Design method about 0.14 THz power divider based on 3 dB directional coupler

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Abstract: A design new method about 0.14 THz power divider based on 3 dB directional coupler was presented. As THz device′s dimension is micro-miniature, especially the key structure such as power divider′s, it is extraordinary difficult to fabricate by precise machining. Traditional 3 dB directional coupler has 90° electric bridge structure, whose length between coupler slots is only less than 0.5 mm. This size nearly cannot bear the machining stress in processing. By means of analyzing the phase relationship between the direction coupler′s branches, it is known that if the length between coupler slots increases only half-wave length′s integer-multiple, the phase contrast between branches is still 90°. As a result, the bandwidth is sacrificed. Since the dimension of coupling slot increases, this structure makes precise machining easy, and it has a band width about 10% at least yet. Analysis of simulation result provides the verification. The measured insert loss from 0.133 THz to 0.147 THz is less than 1 dB, and the return loss is less than −20 dB.

Key words: 0.14 THz; power divider; directional coupler; machanical processing

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基于 3 dB 定向耦合器的 0.14 THz 功率分配器设计方法

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摘 要: 介绍了一种基于 3 dB 定向耦合器的 0.14 THz 功率分配器设计方法。由于太赫兹频段的器件尺寸越来越小型化、微型化，特别是对于功率分配器中的核心结构，造成精密机械加工方式难以实现。典型的波导 3 dB 定向耦合器结构是 90°电桥结构,其耦合缝隙之间的间距仅有不到 0.5 mm,这样的尺寸是机加时产生的应力难以承受的。通过分析波导定向耦合器支路间的相位关系得出:如果耦合缝隙的间距增加到半波长的整数倍,支路间的相位差仍为 90°,但这样变化的结果是带宽的降低。通过耦合缝隙间距的适度增加,降低了机加的难度,工作相对带宽降到 10%。经仿真分析,结果得到了验证。加工的样品测试结果表明,在 0.133~0.147 THz 的频率范围内,插入损耗小于 1 dB,回波损耗小于-20 dB。

关键词: 0.14 THz; 功率分配器; 定向耦合器; 机械加工

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0 Introduction

Recently, significant progress has been made in improving the performance of short millimeter-wave solid-state power amplifiers (SSPAs). These developments have spawned a wide array of military and commercial applications such as anti-collision radars, adaptive phased arrays, satellite communications, and local multipoint distribution systems. And transistor technologies have improved to the point that solid-state amplifiers operating above 300 GHz have become viable for the first time[1]. Although no hard rule exists for the practical operating limit of a hard for a given transistor f-max, a good practical rule of thumb is to choose a transistor with an fmax 50%-100% higher than the target operating frequency of the circuit [2]. In the past few years, our group has developed both InP HEMT and HBT technologies with an f_{max} > 1 THz and 0.62[3].

Despite these advances, most millimeter-wave systems are limited by the modest output power of solid-state devices. A possible way to remedy this fundamental limitation is to combine power from many solid-state devices using quasi-optical or spatial power combining[4]. Several spatial and quasi-optical power-combining techniques have already been proposed for the design of high-power millimeter-wave solid-state amplifiers[5-7].

Critical to achieving high RF output power is realizing appropriate on-chip power combining schemes at 220 GHz. A good deal of work on SSPA's using multi-way power combiner has recently been done at frequencies higher than 220 GHz. A balanced power amplifier using branch-line couplers reached 6.1 mW at 270 GHz[8]. This result was measured on-wafer and the amplifier was only partially saturated due to drive power constraints. A 338 GHz balanced power amplifier has also been reported with 10 m W of saturated power[9]. To reach ≥50 mW at 220 GHz, the amplifier[10] presented uses an 8-way power combining for a total output transistor periphery of 0.8 mm. Power combining is done at two levels, a 2-way quadrature phase combiner for balanced operation, and a 4-way power combiner using a CPW Dolph-Chebyshev transformer. The highest frequency power amplifier using Dolph-Chebyshev transformer was implemented in microstrip and achieved 427 mW of output power at 95 GHz[11].

This paper presents a novel method about 0.14 THz power divider based on 3 dB directional coupler, whose analysis of simulation result provides the verification. The measured insert loss from 0.133 THz to 0.147 THz is less than 1 dB, and the return loss is less than -20 dB.

1 Knowledge and analyzing

Typical circuit-level divider/combiners can be classified as resonant and non-resonant. The resonant divider/combiner circuits include rectangular and cylindrical waveguide resonant cavity combiners. The non-resonant type includes the radial-line, hybrid-coupled, and Wilkinson-type combiners[12]. Resonant type combiners, in general, are suitable for high combing efficiency because the output power of the devices combine directly with minimum path loss. However, they have a narrower band width (typically in the 4%-5% range) compared to non-resonant circuits[13].

