Millimeter Wave Power Divider Based on Frequency Selective Surface

Wenyan Ji[#], Haitao Wang[#], Xiaoming Liu[#], Yuan Yao[#], Junsehng Yu[#], Xiaodong Chen*
[#]School of Electronic Engineering, Beijing University of Posts and Telecommunications, 279 Box, No.10 Xitucheng Road, Haidian District, 100876, Beijing, China
* School of Electronic Engineering and Computer Science, Queen Mary, University of London, UK
wenyanji_1989@126.com

***Abstract-* Investigations into a device that separates one input signal into two signals of equal power, namely 3dB power divider, were carried out. This paper presents 3dB power divider using double layer metal slotted structure without any dielectric plate. The proposed structure with low coupling effect operates at 54GHz and has a 2GHz bandwidth. All the operating principles and simulation characteristics of the device are discussed in this paper.**

I. INTRODUCTION

Power dividers are widely used in various microwave applications such as antenna feeds, balanced mixers, balanced amplifiers, and phase shifters due to its compactness, small weight and high reliability. For power divider, the properties such as insertion loss, isolation, phase imbalance, amplitude imbalance and other indicators have an important impact on the performance of the whole system. The most widely known power dividers are the Wilkinson, hybrid ring, and T-junction [1]-[2]. At millimeter frequency band, the miniaturized broadband power divider design is trapped by the following problems, including the smaller distance and the mutual coupling effect. Much efforts has been devoted to the design of the power diving devices [3]-[6] with lower loss in nature in the past two decades. Soroka et al[3], Bozzi et al[4] and Dittloff et al[5] individually reported power dividers based on waveguide structures. Taking isolation into consideration, Song et al[6] reported power dividers based on integrated waveguide in 2007. Although certain isolation between output ports has been realized, the insertion loss is considerably higher than those waveguide dividers.

Quasi-optical technology is an advanced technique in which various kinds of quasi-optical devices are used to adjust the electromagnetic signals. Quasi optics involves beams of radiation propagating in free space which are limited in lateral extent when measured in terms of wavelengths and for which diffraction is of major importance. In the area of quasi-optical techniques, the quasi-optical components can be used as polarization processing device, filters and diplexers, quasi-optical ferrite devices, resonators, quasi-optical power combining components and other quasi-optical components[7].

After compared with other design methods, the characteristics such as strong ability in dealing with high-power radiation, lower path and insertion loss, no isolation problem and powerful in multi-polarization processing, make using the quasi-optical technique to design the power divider be the most suitable scheme.

There are many ways in the design of quasi-optical devices, such as dielectric plate, frequency selective surface (FSS), polarization grating and so on. In this paper, two types of FSS structure were proposed.

II. PRINCIPLE OF THE METHOD

Due to the high frequency of millimeter-wave, many factors need to be taken into consideration when choosing the design scheme. Using dielectric plate to allocate the power has various advantages, such as easy to design, more parameters can be optimized.

$$\begin{cases} \Gamma = \dfrac{\sqrt{\varepsilon_{r2}} - \sqrt{\varepsilon_{r1}}}{\sqrt{\varepsilon_{r2}} + \sqrt{\varepsilon_{r1}}} \\ T = \dfrac{2\sqrt{\varepsilon_{r1}}}{\sqrt{\varepsilon_{r2}} + \sqrt{\varepsilon_{r1}}} \end{cases} \quad (1)$$

Where εr1 and εr2 represent the dielectric constant of the two medium respectively. Then the ratio of the reflected energy and the incident energy can be expressed as Γ^2. In order to design the 3dB power divider, the reflection coefficient should satisfy the condition (2). After deduced from (1) and (2), the final design parameters of the dielectric plate can be summarized as (3)

$$\Gamma^2 = 0.5 \quad (2)$$

$$\varepsilon_{r2} = 9\varepsilon_{r1} \quad (3)$$

However, this design method also brings out some disadvantages, for instance, the operating bandwidth, the material loss and the power affordability of the material. Thus, this approach has the possibility in practical application, but the material is a critical problem.

