ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPTS039

DESIGN OF A COMPACT VARIABLE X-BAND RF POWER SPLITTER

Focheng Liu[1,2], Jiaru Shi[1,2] , Hao Zha†[1,2], Huaibi Chen[1,2], Jiayang Liu[1,2], Zening Liu[1,2]
[1]Department of Engineering Physics, Tsinghua University, Beijing, China
[2]Key Laboratory of Particle and Radiation Imaging of Ministry of Education, Tsinghua University, Beijing, China

Abstract

This paper presents a design of a compact variable X-band RF power splitter. The RF power splitter includes one input port and two output ports, and the power division ratio can be adjusted by changing the position of a short circuit piston. This system keeps a good match (less than -40 dB) at any power division ratio. An E-bend waveguide structure is selected to make the geometry more compact (11cm in length, 3.5cm in width and 5 cm in height). Special studies was conducted to sustain a low surface electrical field (maximum 65 MV/m at 100 MW input), and large bandwidth (250MHz). This power splitter is designed for high-power test stand at Tsinghua University.

INTRODUCTION

A high RF power (50 MW) X-band test stand was constructed at Tsinghua University [1]. Accurate power adjustment and division is required for different situations, such as high-power performance tests of new designed RF components and several branch experiments simultaneously.

A usual approach to adjust the power level is to change the power of input signal or the emit current of the klystron. This approach changes the working state of the power source which is hard to measure. A design of power splitter with arbitrary division ratio was presented in ref [2], which is able to adjust the input power at the device under test without changing the power source. Another advantage is only one klystron used in this approach, different from two klystrons sources system presented in ref [3]. The design of power splitter was manufactured and was installed in the X-Box test stand at CERN.

RF power splitter has been researched for years [4-8].As Fig.1 showing, this method uses only one klystron as power source and the driving power is divided into two ways through power splitter: one port is connected to next devices, another is connected to matched RF load or attenuator with low power controlling and measuring system followed. To realize power splitter's function, this component should have following features: power division ratio can be adjusted to arbitrary number; whole component should be matched, which means little reflection in input port. To bring it into practical application on high-power test stand (power level up to 100MW), surface electronic field, compactness, and bandwidth should also be considered.

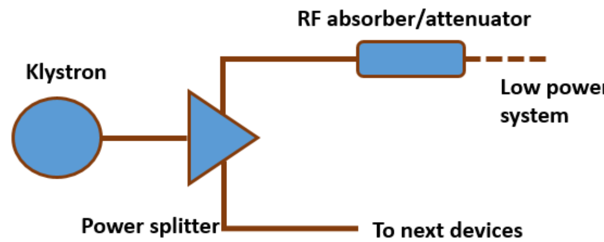


Figure 1: RF power splitter.

This paper presents a more compact design by optimization of RF circular polarizer and using E-bend waveguides.

PRICIPLE OF DESIGN

The detailed principle is explained in Ref [2]. A different explanation is briefly showed in this part. Fig. 2 shows the schematic of choke-mode. Choke-mode basically is a three-port tee junction, and a designed component as RF impedance combiner so that impedance seen from each port is the sum of other two port. If one port is matched as output while another port is shorted with phase difference φ, the normalized impedance seen by the input port can be calculated:

$$Z1 = Z2 + Z3 = j\tan\varphi + 1$$

Where Z1，Z2，Z3 are, respectively, the impedance of three ports, and j is the imaginary unit.

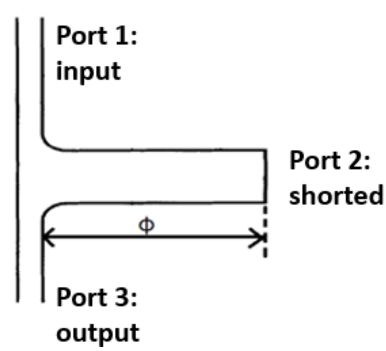


Figure 2: Schematic of choke-mode.

So the impedance of input port can be adjusted by changing the position of shorted plane connected to port 2. When phase difference $\varphi = N*\pi$, $Z1 = 1$, meaning choke-mode is fully open without any reflection; when phase difference $\varphi = \frac{\pi}{2} + N*\pi$, $Z1 = \infty$, meaning choke-mode is fully closed with all power reflected. Thus, choke-mode equals a switch in transmission line.

