JOURNAL OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 12, NO. 2, 171～175, JUN. 2012

http://dx.doi.org/10.5515/JKIEES.2012.12.2.171
ISSN 2234-8395 (Online) · ISSN 2234-8409 (Print)

A New Broadband Microstrip-to-SIW Transition Using Parallel HMSIW

Dae-Keun Cho · Hai-Young Lee

Abstract

In this work, a new microstrip-to-substrate integrated waveguide (SIW) transition using the parallel half-mode substrate integrated waveguide (HMSIW) is proposed. The proposed transition consists of three sections : a microstrip, parallel HMSIWs, and an SIW. By inserting the parallel HMSIWs section between the microstrip section and the SIW section, the proposed transition can improve the return loss characteristics of the near cut-off frequency because the HMSIWs section has a lower cut-off frequency than the SIW section (8.6 GHz). The lower cut-off frequency is achieved through gradual electromagnetic field mode changes for a low reflection. The measured return loss is less than 20 dB in the of 9.1~16.28 GHz freqeuncy range for the back-to-back transition. The measured insertion loss is within 1.6 dB for the back-to-back transition. The proposed transition is expected to play an important role in wideband SIW circuits fed by a microstrip.

Key words: Broadband, Half-Mode Substrate Integrated Waveguide, Substrate Integrated Waveguide, Transition.

Ⅰ. Introduction

A substrate integrated waveguide (SIW), constructed with two parallel rows of via-holes in a metalized planar substrate, has become an attractive transmission structure because of its manufacturing simplicity and its benefits from the low production cost of the PCB process, compact size, low loss, and high quality factor. The SIW has been presented in the form of filters, couplers, dividers, and antennas. However, these components must be interconnected with planar structures to provide the means for measuring to allow the SIW components to be completely integrated with planar active circuits [1], [2].

Typical transitions for the SIW have been presented, including the tapered microstrip transition, the CPW transition, and the rectangular waveguide transition. The tapered microstrip transition has been widely used; it is a very simple structure and has low loss. The performance of the transition is better when compared to other microstrip transitions [3]～[6] or coplanar transitions [7], [8].

However, the conventional tapered microstrip transition is unable to cover the complete fundamental-mode SIW bandwidth. The operating bandwidth of the SIW commonly begins after some frequency band above the SIW's cut-off frequency. Thus, signals occupying the near cut-off frequency region experience distortion due to the variation in the propagation delay for different spectral components of the signal [9].

This work presents a new microstrip-to-SIW transition using the parallel half-mode substrate integrated waveguide (HMSIW). The proposed transition consists of the parallel HMSIWs section between the microstrip section and the SIW section. The proposed transition can reduce the discontinuity effect due to the capacitance effect in the HMSIWs section and the gradual mode matching in the entire structure. The proposed transition has better matching characteristics than the conventional tapered microstrip transition in the fundamental-mode SIW bandwidth region. Thus, the combination of these three sections allows us to obtain broadband characteristics over the complete fundamental-mode SIW bandwidth.

Ⅱ. Structure and Design

Fig. 1 shows the proposed transition as back-to-back from a microstrip line to an SIW within the same dielectric substrate. The transition consists of three sections: the microstrip line section, the parallel HMSIWs

---

Manuscript received April 30, 2012 ; Revised May 30, 2012 ; Accepted June 1, 2012. (ID No. 20120430-011J)
Microwave Application Laboratory, Ajou University, Suwon, Korea.
Corresponding Author : Hai-Young Lee (e-mail : hylee@ajou.ac.kr)

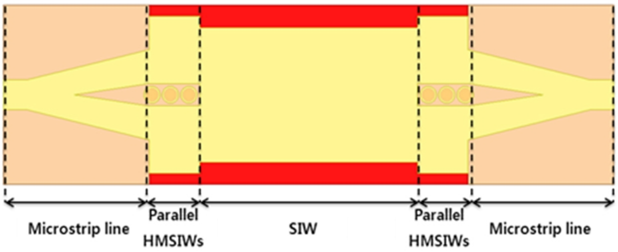


Fig. 1. Proposed SIW transition.

section, and the SIW section. The cut-off frequencies of the SIW mode and the HMSIWs are simply calculated as follows [2], [10].

