A Wideband Microstrip Line-to-waveguide Transition on LCP for 70 and 80 GHz-band Applications

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Abstract— In this paper, a broadband microstrip line-to-waveguide transition has been presented for millimeter-wave module applications. For wide bandwidth applications, the radial microstrip line (MSL) probe and extended GND plane on the low-loss organic dielectric substrate are designed. The designed and tested performance of the transition is characterized in terms of an insertion and return loss. Considering the loss contribution of the cable adapter and waveguide transition for the measurement, the loss of the fabricated transition is analyzed as −1.88 and −2.01 dB per a transition at 70 and 80 GHz, respectively and its bandwidth for reflection at −10 dB is 26 GHz from 67 to 95 GHz.

1. INTRODUCTION

Recently, because of high demands for several high-data-rate wireless services, millimeter-wave (mm-wave) frequency band has been increased to higher mm-wave band. Especially, 71 ∼ 76 and 81 ∼ 86 GHz bands known as "E-band" are widely used around the world for high-capacity point-to-point wireless communications applications [1]. E-band wireless systems offer the most competitive alternative to Ka-band and V-band systems and buried fiber because of very wide available bandwidth (BW) of 10 GHz, low-loss propagation characteristics in free space, and cost effective solution in terms of license and installation.

In general, mm-wave circuits, components, and modules are designed using several technologies and materials. Therefore, they are integrated and assembled in the system by using various transmission lines; microstrip line, coplanar line, waveguides et al.. Therefore, a low-loss transition between them is one of key elements in the mm-wave system integration. In nature, simple design, wide bandwidth, and low loss are key issues for mm-wave system applications.

A well-known electrical-probe (E-probe) transition [2] with a back-short waveguide on the dielectric substrate has been used because of its simple mode transformation and easy design, compared to other perpendicular transitions [3, 4] and also no additional substrate is required. However, narrow operation bandwidth is the essential drawback. For broad bandwidth applications, a waveguide transition using a quasi-Yagi Uda antenna printed on the substrate was proposed [5], but air bridges and a trenched metal block were needed. A very wide bandwidth of 24.9 GHz was achieved [6] by controlling the position of the probe and length of an extended ground (GND) [7] related to the reactance of the probe. The dielectric material as well as the transition structures should be considered for low-loss transition design. In general, RT/Duroid 5880 [3, 4, 6] and low- temperature co-fired ceramic (LTCC) [5] as a substrate have been frequently used for mm-wave applications, because of a very small loss tangent and low coefficient of thermal expansion (CTE). Considering integration into inner layers of printed circuit boards (PCBs), low-loss organic material; Liquid Crystalline Polymer (LCP) has been utilized for microwave and mm-wave module applications [8].

In this work, a wide band microstrip line (MSL)-to-waveguide (WG) transition has been presented for E-band applications. For its wide operational bandwidth, a simple radial probe and extended GND (E-GND) are designed on the LCP organic dielectric substrate. The designed and measured results are characterized in terms of an insertion and return loss.

2. DESIGN OF A MSL-TO-WR12 TRANSITION

The transitions were designed on the LCP substrate and whose relative dielectric constant, loss tangent, and height of the LCP substrate are 3.16, 0.0045, and 100 μm, respectively at 70 GHz and metal (Cu) patterns on the substrate is 8 μm thick.

Figure 1 shows the cross-sectional view of the MSL-to-WG transition. A MSL-to-WG transition is composed of a rectangular open-ended WG, short-circuit WG, and LCP dielectric substrate with the radial electrical probe. The probe and GND patterns are designed on the both side of the substrate. Via holes are formed around WG in the LCP substrate. For 70 and 80 GHz applications, the WR12 WG was used and its rectangular size is 3.1 mm × 1.55 mm. The LCP dielectric substrate is placed on the open-ended WR12 (lower WG) and then the short-circuited WG is on it as shown

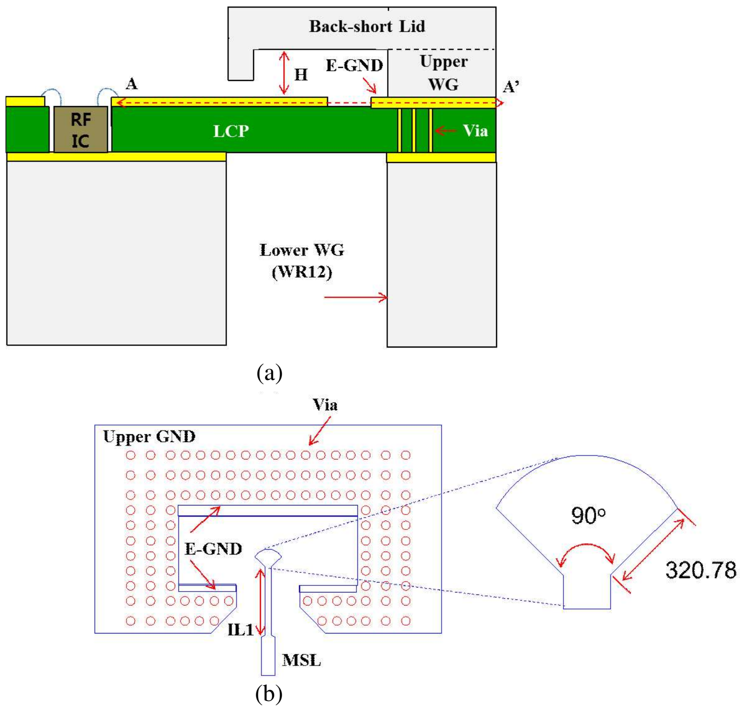


Figure 1: The cross-sectional view of (a) the MSL-to-WG transition and (b) the planar view at the A-A' plane.

