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Transitions from SIW to Various Transmission Lines for Substrate Integrated Circuits

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Abstract

The demands in the microwave and millimeter wave research community are of miniaturized and inexpensive system designs on Substrate Integrated Circuit (SIC) platform. However, a system may have components designed in separate technologies. Thus, in a system, to integrate components of various transmission technologies on a single substrate, their transitions are necessary. Substrate Integrated Waveguide (SIW) which is a planar analogy of the waveguide proves to be a promising SIC technology due to its properties of better power handling, low loss, light weight and easy implementation. Accordingly, various types of transitions from SIW to other transmission lines are studied.

1. Introduction

Any commercial RF System such as Radar, Ground Penetrating Radar (GPR), etc are characterized by components having low loss, high yield and compact designs. In such systems, non-planar structures like waveguide and coaxial lines provide low loss, high Q performances but they are bulky and hence planar structures like microstrip, coplanar waveguides (CPW) becomes attractive as low-cost and easy-to-handle designs. However, they are lossy. A new scheme, Substrate Integrated Circuit (SIC), was proposed to eliminate the drawbacks of the planar and non-planar circuits by synthesizing the entire system within a single substrate [1]. This can be achieved by realizing the non-planar structures in a planar form and thus integrating them with the other planar structures in the system on the same substrate, which can be fabricated with the existing planar PCB fabrication techniques. Apart from passive circuits and antennas, SIC is open to the implementation of active circuits as well, as it facilitates the embedding of active devices on the same substrate, unlike waveguides and coaxial lines where packaging and wideband impedance matching between the guide and the active device becomes a difficulty. Generally, apart from antennas, wireless systems are made up of several other microwave or millimeter wave components and they need not necessarily be constructed using the same technology. It is thus, very important to have a near to perfect impedance matching and mode matching between the ports of the transition and the technologies. The transitions available between different planar and non planar structures such as waveguide, coaxial, microstrip, etc are bulky and the mechanical fabrication involved in it makes it expensive and complex [2]. Due to its planar construction and conformability, SIC technology allows interconnection of different transmission lines through simple transitions. Over the past few years, Substrate Integrated Waveguide (SIW) is gaining popularity as an emerging technology in SIC microwave and millimeter-wave systems [3, 4]. SIW inherits the lower loss and higher quality factor properties from the waveguide due to the construction of the sidewalls and thus can handle power at higher frequencies. SIW being compact and inexpensive [4], the transition between SIW and other structures becomes easier. It can be integrated with other planar and non-planar structures in higher degree of integration and dense packaging systems [3].

This paper presents a study of various transitions between SIW and other technologies like waveguide, coaxial, microstrip and CPW along with their advantages and disadvantages [5-33]. In systems such as Radar, GPR, satellite communication systems, SIW transitions are reported to integrate components like power dividers [4, 10], antenna [15], and filter [22].

2. SIW to Waveguide Transitions

Rectangular waveguides being bulky still find usage in various high frequency microwave and millimeter-wave applications, due to its lower loss and power handling capabilities. However, for a complete system a transition between SIW and rectangular waveguide is necessary. Due to the cross-sectional width and dielectric differences between both the guides, there is an impedance mismatch between them which lead to loss. Therefore, proper transitions which match the impedance between both the waveguides have been designed.

The first transition between waveguide to SIW is reported in 2003, which demonstrates that the energy is transferred through an input-coupling aperture made on the bottom conductor layer of the PCB [5]. The Ka-Band transition presents a 15dB return loss bandwidth of 8%. In [6], the transition is initiated from a radial probe extended from the SIW, which is inserted in a height-tapered waveguide. Though, it exhibits a higher bandwidth of 33.03%, the insertion loss is poor. Longitudinal slots are also used to couple energy from SIW to the waveguide. When the substrate with a longitudinal slot etched on the broad wall of the SIW is surface mounted to the standard flange of the waveguide, it acts as the window to transfer energy [7], however, the design suffers from narrow bandwidth of 800MHz. In order to increase the bandwidth upto 1.72 GHz, two longitudinal slots of different lengths can be simultaneously resonated at close frequencies [8]. The longer slot is resonating at the lower frequencies, whereas the shorter slot is excited at the upper edge of the frequency band. A multiple substrate layered V-Band transition is documented in [9], where the signal propagates from the bottom SIW substrate to the second substrate level through a longitudinal slot. The second substrate acts as a short vertical waveguide section. The signal now couples from the second substrate to the third substrate through another longitudinal slot. The upper layer of the topmost substrate behaves as an aperture coupled patch antenna, which transfers the signal into the waveguide. The structure gives an effective 10 dB bandwidth of 35%. Transverse slot is also used in SIW transitions to develop a power divider, where an extra substrate layer is sandwiched in between the etched transverse slot SIW and rectangular waveguide [10]. The middle substrate has only one copper layer facing the rectangular waveguide, which acts as the radiating microstrip patch. The power divider could present a narrow bandwidth of 5.6% only. However, both [9, 10] are bulky. An 8 GHz broadband SIW transition is developed by realizing an antipodal quasi-Yagi Antenna probe on the same SIW substrate, and then inserted vertically into the waveguide at the center [11]. In [12], along with two stepped ridges in the waveguide flange, an additional arrangement of etched coupling aperture on the broad wall of the SIW is made to obtain a 7.05 GHz broadband response in Ka-Band. An improved, compact and broadband transition technique had been proposed in [13], where the aperture is designed to create three coupled resonators. In another new type of back-to-back W-Band transition, the SIW is tapered to increase its width and then extended as a wave-impedance transformer into a smooth height tapered waveguide [14]. The measured bandwidth is 26%. Instead of tapering the height of the waveguide, height-stepped waveguide are also incorporated [15] in the design of transitions. The structure can be further extended along with an arrangement of either a single-step widening transformer [16] or normal inserted substrate taper [17] for better performance. Recently, antipodal finline tapers are reported in the construction of SIW to waveguide transition [18].