$$f_{c_{SIW}} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a_{SIW}}\right)^2+\left(\frac{n\pi}{b_{SIW}}\right)^2} \qquad (1)$$

$$f_{c_{HMSIW}} = \frac{c}{4\sqrt{\varepsilon_r}\,a_{HMSIW}} \qquad (2)$$

The SIW does not allow TM modes guidance. Therefore, single-mode bandwidth is guaranteed with the TE_{10} mode related to the TE_{20} mode [11]. Thus, similar to the conventional rectangular waveguide, the SIW bandwidth is defined between 1.25 f_c and 1.9 f_c (f_c: fundamental-mode rectangular waveguide cut-off frequency) [12]. Therefore, the proposed transition should improve the matching characteristics between f_c and 2 f_c so that it has the complete fundamental-mode SIW bandwidth. By inserting the parallel HMSIWs section between the microstrip section and the SIW section, the proposed transition can improve the return loss characteristics of the near cut-off frequency because the HMSIWs section has a lower cut-off frequency than the SIW section (8.6 GHz). This is achieved through gradual electromagnetic field mode changes to obtain a low reflection ($S_{11}<-20$ dB). Fig. 2 is the geometry of the optimized transition. The SIW section is designed to have a cut-off frequency (8.6 GHz). For impedance matching, the microstrip taper connects the microstrip section to the parallel HMSIWs section. Using formulas (1) and (2), the width of the SIW is 12mm and the width of the HMSIW is 6mm. The proposed transition achieves impedance matching and mode transformation between different transmission sections (the microstrip, the parallel HMSIWs, and the SIW). Fig. 3 shows the parallel HMSIWs section. It has two HMSIWs and via-holes between the parallel HMSIWs. By inserting the via-holes on the parallel HMSIWs section, the matching characteristics of the proposed transition are improved by the capacitance effect between the parallel HMSIWs and the via-holes.

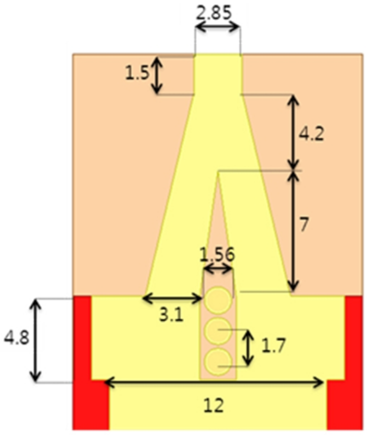


Fig. 2. Configuration of the optimized transition(unit: mm).

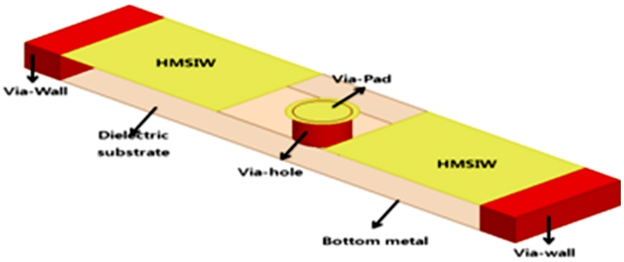


Fig. 3. Configuration of the parallel HMSIW sections.

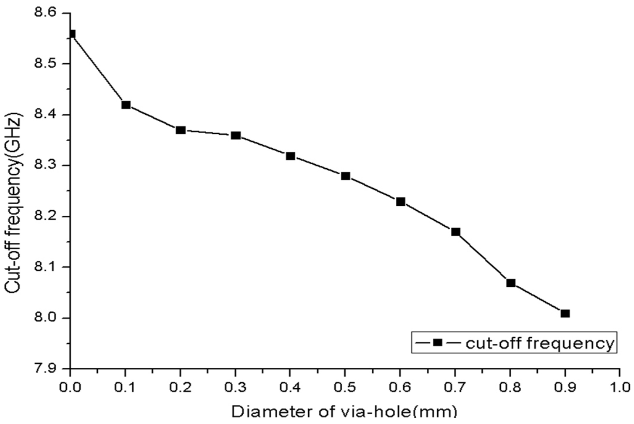
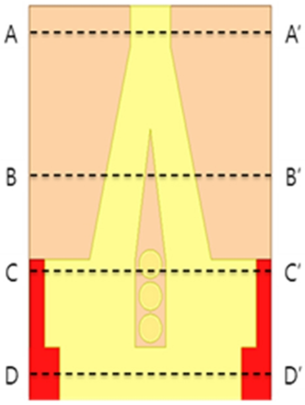


Fig. 4. Simulated cut-off frequency versus the via-hole diameter.

