Full $H$-band Waveguide-to-Coupled Microstrip Transition Using Dipole Antenna with Directors

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Abstract: In this paper, we propose low-loss and broadband terahertz (THz) waveguide-to-coupled microstrip transitions using dipole antenna with directors. The simulation and measurement show that insertion/return loss and bandwidth of the waveguide transition can be improved by adding two directors to the basic dipole antenna. The fabricated transition with two directors on a 50 μm-thick quartz substrate exhibits a back-to-back insertion loss of 1.5 dB and return loss better than 15.0 dB across full $H$-band (220–325 GHz). This belongs to the excellent performance compared with the reported $H$-band waveguide transitions using dipole antenna.

Keywords: Terahertz, waveguide transitions, dipole antenna

Classification: Microwave and millimeter-wave devices, circuits, and modules

References


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1 Introduction

Recently, integrated circuits (ICs) operating in terahertz (THz) frequencies such as amplifiers, mixers, oscillators, and detectors have been successfully reported using heterojunction transistors (HBTs) or high-electron mobility transistors (HEMTs) [1]–[3]. THz ICs are generally fabricated using planar transmission lines such as microstrip lines or grounded coplanar waveguides (GCPWs). Therefore, low-loss and broadband transitions from waveguide-to-microstrip or GCPWs are essential to package THz ICs in the waveguides for module and system applications. Several THz waveguide-to-microstrip transitions have been proposed using E-plane probes, dipole antenna, and fin-lines [4]. The transitions using dipole antenna have shown low-loss and wideband performance in THz frequencies with a compact size and input/output ports aligned in the waveguide direction. In [5] and [6], low noise amplifier (LNA) modules were reported at 170–280 GHz and 340–380 GHz using the dipole transition on 50 μm-thick InP substrate. Insertion loss per single transition was 0.8 and 1.0 dB, respectively, with relatively narrow bandwidth of return loss. Although this result is good enough for LNA module fabrication, it can be further optimized to achieve better performance for other applications requiring lower loss and wider bandwidth.

In this work, we introduce directors to improve insertion/return loss and bandwidth of waveguide-to-coupled microstrip transitions using dipole antenna. We design and compare the performance of the transitions by increasing the number of directors. Finally, we present the optimized waveguide-to-coupled microstrip transition with two directors operating at full $H$-band (220–325 GHz).

2 Design of the Transitions

Fig. 1 (a) shows the waveguide-to-coupled microstrip transitions using dipole
antenna without directors in [5][6]. As shown in this figure, the substrate with dipole antenna is placed in the central E-plane of waveguide to transform TE$_{10}$ mode of waveguide to the mode of coupled line. This study focuses on the effect of directors on the transition performance, so is not included the transition from coupled lines to microstrip lines or CPWs which can be easily designed using balun or half-wave long lines as demonstrated in [5][7]. More importantly, coupled lines can be directly used in the design of differential or balanced THz circuits without requiring transitions or baluns. The ground plane of the substrate, which lies on the metallic pedestal, serves as a reflector in the dipole antenna, improving radiation pattern [8].

In order to improve the performance of the dipole transitions, we introduce directors which is able to increase directivity and bandwidth of dipole antenna [9]. We designed and optimized dipole transitions using 50 μm-thick quartz substrate with dielectric constant of 3.78 as the number of directors increases. The full-wave simulation was performed to optimize the dimensions and find the performance of transitions depending on the number of the directors. It is found from this simulation that the performance in terms of insertion and return losses can be gradually improved by increasing the number of directors up to two. More than two directors rather degrades the performance. Therefore, the optimum number of directors is determined to be two. Fig. 1 (b) shows the dimensions of the optimized transitions with two directors.

Fig. 2 shows the simulated S-parameters of the transitions with no and two directors. Insertion loss (-20log|S$_{21}$|) is reduced from 1.06 to 0.93 dB in full H-band by adding two directors. Note that the loss is an average value across H-band (220–325 GHz) and the graph displays the data from 220–330 GHz. In addition, the ripple in insertion loss is reduced from 2.08 to 1.43 dB. Return loss (-20log|S$_{11}$|) is also greatly improved as shown in Fig. 2 (b). Bandwidth of 15-dB return loss is improved from 43.0 to 82.5 GHz. Fig. 2 (c) shows the simulated electric field distribution of the back-to-back transition with two directors in the E- and H-planes at 270 GHz. They illustrate that the designed transition enables the electromagnetic wave to propagate from waveguide to coupled line and vice versa.
Note that the field on the substrate is concentrated on the dipole and coupled lines.

