

Half-Mode Substrate Integrated Waveguide Amplifier Using Lumped-Element Transition

Dong-Sik Eom · Hai-Young Lee*

Abstract

This paper proposes a half-mode substrate integrated waveguide (HMSIW) amplifier using lumped-element transition. The input and output impedances of this amplifier are matched by the lumped-element transition structure. This structure provides compact impedance and mode matching circuits between the HMSIW and a stand-alone amplifier. Surface mount technology inductors and capacitors are implemented to realize the lumped-element transition. A prototype of the proposed HMSIW amplifier shows 15 dB gain with 3 dB bandwidth of 4 to 7.05 GHz in a simulation and measurement.

Key Words: Amplifier, Half-Mode Substrate Integrated Waveguide (HMSIW), Lumped Element, Substrate Integrated Waveguide (SIW), Transition.

I. INTRODUCTION

A substrate integrated waveguide (SIW) is a well-known type of planar formed waveguide on a printed circuit board (PCB). An SIW is formed with two parallel metallic via holes or grooves in the PCB. Compared with traditional, bulky waveguide, an SIW provides easy-to-fabricate structures, small-sized circuits, and good integration with planar circuits. Studies have already developed various passive and active SIW circuits and devices [1–10]. Of these active SIW amplifiers [1–4] are complicated to design because the signal and ground of the SIW are electrically shorted by metalized via holes or grooves, and they need input and output impedance matching as well as mode conversion circuits between the amplifier and the SIW. A mode conversion circuit, also called the transition structure between the SIW and the planar transmission lines—microstrip (MS), coplanar waveguide (CPW) or conductor-backed coplanar waveguide (CBCPW)—is needed because the SIW and planar

transmission lines have different mode characteristic.

An X-band SIW amplifier using a DC-decoupled transition structure between the SIW and the MS was firstly proposed [1]. However, the DC-decoupled transition structure has to be designed very carefully, because the mode and impedance matching properties are very sensitive to the coupling factor of the DC-decoupled transition. SIW power amplifiers using CB-CPW-to-SIW and MS-to-SIW transitions were proposed to realize an input/output matching network in the SIW [2, 3]. However, it is hard to tune the matching network after PCB fabrication, and the transition length between the SIW and the CBCPW or MS remains long. Note that the long transition structure may cause unwanted coupling and radiation around the circuits [7]. A corrugated SIW distributed amplifier was also reported; however, its performance was not optimized [4].

This study proposes a half-mode SIW (HMSIW) amplifier using HMSIW-to-MS lumped-element transition. The proposed structure was developed using an HMSIW platform that

Manuscript received July 4, 2016 ; Revised December 27, 2016 ; Accepted December 31, 2016. (ID No. 20160704-019J)

Department of Electronics Engineering, Ajou University, Suwon, Korea.

*Corresponding Author: Hai-Young Lee (e-mail: hylee@ajou.ac.kr)

This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

© Copyright The Korean Institute of Electromagnetic Engineering and Science. All Rights Reserved.

reduces the SIW structure size by half, and it supports the $TE_{0,5,0}$ half-mode [8]. The lumped-element transition structure was realized using a surface mount technology (SMT) inductor and capacitor to reduce the length of the conventional transition structure [9, 10]. The proposed structure is easy to design and enables tuning of the amplifier input/output matching network by using lumped-element transition after PCB fabrication.

II. HMSIW TRANSITION TO MICROSTRIP AND HMSIW AMPLIFIER DESIGN

Fig. 1(a) and (b) show the conventional and incomplete transition structures, MS-HMSIW-MS [5] and MS-HMSIW, respectively, on the Taconic TLX substrate (dielectric constant = 2.55, height = 0.508 mm). These transition structures were verified by simulation using ANSYS HFSS ver. 14. Note that ports 1 and 2 in Fig. 1(a) and (b) were excited as a 50- Ω lumped port, and not a wave port in the HFSS simulation.

Fig. 2 shows simulation results of the MS-HMSIW-MS and MS-HMSIW structures. In Fig. 2(a), the simulated return losses of the MS-HMSIW-MS are under -15 dB from 4.13 to 6.8 GHz, and in Fig. 2(b), the MS-HMSIW-MS structure shows good matching at 50 Ω from the Smith chart. Note that the simulated HMSIW length is $\lambda_c/4 \approx 30$ mm. Fig. 2(c) shows the simulated return losses of the incomplete MS-HMSIW transition. However, the incomplete transition structure shows return losses of around -8 dB at ports 1 and 2 because the port-2 impedance is not located on 50 ohm. The port-2 impedance is located at $24.86 + j12.63 \Omega$ at 6 GHz, as seen in the Smith chart in Fig. 2(d). To match the port-2 impedance to 50 Ω , a lumped-element matching circuit is used.