FSS is a periodic assembly of one- or two-dimensional resonant structures, either as apertures in a thin conducting sheet or as metallic patches on a substrate, which may have a band-pass or band-stop function respectively. The FSS structure has a phenomenon with high impedance surface that reflects the plane wave in-phase and suppresses surface wave [8]. FSS are used in various applications, such as reflector antenna system of a communication satellite, deep space exploration vehicle for multi frequency operations, band pass radomes for missiles etc [9]-[11]. Frequency Selective Surface is one of the most widely used device in quasi-optical system, with the main function of selectively reflecting and transmitting the electromagnetic waves of different frequencies. After compared with dielectric plate, easy to realize and simple structure make FSS become the most suitable design scheme.

In this paper, considering the simple structure, the enough bandwidth and the coupling effect in improving the in-band characteristics, the double-layer metal slotted structure was chosen. And two double-layer slotted shapes were chosen for the simulation.

A. Rectangular slotted structure

In the process of FSS design, all the characteristics of FSS are not only related with the geometric shape, the size, the arrangement, the cycle, the thickness of the dielectric substrate, the electromagnetic properties, the number of layers of the unit cell, but also with the incident direction and polarization direction of the incident wave. As stated in the Introduction, the design started with the double-layer metal slotted FSS unit cell with the following parameters. All the structure diagram of this slotted FSS is showed in Fig. 1(a), the incident angle and incident way is shown in Fig. 1(b) and Fig. 1(c) presents the three-dimensional simulation model.

The detailed parameters of the FSS structure are listed in Table I and the specific definitions of them are marked in Fig. 1(a).

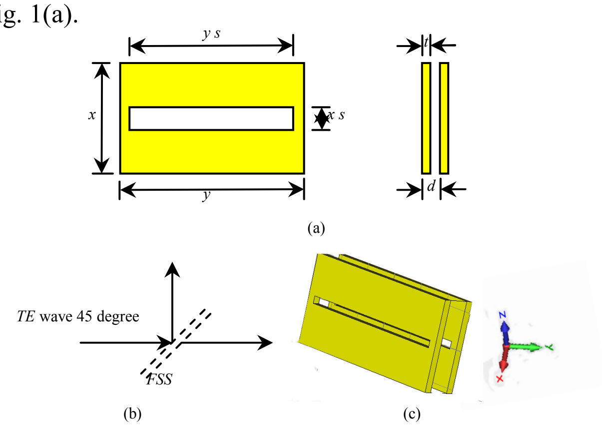

Figure 1. (a) Structure diagram of the slotted FSS (b) The incident angle and incident way (c) Three-dimensional simulation model

Table I
Fixed parameters

parameter	The definition of parameter	value
d	The distance between the two layers	0.65mm
t	The thickness of the metal layer	0.071mm
x	The periodic length in x direction	3.7mm
xs	The slot width in x direction	0.3mm
y	The periodic length in y direction	6.2mm
ys	The slot width in y direction	5.88mm
theta	The spherical angle of incident direction	45deg
phi	The azimuth of the incident plane	90deg

B. Hexagonal structure

All the structure diagram of this slotted FSS is showed in Fig. 2(a), the incident angle and incident way is shown in Fig. 2(b) and Fig. 2(c) presents the three-dimensional simulation model.

The detailed parameters of the FSS structure are listed in Table II and the specific definitions of them are marked in Fig. 2(a).

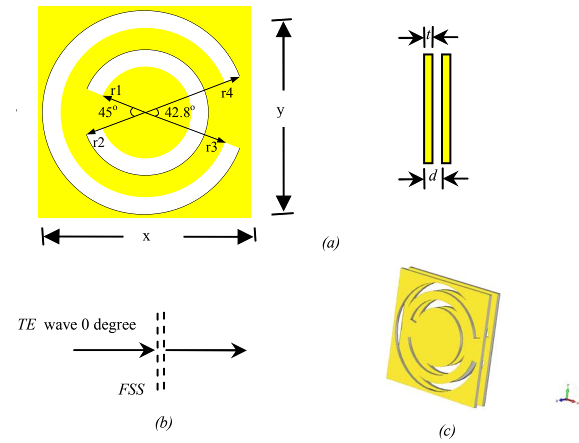

Figure 2. (a) Structure diagram of the slotted FSS (b) The incident angle and incident way (c) Three-dimensional simulation model

