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Substrate Integrated Waveguide Technology: A Step towards Compact Microwave Structures

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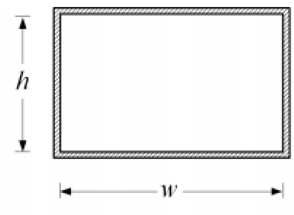
ABSTRACT

In this paper, a comprehensive review about the Substrate Integrated Waveguide (SIW)technology was presented. The advantages and limitations of different types of SIW technologies were studied. The usage of metallic vias in a dielectric substrate is a key in obtaining planar waveguide form in SIW technology. The design rules of basic SIW are considered. To obtain compact structure Half mode and Quarter mode SIW structures are explored. The advantages of using a coaxial SIW in filtering applications is highlighted and developments in Empty SIW cavities is investigated.

Keywords: SIW, FOLDED SIW, HMSIW, QMSIW, CSIW, ESIW

I. INTRODUCTION

The ability to integrate microwave systems in single device makes Substrate Integrated Waveguides (SIW)as one of the preferred technologies. Its capability to implement passive components, active devices, and antennas by using a single technology and manufacturing process is making it as a choice of designers in electromagnetic domain. Low loss components usually realized in waveguide technology, which are bulky in nature. Several efforts are taken to reduce the weight of waveguide components. Waveguide components lack in flexible integration with other components.



(a)

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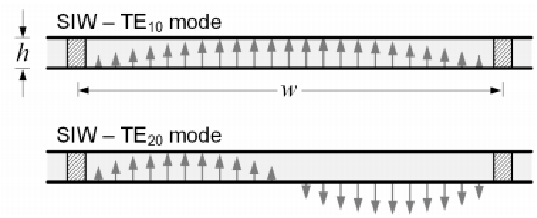

(b)

Fig.1.Geometry comparison of a standard and an integrated waveguide: (a) Cross section of a standard rectangular waveguide; (b) Cross section of a substrate integrated waveguides, and electric field of the first two modes.[1]

SIW is the integrated version of this technology and is very competitive from the point of view of losses. SIW technology allows to implement interconnects and cavities by using a standard printed-circuit board (PCB) process, based on a laminated dielectric substrate and metal vias that provide the lateral confinement. [1]. SIW technology presents several advantages over other planar technologies such as complete shielding, and low loss, while preserving a low fabrication cost and a well-established manufacturing process.

II. SUBSTRATE INTEGRATED WAVEGUIDES:

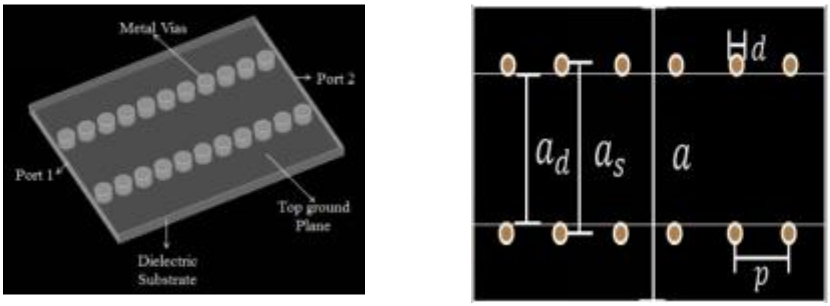

Fig.2: Geometry of SIW

SIW is a new planar platform in which the microstrip line and rectangular waveguide are fully integrated on the same substrate. The cutoff frequency depends on the vias dimension and spacing. It Allows the propagation of TE modes, by considering the metallic vias as its sidewalls.

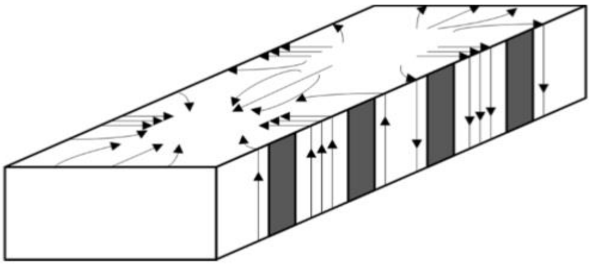

Fig.3.TE surface currents distribution of the rectangular waveguide with slots on the narrow walls.