Murata SMT 0.2 nH series inductor with 0603 mm² size and a 0.4-pF shunt capacitor were used between the HMSIW and

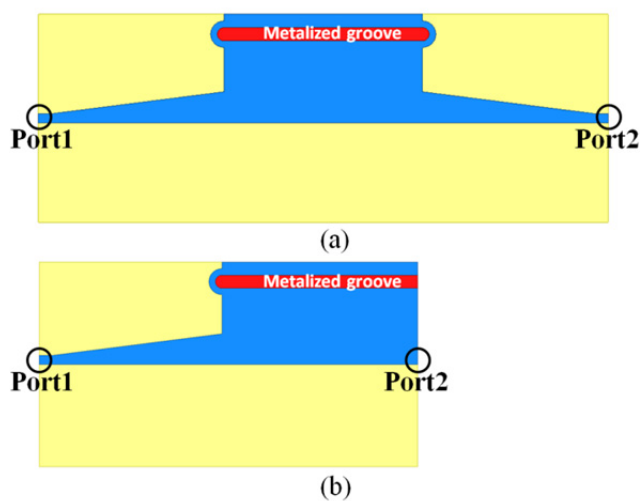


Fig. 1. (a) Conventional MS-HMSIW-MS transition structure. (b) Incomplete MS-HMSIW transition structure.

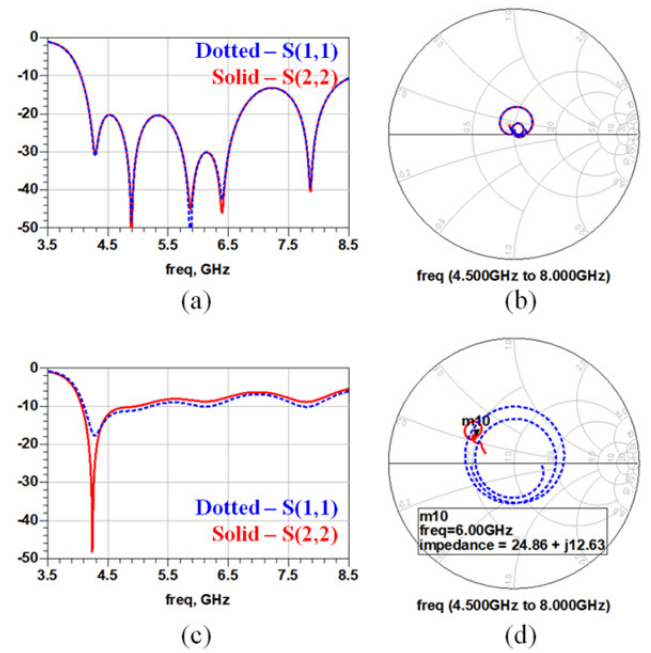


Fig. 2. (a) Simulated return loss of conventional MS-HMSIW-MS transition. (b) Smith chart of simulated reflection coefficient of conventional transition. (c) Simulated return loss of incomplete MS-HMSIW transition. (d) Smith chart of simulated reflection coefficient of incomplete transition.

the MS, as shown in Fig. 3(a). Note that the shunt capacitor is bridged with the MS-edge and the extended top-grounded metal pad. The 0.2 nH series inductor moved the $24.86 + j12.63 \Omega$ impedance to $25.1 + j24.77 \Omega$ at 6 GHz, and the 0.4 pF shunt capacitor changed the $25.1 + j24.77 \Omega$ impedance to 50 Ω , as shown in Fig. 3(b). As a result, the return losses improved after evaluating the proposed lumped-element transition,

