Design of A Compact Four-Way Micro-strip Power Divider

Xiaotao Cai[1,a], Huifeng Wang[1], Xiaosong Qu[1], Limin Zhang[1]

[1]Beijing Institute of Radio Metrology and Measurements, Beijing, 100854, China

[a]cxttju@126.com

Keywords: Power divider, Four-Way, Micro-Strip

Abstract. A four-way micro-strip power divider is proposed in this paper, which has compact structure. During the operation frequency band (2-4GHz), the designed power divider has good performance of impedance matching at five ports and the measured VSWR of each output port are all less than 1.25. The isolation between two output ports is better than -20dB. The insert loss is less than 1dB. The designed power divider is fabricated to validate the design. The proposed power divider is measured and the simulated and measured results have a good agreement.

Introduction

With the rapid development of microwave technology, power divider has become a key component in radio frequency and various microwave systems, especially in microwave and millimetre wave integrated circuits for lossless power division and combining [1].Therefore, the power divider with good performance has become hot research direction in the field of radio and microwave.

The original power divider is a three-port completely matching structure, which consists of two quarter-wavelength transmission lines at the design frequency and a resistor chip. And the resistor chip is placed between the output ports in order to provide good isolation [2]. Moreover, micro-strip lines are compact and low cost, and have been widely used, but they are relatively lossy. However, they are convenient for planar circuits and subsystems like feed networks [3].

Therefore, in modern design of microwave circuit, multi-way micro-strip power divider plays more and more important role in phase-array antennas, power amplifiers and multi-port circuits due to its advantages, such as planar structure, easiness of circuit design and good isolation, which has become the hot researching aspects in the design of power divider [4-5]. A Y-junction four-way power divider with low return loss and high Q-factor is proposed in [1]. A compact wide band eight-way at X-band based on substrate integrated waveguide is presented in [3]. In [6], an improved W-band four-way power divider using turnstile coupling waveguide is proposed. A multi-way power divider by interconnecting two-way power dividers with fewer output ports by transforming them into multi-section stepped-impedance transformers is proposed in [5].

In this paper, a compact four-way micro-strip power divider is proposed. The designed power divider has good performance of impedance matching at five ports, good isolation between two output ports and insert-loss between input port and output ports. The proposed power divider is fabricated and measured to validate the design. A good agreement can be achieved between the simulated and measured results.

Power Divider Structure

A four-way power divider can be realised by interconnecting three two-way power dividers using the two-stage structure shown in Fig.1 [5]. In Fig.1, port 1 is the input port and ports 2-5 are four output ports. The two-way power divider is the popular power divider, which is derived from the classic Wilkinson power divider. The classic Wilkinson power divider is a three-port structure. The characteristic impedance for each input and output transmission lines is Z_0 with the usual value of 50ohm, and the impedance between the input and output ports for the two-way divider is $\sqrt{2}Z_0$. The isolation resistor with the value of Z_0 is connected between two output ports, which plays an important role in the port isolation.