in Fig. 1(a). Conductor patterns on the LCP substrate are designed as shown in Fig. 1(b). A length (H) of the short-circuit WG is a quarter of guided wavelength of the WG ($\lambda g/4$), in order to couple electric current on the probe to TE10 dominant mode of the WG. For suppression of parallel-plate leakage (PPL) in the LCP substrate, vias are placed as shown in Fig. 1(b). In order to achieve a wide-band impedance matching, the extended GND and radial patch are designed as shown in Fig. 1(b). The widths of the extended GND at the upper and lower side of the WG are 230 and 130 μm, respectively. The length and angle of the radial probe are 320.78 μm and 90, respectively. They were optimized for broadband characteristics of the transition. Narrow MSL between the MSL and radial probe is designed for impedance matching. Its width and length are 0.11 and 1.184 mm, respectively. The Width of the 50-Ω MSL is 0.236 mm.

In order to evaluate the transitions, they were designed in a back-to-back structure and length between two transitions was 20.6 mm The designed results of the back-to-back structured transition are presented in Fig. 2. Its BW for return loss (RL) at −20 dB is 26 GHz from 61 to 87 GHz. An insertion loss (IL) is −1.67 and −1.95 dB at 70 and 80 GHz, respectively.

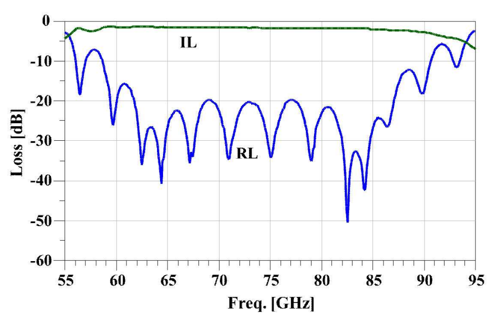
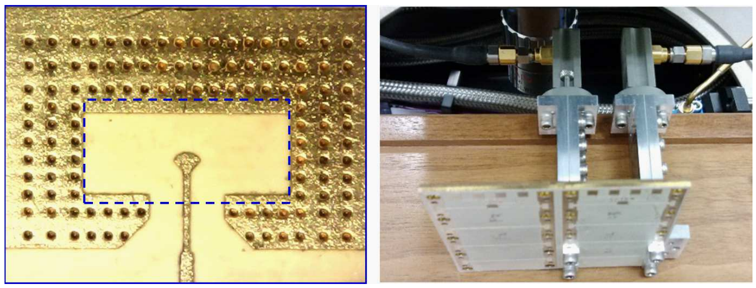


Figure 2: Designed results of the MSL-to-WG transition.

3. FABRICATION AND MEASUREMENT OF THE MSL-TO-WR12 TRANSITION

The designed transition was fabricated in a commercial printed circuit board (PCB) foundry. Fig. 3(a) shows the fabricated transition on the LCP substrate For the test, the fabricated LCP substrate including transition patterns is attached on the lower WR12 in aluminum (Al) block by using a conductive epoxy. The upper WR12 and back-circuit cover are placed on the substrate in order. All parts are tightened by screws. By using a vector network analyzer (VNA) the fabricated back-to-back transition were tested. After calibration, adapters (1.0 mm male cable-to-WR10) and WG transitions (WR10-to-WR12) were connected to the cable of the VNA. Fig. 3(b) presents a photograph of device under test (DUT) for the fabricated board including several transitions. The test frequency was from 67 to 95 GHz. The dashed line is the size of the WR12 WG.



(a) (b)

Figure 3: Fabricated transition (a) and test set-up of the fabricated transition. (b) [Two W-band adapters and waveguide transitions are used for test].

Figure 4 presents the measured insertion loss (IL) and return loss (RL) of the fabricated transition in the back-to-back structure. All test results are degraded compared to the simulated ones because of high-loss calibration using several adapters and WG transitions. The RL of the proposed transition shows less than −10 dB at all test frequencies. The IL of −8.9 and −9.2 dB is obtained at 70 and 80 GHz, respectively. The loss including the 20.6 mm long MSL, adapters, and WG transitions is −5.14 and −5.18 dB, at 70 and 80 GHz, respectively. Considering the loss contribution, the transition loss is analyzed as −1.88 and −2.01 dB per a transition

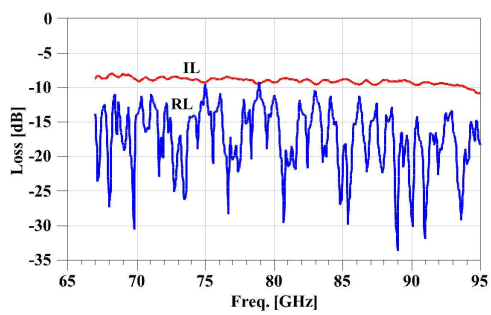


Figure 4: Measured IL and RL characteristic of the fabricated transition.

4. CONCLUSION

A wide-band microstrip (MSL)-to-waveguide transition has been presented for millimeter-wave applications. In order to improve its operational bandwidth, the radial MSL probe is designed on the low-loss organic dielectric substrate. Considering the loss contribution of the cable adapter and waveguide transition for the measurement, the proposed transition loss can be analyzed as −1.88 and −2.01 dB per a transition at 70 and 80 GHz, respectively. Its operational bandwidth of 26 GHz is obtained for reflection at −10 dB.

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