**3 Experimental Results**

To verify the proposed idea, two transitions (one with no director and the other with two directors) were designed and fabricated as shown in Fig. 3 (a) and (b). Fig.
3 (c) demonstrates the transition with two directors mounted in the waveguide. It sits on the metallic pedestal as illustrated in Fig. 1 (a). The waveguide split-blocks were manufactured in using aluminium by standard machining technique. The size of the waveguide blocks is $3 \text{ cm} \times 3 \text{ cm} \times 3 \text{ cm}$ as shown in Fig. 3 (d). For the comparison, standard WR-03 straight waveguide with the length of 3 cm were also manufactured. The performance of the fabricated waveguide transitions was measured at $H$-band after through-reflect-line (TRL) calibration using WR-03 waveguide short and through sections.

![Fig. 4. Simulation and measurement results of the fabricated 3 cm-long waveguide jigs: (a) standard straight waveguide, (b) transition jig without the transition substrate, and (c) electric field distribution of transition jig in H-plane at 270 GHz.](image)

Fig. 4 (a) shows the simulation and measurement results of the 3 cm-long standard WR-03 straight waveguide. The measured insertion loss was 0.75 dB on average in $H$-band which is close to the simulation result of 0.52 dB. Fig. 4 (b) show the performance of the transition jig itself without the transition substrate mounted. Note that there is a metallic pedestal in the middle of the 3 cm-long waveguide. The insertion loss was greater than 10 dB with very poor return loss thanks to the metallic pedestal which prevents the electromagnetic wave from directly propagating through the waveguide as shown in Fig. 4 (c).

Fig. 5 shows the comparison of the measured $S$-parameters of the transitions. As shown in Fig. 5 (a), the average insertion loss across full $H$-band was decreased from 1.90 to 1.51 dB with the reduced ripple from 0.99 to 0.73 dB by adopting two directors. Furthermore, the transition with two directors exhibits return loss better than 15.0 dB across full $H$-band as shown in Fig. 5 (b), which is much better than the conventional transition. The bandwidth of 10-dB return loss is increased from 98 to 110 GHz. This result demonstrates that the insertion/return loss and
bandwidth can be improved by adding two directors as in the simulation.

![Graph](image)

**Table 1.** Reported dipole antenna transitions around $H$-band.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Substrate/thickness</th>
<th>Loss per transition (dB)</th>
<th>Bandwidth* (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5] 170–280</td>
<td>InP / 50 μm</td>
<td>0.8</td>
<td>38</td>
</tr>
<tr>
<td>[10] 270–330</td>
<td>InP / 50 μm</td>
<td>1.5</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>This work</td>
<td>Quartz / 50 μm</td>
<td>0.38**</td>
<td>&gt; 115</td>
</tr>
</tbody>
</table>

*for 15-dB return loss  
**The loss of the 3 cm-long straight waveguide was subtracted.

**Fig. 5.** Measurement results of the fabricated transition: (a) insertion loss ($S_{21}$) and (b) return loss ($S_{11}$).

Table 1 compares the performance of the reported transitions using dipole antenna. The optimized transition with two directors exhibits the measured insertion loss of 0.38 dB per transition across full $H$-band. It also exhibits excellent bandwidth of 15-dB return loss broader than 115 GHz (full $H$-band).

**4 Conclusion**

In this letter, low-loss and broadband waveguide-to-coupled microstrip transition was developed using dipole antenna. The simulation and measurement proved that adding two directors can greatly improve the loss and bandwidth performance of the dipole transitions. It showed low-loss flat insertion loss and excellent return loss across full $H$-band. Therefore, it can be applied to design various differential planar THz circuits with waveguide input and output, which can be useful for the implementation of low-cost and high-performance THz modules and systems.

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