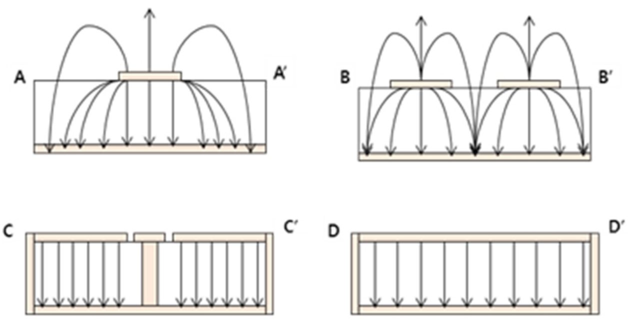
Fig. 4 shows the simulated cut-off frequencies to the via-holes diameter in the center of the parallel HMSIWs section. Using a 3D simulation tool (HFSS), the design structure is a parallel HMSIWs structure in a back-to-back type from the microstrip line to the HMSIWs. This is confirmed by varying the diameter of the via-hole. Fig. 4 shows the simulated results of the via diameter from 0 mm to 1 mm. The diameter of the via-pad is designed 0.2 mm larger than the diameter of the via-hole in the center of the parallel HMSIWs section. In Fig. 4, when the diameter of the via-holes increases, the cut-off frequency is lowered because of the capacitance effect. The HMSIWs section with the via-holes has a lower cut-off frequency than the SIW section (8.6 GHz). The proposed transition matches the matching at a lower frequency than 8.6 GHz. By inserting via-holes between the HMSIWs, the parallel HMSIWs section with the via has a lower fundamental mode cut-off frequency than the SIW section in the same width (12 mm). Thus, the proposed transition can improve the matching characteristics because the dispersive band moves to a lower frequency than the original guard-band.

2-1 Gradual Mode Transformation

Accurate impedance matching and complete mode transformation between different transmission lines are important for broadband characteristics. Thus, the transition is important to transform the electromagnetic field mode. Fig. 5 illustrates the proposed transition. It consists of 4 sections: the microstrip section (A-A'), the dividing section (B-B'), the parallel HMSIWs section (C-C'), and the SIW section (D-D'). The proposed transition can improve the matching characteristics because of the gradual mode matching of the entire structure. At first, the quasi-TEM mode in the microstrip section gradually changes to the quasi-TE_{10} mode in the parallel HMSIWs section and the quasi-TE_{10} in the parallel HMSIWs section gradually changes to TE_{10} in the SIW section. Progressive changes in the electromagnetic field mode are achieved through the gradual changes to obtain a low reflection ($S_{11} < -20$ dB).



(a) Top view



(b) The E-field gradation

Fig. 5. The structure of the proposed transition.

2-2 Simulated Results

The proposed transition has been optimized with a 3-D FEM simulator (HFSS), as shown in Fig. 1, where a Taconic TLY-5 is used, with $\varepsilon_r = 2.2$, $\tan\delta = 0.0009$, thickness=0.787 mm. The conventional tapered microstrip transition and the proposed transition are 48 mm and 49.2 mm long, respectively. Fig. 6 shows the simulated results of the conventional tapered microstrip transition and the proposed transition. Return loss characteristics of less than 20 dB are observed at the 11~18.6 GHz frequency range (the conventional tapered microstrip transition) and the 9.2~21.74 GHz frequency range (the proposed transition) for the back-to-back transition. As simulated results, the insertion loss of the SIW section without the HMSIWs section and the transition section is 0.06 dB at 10 GHz. In the bandwidth range of the proposed transition, the simulated insertion loss of the back-to-back transition is within 1 dB while that of the conventional tapered microstrip is within 0.99 dB. The matching characteristics of the proposed transition are better than the conventional tapered microstrip transition from f_c (8.6 GHz) to 1.25 f_c (10.75 GHz). Therefore, the proposed structure has good matching characteristics from 1.06 f_c to 2.52 f_c. In the bandwidth ran-

