Half Mode Substrate Integrated Waveguide 90° Coupler

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Abstract

Objectives: In the microwave band, couplers based on substrate integrated waveguides (SIW) take advantage of this technology’s performance such as low profile, low insertion losses, low interference. On the other hand suffers from the inconvenient of size. The motivation of this work is to develop a SIW 90° coupler using the new HMSIW technology to obtain a more compact SIW 90° coupler. Methodology: Recently, a new planar structure of waveguides has been proposed, called substrate waveguide (SIW). They are richly used and applied to stimulate high-quality devices for waves and millimeter waves thanks to its performances such as low-loss, high density of integration. A new half-mode substrate integrated waveguide 90° coupler (HMSIW) is proposed, with the aim of maintaining good coupler performance with a reduction of more than half of size. Findings: As compared with SIW coupler, the size of the HMSIW coupler is cutted down by approximately 62%. 90-degree phase shift delimited by the output port and the coupling port in the frequency bandwidth from about 10 GHz to 12.9 GHz is the coupler's requirements. Since the proposed HMSIW couplers have characterized with a compact size, they could be integrated with other passive and active components. Application/Improvements: The HMSIW coupler achieves good performance that’s why they could be employed in communication applications and as essential elements for the manufacturing of other microwave devices.

Keywords: Communication Applications, 90° Coupler, Half Mode Substrate Integrated Waveguide, Microwave Devices, Substrate Integrated Waveguide

1. Introduction

In order to develop successful commercial RF broadband systems, the characteristics of low-cost, mass-producible, high-performance and high field microwave and millimeter-wave technologies are critical. That's why the circuit design should be made carefully. When designing high-performance millimeter-wave systems, the classical waveguide technology is still considered as the mainstream. However for low-cost mass-production, this matured scheme is not suitable. Manufacturers have a real problem concerning the tedious and expensive post fabrication tuning and assembling.

In the past decades, a new technology called substrate integrated waveguides (SIWs) have played a dominant role in the manufacturing of microwave and millimeter-wave dispositive, because it has several attractive advantages of high Quality-factor, high-power handling capability low loss and cost, and easy integration with other passive and active planar components. In addition, many structures are developed, such as ridge and folded, are presented so that to improve the performance of conventional SIWs. Besides, while designing the couplers, antenna, bandpass filters, phase shifter, and power dividers, we have successfully applied the half-mode SIW which is one of the adjustments and fills the half area of regular ones wide mono-mode bandwidth for passive components.

Recently, we have proposed and applied the half mode substrate integrated waveguide (HMSIW) so that to

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develop couplers. The HMSIW characterizes nearly with the same improvements of SIW and has approximately 50% size reduction.

In this paper, we propose a new type of half-mode substrate integrated waveguide (SIW) periodically loaded with different lumped elements and structures. We simulate the SIW and HMSIW coupler by both the Ansoft High Frequency Structure Simulator HFSS and CST Microwave Studio.

2. SIW Design

The SIW is composed of two metal planes bonded to the top and bottom of a dielectric substrate of height \( h \). These two ranges of metal arrays called via guide the EM fields through the structure of the SIW structure. The width of the guide is \( a \), the diameter of the metal vias is \( d \) however, the space between two consecutive vias is \( s \). The geometric parameters are primarily determined by the relationship between the classic rectangular waveguide and the SIW as shown in (Figure 1).

\[
a = a_{eq} - \frac{d^2}{0.95s}
\]

Noting that \( a_{eq} \) is the width of the equivalent rectangular waveguide.

3. Coupler Design

Figure 2 focuses on an SIW 90° coupler. The substrate material for all the eight designed SIW couplers is Rogers RT5880, with relative dielectric permittivity “\( \varepsilon_r = 2.2 \)”. We have also considered a thicknesses “\( h_1=0.5\text{mm} \)”, the diameter of the metallic holes “\( D=0.4\text{mm} \)” and the distance between the vias “\( s=0.7\text{mm} \)”. The coupler’s size is “\( 0.5\times 45\times 90 \text{mm}^2 \)”.

The transition for simulation is the SIW-microstrip where \( w_1=2.6\text{mm} \), \( t_1=20.5\text{mm} \) and \( t_2=7.2 \text{mm} \). In addition to Port 1 and Port 4 which are the sum ports and port 2 and Port 3 which are the difference ports. Noting that, when electromagnetic power is injected into Port 1, half of the power goes to Port 2 and another half goes to Port 3. Table I lists the geometry parameters for a coupler for the 9.4 to 12.7 GHz frequency band after optimization with Ansoft HFSS.

|       | h   | t1  | t2  |
|-------|-----|-----|-----|
| a     | 12.25mm | 2.2mm | 20.5mm | 7.2mm |
| w2    | 3.7mm  | 4.1mm | 10.4mm | 10.4mm |

Simulated S parameters results of SIW 90° coupler are presented in Figure 3. Better than 10 dB stands for the return losses (S11) and isolation (S41), in 9.4 to 12.7 GHz. Besides, the transmission coefficients S21 and coupling
coefficient $S_{31}$ are all about 3 dB and 4 dB at 12 GHz, respectively with a bandwidth of 27%.

We present the simulated electric field distributions for the SIW coupler in Figure 5.

### 4. H MSIW Coupler Design

In order to design a compact circuit we can apply the half mode waveguide concept. The H MSIW exhibits the appealing performances of SIW with an approximately half reduction in size compared to the original version. It has the merits of low insertion loss, high quality factor and higher integration with other planar compact configuration.

We design the H MSIW with the same substrate, the same thickness of 0.5 mm and the same relative dielectric constant of 2.2. The width of the H MSIW coupler $W_h$ is 16.8 mm and the $a_1$ is 6.15 mm. Moreover, the other parameters of the H MSIW coupler are the same as SIW coupler.

A 90° coupler is presented in Figure 6, where each branch of the circuit is a half mode substrate integrated waveguide. Noting that, its size is only the 38% of its full size counterpart. In addition, when Port 1 or Port 4 is excited the input power is equally directed to Port 2 and Port 3.

Figure 7 and Figure 8 present the S parameters of the H MSIW coupler. The isolation $S_{41}$ is lower than -10 dB over the frequency of 10 GHz to 12.9 GHz. The transmission parameters $S_{21}$ and the coupling parameters $S_{31}$ are 3 dB and 5 dB in 9–12.9 GHz with a bandwidth of 24%.

Figure 9 shows the simulated phase difference between the through port and coupled port of the H MSIW 90° coupler is distributed in the range 86° to 94° in the frequency band.
We also present the simulated electric field distributions in this novel design in Figure 10, in which we obtain good agreements for all samples.

The HMSIW coupler has the advantages of lower insertion loss, larger bandwidth, higher compactness, and these characteristics are clearly much better than those obtained by using conventional SIW technique. So, as compared with SIW coupler and the HMSIW coupler, the size of the HMSIW coupler is reduced by nearly 62%.

5. Conclusion

In this work, we propose a novel design of HMSIW 90° coupler which is characterized with low profile, low insertion loss, and higher integration with planar devices integration devices. As the simulated results make clear, it is characterized with a bandwidth of 24%, and phase differences between outputs which are 86° -94° for the out-of-phase operations. This HMSIW coupler is an essential component to find applications in microwave communication systems because of its wide bandwidth and miniature structure.

6. References

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