Table II
Fixed parameters

parameter	The definition of parameters	value
d	The distance between the two layers	0.5mm
t	The thickness of the metal layer	0.15mm
x	The periodic length in x direction	4.4mm
y	The periodic length in y direction	4.4mm
r1	The radius of circle	1.14mm
r2	The radius of circle	1.46mm
r3	The radius of circle	1.78mm
r4	The radius of circle	2.10mm
theta	The spherical angle of incident direction	0deg
phi	The azimuth of the incident plane	0deg

III. SIMULATION RESULTS

Following the process previously introduced, the two types of frequency selective surface unit cell can be established, which are shown in Fig. 1[c] and Fig. 2[c] respectively. And Fig. 3- Fig. 7 display the simulation results of the rectangular slotted structure, while Fig. 8-Fig. 12 display the simulation results of the hexagonal structure.

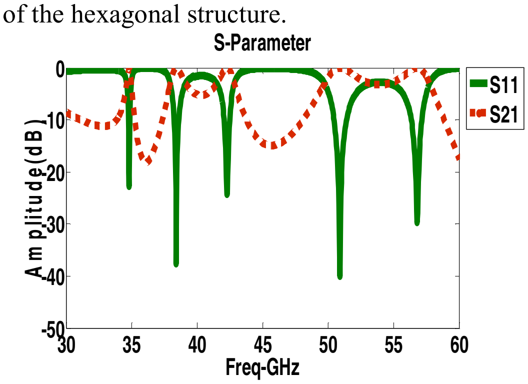

Figure 3. TE wave reflection and transmission s-parameters

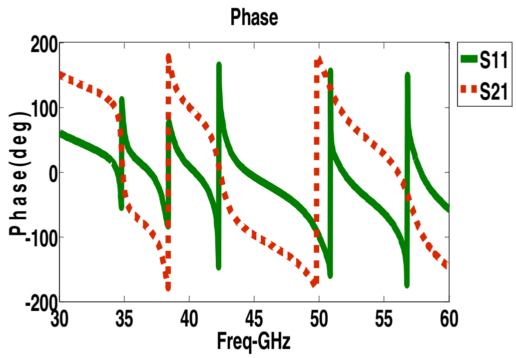

Figure 4. TE wave reflection and transmission phase

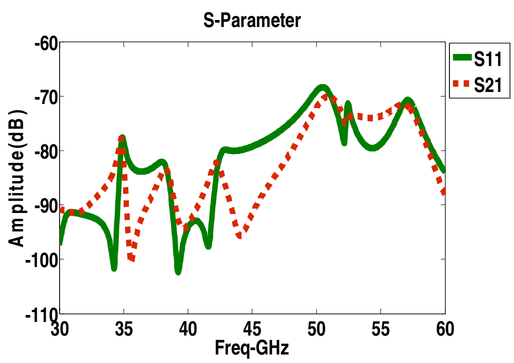

Figure 5. S-Parameters of TE coupling to TM

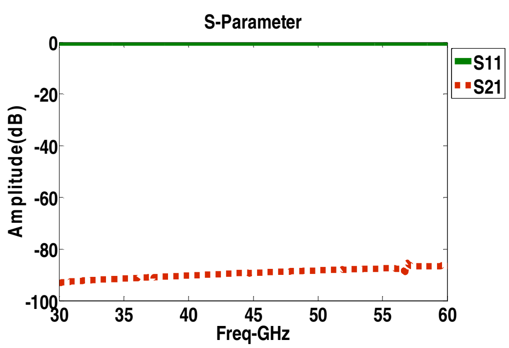

Figure 6. TM wave reflection and transmission S-Parameter

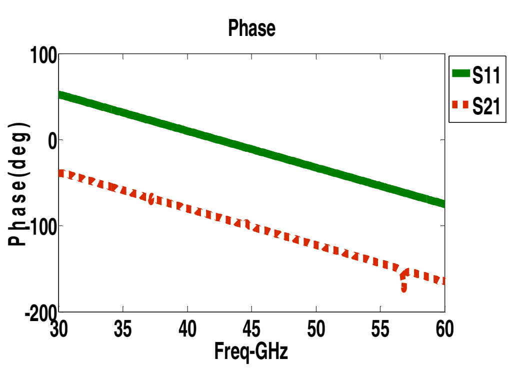

