Substrate Integrated Waveguide with Corrugated Wall

Denis G. Chen, and Kimberley W. Eccleston
Department of Electrical and Computer Engineering
University of Canterbury, Christchurch, New Zealand
denischn@gmail.com; kim.eccleston@canterbury.ac.nz

Introduction

Substrate integrated waveguide (SIW) allows waveguide techniques to be implemented on PCBs [1]. The technology has been successfully applied to a number of devices such as filters, couplers, dividers, slot array antennas [2], oscillators, six port circuits, and circulators [3]. Its models and numerical analysis techniques have also been extensively researched [4].

One particular challenge facing SIW circuits is their integration with active components that require DC biasing. An inherent DC short-circuit is formed between conventional SIWs' top and bottom waveguide plates due to the conducting vias. Several schemes have been proposed to address this issue. They include the use of discrete capacitors on microstrip lines leading up to the SIW circuit [5], embedding an interdigitated capacitor into the SIW-to-microstrip transition [6], and using AC coupling on half mode SIW [7]. None of the existing methods allow direct shunt connection of active components, such as Gunn diodes, into a waveguide. Compromises are usually made to accommodate the need of DC bias; and consequently, the advantages of SIW structure are not fully utilized and the solution is suboptimal.

In this work we propose a new SIW structure, called the corrugated SIW (CSIW), which does not require conducting vias to achieve TE_{10} type boundary conditions at the side walls. Instead, the vias are replaced by quarter wavelength microstrip stubs arranged in a corrugated pattern on the edges of the waveguide. This, along with series interdigitated capacitors [6], results in a waveguide section comprising two separate conductors, which facilitates shunt connection of active components such as Gunn diodes [8]. The concept of this arrangement is shown in Fig. 1.

Proposed Corrugated Substrate Integrated Waveguide

The layout of a CSIW and its critical dimensions are given in Fig. 2. The waveguide width (a), and 50Ω microstrip to SIW transition are designed according to previously described methods [3, 9]. They can be fine tuned and optimized separately by way of EM simulations.

The length of the corrugated wall stubs (t) is approximately one quarter of the TEM guided wavelength (λ_g) at the centre frequency. This estimation is refined by EM simulation which accounts for fringing effects and transition from TE_{10} mode to quasi-TEM mode at the side wall.

Different combinations of stub spacing (u) and width (v) have been investigated. We conclude that they have very little impact on the overall performance of the CSIW. Rules for choosing equivalent dimensions in conventional SIWs can be applied here and values suitable for fabrication should be adopted for the final design.

Application of CSIW in X-band

Fig. 3 shows a set of back-to-back SIWs, corrugated and conventional, fabricated on 60 mil thick Taconic RF-30 ($\varepsilon_r = 3.0$) PCB with 35 µm copper layer on both sides. Two sets of SIWs were made with different waveguide section lengths: one 81 mm and another 46.5 mm.

The SIWs were designed for X-band (8.2 GHz to 12.4 GHz), and the resulting structure parameters are given in Table 1. The internal width (a) and the microstrip transitions are the same for both SIW and CSIW. The parameters d and s refer to the via diameter and spacing for the conventional SIW respectively. The substrate thickness, and hence waveguide height, is denoted as b. The surface current density plot for both SIW and CSIW at 10 GHz is shown in Fig. 4 and this is consistent with the TE_{10} mode.

a	b	ε_r	d	s	m_l	m_w	w	l	u	v	t
13.5	1.524	3.0	1.0	2.0	4.0	4.0	7.0	17.5	1.0	1.0	5.5

Table 1. Optimized dimensions for conventional and corrugated SIW in mm.

S-parameter measurements were performed using an Agilent E8362B 20 GHz vector network analyzer. Results for the 46.5 mm waveguides are given in Fig. 5. Measured return loss is better than 10.3 dB for CSIW and 8.6 dB for SIW; global insertion loss is lower than 3.5 dB for CSIW and 2.9 dB for SIW.

Based on the multiline calibration method [10], the propagation constants (Fig. 6) were extracted from the measurements of the two lengths of CSIW and SIW. The attenuation constant is less than 0.48 dB/cm for CSIW and 0.45 dB/cm for SIW.