3. SIW to Microstrip Transitions

SIW proves to be a technology that bridges the gap between waveguides and microstrip lines by having better loss characteristics [3]. However, it occupies larger area than microstrip [4]. Though, both SIW and microstrip are planar, they exhibit different dominant modes and characteristic impedance. An SIW to microstrip transition overcomes these difficulties over the operating bandwidth.

The basic transition from microstrip to SIW is proposed in [19]. In order to interface signals between the technologies, a tapered microstrip line connects the 50Ω microstrip line to the planar SIW. The entire design is realized on the same substrate. As the signals in both the cases propagate in the same direction and the electric fields are of similar orientation, the taper is able to transform the quasi-TEM mode of the microstrip line to the dominant TE_{10} mode of an SIW. Since there is a mismatch between the width of the 50Ω microstrip line and the SIW width, the taper length has to be taken into consideration for matching the impedance between them. The analytical equations to design the mentioned transition in [19] are elaborated in [20]. To derive the equations the transition is divided into two parts: the tapered microstrip line and the step between the SIW and 50Ω microstrip line. The step is further analyzed by considering the SIW to be a dielectric filled rectangular waveguide having a height equal to the substrate and by modeling the microstrip to an equivalent TEM waveguide. The return loss of the tapered transition is improved by placing an extra pair of metallic via at the tapered line and SIW junction [21]. In another transition, a pair of quarter-wavelength short circuited slots and grounded coplanar waveguide impedance transformer is connected between the microstrip line and the SIW on the same substrate [22]. As the dominant TE_{10} mode enters the transition structure from the SIW, the stronger electric fields at the center enters the GCPW, and the rest gets eliminated by the slots. After the parallel plate modes generated in the GCPW are suppressed by the via-holes on the GCPW planes, the fields are launched in the microstrip line. The measured transition resulted in a 50% bandwidth at V-band. Transition between microstrip and SIW is achieved over a broadband with lower loss in multilayered substrate environment, as well. The structure is using tapered and multi-sectional ridged SIW and tapered microstrip line for the required transition [23].

4. SIW to Coaxial Line Transitions

In applications like GPR, radar where low frequency RF signal is fed to any SIW component through coaxial lines, transformation of TEM waves from the coaxial line to the TE_{10} mode in the lower impedance SIW is necessary. Direct transitions from coaxial line to SIW were reported in [24]-[28]. The designs proposed in [24]-[27] make use of a short-circuited back wall, placed at a quarter wavelength distance from the inner conductor of the coaxial connector. In [24], three different transition techniques are investigated. The primary design has a coaxial Line appended onto the top plane of the SIW such that the inner conductor is inserted into the substrate and shorted onto the ground plane. However, due to mismatch of impedance the bandwidth got restricted to 1.1%. To lower the impedance of the coaxial line to that of the SIW, instead of inserting the inner conductor till the ground plane, a step or taper is installed at the end of the inner conductor midway in the dielectric. The structures present a bandwidth of 14.7% and 13.2 % bandwidth, respectively. A further modification of [24] is suggested through simulation, where an inductive septum is formed after the signal is launched in the SIW [25] and a ring is cut around the contact between the inner conductor and the top conductor of the SIW [26]. In [27], a triangular slot around the inner conductor is used to improve the bandwidth to 30%. Coaxial Line to SIW transitions without the use of any short-circuited back wall have also been reported [28]. Such structures have a ring etched at a certain radius from the inner conductor of the coaxial line. The SMA connector pin is soldered between the top and bottom conductor through a via at the center of the patch. Since no short-circuited back wall is used, both the transitions are wide band. The same concept is applied to transitions between Coaxial lines to ESIW guides [29].

5. SIW to CPW Transitions

Literatures reveal transitions from SIW to CPW as well. In [30], by widening the gap between the parallel lines of the grounded coplanar waveguides (GCPW) to form a stub and further bending it by 90° to form a slot into the SIW, a transition between GCPW and SIW is designed [30]. The stubs are used for impedance matching and the slot radiate into the substrate to excite the SIW. However, it radiates outside the structure as well. A metallic post can initiate the coupling between GCPW and SIW as well [31]. To avoid parallel plate modes, rows of metallic-via on each side of GCPW are used. To nullify the parasitic effect of an open GCPW, an open circuited-stub is inserted between the coupling post and the open GCPW. 70% bandwidth is achieved in a three layer transition design that uses an elevated CPW [32]. Stepped resonator is applied along with the 90 ° bent in [33] to design transitions. This type of transition makes integration of active and passive components simple and inexpensive.

6. Conclusion

Transitions between SIW and other transmission lines such as waveguide, microstrip, coaxial line, CPW for various microwave and millimeter-wave applications are reviewed through standard literature. An overview of the designs and performances are listed in this paper. SIW has been presented as an emerging technology to integrate various transmission lines on a single substrate and thus facilitate advancements in SIC approach. The future scope includes the development of transitions between other substrate integrated circuits (SICs) and to modify the existing bulky transitions with compact, low cost designs at different bandwidths.

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8. References

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