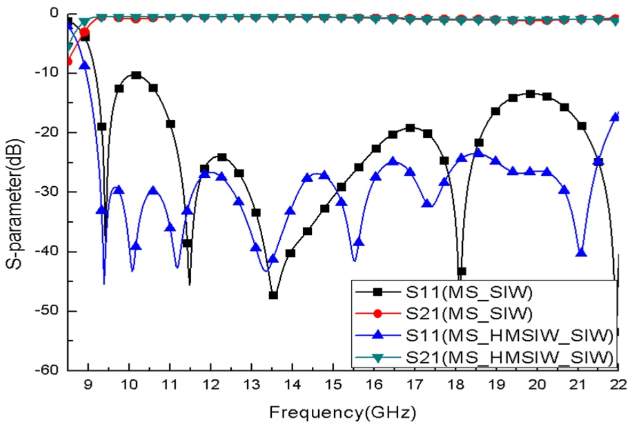


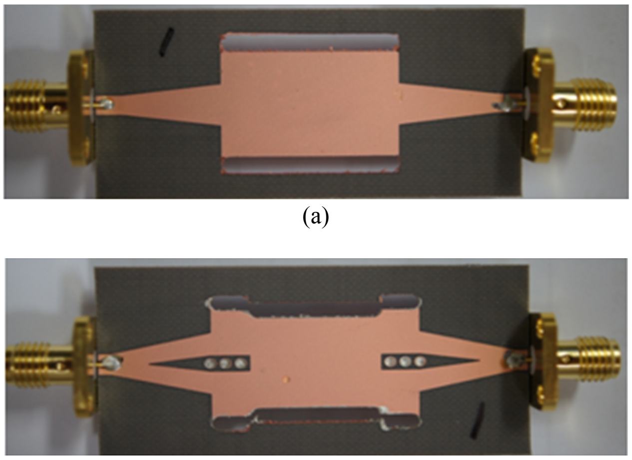
Fig. 6. Simulated S-parameters of the proposed transition and the conventional tapered microstrip transition.

ge, the insertion loss is the same for the conventional tapered microstrip transition and the proposed transition.

The HMSIW structure relies on suppression of the dominant higher-order mode TE_{20}. The TE_{20} mode cannot propagate in such an HMSIW structure so that the bandwidth characteristics of the proposed transition can be enhanced [11]. A return loss of better than 25 dB is achieved in the complete fundamental-mode SIW bandwidth (from 1.25 f_c to 1.9 f_c).

Ⅲ. Measured Results

Fig. 7 shows the fabricated back-to-back device of the designed microstrip-to-HMSIW-to-SIW transition. The back-to-back transitions are measured with the vector network analyzer (up to 20 GHz). Their lengths are approximately the same. Fig. 8 shows the measured results of the conventional tapered microstrip transition and the proposed transition. A return loss of less than 20 dB was been observed in the frequency range of 0.22～14.9 GHz (the conventional tapered microstrip transition) and 9.1～16.28 GHz (the proposed transition) for the back-to-back transition. A return loss of less than 15 dB was observed in the frequency range of 9.24～15.38 GHz (the conventional tapered microstrip transition) and 9.02～18.13 GHz (the proposed transition) for the back-to-back transition. In the bandwidth range of the proposed transition, the measured insertion loss of the back-to-back transition was within 1.6 dB while that of the conventional tapered microstrip was within 1.2 dB. As expected, the proposed transition was the improved return loss characteristics.



(a)

(b)

Fig. 7. Photographs of (a) the conventional tapered microstrip transition and (b) the proposed transition.

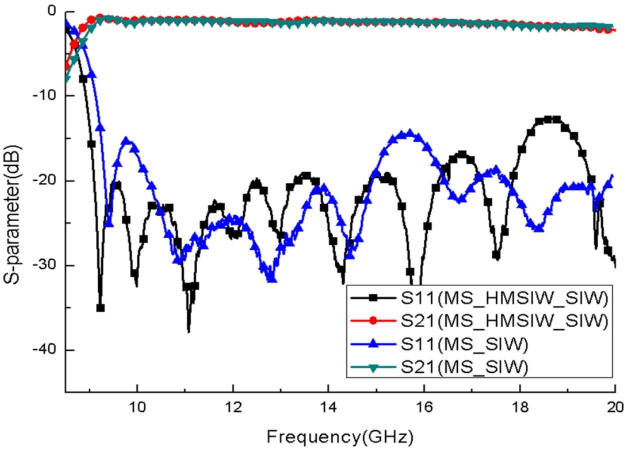


Fig. 8. Measured *S*-parameters of the proposed transition and the conventional tapered microstrip transition.

Ⅳ. Conclusions

A new microstrip-to-SIW transition using the parallel half-mode SIW is proposed. This transition structure consists of three parts: the microstrip section, the parallel HMSIWs section, and the SIW section. Due to the gradual mode matching and the capacitance effecting in the parallel HMSIWs section, the proposed transition has better matching characteristics than the conventional tapered microstrip transition in the near cut-off frequency of the TE_{10} mode. Experimental results of the back-to-back transition show that the measured insertion loss is within 0.7 to 1.6 dB and the 20 dB-return-loss bandwidth is from 9.1 GHz to 16.28 GHz (7.16 GHz). The 15 dB-return-loss bandwidth is from 9.02 GHz to 18.13 GHz (9.11 GHz). Thus, the proposed structure achieves a good matching over the complete fundamental-mode 20 dB-return-loss SIW bandwidth (from 1.05 f_c to 1.9 f_c). In conclusion, the proposed transition can improve the return loss characteristics better than the conventional tapered microstrip transition. The proposed transition can cover the complete fundamental-mode SIW bandwidth. We expect the proposed transition play an important role in the active circuits and passive components based on the SIW.