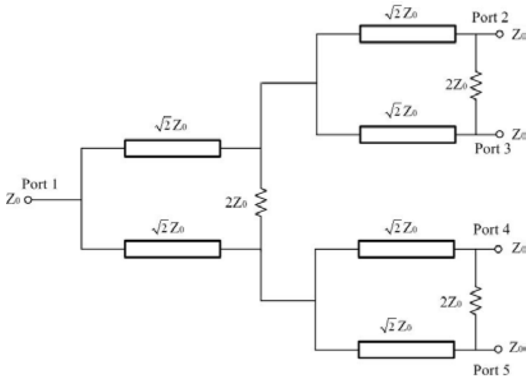

Fig.1 Schematic diagram of four-way power divider

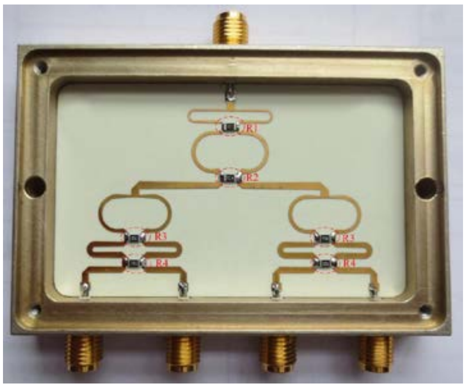

Fig.2 Photo of the fabricated power divider

TABLE Ⅰ Values of The Isolation Resistor（INT: Ω）

Isolation Resistors	R1	R2	R3	R4
Valves	120	220	390	680

The designed four-way power divider is composed of three two-way power divider, which has two-stage structure in order to achieve the performance of wide frequency band. The proposed power divider is designed and optimized using ADS2008U2 and HFSS 11.0 softwares. Based on the simulated structure, the proposed power divider is fabricated and the photo of the designed power divider is shown in Fig.2. As shown in this figure, the proposed power divider has compact structure. All of these transmission lines are printed on the same side of the Taconic RF-35 substrate with thickness of 0.5mm and relative permittivity of 3.48. The isolation resistor between two output ports plays an important role in output ports matching and ports isolation for power diver. The values of the isolation resistor are optimized and selected as in Table Ⅰ. The fabricated power divider is measured with Agilent E8364B to validate the simulated results.

Power Divider Performance

In this section, the characteristics, especially the performance of frequency and scattering parameters are discussed. The scattering matrix of the conventional five-port power divider is shown as below:

$$[S]=\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix}$$

For an arbitrary reciprocal and lossless network, based on unitarily and reciprocity of matrix, we get

$$\left([S]^T\right)^*[S]=1 \qquad S_{ij}=S_{ji}$$

Where $\left([S]^T\right)^*$ is the conjugate transpose matrix of $[S]$. Therefore we can obviously obtain that

$$(S_{11})^2+(S_{21})^2+(S_{31})^2+(S_{41})^2+(S_{51})^2=1$$

Where $(S_{21})^2$ represents the transmission coefficient between port 1 and 2, $(S_{11})^2$ represents return loss of port 1, while $(S_{31})^2$ $(S_{41})^2$ $(S_{51})^2$ represents transmission coefficients between port 1 and 3, 4, 5 respectively. Theoretically $(S_{12})^2$ is about 1/4 for four-way power divider, so we can obtain as follows

$$(S_{22})^2+(S_{32})^2+(S_{42})^2+(S_{52})^2=3/4$$

The resonant frequency of the designed power divider is tuned for 2.4GHz with the operation frequency bandwidth of 2GHz, i.e. from 2GHz to 4GHz, which can cover LTE, Bluetooth, 3.5Wimax and S frequency bands [7]. Therefore, the proposed four-way power divider has good application. In order to achieve good performance as soon as possible, the proposed power divider is firstly designed using the software ADS2008U2 to get the good simulated performance. The designed model in ADS is simulated again using the software HFSS. However, the performance of port one in software HFSS is worsened, which is close to the measured result. In order to get the good performance of input port, adding a stub on the micro-strip line of port one leads to the good characteristic of VSWR at input port. The simulated VSWR with and without the stub at port one is illustrated in Fig.3. From this figure, it can be obviously seen that the performance of VSWR at input port with the stub is better than the performance without the stub.

