

An Integrated Transition of Microstrip to Substrate Integrated Nonradiative Dielectric Waveguide Based on Printed Circuit Boards

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Abstract—Multilayer circuit is essential for hybrid integrated technology. In this paper, a triple-layer transition of microstrip line to substrate integrated nonradiative dielectric waveguide (SINRD) is presented, of which the SINRD waveguide is fabricated directly on PCBs through air holes. Due to this integrated transition, the realization of hybrid integrated systems directly connected with planar circuits is possible. Furthermore, to use SINRD waveguide fabricated on PCBs instead of traditional NRD is because that mechanism and integration of the former are much easier. In addition, a double-layer transition is also proposed to compare with the triple-layer transition and to demonstrate that the leakage loss from the uncovered SINRD waveguide is negligible. Finally, the simulation results of the transition of conventional NRD guides are compared to those of SINRD guides. Good agreements can be found.

I. INTRODUCTION

The past decade has seen a huge growth in the area of microwave applications, resulting in an ever increasing demand for bandwidths, which pushes the microwave applications in the region of millimeter wave. And nonradiative dielectric waveguide (NRD) has been proved to be a promising candidate of traditional waveguide in microwave and particularly millimeter wave region due to its superior performance.

NRD guide was first proposed by Yoneyama and Nishida [1]. It consists of a dielectric strip sandwiched by two parallel conducting plates, which separates less than $\lambda/2$, λ is the free-space wavelength. In such a case, LSE_{mn} and LSM_{mn} modes of the NRD guide are below cut-off and vanish gradually out of the central dielectric strip. Due to this unique feature, NRD is a waveguide with mostly no radiation loss at bends and discontinuities. Thus it has been used to design a class of active and passive circuits for microwave and millimeter wave systems.

However, NRD, as a nonplanar structure, can hardly meet all the severe requirements independently, e.g., compactness, simple mechanization, low conduction and radiation losses for millimeter wave systems. Resulting from these inevitable problems, planar integrated circuits still play important roles in microwave and millimeter-wave systems. Therefore, it is a vital key to combine planar circuits with the nonplanar structure. To do so, an appropriate transition exploiting both advantages and avoiding both drawbacks is critical [2],[3].

To realize the hybrid planar/NRD integration technology, a series of transitions have been studied, e.g., the transitions from microstrip line to NRD, and slotline to NRD. However, all of these transitions are fabricated in the use of conventional NRD guide, which is not easy to implement and has bad mechanical tolerance, especially in higher frequency spectrum. To overcome these difficulties, a simple type of NRD guide which is formed by drilling via-holes directly on printed circuit boards (PCB) is proposed [4]. As a result, this kind of structure can easily integrate with other planar circuits.

In this paper, a double layers integrated transition of microstrip line to substrate integrated nonradiative dielectric waveguide (SINRD) is proposed. With the ground of microstrip line covering on one side of the SINRD and none on the other, the performance of the transition is acceptable. It means that leakage losses derived from the via-air slots are suppressed through carefully designing the dimensions and patterns of the via-air slots. Also, a three layers integrated transition of microstrip line to SINRD is presented. With both sides of the SINRD are covered by the grounds of the two microstrip lines respectively, leakage loss are completely suppressed. And transitions formed on the top and the bottom plates of the NRD guide means that hybrid integrated transition of planar to NRD guide is flexible, and multilayer systems can be designed as compact as possible and no space is waste. Simulation results have demonstrated that the transition of microstrip line to SINRD fabricated directly on PCBs offer high coupling efficiency and low power loss. It means that this new type of transition promises to be useful in the future.

II. EXISTED INTEGRATION TECHNOLOGY BASED ON NRD GUIDE

To throw light on the motivation of proposing a new form of hybrid integrated transition, it is necessary to firstly discuss the shortcomings of the existed integrations based on NRD guide before moving forward to the details of the presented hybrid integrated technology. The traditional active circuits based on NRD guide are usually designed with two-terminal active devices which are mostly inserted into the NRD central strip through a planar surface sheet [5]. However, the active

devices are not involved in the planar circuits to which the signals directly transmit from NRD guide. And impedance mismatch between NRD guide and planar circuits is also a headache problem. To solve it, a thin dielectric sheet with air-gap dimension is used. Therefore, the air-gap (separation between the metallic plates of NRD guide), directly limiting the dimensions of the dielectric sheet which connects the NRD guide and the planar mount, is vitally critical, particularly in mm-wave frequencies even involving with two terminal devices. When three terminal devices are used in practical circuits, it is almost impossible to integrate the NRD guide with the planar mount using the mentioned technology. It is superior to coherently combine these two dissimilar structure, considering the fact that planar circuits is suitable to integrated both two and three active terminal structures but will exhibit bad transmission loss at mm-wave in design of passive devices, and the fact that NRD guide is a counterpart in design of passive devices. Follow this concept, both advantages could be inherited and drawbacks could be eliminated.