Figure 7. TM wave reflection and transmission phase

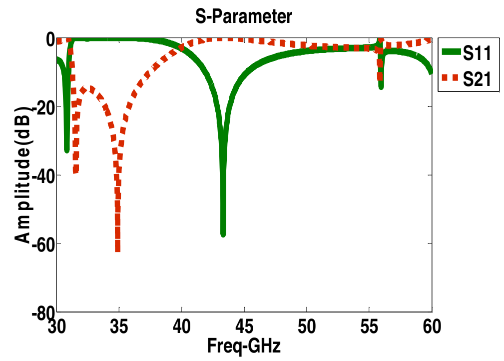

Figure 8. TE wave reflection and transmission s-parameters

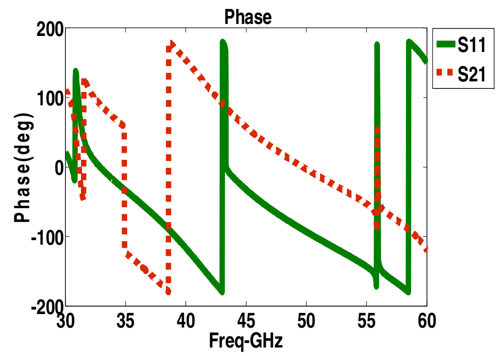

Figure 9. TE wave reflection and transmission phase

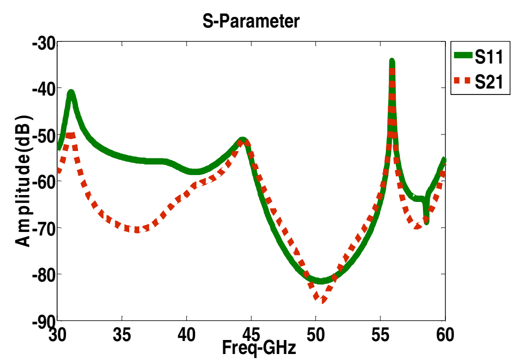

Figure 10. S-Parameters of TE coupling to TM

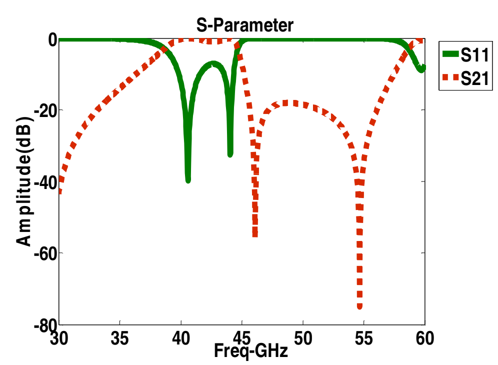

Figure 11. TM wave reflection and transmission S-Parameter

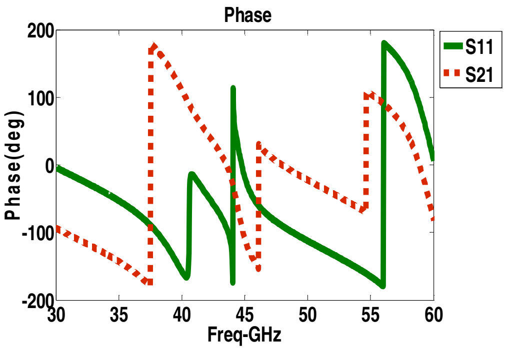

Figure 12. TM wave reflection and transmission phase

For A structure, Fig. 3 and Fig. 4 are the simulation results of S-Parameter and phase respectively when the incident wave is TE wave, also the detailed values of S-Parameter in different frequency points are shown in Table III. Fig. 4 shows that the phase difference in 53GHz-55GHz is about 90^0. Both the figure and data prove that the proposed FSS structure can realize the design of 3dB power divider. Fig. 5 represents the transmission and reflection S-Parameters of TE wave couples to the TM wave, both of them are less than -70dB in 53GHz to 55GHz band, which means that the coupling component is very small. The simulation results are shown in Fig. 6 and Fig. 7 when choose the TM wave as the incident wave.