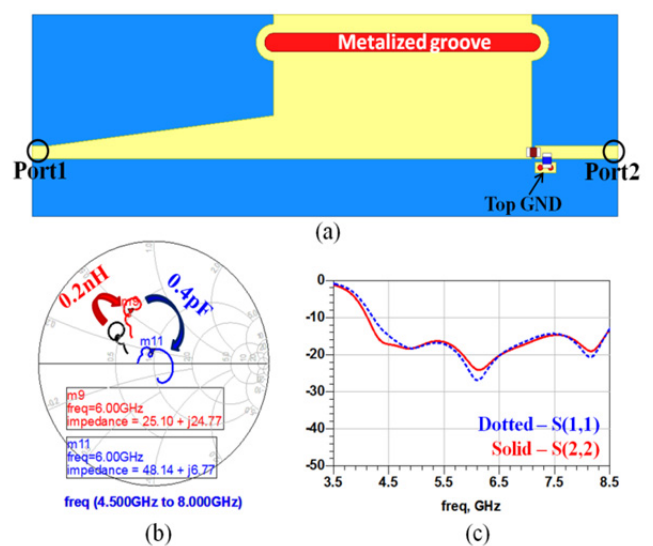


Fig. 3. (a) Lumped-element matching circuit between HMSIW and MS. (b) Simulated port-2 reflection coefficient after lumped-element matching. (c) Simulated return losses after lumped-element matching.

as shown in Fig. 3(c). Note that the $50\ \Omega$ lumped-port was induced to ports 1 and 2 in the HFSS simulation, as shown in Fig. 3(a).

The back-to-back transitions of conventional [5] and lumped-element transition [9] structures were designed and compared to verify the performance, as shown in Fig. 4(a) and (b). The lumped-element transition has a short transition length compared with the conventional transition, as shown in Fig. 4(a). The $0.2\ \text{nH}$ series SMT inductor and $0.4\ \text{pH}$ shunt capacitor were attached on the matching section. SMA connectors were soldered to the edge of the MS line for the measurement. The measurements were conducted using the Agilent N5230A vector network analyzer. Fig. 4(b) shows the measured S -parameters of the conventional and lumped-element transition structures. The measured insertion loss of the lumped-element structure remains within $0.7\ \text{dB}$ from 4.15 to $6.88\ \text{GHz}$. The measured return loss is below $-15\ \text{dB}$ from 4.2 to $6.7\ \text{GHz}$. The return loss bandwidth of the lumped-element transition structure is narrower than that of the conventional structure because lumped-element matching provides a narrower bandwidth than distributed matching of the tapered line [11]. However, the lumped-element transition structure provides a physically short transition length and shows insertion loss similar to that of the

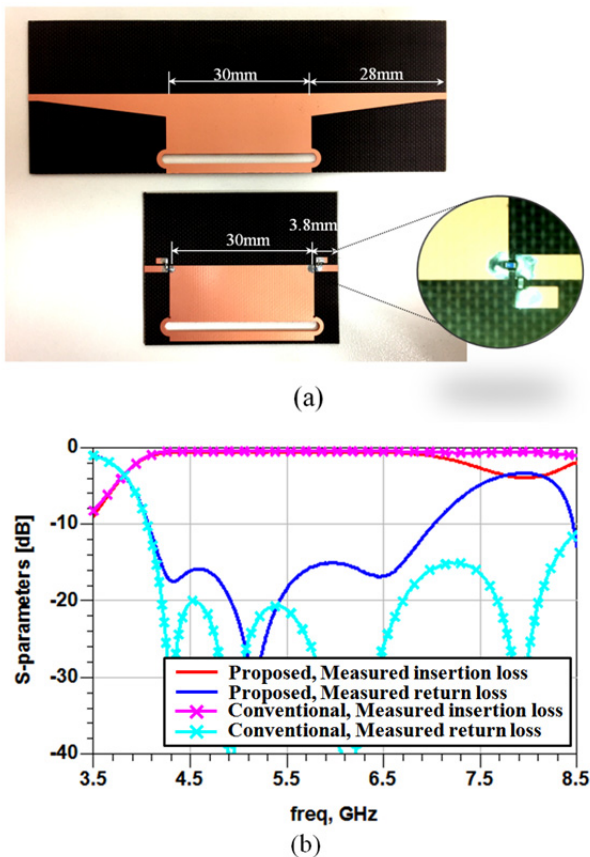


Fig. 4. (a) Back-to-back transition structure of conventional and lumped-element designs. (b) Measured S -parameters of conventional and the proposed designs.