III. DESCRIPTION OF THE PRESENTED TRANSITION

An integrated transition derived from the concept of the aperture coupling is presented in Fig.1 on the basis of the above the background. This geometry consists of a microstrip line deposited on the top plate on NRD guide. The rectangular couple aperture is etched on the ground plane which is also shared by the NRD guide as its metallic plate. And the microstrip line is perpendicular to the rectangular slot and NRD's central dielectric strip simultaneously. As is known, LSM_{11} , as a nonradiative mode in NRD guide, is usually preferred for practical applications. The electrical field of this mode is orthogonal to the air-dielectric interface of the NRD guide, while the magnetic field is parallel to the same interface as is shown in Fig. 2. The fundamental mode of the microstrip line is quasi-TEM, which revolves around the microstrip line and propagates along it. Therefore, both magnetic fields of the quasi-TEM and LSM_{11} in microstrip line and NRD respectively match well through the rectangular coupling slot. Signals could run from the microstrip line via the slot on the common shared ground to the NRD guide system.

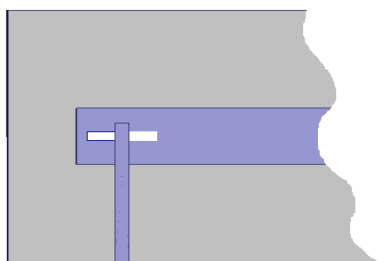


Fig.1 Geometry of the transition from microstrip line to NRD guide

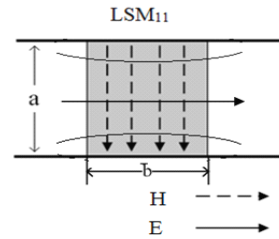


Fig.2 Field lines in a cross-sectional plane of NRD guide

Clearly, the microstrip line can be attached on either side of the NRD guide, which gives rise to both triple-layer transition and double-layer transition in this paper. While double-layer transition is promised to show the acceptable leakage loss from the uncovered SINRD guide, triple-layer transition presents some additional interesting benefits. First, a complete integrated system can be designed as compact as possible if both sides of the NRD guide are used and no space is wasted. On the other hand, by arranging the circuits of possible interference or cross-talk on the opposite sides of the NRD guide, the unwanted effects between them can be partially or completely suppressed. Therefore, this proposed triple-layer hybrid technology is compact, self-packaged and can be developed to reach a higher level of circuit integration.

IV. TOPOLOGY OF THE SINRD BASED ON PCBs

Due to the fact that the substrate thickness should be less than the $\lambda/2$, it is difficult to implement NRD guide circuits in mm-wave frequencies. This is because mechanical tolerances related to the substrate thickness become more and more serious when the wavelength decreases. Following this problem, a lot of attempts have been made to realize NRD guide in planar versions, and so far, have received several effective structures, e.g. nonradiative perforated dielectric waveguide (NRPD)[6] and substrate integrated nonradiative dielectric waveguide (SINRD)[7]. Both cases actually eliminate the alignment problems of conventional NRD guide, however, the potential mechanical difficulty still exists. Fig. 3 presents a new scheme of manufacturing SINRD directly on printed circuit boards (PCBs). It is formed by drilling a series

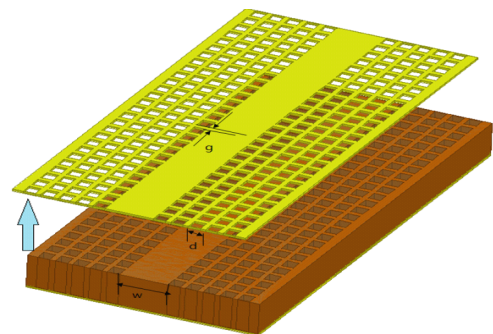
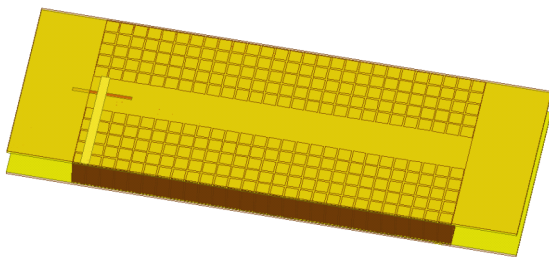