This work was supported by the National Space Laboratory (NSL) program under the Korea Science and Engineering Foundation funded by the Ministry of Education, Science and Technology (2011-002-9879).

References

[1] D. Deslandes, K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwa-*

ve Wireless Compon. Lett., vol. 11, no. 2, pp. 68-70, Feb. 2001.

[2] S. Lee, S. Jung, "Ultra-wideband CPW-to-substrate integrated waveguide transition using an elevated-CPW section," *IEEE Microwave Wireless Compon. Lett.*, vol. 18, no. 11, pp. 746-748, Nov. 2008.

[3] N. Jain, N. Kinayman, "A novel microstrip mode to waveguide mode transformer and its applications," *IEEE MTT-S Int. Microwave Symp. Dig*., vol. 2, pp. 623-626, 2001.

[4] T. H. Yang, C. F. Chen, T. Y. Huang, C. L. Wang, and R. B. Wu, "A 60 GHz L TCC transition between microstrip line and substrate integrated waveguide," *Proc. APMC*, vol. I, pp. 4-7, Dec. 2005.

[5] M. Abdolhamidi, A. Enayati, M. Shahabadi, and R. Faraji-Dana, "Wideband single-layer DC-decoupled Substrate Integrated Waveguide (SIW)-to-microstrip transition using an interdigital configuration," *Asia-Pacific Microwave Conference*, Dec. 2007.

[6] C. -K. Yau, T. -Y. Huang, T. -M. Shen, H. -Y. Chien, and R. -B. Wu, "Design of 30 GHz transition between microstrip line and substrate integrated waveguide," *Asia-Pacific Microwave Conference*, Dec. 2007.

[7] D. Deslandes, K. Wu, "Integrated transition of coplanar to rectangular waveguides," *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 619-622, May 2001.

[8] D. Deslandes, K. Wu, "Analysis and design of current probe transition from grounded coplanar to substrate integrated rectangular waveguides," *IEEE Trans. Microwave Theory & Tech*., vol. 53, pp. 2487-2494, Aug. 2005.

[9] N. Smith, R. Abhari, "Dispersion-equalization techniques for substrate integrated waveguide interconnects," *IEEE Trans. Microwave Theory Tech.*, vol. 58, no. 12, pp. 3824-3831, Dec. 2010.

[10] Q. Lai, C. Fumeaux, W. Hong, and R. Vahldieck, "Characterization of the propagation properties of the half-mode substrate integrated waveguide," *IEEE Trans. Microwave. Theory Tech*., vol. 57, no. 8, pp. 1996-2004, Aug. 2009.

[11] Z. -Y Zhang, K. Wu, "Broadband half-mode substrate integrated waveguide (HMSIW) Wilkinson power divider," *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 879-882, Jun. 2008.

[12] D. Deslandes, "Design equations for tapered microstrip-to-substrate integrated waveguide transitions," *IEEE MTT-S Int. Microwave Symp. Dig*., pp. 704-704, May 2010.

Dae-Keun Cho

received the B.S. and M.S. degree in electronics engineering from Ajou University, Suwon, Korea, in 2011 and 2013, respectively. His current research interests include microwave and millimeter-wave passive circuit design, SIW circuit and antenna design.

Hai-Young Lee

received the B.S. degree in electronics engineering from Ajou University, Suwon, Korea, in 1980, the M.S. degree in electrical engineering from the Korea Advanced Institute of Science and Technology (KAIST), Seoul, Korea, in1982, and the Ph.D. degree in electrical engineering from The University of Texas at Austin, in 1989.From 1982 to 1986, he was with the Ministry of National Defense, Seoul, Korea, as a senior research engineer in the fields of electromagnetic compatibility and wave propagation. From 1990to 1992, he was in charge of the Advanced Research Division I (Compound Semiconductor Devices Division) at the LG Electronics Institute of Technology, Seoul, Korea. In 1998, he was a Visiting Professor at the University of California at Los Angeles. He served for the President of the Korean Institute of Electromagnetic Engineering and Science (KIEES) in 2010 and the President of the User Council at Korea Advanced Nano Fab Center (KANC), Suwon, Korea from 2004 to 2009. Since 1992, he has been with the Department of Electronics Engineering, Ajou University, Suwon, Korea, as a Professor. His current research interest lies in the fields of microwave and millimeter-wave circuits design and testing, RF System-On-a-Package (SOP), and EMI/EMC for power and environmental applications.