- For a rectangular waveguide, cut off frequency of arbitrary mode is:

$$f_c = \frac{c}{2\pi}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

Where

c: speed of light,

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m, n: mode numbers

a, b: dimensions of the waveguide

For TE_{10} mode, the much-simplified version of this formula is: $f_c = \frac{c}{2a} f_c = \frac{c}{2a}$

For SIW with same cut off frequency, dimension "$a_d a_d$" is found by: $a_d = \frac{a}{\sqrt{\varepsilon R}} a_d = \frac{a}{\sqrt{\varepsilon R}}$

- Design equation for SIW:

$$a_s = a_d + \frac{d^2}{0.95p} a_s = a_d + \frac{d^2}{0.95p}$$

Where d: diameter of the via

p: pitch (distance between the vias)

D and P should be measured precisely to ensure loss free radiation between the metallic-vias because of diffraction.

d ≤ λg /5

p ≤ 2d , λg is the guided wavelength.

III. FOLDED SIW CAVITY

The Idea behind folded SIW is to use two-layer topology to reduce the footprint by folding the structure around a metal septum [2]. This solution allows reducing the footprint of the structure by a factor two. (Fig. 4). One side, the metal septum between the two layers is connected to the side posts whereas it leaves a gap on the opposite side thus creates a U-shaped waveguide. The electric field of the fundamental mode of the folded SIW in Fig. 4 is similar to the fundamental TE10 mode of the standard rectangular waveguide, once the waveguide is folded around the metal septum. Conversely, the electric field of the second mode of the folded SIW in Fig. 5 corresponds to the TE20 mode of the standard rectangular waveguide, after folding the structure around the metal septum.

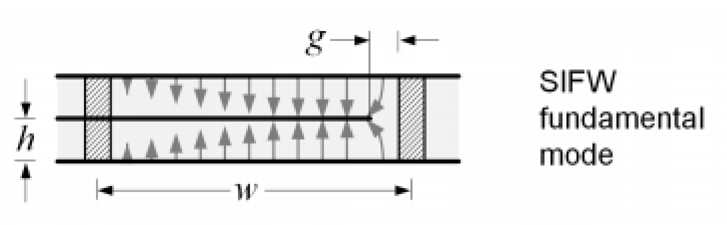

Fig. 4. Geometry of a folded SIW and representation of the electric field TE10modes.

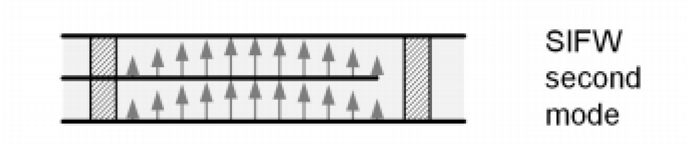

Fig. 5. Geometry of a folded SIW and representation of the electric field TE20modes.

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The fundamental mode exhibits an odd symmetry with respect to the middle plane between the two dielectric layers, while the second mode shows an even symmetry. Because of its topology, this structure can be easily fed by stripline and, thanks to the modal symmetry, the stripline excites the fundamental mode but not the second (TE20) mode, thus resulting in a wider spurious free behaviour. The gap g between the metal septum and the side posts (Fig. 4) affects the resonance of the folded waveguide by changing the electrical length of the structure. In particular, the narrower the metal septum, the higher is the waveguide cut-off frequency.

IV. HALF-MODE SIW CAVITY

As shown in Fig. 1b, the fundamental mode of the SIW structures exhibits a magnetic wall in the vertical symmetry plane. This suggests that it is possible to use just a half of the SIW if the cut is closed with a magnetic wall. Unfortunately, on the contrary of the electric wall that can be created simply by a metallic material, the magnetic wall is more difficult to realize. The behaviour of the magnetic wall can be approximated by exploiting a high impedance load. According to Fig. 6, an abrupt interruption of the upper SIW wall results in a high impedance discontinuity. This effect can be considered a sort of virtual magnetic wall, and this allows to obtain the half-mode substrate integrated waveguide (HMSIW).[3]

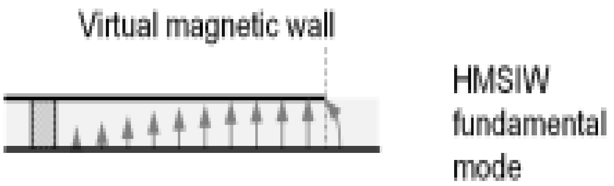

Fig. 6. Geometry of a half-mode SIW and representation of the electric field of the fundamental mode.