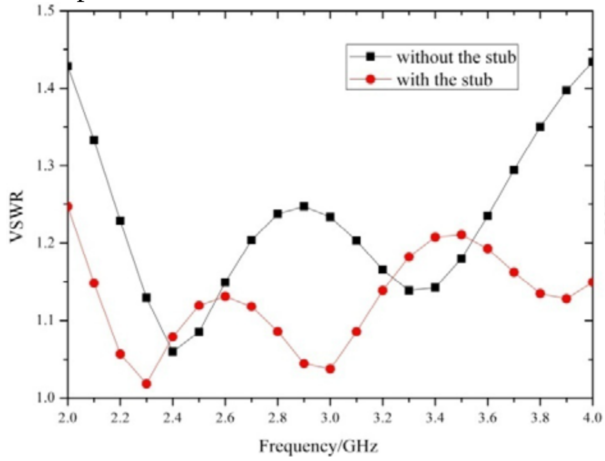

Fig.3 Simulated VSWR with and without the stub at port 1

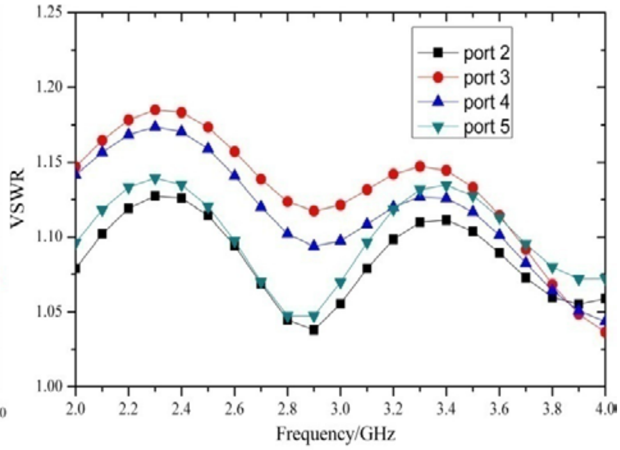

Fig.4 Simulated VSWR at output ports

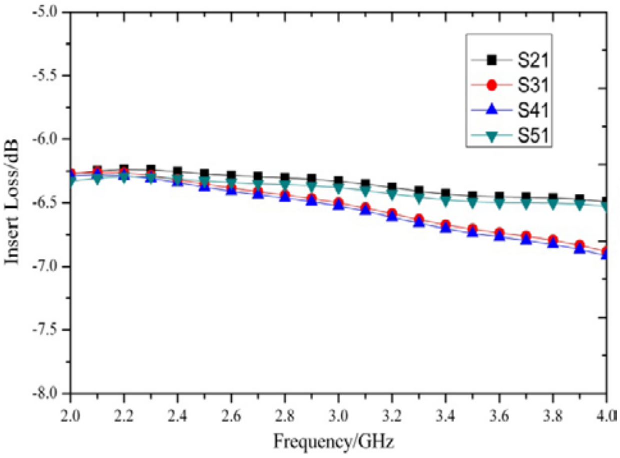

Fig.5 Simulated insert loss between input and output ports

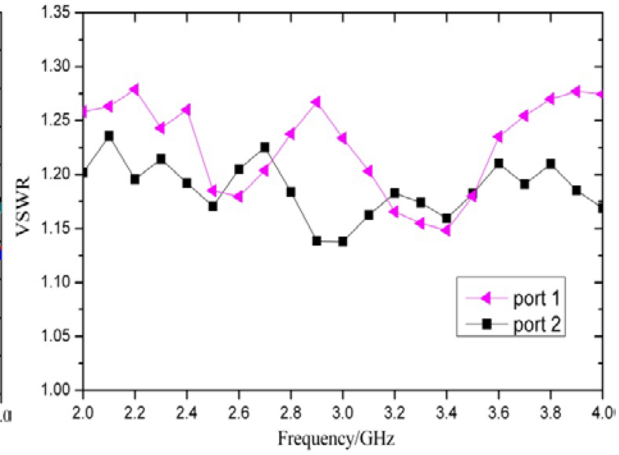

Fig.6 Measured VSWR at input and output port

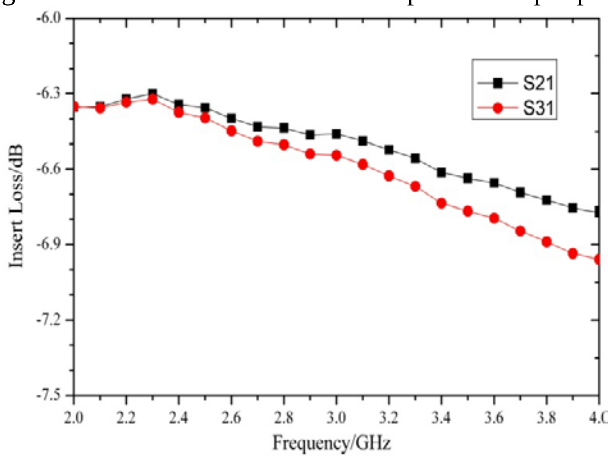

Fig.7 Measured Insert loss of S21 and S31

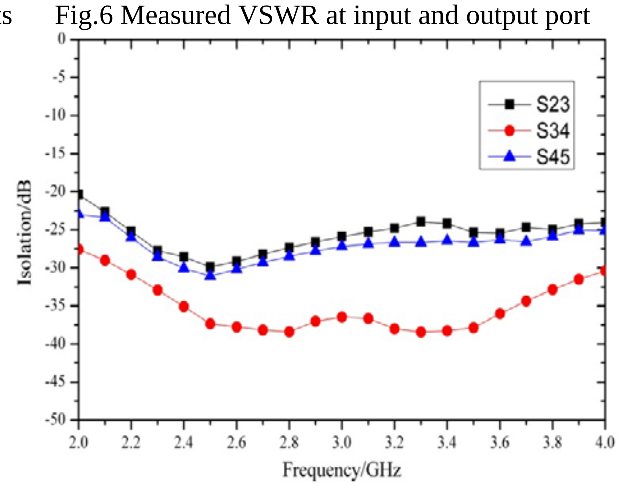

Fig.8 Measured isolation of S23, S34 and S45

According to the simulated results of HFSS, the VSWR of four output ports has good performance, which are better than the simulated VSWR of input port. Therefore, the output ports don't need adding the stub to get good impedance matching. The simulated results of VSWR of four output ports, port 2, 3, 4 and 5, are illustrated in Fig.4. As shown in this figure, the output ports of the designed four-way power divider have good performance of VSWR to satisfy the requirements of engineering.

Insert loss and isolation are two important values to the design of power divider. The simulated insert loss between the input port and output ports is illustrated in Fig.5. As shown in this figure, the designed four-way power divider has good performance of insert loss, which has little influence on the performance of the system. As can be seen from Fig.4, four output ports (port 2, port 3, port 4 and port 5) of the designed power divider have the similar VSWR performance. Therefore, the VSWR of port 2 is selected to illustrate the VSWR performance of the designed power divider. The measured VSWR performance at input port and output port 2 is shown in Fig.6. From this figure, the designed power divider has good VSWR performance. Due to the symmetric structure of the designed power divider, S21 and S51, S31 and S41 have the similar performance, therefore measured S21 and S31 is selected to illustrate the measured insert loss of the power divider, which is shown in Fig.7. It can be seen that during the operation frequency band the measured insert loss is below 1dB.

The isolation coefficient is very important to the power divider, S23, S34 and S45 are selected to illustrate the measured isolation of the power divider due to symmetric structure of the designed power divider, which is shown in Fig.8. As can be seen from this figure, the isolation between port 3 and port 4, which derived from the different micro-strip, have the better performance of isolation