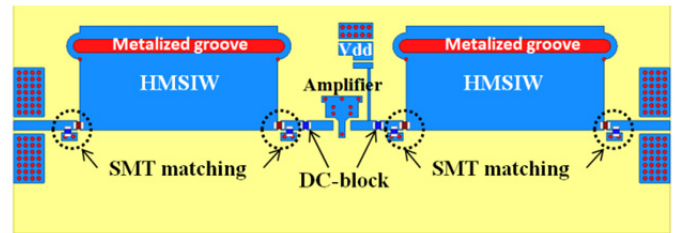


Fig. 5. Building blocks of proposed HMSIW amplifier.

conventional structure in the pass-band.

Fig. 5 shows the proposed HMSIW amplifier design and its building blocks. The amplifier is bridged with the HMSIW through the SMT matching section, which plays a role in the HMSIW-to-MS transition and input/output matching networks of the amplifier. Mini-circuit GALI-33+ amplifier was implemented to demonstrate the proposed HMSIW amplifier, and the input and output of the amplifier have $50\ \text{pF}$ DC-block capacitors. The input and output impedances of the GALI-33+ amplifier are $50\ \Omega$. Note that if the input/output of the amplifier are not $50\ \Omega$, the input/output impedances of the amplifier should be matched with the HMSIW by changing the values of the lumped-elements.

III. EXPERIMENTAL RESULTS

Fig. 6 shows the proposed HMSIW amplifier. This amplifier is biased at $4.3\ \text{V}$ with dc current of $45\ \text{mA}$. The proposed am-

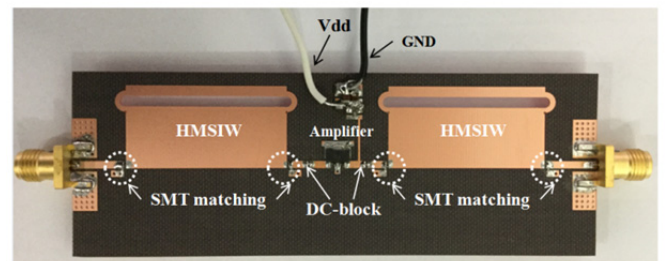


Fig. 6. Proposed HMSIW amplifier.

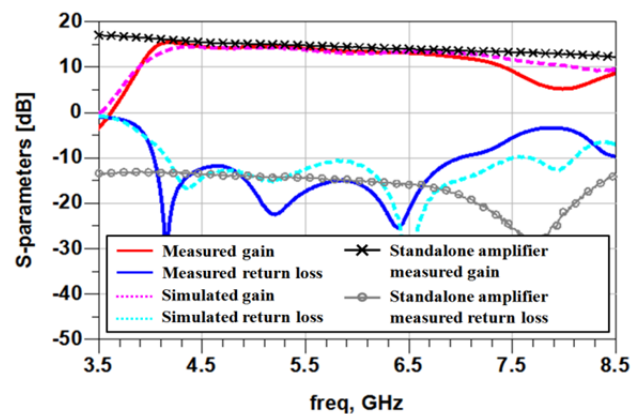


Fig. 7. Measured S -parameters of proposed HMSIW amplifier and stand-alone amplifier.

plifier was simulated and measured. Fig. 7 shows the simulated and measured small-signal gain and return loss of the proposed structure compared with that of the measured stand-alone amplifier. The proposed amplifier has 15 dB gain with 3 dB bandwidth from 4 to 7.05 GHz. The measured return loss is as low as 10 dB from 4.04 to 6.99 GHz. The measured results show good agreement with the simulation results.

IV. CONCLUSION

This study proposes an HMSIW amplifier with a lumped-element transition circuit. The lumped-element transition structure has short transition length, and it may reduce the possible radiation to nearby devices compared with the conventional transition structure. The proposed HMSIW amplifier was designed, simulated, and measured. The results indicate that it is promising for small-sized SIW circuit integration.