As shown in Fig.1, the port P1, P2, P3 and P4 are the input port, isolation port, through port and coupling port respectively. In traditional divider based on 90° waveguide directional coupler, the length $w = d = \lambda/4$, and P3, P4 have 90° phase contrast. As terahertz device's dimension is micro-miniature, especially the key structure such as power divider's, it is extraordinary difficult to fabricate by precise machining. At 0.14 T Hz the length M (in Fig.1)

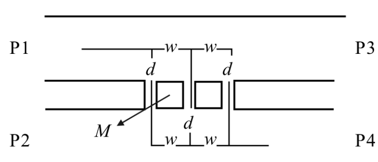


Fig.1 Traditional 90° waveguide directional coupler structure

between coupling slots is only less than 0.5 mm. This size nearly can′t bear the machining stress in processing.

By means of analyzing the phase relationship between the direction coupler′s branches, it is known that if the length between coupling slots increases only half −wave length′s integer multiple, the amplitude relation between branches isn′t variation. Since the dimension of coupling slot increases, this structure makes precise machining easy.

As a result, the band width will be sacrificed along with the increment of the length w. If the length increases only $\lambda/2$, the band width will be keep at about 10% at least. Additionally, the phase difference between branches will be fixed when the length d is fixed.

2 Design and simulation

For verifying the plan above, and designing corresponding structural style, traditional structure can be original mold to obtain the initial value, then adding the length $\lambda/2$ to the coupling section. The original model is shown in Fig.2.

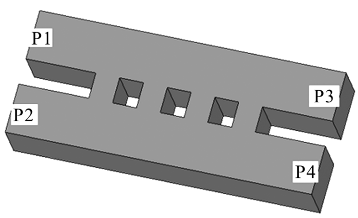
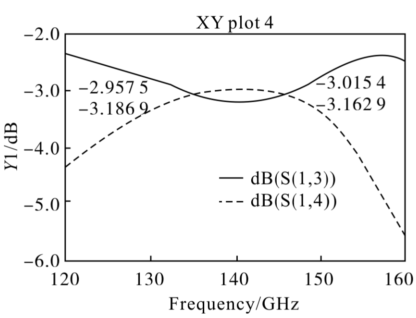
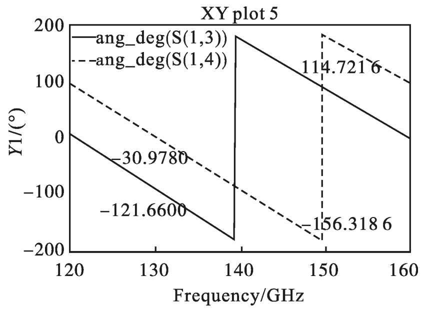


Fig.2 Traditional structure for original mold

It is easy gotten the simulation results in Fig.3 by Ansoft HFSS.



(a) Amplitude result



(b) Phase result

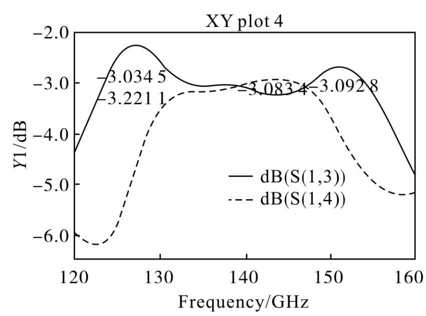
Fig.3 Traditional coupler structure′s simulation results

The wave length of TE10 mode at 0.14 THz can be determined by:

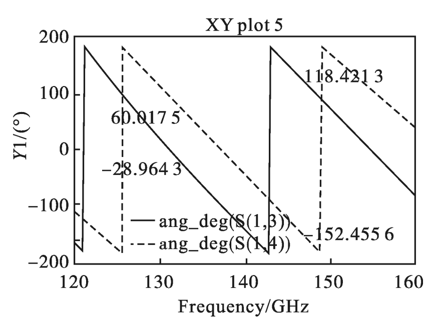
$$\lambda_g=\frac{2\pi}{\beta}\frac{2}{\sqrt{(2f)^2\mu\varepsilon-\left(\frac{1}{a}\right)^2}} \qquad (1)$$

The length between coupling slots increases 1.3 mm. The simulation result is shown in Fig.5.

From Fig.3 (a) and Fig.4 (a) it can see that the relative bandwidth is only about 10%. As we know this structure can possess relative bandwidth at least 15%[14]. So we know that the bandwidth reduces with the increasing coupling slots distance. The phase difference between port P3 and port P4 is $\pi/2$ still (Fig.4 (b)). In addition, the increasing size isn′t $\lambda/2$



(a) Amplitude result



(b) Phase result

Fig.4 Simulation results with distance increasing just right. The reason is that the mode in coupling structure has difference wave length, and it can′t be calculation by the same parameter.

One method to spread the bandwidth is increasing the amount of the coupling slots, and this can be realized well at millimeter band. As we know, the total size of the coupling slots is bigger, the coupling degree is more. For keeping the coupling degree at 3 dB, the only thing we can do is decreasing the coupling slot′s dimension. However the coupling slot at 0.14 THz is less than 0.4 mm (about 0.38 mm) when the coupling slots′ amount is four and each coupling slot is equal width (Fig.2). Since the cutter diameter less than 0.4 mm is high cost and instability, the dimension can′t be decreased. It can be solved through over-mode waveguide shown in Fig.5.