The discrepancies between measurement and simulation are largely attributed by the irregularities in the fabrication process; nonetheless, the results are sufficient to confirm that the CSIW offers performance comparable to that of the conventional SIW.

The interdigitated capacitor on the DC decoupled CSIW (Fig. 7) was designed following a method similar to [6]. It uses 13 fingers of 3.2 mm length, and a gap of 0.3 mm. Measured results (Fig. 8) suggest that the two capacitors increased insertion loss by approximately 0.5 dB overall when compared to CSIW results in Fig. 5.

Conclusion

A novel corrugated SIW has been shown to have comparable performance to the conventional SIW. It has the additional advantage of complete DC isolation between its top and bottom plates. This permits shunt connection of active components in the waveguide for a variety of applications.

Acknowledgement

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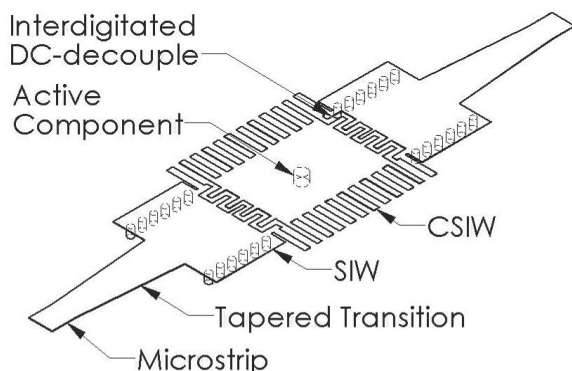
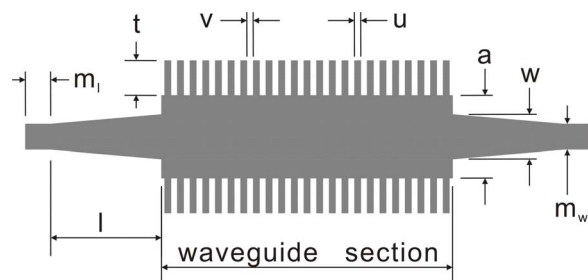Figure 1. DC decoupled CSIW with embedded component.
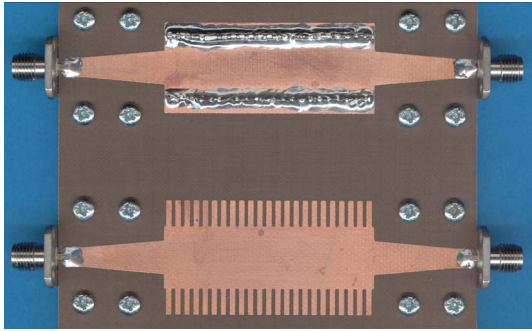

Figure 2. CSIW layout.

Figure 3. SIW and CSIW with 46.5mm waveguide length.

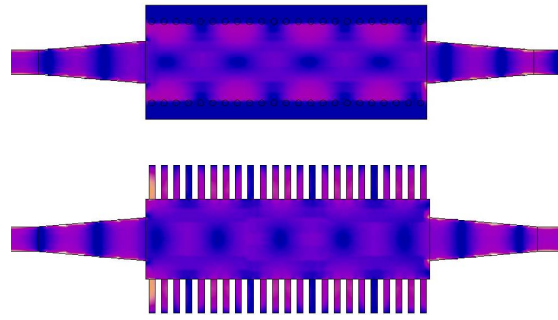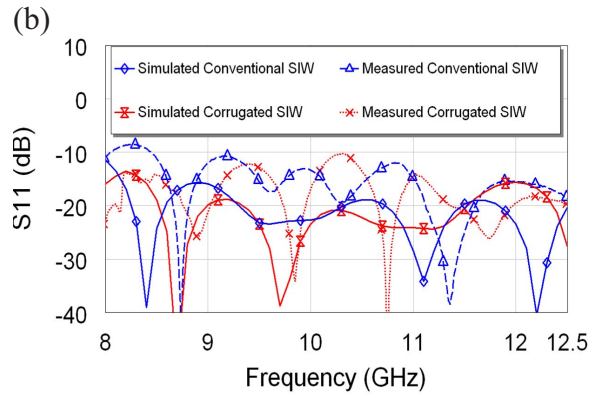Figure 4. Surface current density plot of SIW and CSIW at 10 GHz.
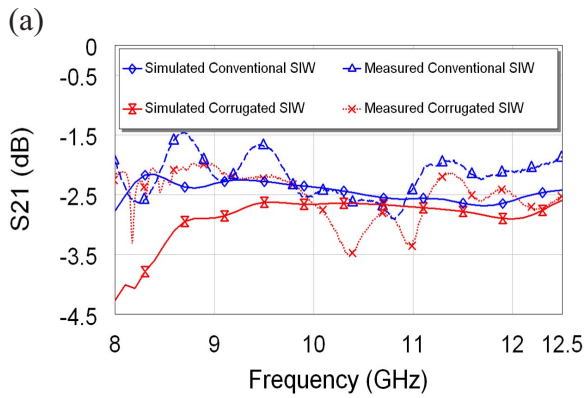
(a)