REFERENCES

- [1] M. Abdolhamidi and M. Shahsbadi, "X-band substrate integrated waveguide amplifier," *IEEE Microwave and Wireless Components Letters*, vol. 18, no. 12, pp. 815–817, 2008.
- [2] Z. Wang, S. Adhikari, D. Dousset, C. W. Park, and K. Wu, "Substrate integrated waveguide (SIW) power amplifier using CBCPW-to-SIW transition for matching network," in *Proceedings of IEEE MTT-S International Microwave Symposium Digest*, Montreal, Canada, 2012, pp. 1–3.
- [3] Z. Wang and C. W. Park, "Novel substrate integrated waveguide (SIW) type high power amplifier using microstrip-to-SIW transition," in *Proceedings of Asia-Pacific Microwave Conference*, Seoul, Korea, 2013, pp. 101–103.
- [4] K. Eccleston, "Corrugated substrate integrated waveguide distributed amplifier," in *Proceedings of Asia-Pacific Microwave Conference*, Kaohsiung, Taiwan, 2012, pp. 379–381.
- [5] W. Hong, B. Liu, Y. Wang, Q. Lai, H. Tang, X. X. Yin, Y. D. Dong, Y. Zhang, and K. Wu, "Half mode substrate integrated waveguide: a new guided wave structure for microwave and millimeter wave application," in *Proceedings of Joint 31st International Conference on Infrared Millimeter Waves and 14th International Conference on Terahertz Electronics*, Shanghai, China, 2006, pp. 219–219.
- [6] Y. Ding and K. Wu, "Substrate integrated waveguide-to-microstrip transition in multilayer substrate," in *Proceedings of IEEE MTT-S International Microwave Symposium Digest*, Honolulu, HI, 2007, pp. 1555–1558.
- [7] D. S. Eom and H. Y. Lee, "Broadband half mode substrate integrated waveguide attenuator in 7.29–14.90 GHz," *IEEE Microwave and Wireless Components Letters*, vol. 25, no. 9, pp. 564–566, 2015.
- [8] Q. Lai, C. Fumeaux, W. Hong, and R. Vahldieck, "Characterization of the propagation properties of the half-mode substrate integrated waveguide," *IEEE Transactions on Microwave Theory and Techniques*, vol. 57, no. 8, pp. 1996–2004, 2009.
- [9] D. S. Eom and H. Y. Lee, "SIW/HMSIW-to-microstrip transitions using lumped-elements and their quadrature power divider application," in *Proceedings of IEEE MTT-S International Microwave Symposium Digest*, San Francisco, CA, 2016, pp. 1–4.
- [10] D. S. Eom and H. Y. Lee, "Substrate integrated waveguide transitions to planar transmission lines using lumped elements and their applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 12, pp. 4352–4361, 2016.
- [11] D. M. Pozar, *Microwave Engineering*, 3rd ed. New York, NY: John Wiley & Sons, 2005, pp. 225–260.

Dong-Sik Eom



received the M.S. degree in Electronics Engineering from Ajou University, Suwon, Korea, in 2009, where he is currently pursuing the Ph.D. degree in Electronics Engineering. From 2009 to 2011, he was an RF hardware design engineer with AR Tech, where he was involved in radar module and frequency up-down converter design for national defense applications. Since the summer of 2011, he has been with

the Free-Standing Bulk Acoustic Wave Resonator (FBAR) Design Group, Wireless Semiconductor Division, Broadcom Limited (formerly Avago Technologies), San Jose, CA, USA. His current research interests include substrate integrated waveguide (SIW) components and circuit design and FBAR filter, duplexer, quadplexer, and low-loss antenna matching circuit designs for FBAR multiplexer and switchplexer applications.

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), Daejeon, Korea, in 1982, and the Ph.D. degree in Electrical Engineering from The University of Texas at Austin, TX, USA, in 1989. From 1982 to 1986, he was with the Ministry of the National Defense, Seoul, Korea, as a Senior Research Engineer, where he was

involved in the fields of electromagnetic compatibility and wave propagation. In 1998, he was a Visiting Professor with the University of California at Los Angeles, CA, USA. From 1990 to 1992, he was the Head of the Advanced Research Division 1 (Compound Semiconductor Devices Division), LG Electronics Institute of Technology, Seoul, Korea. He served as the Chairman of IEEE Microwave Theory and Techniques Society (Korea Chapter) from 2004 to 2007. Since 1992, he has been with the Department of Electronics Engineering, Ajou University, Suwon, Korea, as a Professor. In 2010, he served as the president of the Korean Institute of Electromagnetic Engineering and Science (KIEES). He also served as the President of the User Council at Korea Advanced Nano Fab Center (KANC) from 2005 to 2010. He founded the GigaLane Company, Gyeonggi-do, Korea, in 2001, and managed it as the President until 2006. His current research interests lie in the fields of microwave and millimeter wave applications of substrate integrated waveguide (SIW), system-on-a-package (SOP), high-speed interconnections and EMI/EMC for digital application, and RFIC design and testing.