Novel broadband coupler based on corrugated half mode substrate integrated waveguide

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Abstract: In this letter, a broadband coupler is presented that makes use of a corrugated half mode substrate integrated waveguide (CHMSIW) technique using a printed circuit board process. The coupler is realized by parallel CHMSIW lines where the vias to form the sidewalls of the HMSIW are placed with the open-circuit quarter-wave-length microstrip stubs and the energy couples by magnetic field. Compared with conventional SIW coupler, it is easily integrated with active devices because it can isolate better the CHMSIW input/output ports from the ground plane. The coupler is simulated and measured at 9.5–17.5 GHz. The result of measurement shows a good agreement with the result of simulation.

Keywords: SIW, HMSIW, CSIW, CHMSIW, coupler

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

References

1 Introduction

In recent years, with the rapid development of microwave and millimeter communications systems, the substrate integrated waveguide technology [1] has attracted many people attention owing to its low cost and completed planar structure, some high quality microwave and millimeter devices have also been proposed [2, 3, 4, 5, 6, 7, 8, 9, 10]. In these literatures, there have been only a limited number of active circuits described [11, 12], since the design of both mechanical support and dc bias are a big challenge in active waveguide circuits based on SIW and related technology.

Microstrip and other planar transmission lines are easily integrated with active devices because they inherently comprise two dc isolated conductors. For substrate integrated waveguide circuits, the characteristic of the single conductor not only makes the challenge more difficult to be solved but also limits the application of active devices. As we know, the vias to form the sidewalls of the SIW and HMSIW can be placed with the open-circuit quarter-wave-length microstrip stubs [13]. In Fig. 1, the structure denoted the corrugated SIW (CSIW) can also support the TE_{10} mode and isolate better the SIW/HMSIW input/output ports from the ground plane.

In Fig. 1(a), Port 1 is the input port and Port 2 is the output port. The magnetic field distributions of CSIW is shown in Fig. 1(b).

![Fig. 1. Dominant field distributions of CSIW](image)

In this letter, based on corrugated half mode substrate integrated waveguide (CHSIW) line technology [14], we present a novel coupler which couples energy by magnetic field between two corrugated half mode SIW lines. Compared with the conventional SIW coupler, it is easily integrated with active devices because the input/output ports is isolated from the ground plane.
2 Design consideration

The configuration of the CHMSIW coupler is illustrated in Fig. 2. The coupler circuit consists of input, through, coupled and isolated ports. In the input port1, the input power is partly transmitted into through port4 by CHMSIW transmit line, and the rest of the power is coupled to the coupled port3 by magnetic coupler between CHMSIW transition line. In isolated port2, no energy appears.

The details of designing CHMSIW coupler are as follows: According to the design considerations in [1] and [2], the first is to select the width of the SIW depending on the interesting frequency range. The initial width of HMSIW (w5+L5 in Table I) can be then determined as the half of the SIW counterpart. Second, on account of the introduction in [9, 10], the initial transition width between input/output ports of the HMSIW is around half of their SIW. Third, on the basis of above, open-circuit quarter-wave-length microstrip stubs are in place of vias which are usually used to form the sidewalls of the CHMSIW. By tuning the values of w4 and L2, identical coupled power is obtained in through port2 and coupled port4. Lastly, for identical phase difference in output port and good impedance matching in input port, the values of L1,L2,L3,L4 and w2,w3,w5,w6 should be well adjusted.

After optimization with Ansoft HFSS, the accurate parameters for 3-dB coupler at 9.5–17.5 GHz frequency band are listed in Table I, and dimension illustration of HMSIW coupler are shown in Fig. 2a. In Fig. 3 and Fig. 4, Both of the E-field and
H-Field distribution with different frequency are calculated by Ansoft HFSS. As shown in Fig. 3 and Fig. 4, the operation mode gradually transits from half TE1,0 mode to quasi-TEM mode which is the dominant mode in microstrip. Due to the variation of the mode, the E-field center of mode is changing which causes the changing of the equivalent coupling gaps and the constant coupling coefficient of 3 dB is maintained. Meanwhile, it can be seen that the energy from port 1 propagates along CHMSIW lines and is then coupled to the port3 and Port 4 respectively. No obvious energy is seen in the isolated port2 of the coupler.

<table>
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<tr>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
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<td>6.00</td>
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<td>W3</td>
<td>W4</td>
<td>W5</td>
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</tr>
<tr>
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<td>0.80</td>
<td>2.81</td>
<td>0.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 3. E-field distribution of CHMSIW coupler](image)

![Fig. 4. H-field distribution of CHMSIW coupler](image)

### 3 Simulated and experiment results

The CHMSIW coupler has been designed, fabricated and measured. The PCB layout of the coupler is shown in Fig. 2b, where the thickness of the dielectric substrate is 0.635 mm with $\tan \sigma = 0.0035$ and $\varepsilon_r = 9.5$. The simulating S parameters are shown in Fig. 5. We can see that equal power division (3.2 dB ± 0.5 dB) is achieved at approximately 9.5–17 GHz, which is close to the expected value of 3.01 dB, Fig. 5 also shows that more than 10 dB isolation and more than 15 dB isolation.
return loss is achieved in 10–16.5 GHz. In Fig. 6, it can be seen that the simulating phase difference between the through port and coupled port i.e. port 3 and port 4 is close to 90 degree which is the theoretical phase difference.

In contrast, the result of the measurement also shows in Fig. 5 corresponding. In the frequency range 10–16 GHz, the measured return loss (S11) is below −15 dB and less than −10 dB from 9.5 GHz to 17.5 GHz. The measured isolation (S31) is above 10 dB in the range 9.7–17.5 GHz, and better than 15 dB from 10.5 GHz to 16 GHz. With the acceptable performance of S11 and S41, a measured power equality of 4.3 dB ± 0.5 dB for S31 and S41 is achieved in the frequency range of 10.5–16.5 GHz. It should be noted that the above measured result includes the loss of the SMA connectors, which is approximately 0.7 dB in total in 9.7–17.5 GHz according to the result of measurement. Since both the return loss and isolation is of good performance, the insertion losses mentioned above can be subtracted from the performance of S31 and S41 directly, and then the actual power equality for the proposed HMSIW coupler is about 3.6 dB ± 0.5 dB or better.

In Fig. 5, a deviation of both the simulated and measured phase difference can be found, which may be caused by the compromise. The measured phase difference is 90 ± 5 degree from 11.2 to 16 GHz. The measured data are consistent with the simulated results in the considered frequency range.
4 Conclusion

A novel CHMSIW 3-dB coupler has been proposed. The coupler has been designed, fabricated using standard PCB process. A power equality of $3.6 \pm 0.5$ dB is achieved with an output phase difference of $90 \pm 5$ degree in 11.2–16 GHz. The measured and simulated results are in good agreement.

Acknowledgments

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