the strengths of air-filled waveguides and SIW, the transition between these two different structures is in great demand and several works have been reported in the literature [1–7]. However, the presented transition structures still suffer from large insertion losses (> 0.8 dB) at Ka-band, which is intolerable in SatComs applications.

In this paper, a novel waveguide to SIW transition is presented based on a 4-stage ridged waveguide transformer. This transition provides an insertion loss lower than 0.59 dB over the entire Ka-band from 26.5 GHz to 40 GHz. Additionally, it allows a reduction in manufacturing complexity by reducing the need of small diameter cutters (E-field is concentrated in the ridges), as well as reducing metal usage and weight compared to full-width transitions in [4].

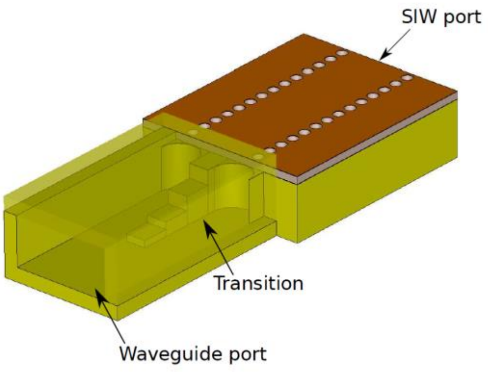

Fig. 1 *3D view of the proposed transition*

Design: The 3D model of the proposed transition is shown in Fig. 1. The design of the proposed transition begins by calculating an SIW transmission line dimensions (Fig. 2). For a standard SIW, the width depends on the substrate (dielectric constant ϵ_r), via diameter d and the pitch p between vias. The resulting SIW width is given by [8]

$$a_{siw} = W_{eq} + p(0.766e^{0.4482\frac{d}{p}} - 1.176e^{-1.214\frac{d}{p}}) \tag{1}$$

where W_{eq} is the effective waveguide width, calculated by

$$W_{eq} = \frac{c}{2f_c\sqrt{\epsilon_r}} \tag{2}$$

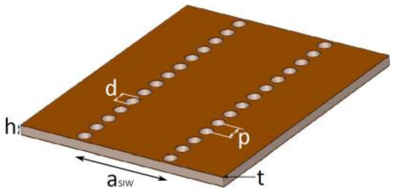

Fig. 2 *SIW geometry*

With the defined SIW dimensions, the waveguide to SIW transition is then designed based on a ridged stepped-impedance transformer. In this work, a four-stage transition is considered. Each stage consists of a single-ridged step to create a progressive impedance transformation ratio. The geometric parameters of the design are given in Fig. 3, where the longitudinal and cross section views are illustrated. The principle of operation is matching TE_{10} mode from waveguide to the SIW by employing a multistage impedance transformation, which is a well-known technique in planar circuit design. To adapt to the height of the SIW, the last ridge height is given by

$$H_4 = b - h, \tag{3}$$

where b is the waveguide height and h is the SIW height. The rest of the heights are deployed to double the previous one and create the desired impedance transform ratio, so that

$$H_k = 2H_{k-1} \tag{4}$$

In addition, the ridge structure allows the use of bigger diameter cutters for the Computer Numeric Control (CNC) manufacturing thus reducing costs and tolerances in the zones with higher electric fields.

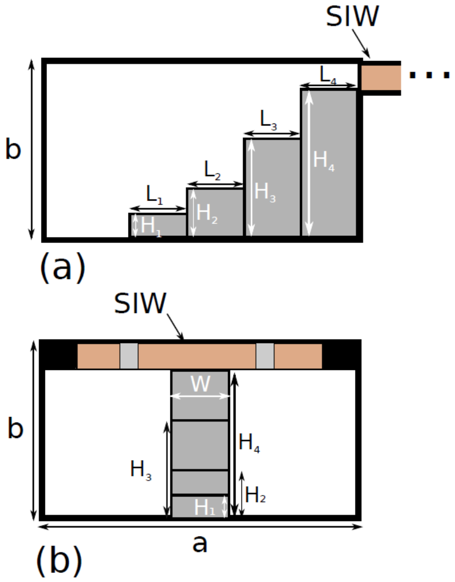

Fig. 3 *Dimensions of the design. (a) Longitudinal view. (b) Cross section.*

Simulated and measured results: For verification, a prototype has been designed and manufactured for Ka-band operation by using standard WR-28 waveguide (7.112 mm x 3.556 mm). Simulations are carried out using commercially available CST software. The SIW is designed with the Rogers RF/Duroid 5880 substrate, where dielectric constant value $\varepsilon_r = 2.2$ and thickness $h = 0.254\,mm$. Considering $d = 0.8\,mm$ and $p = 1.1\,mm$ (with $f_c = 21$ GHz), the width given by (1) is $a_{SIW} = 5.3\,mm$, which is less than the width of the implemented waveguide, enabling the physical realisability. At the centre frequency (33 GHz) of the Ka-band the guided wavelength is $\lambda_g = 11.8\,mm$. The initial ridge lengths are set to $L_k = 2.95\,mm$ (k is the stage number) and the width W of all the ridges is 1.5 mm.