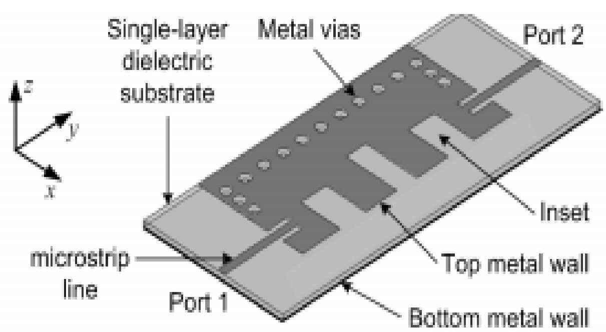

Fig. 7. Geometry of a filter based on the half-mode SIW cavity (from [4])

The same concept can be exploited in the design of cavity resonators, to be adopted in the implementation of filters. Of course, the fact that the impedance is high but not infinite leads to an electromagnetic field that is not completely confined inside the SIW. Therefore, a small leakage due to radiation is present. This effect decreases the Q-factor. In any case, lower SIW height h or higher dielectric constant allow the implementation of a better virtual magnetic wall (with a higher Q-factor). By the HMSIW technology, it is possible to realize a filter with a geometry very similar to that used for folded waveguide, as firstly proposed in [4]. In fact, the fundamental mode of the HMSIW can be excited by a microstrip line, same as the fundamental mode of the folded SIW can be excited by a stripline. According to Fig. 7, wide HMSIW sections can be exploited as resonators, while narrower sections can be used to implement admittance inverters. By adopting the proposed geometry, a four-pole filter with central frequency at 4.5 GHZ and 1.4 GHz bandwidth has been designed and manufactured in [4]. Dual layer HMSIW is used to get compact couplers and phase shifters in [9]. A 60-GHz on chip HSIW bandpass filter using GaAs technology is proposed in [10].

V. QUARTER-MODE SIW CAVITY

The idea of HMSIW cavity can be used to attain a quarter mode SIW cavity (QMSIW). As shown in Fig. 9, a quarter mode-SIW cavity can be found by cutting a rectangular SIW cavity into four parts along the symmetry planes [5]. This is obtained by eliminating the topmost metal wall and metal vias of three quarters of the cavity, thus dropping the footprint of the cavity by 75%.

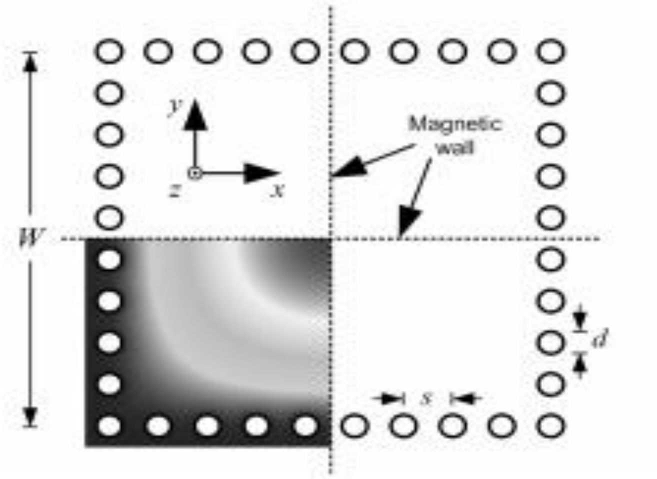

Fig. 8. Geometry of a quarter-mode SIW cavity and representation of the electric field of the fundamental mode (from [5]).

VI. COAXIAL SIW RESONATOR

The coaxial SIW concept was first presented in [6], where the authors proposed the implementation of a comb line resonator by presenting a plated via hole at the centre of a square SIW cavity. This plated via hole acts as the inner conductor of a short section of a transverse EM-mode coaxial line along the vertical direction (i.e., the substrate thick ness), while the outer conductor is defined by the SIW post wall. To define the coaxial resonator, the inner via hole is be short-circuited at the bottom ground plane and ended in a metal patch at the top. A schematic of the structure is shown in Figure 9 (a).