The schematic of the RF power splitter is shown in Fig.3. Two choke-mode are introduced in 3-port network, and

† zha_hao@mail.tsinghua.edu.cn

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPTS039

they work at different working state because of π/2 phase difference. When choke 1 is open, choke 2 is closed; similarly, while choke 1 is closed, choke 2 is open. Power division ratio can be adjusted into arbitrary number between these two extreme cases, with constant π/2 phase difference during adjustment.

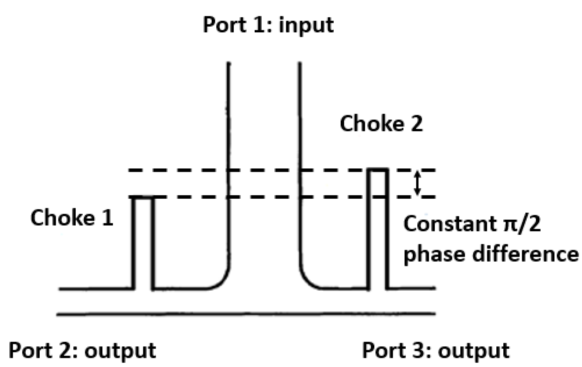


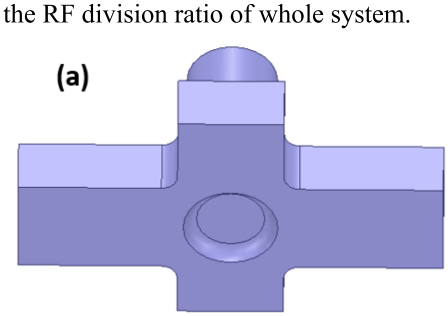
Figure 3: Schematic of RF power splitter.

To ensure input port is always matched at arbitrary division ratio, distance between two choke-mode and junctions should be well-designed [2]. Because of the limit of paper, explanation isn't included this time.

DESIGN AND OPTIMIZATION

RF Circular Polarizer

System shown in Fig.3 is a 5-port network needing two variable shorted plane, and it would make adjusting process complicated. The design can be simplified by replacing two single-mode ports with two different modes in one port. An appropriate choice is TE11 mode in circular waveguide, which is polarization degenerate and similar to TE10 in rectangular waveguide. RF circular polarizer can achieve such function [9], and design is modified by changing the convex bottom cylinder into concave stub, to making geometry more compact, as shown in Fig.4 (a). As Fig.4 (b) showing, when RF signals come from the left port (port 4), the polarizer can fully reflect all power back to port 4 and no signal can be transmitted to the right port (port 5). The requirement of constant π/2 phase difference can be easily satisfied by lengthening λ/4, and the phase of reflected signals can be adjusted by mechanically changing the position of a short-circuit piston, which equals to adjusting the RF division ratio of whole system.



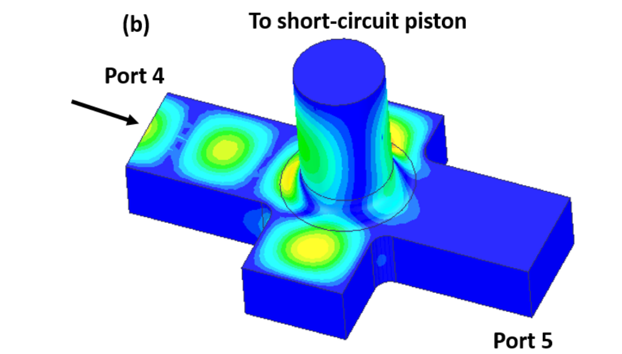


Figure 4: RF circular polarizer: (a) geometry (HFSS model); and (b) power distribution.

RF Power Splitter Using E-Bend

Thanks to the modified design of RF polarizer, E-bend waveguide structure has special advantage to make geometry more compact. As shown in Fig.5, the bottom of polarizer is faced with inside of component using E-bend. The dimension of whole component is 11cm in length, 3.5cm in width, 5 cm in height without piston counted.