than that performance, which derived from same micro-strip, such as port 2 and port 3, or port 4 and port 5. That is because the different second-level micro-strip is helpful to the isolation between the output ports, which derived from these different micro-strips. It can be seen from this figure that four output ports of the designed four-way power divider have good isolation performance between each other.

As can be seen from Fig.3 to Fig.8, a good agreement between the simulated and measured results of scattering parameters is achieved. The discrepancies between them are due to the use of radio connector, fabrication tolerance, soldering effect and the limited accuracy of the available tools, etc.

Conclusion

In this paper, a four-way micro-strip Wilkinson power divider is proposed, which has compact structure. The measured result illustrates that during the operation frequency band, the designed four-way power divider has a good performance of return loss at three ports, isolation and insert loss. The designed power divider is fabricated and measured. A good agreement between the simulated and measured results validates the design. The proposed four-way power divider has a good potential for LTE, Bluetooth, 3.5Wimax and S frequency band applications.

References

[1] Zou X., Tong C.-M, Yu D.-W., “Y-junction power divider based on substrate integrated waveguide”, Electronics Letters, vol.47, no.25, pp.1375-1376, 2011.

[2] Wei Zhou, Noordin N.H., Haridas N., et al, “a WiFi/4G compact feeding network for an 8-element circular antenna array”, Antennas and Propagation Conference, pp.1-4, 2011.

[3]K.Song, Y.Fan, et al, “eight-way substrate integrated power divider with low insertion loss,” IEEE transactions on microwave theory and techniques, vol.56, no.6, pp.1473-1477, 2008.

[4] Okamura S., Xiaolong Wang, et al, “a general model of modified Wilkinson power dividers with additional transmission lines”, 41st European Microwave Conference, pp.834–837, 2011.

[5]Yansheng Xu and R G.B, “design of multi-way power divider by using stepped-impedance transformers,” IEEE transactions on microwave theory and techniques, vol.60, no.9, pp.2781-2790, 2012.

[6]Ming Wang, Xiaoqiang Xie, et al, “a compact four-way power combiner/divider in W-band,” Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, pp.47-50, 2013.

[7] Xinyi Tang, Mouthaan K., “analysis and design of compact two-way Wilkinson power dividers using coupled lines,” Asia Pacific Microwave Conference, pp.1319–1322, 2009.