A right-angle wideband transition between differential microstrip line and rectangular waveguide

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Abstract: In this letter, a right-angle full Ka-band differential microstrip line (DML) to rectangular waveguide transition is proposed. A novel coupling probe configuration, which is considered to be a combination of a strip loop and a slot loop, is developed to improve the bandwidth of the transition. The 15 dB fractional bandwidth is increased from 33 to 40.6 \% compared with the right-angle DML-to-waveguide transition using multilayer PCB structure. To verify this transition, a back-to-back prototype is fabricated and measured. It provides an insertion loss of less than 1.2 dB and a return loss of better than 15 dB within a wide frequency range from 26.5 to 40 GHz. The measurement results show good agreements with the simulation ones.

Keywords: wideband, transition, differential microstrip line, rectangular waveguide

Classification: Microwave and millimeter wave devices, circuits, and systems

References


1 Introduction

Rectangular waveguide is often adopted in millimeter-wave circuits and subsystems for its high-Q property. On the other hand, the microstrip line is the most popular planar transmission line in millimeter-wave technology due to the advantage of low profile. Hence, interconnections between microstrip lines and rectangular waveguides are usually needed in millimeter-wave applications [1-4]. Recently, the differential circuits become more and more popular in communication systems, since they have higher immunity to the interference, crosstalk, and environmental noise compared with the traditional single-ended circuits [5]. With the rapid growth of the differential circuits, the transitions, which can support direct connection between differential microstrip lines (DMLs) and rectangular waveguides, have attracted great attentions.

According to the requirements of different systems, the in-line and right-angle transitions from DML to waveguide have been developed [6-9]. In [6], the fin-line topology is used to improve the bandwidth of the in-line transition. But it has a bulky size, which leads to difficulties for the use in compact millimeter-wave circuits, and a return loss of only 8-10 dB over the most of the working frequency range. As for the right-angle transition, the bandwidth is still relatively narrow, which limits its application in the broadband circuits. In [7], a DML-to-waveguide transition is realized at W band using differential patch antenna, and the relative bandwidth of the transition is 11 %. The transition using short-ended slot line is described in [8], and a relative bandwidth of 20.2 % is obtained. A broader transition using multilayer PCB structure is designed at V band [9], and a relative bandwidth of 33% is achieved. However the insertion loss of this transition is a little big, which is less than 2.3 dB from 50 to 70 GHz for a single transition.

In this work, a right-angle DML-to-waveguide transition based on the dual loop coupling structure is presented. The strip loop and slot loop (strip/slot loop), which are used to construct the dual loop coupling structure, are designed to be operated
at a lower frequency and higher frequency, respectively. By using this novel dual-band design, a wide bandwidth of the transition is achieved.

2 Configuration and design

Fig. 1 shows the structure of the proposed transition, which consists of the DML, strip/slot loop coupling structure, and rectangular waveguide. The strip/slot loop, which is excited by a differential input RF signal, is inserted into the rectangular waveguide from the short side wall of the waveguide. The substrate used for the proposed transition is the Roger's RT/Duroid 5880 substrate with a relative permittivity of 2.2 and thickness of 0.127 mm. The width and gap of the DML are chosen to be 0.34 mm and 0.2 mm respectively, which provides a differential impedance of 100 Ω. The waveguide is a standard WR-28 rectangular waveguide with an inner dimension of 7.112×3.556 mm, which will ensure single TE10 mode propagation in the Ka band.

Fig. 1. Proposed transition from DML to rectangular waveguide

Fig. 2. Top view of the proposed transition

As shown in Fig. 2, the strip/slot loop is adopted to couple the electromagnetic energy from the DML to waveguide. The slot loop is fully enclosed by the strip loop, which helps to realize the compact size of the transition. The strip loop and
slot loop are operated at their resonant frequencies $f_1$ and $f_2$, respectively. The $f_1$
mainly depends on the width $W_1$ and length $L_1$ (see Fig. 2), while the $f_2$ greatly
depends on the circumference of the annular ring slot. Therefore, the overall
configuration can be operated at both $f_1$ and $f_2$. By proper selection the $f_1$ and $f_2$, a
wide bandwidth can be obtained. Moreover, the two resonant frequencies are also
influenced by the waveguide walls surrounded, which works as shielded walls for
the strip/slot loop. The coupling effects between the strip/slot loop and waveguide
walls can shift the resonant frequencies of two loops. The transition is simulated
and accomplished using Ansoft HFSS. By optimizing the dimensions of the
strip/slot loop as well as the distance from the waveguide walls, and the position of
the waveguide backshort, a wideband operation is realized. Table I shows the final
dimensions of the transition.