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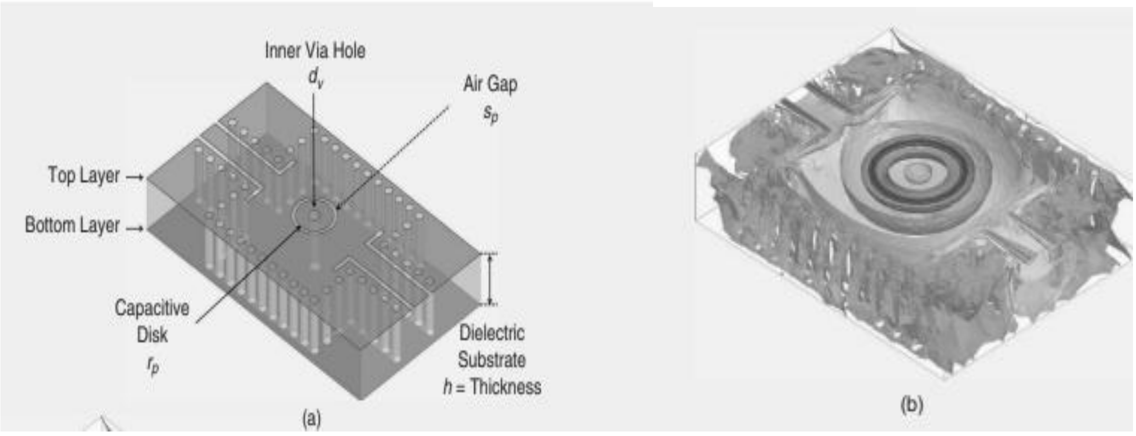

Fig. 9. a) A coaxial SIW resonator. (b) An electric field distribution at the top plane

The metal patch is then isolated from the top ground plane by an isolating gap, thereby introducing an important capacitive load through the established fringing fields, as can be seen in Figure 9(b). The main potential advantages of coaxial SIW structures are as follows.

• By increasing the length of the post or the loading capacitance, a huge size reduction can be achieved compared to conventional SIW cavity resonators.

• Both inductive and capacitive couplings can be achieved on the top layer to obtain filter responses allocating finite transmission zeros. Moreover, other advanced topologies, such as multimode resonators, singlets, and doublets, can also be implemented by translating their well-known metallic waveguide counterparts.

• The easy access to loading capacitance enables the direct integration of lumped capacitors as well as tuning elements, such as varactors, p-i-n diodes, or RF MEMS.

Tunable coaxial SIW filters were designed and good electrical performance with size reduction is achieved.

VII. EMPTY SIW

To reduce the dielectric losses at high frequencies, a novel type of SIW structure is proposed in [7]. The increase in insertion loss is controlled by removing the dielectric completely from the structure, thus maintains the require Q factor. It retains the advantages of low cost, low profile, easy manufacturing, and integration in a PCB of normal SIW candidate with reduced loss value.[7]

The ESIW was first presented in [8]. The lateral walls of the waveguide are formed by cutting a rectangular hole in the PCB, and plated with typical via metallization procedure. The waveguide is closed by attaching two metallic covers to the main PCB substrate. One of the covers acts as the upper waveguide wall while the other becomes the lower face of the waveguide (Fig .10).

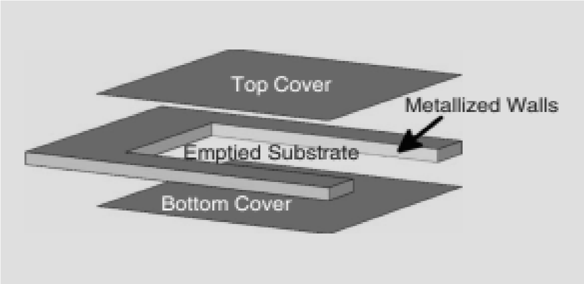

Fig 10. The fabrication of the ESIW

To ensure proper functioning of ESIW, very high-quality electrical connection among these different layers must be used. A tin based soldering paste is used to solder the layers by applying the paste on top and bottom layers. After assemble of structure, the solder paste is dried in a reflow oven. A solid tin layer is formed to connect the main layer with the covers. The placement of the covers is not critical because all of the important elements are located in the central layer and fabricated on the same PCB. Plane metal laminates are used as covers. When additional PCB sheets are used as covers, they are used to hold additional circuitry for interacting with integrated waveguides while designing reconfigurable waveguides. The ESIW, has geometry very similar to that of the rectangular waveguide, but with low profile and low cost. Air filled SIW (AFSIW) and Hallow SIW(HSIW) are also developed and studied in literature.

VIII. CONCLUSION

Basic characteristics of various SIW structures are presented to highpoint the effectiveness of this evolving technology. Design rules that are significant for the development of SIW structures and other circuits are discussed.

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