(b)

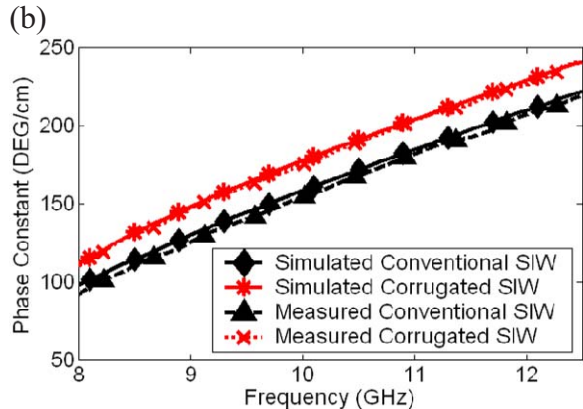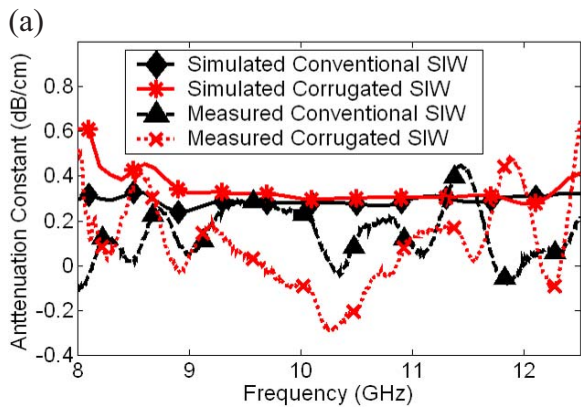Figure 5. S-parameters of the waveguides. (a) S21. (b) S11.

(a)

(b)

Figure 6. Propagation constant of the waveguides. (a) Attenuation constant. (b) Phase constant.
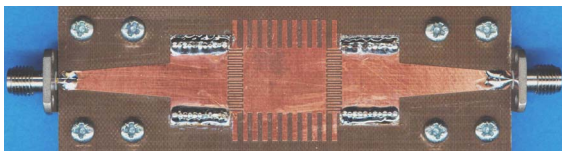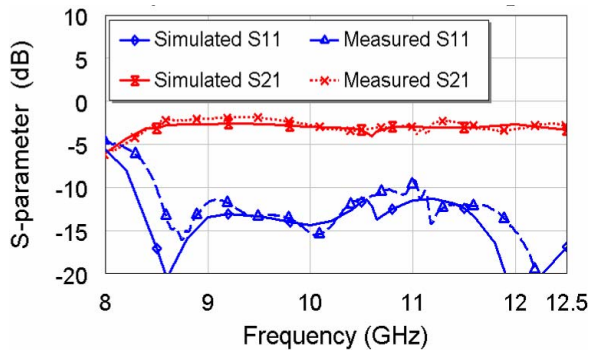

Figure 7. DC decoupled CSIW with 46.5mm total waveguide length.

Figure 8. S-parameters of the DC decoupled CSIW.