Table I. Dimensions of transition (units: millimeters)

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>L1</th>
<th>S1</th>
<th>W2</th>
<th>L2</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.54</td>
<td>1.5</td>
<td>0.15</td>
<td>0.34</td>
<td>2.08</td>
<td>0.2</td>
</tr>
<tr>
<td>D</td>
<td>a</td>
<td>b</td>
<td>Lshort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>7.112</td>
<td>3.556</td>
<td>1.44</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

The simulated mixed mode $S$-parameters [10] for the transition depicted in Fig.1
are shown in Fig. 3. The modes on the DML port (port 1) are differential and
common modes, while the mode on the waveguide port (port 2) is TE10 mode. As
shown in Fig. 3, the simulated differential mode reflection coefficient ($S_{11}^{dd}$) and
common mode transmission coefficient ($S_{21}^{cc}$) are less than -15.2 dB and -50.1 dB,
respectively, in the frequency range of 26.5 to 40 GHz, which indicates that a
broad bandwidth of differential mode signal and a strong suppression of the
common mode signal are achieved by the proposed transition.

![Simulated S-parameters of the transition](image)

**Fig.3.** Simulated S-parameters of the transition
3 Experimental results
A back-to-back prototype, which is shown in Fig. 4, was designed and fabricated utilizing the proposed structure. The reflection and transmission characteristics of the fabricated transition were measured by the Agilent vector network analyzer E8363B. The measured results compared with the simulated performance are presented in Fig. 5. The measured return loss of the back-to-back transition is better than 15 dB in the whole Ka-band from 26.5 to 40 GHz. The measured insertion loss, which includes the loss of a 25.5 mm DML, is better than 1.2 dB. The loss of the DML utilized in the back-to-back transition is calculated as approximately 0.015 dB/mm at the Ka-band by the numerical simulations. Thus, the DML with 25.5 mm length has about 0.383 dB loss, and the insertion loss of a single transition is estimated as less than 0.41 dB over the entire Ka-band. Moreover, a small frequency shift between the simulated and measured return losses is observed, which is mainly contributed to the errors of the fabrication and assembly.
Table II summarizes the performances of the proposed right-angle DML-to-waveguide transition with previously reported works for comparison. The relative bandwidth of the proposed transition, which is 40.6% (with return loss of more than 15 dB), is significantly improved compared with the other right-angle transitions shown in Table II. This transition can be widely adopted in broadband millimeter-wave hybrid integrated circuits and subsystems with differential interfaces.

Table II. Comparisons of right-angle DML-to-waveguide Transitions

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Center Freq(GHz)</th>
<th>BW(%)</th>
<th>RL(dB)</th>
<th>IL(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[7]</td>
<td>96</td>
<td>11</td>
<td>&gt;15</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>[8]</td>
<td>80</td>
<td>20.2</td>
<td>&gt;10</td>
<td>&lt;1.92</td>
</tr>
<tr>
<td>[9]</td>
<td>60</td>
<td>33</td>
<td>&gt;15</td>
<td>&lt;2.3</td>
</tr>
<tr>
<td>This work</td>
<td>33.25</td>
<td>40.6</td>
<td>&gt;15</td>
<td>&lt;0.41</td>
</tr>
</tbody>
</table>

4 Conclusion
A novel right-angle DML-to-waveguide transition is presented in this work. A wide operation bandwidth is achieved by using the dual loop coupling structure, which consists of a strip loop and slot loop. A back-to-back configuration is fabricated and measured at Ka band. Reasonable agreements between the simulated and measured results are observed.

Acknowledgments
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