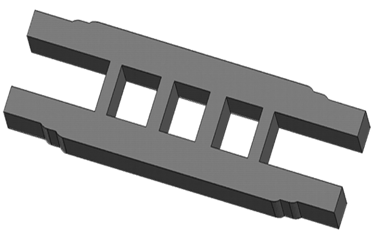


Fig.5 Divider with over-mode waveguide structure

To reduce the reflection loss of the over-mode waveguide, a quarter-wavelength step shape impedance transformer is used. Moreover the lengths and distances of coupling slots can be set unequal value to match better. It should be noticed that the least size of the coupling slot should be more than 0.4 mm, because this dimension is the suitable cutter diameter currently. Considering practical application, the design of four way divider is shown in Fig.6.

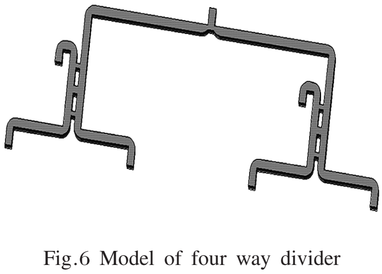
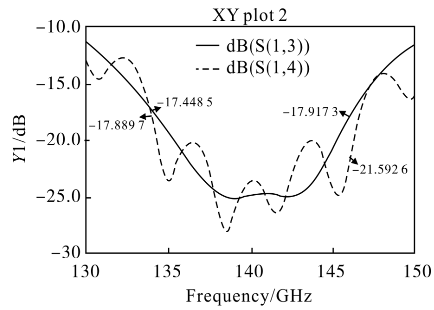
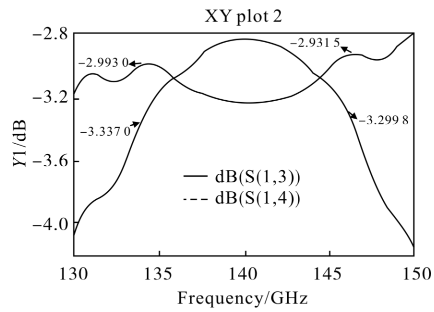


Fig.6 Model of four way divider

By optimizing the coupling structure and the *T* junction, we can obtain the simulation result in Fig.7.



(a) S11 and S12



(b) S13 and S14

Fig.7 Simulation results after optimizing

We can find that the insert loss flatness between branches is less than 0.4dB in 10% band width (from 0.133 THz to 0.147 THz).

3 Fabrication and measurement

The module is shown in Fig.8, and the material is copper, which is control smoothness of the gold plating well. All of the distribution ports arrange at the same plane surface. It can be easy combined a few modules.

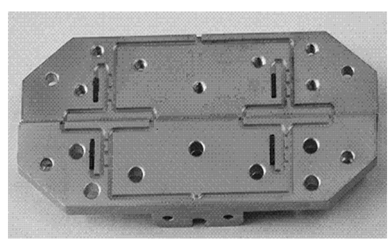


Fig.8 Four way divider module

For obtaining the insert loss of the module, a back-to-back testing is used. The vector network analyzer (ZVA-50) test system with expansion units is shown in Fig.9.

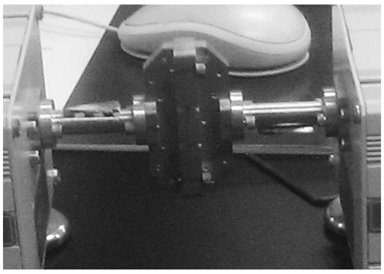


Fig.9 Test system of divider back-to-back connection

The result of the test is shown in Fig.10.

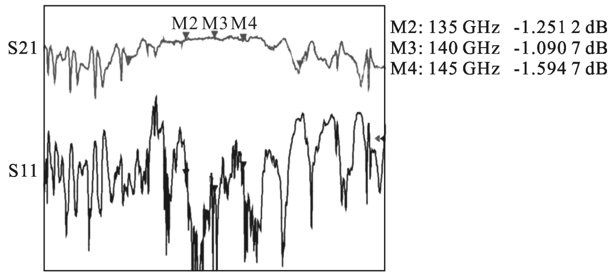


Fig.10 Test result

4 Conclusion

Actually, we should measure the loss of each distribution port, and compare its flatness. Then the more precise data can be obtained. Since the distribution port is arranged at the same plane surface for power combining, it is inconvenient to test by VNA. The back-to-back testing can obtain double insert loss of the divider approximately. From Fig.10, we can see that the insert loss from 0.133 THz to 0.147 THz is less than 1 dB, and the return loss is less than −20 dB. One of the next work is spreading the band width further from 10% to 15% by using over-mode and multi-slot.

This paper presents a novel method about 0.14 THz power divider based on 3 dB directional coupler. Diverse to traditional 3 dB directional coupler, it makes precise machining easy by increasing the length between coupler slots half-wave length′s integer-multiple. The phase contrast between branches is still 90°, and the bandwidth is sacrificed. The method is confirmed available by fabrication and measure result.

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