For B structure, Fig. 8 and Fig. 9 are the simulation results of S-Parameter and phase respectively when the incident wave is TE wave, also the detailed values of S-Parameter in different frequency points are shown in Table IV. Fig. 9 shows that the phase difference in 53GHz-55GHz is about 90^0.But the incident angle is 0^0, so the phase difference can't meet the design requirement, it should be 180^0. Therefore, the B structure can't be used to design the 3dB power divider. And Fig. 10, Fig. 11 and Fig. 12 represent the parametric curves just as introduced in A structure.

Table III

TE INCIDENT WAVE S-PARAMETERS FOR A STRUCTURE

Freq(GHz) / Amp(dB)	53	54	55
Reflection	-3.1911	-2.7641	-3.3418
Transmission	-2.8372	-3.2714	-2.7024

Table IV

TM INCIDENT WAVE S-PARAMETERS FOR B STRUCTURE

Freq(GHz) / Amp(dB)	53	54	55
Reflection	-3.1246	-3.0186	-2.8998
Transmission	-2.8991	-3.0021	-3.1237

IV. CONCLUSION

In this paper, two types of double-layer metal slotted frequency selective surface used for the 3dB power divider application were introduced and realized. After analyzing and calculating from the simulation results, it is clear that the rectangular slotted structure power divider operates at 54 GHz, with the bandwidth of 2GHz, and meets 90 degree phase difference requirements, while the hexagonal structure failed to satisfy the phase difference requirements. This type of FSS named as 3dB power divider can be applied in the aerospace situation where we need the power in two directions be equal.

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REFERENCES

[1] E. Wilkinson, "An N-way hybrid power divider", IEEE Transactions on Microwave Theory and Techniques, vol. 8, no. 1, pp. 116–118, January 1960.

[2] David M. Pozar Microwave Engineering Third Edition[M]. Beijing Electronic Industry Press, 2006; 274-277

[3] A.S.Soroka, A.O.Silin,"Simulation of Multichannel Waveguide Power Dividers",MSMW'98 Symposium Proceedings. Kharkov, Ukraine, vol 2,pp.634-635, Sept.1998

[4] Maurizio Bozzi', Luca Perregrinil,"A Compact, Wideband, Phase Equalized Waveguide DividerKombiner for Power Amplification",33rd European Microwave Conference - Munich pp.155-158, 2003.

[5] J. Dittloff, J. Bornemann," Computer Aided Design of Optimum E-or H-Plane N-Furcated Waveguide Power Divider,"17th European Microwave Conference. pp.181-186,Otc 2003.

[6] K. Song, Y. Fan and Y. Zhang, "Investigation of a power divider using a coaxial probe array in a coaxial waveguide," Microwave, Antennas & Propagation, IET, vol.1, Issue 4.pp.900-903, Aug. 2007

[7] Goldsmith, P.F. "Quasi-Optical Techniques" Proceedings of the IEEE Volume: 80 Issue:11

[8] Hsing-Yi Chen and Yu Tao, —Bandwidth Enhancement of a U-Slot Patch Antenna Using Dual-Band Frequency-Selective Surface With Double Rectangular Ring Elements□, MOTL Vol. 53 No. 7, pp 1547-1553, (July 2011).

[9] Sung, G.H.-h, Sowerby, K.W.Neve , M.J.Williamson A.G , A Frequency selective Wall for Interface Reduction In Wireless Indoor Environments□ Antennas and Propagation Magazine, IEEE ,Vol 48,Issue 5, pp 29-37,Oct 2006.

[10] D.H. Werner and D. Lee, —A Design Approach for Dual-Polarised Multiband Frequency Selective Surface using Fractal Elements□ IEEE International Symposium on Antennas and Propagation digest vol. 3,Salt Lake City Utah, pp. 1692-1695, July 2000.

[11] T.K. Wu, —Frequency Selective Surface and grid array□, A Wiley Interscience publication, pp. 5-7, 1995.