Fig.3 View of the SINRD based on PCBs

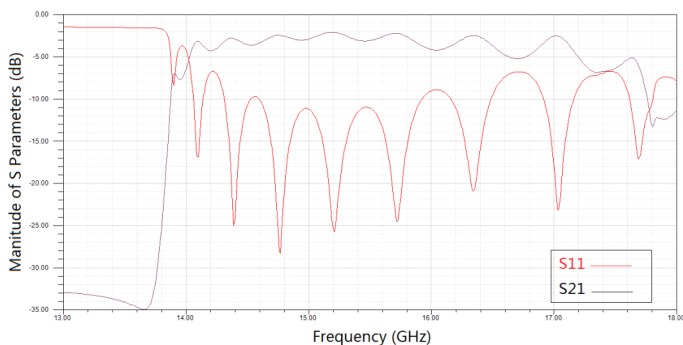
of via-slots on PCBs instead of naked dielectric substrates, and with an absence of holes in the central channel of the PCBs. By carefully design of the patterns and dimensions of the via-slots, leakage loss from the uncovered via-slots can be controlled to a minimum value. In Fig. 3, the via-slots are square holes with width d and gap g . In this scheme of SINRD guide, a clear and regular equivalent width of the NRD central dielectric strip W is shown in Fig. 3. Simulation results of a new scheme of transition making use of this SINRD guide technology will be presented in next section.

V. PERFORMANCE OF THE PROPOSED TRANSITION

According to the above mentioned technologies, this section will analysis the electrical performance of the proposed transition of microstrip line to SINRD guide directly formed on PCBs through aperture coupling theory. Fig. 4(a) shows a triple-layer transition of microstrip line to SINRD waveguide. In Fig. 4(a) a pair of transitions are fabricated on the opposite sides of the SINRD guide, and interconnected through SINRD guide with a length of 67.4 mm. The SINRD is made directly on a $67.4 \times 31.6 \text{ mm}^2$ rectangular PCBs with a height of 7.5 mm (Rogers TMM3, $\epsilon_r=3.2$) by drilling 5 rows of via-slots on each side of the central channel. The width of the hole-absence region is 7 mm. As is shown in Fig. 4(a), the via-slots are square holes with a width of 2.2 mm. In such a structure, the height of 7.5 mm and central width of 7 mm refer to the values of a and b in a conventional NRD guide as is shown in Fig. 2, which decide its operating frequency around 15GHz. The microstrip line is fabricated on a

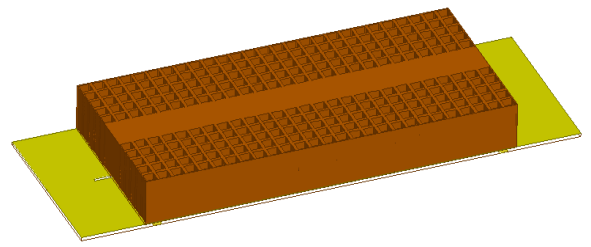


(a)

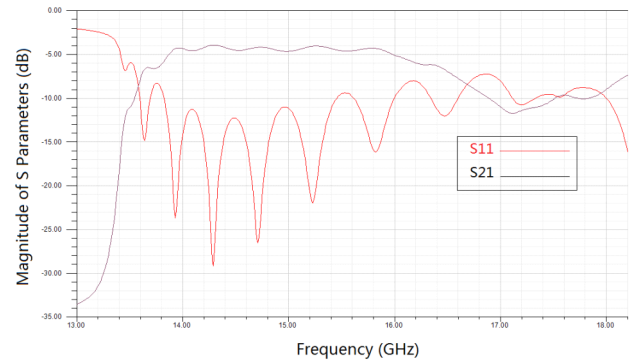


(b)

Fig. 4 (a) View and (b) Simulation results of the triple-layer transition from microstrip line to SINRD guide