After tuning and optimising for minimum insertion and reflection loss in the entire Ka-band, the resulting dimensions are shown in Table 1.

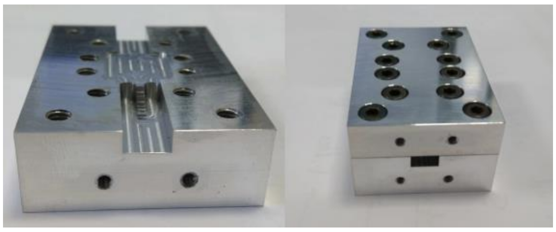

Fig. 4 *Photo of the manufactured back-to-back transition prototype.*

Fig. 5 *Setup for the measurement of the prototype.*

Table 1: Final optimised parameters. All units in *mm*.

Ridge stage	**1**	**2**	**3**	**4**
H	0.5	1	2	3.046
L	2	2	2	2

The photo of the manufactured prototype is presented in Fig. 4, which consists of two transitions back-to-back. The measurements have been conducted with an Agilent N5225A network analyser and Fig. 5 shows the experimental setup. The simulated and measured results are given in Fig. 6. The measured insertion loss is lower than 0.59 dB and return loss is higher than 14.2 dB over the entire Ka-band (26.5 - 40 GHz). Considering two transitions in a back-to-back configuration in the prototype, the resulting insertion loss for a single transition is lower than 0.295 dB. The discrepancy between measured and simulated results is mainly due to manufacturing tolerances. Furthermore, the performances of the proposed waveguide to SIW transition compared with others are summarised in Table 2.

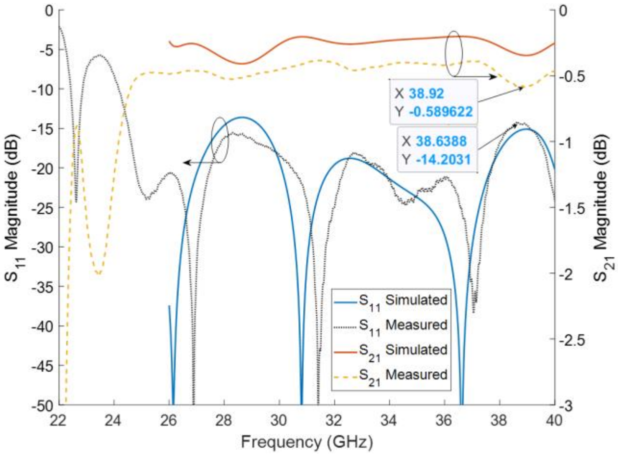

Fig. 6 *Simulated and measured results of the back-to-back structure.*

Table 2: Comparison of waveguide to SIW transitions (back-to-back implementations)

	Freq. (GHz)	**BW (%)**	**IL (dB)**	**RL (dB)**
[1]	26.5 – 40	40.9	<1.1	>15
[2]	26.5 – 40	40.9	<1.4	>15
[3]	Centre at 26 GHz	6.6	<1.5	>15
[4]	32 – 50	45	<0.8	>15
[5]	28.3 – 39.5	33	<1.4	>14
[6]	34.2 – 35.3	3.2	<3.4	>11
This work	**26.5 – 40**	**40.9**	**<0.59**	**>14.2**

Conclusion: In this paper, a low-loss waveguide to SIW transition based on a ridged stepped-impedance transformer has been proposed. The manufactured back-to-back prototype has an insertion loss lower than 0.59 dB and a return loss higher than 14.2 dB in the entire Ka-band. The employment of ridges in the transition not only achieves a lower insertion loss but reduces the manufacturing tolerances as well as the weight of the metal material. Hence, the proposed waveguide to SIW transition provides a promising approach in SatComs applications.

Acknowledgments: This work was supported by the EPSRC (UK) under Grant EP/V002635/1.

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