(a)



(b)

Fig. 5 (a) View and (b) Simulation results of the double-layer transition from microstrip line to SINRD guide

$90.6 \times 31.6 \text{ mm}^2$ substrate (Rogers 5880, $\epsilon_r=2.2$) with a thickness of 0.52 mm and designed to have an impedance of 50Ω with a strip width of 1.56mm. The coupling aperture on the ground plane is a narrow rectangular slot with $10.5 \times 0.55 \text{ mm}^2$. The distance between the open-ended microstrip line and the aperture center is 3.37 mm, while the SINRD guide open-ended position is 2.24 mm apart from the center of the aperture. Different from those of [3], the rectangular slot in this paper scales out of the SINRD waveguide. To do so, a better bandwidth can be acquired. The two identical microstrip lines are designated as input and output ports in this structure, and Fig. 4(b) plots its transmission and reflection coefficients against frequency. Considering the fact that these simulation results have involved the losses of leakage, dielectric, radiation from the open-ended microstrip line and coupling slot, the bandwidth is generally good. It is found that the reflection coefficient is better than -10 dB over 50% of bandwidth and the transmission coefficient is generally better than -5 dB. In this triple-layer calculation, the interference effects between the input and output ports are suppressed. Fig. 5(a) presents a double-layer structure with the two microstrip lines deposited on the same dielectric substrate and leaving one side of the SINRD waveguide uncovered. Fig. 5(b) plots the simulation results. Compared to those of triple-layer structure, S_{11} changes little (negligible), while the S_{21} decreases by about 2dB. According to the analysis of the uncovered SINRD waveguide directly formed on PCBs mentioned above, this decrease is affected by leakage loss. Furthermore, interference between the two

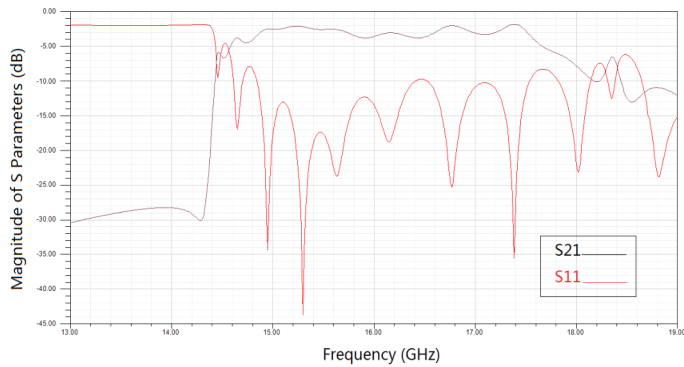


Fig. 6 Simulation results of the transition from microstrip line to conventional NRD guide

microstrip lines is complicated and may derogate the electrical performance. Except this, the bandwidths from 14GHz to 16GHz of both double-layer and triple-layer transitions agree quite well. Finally, the electrical performance of a triple-layer transition connected microstrip line with conventional NRD guide is shown in Fig. 6. It is found that in Fig. 6, with a bandwidth of about 3.2GHz, the reflection coefficient is better than -10 dB over 80% of bandwidth and transmission coefficient is generally better than -4 dB. Considering the additional losses initiated by the via-slots in the form of Fig. 4(a), its simulated electrical performance agrees quite well with those in Fig. 4(b). This demonstrates that SINRD guide directly fabricated on PCBs is suitable for hybrid integrated transition structure.

VI. CONCLUSION

A new type of transition has been proposed, in this paper, to integrate the microstrip line with the planar SINRD guide based on PCBs, at microwave and millimeter-wave frequencies. The shortcomings of traditional hybrid integration techniques have been analyzed. SINRD guide based on PCBs has been proved to be better in mechanism and integration with the planar circuits. Therefore, a new scheme of transition overcoming the drawbacks of the

traditional integration techniques and inheriting the benefits of planar SINRD guide based on PCBs has been acquired. It is found that triple-layer transition, with both sides of SINRD guide covered and interference suppressed, agrees quite well with the transition using conventional NRD guide. It is also found that, by carefully designing the dimensions of via-holes, the leakage loss of the double-layer transition can be controlled. Thus, simulation results indicate that this typical transition is flexible to choose either double-layer or triple-layer form. This study proves that, at microwave and millimeter-wave frequencies, this form of transition is potentially suitable for low-cost applications of hybrid integration systems.

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