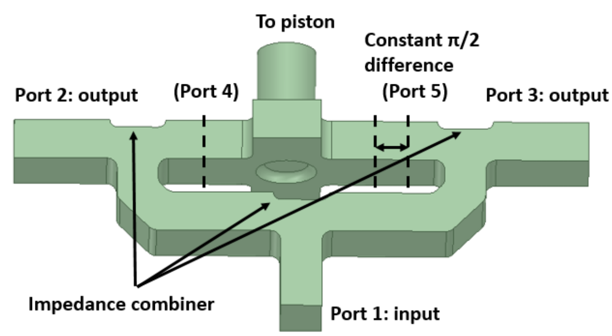
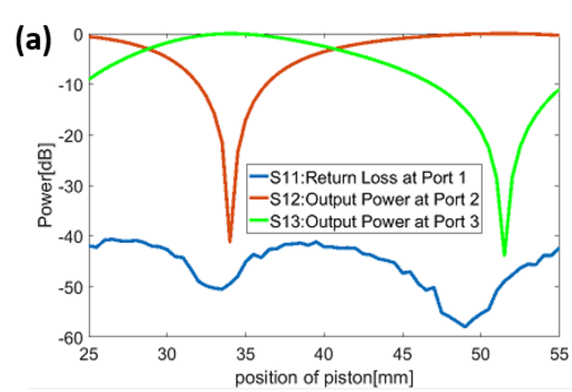


Figure 5: Geometry of RF power splitter (HFSS model).

Output RF power values at each ports are shown in Fig.6 (a). After optimization, arbitrary RF division ratio at port 2 and port 3 is achieved and component is matched at any division ratio with the maximum reflection below -40dB. Surface electrical field distribution when all RF power is output at port 3, as shown in Fig.6 (b). For 100MW peak RF power, the maximum field is optimized to 65MV/m, considered safe without RF breakdown. As shown in Fig.6 (c), the bandwidth is 250MHz for port2 and 320MHz for port3, which is large enough for operating at 11.424GHz as center frequency.



ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPTS039

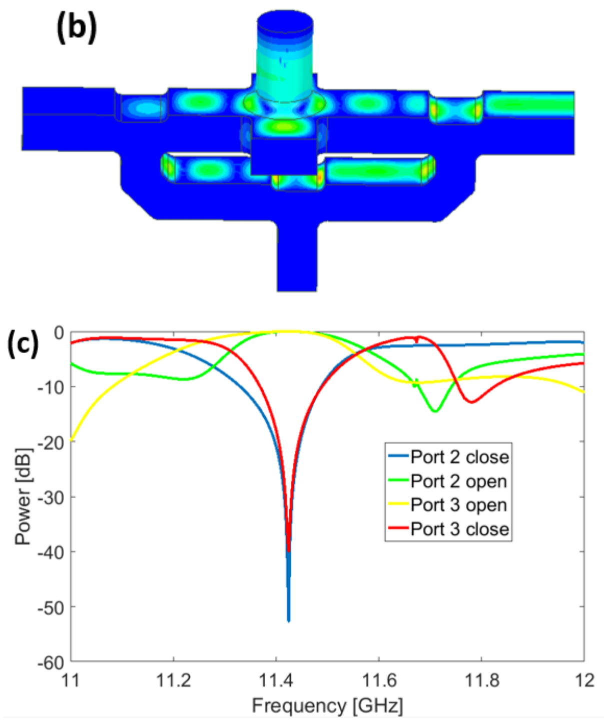


Figure 6: RF splitter using E-bend: (a) power at each port versus position of piston, (b) surface electrical field distribution, and (c) bandwidth of output ports.

CONCLUSION

A compact X-band RF splitter with arbitrary power division ratio was designed. The optimization of RF circular polarizer and E-bend structure makes the geometry of whole component more compact. Meanwhile, the splitter has advantages of low reflection, large bandwidth, and safe surface field for high-power use. This component is designed for the high RF power X-band test stand in Tsinghua University, and will be manufactured in the second half of this year if time permits.

REFERENCES

[1] M. M. Peng, J. Shi, P. Wang, Z. Sun, and D. Zhang, "Deveopment of LLRF System for Tsinghua X-band High Power Test Facility", in *Proc. 13th Symposium on Accelerator Physics (SAP'17)*, Jishou, China, Aug. 2017, pp. 86-88. doi:10.18429/JACoW-SAP2017-MOPH25

[2] Zha H , Syratchev I , Gudkov D , *et al.* Design of a variable X-band RF power splitter[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2017, 859:47-51.

[3] T. Shintake, N. Akasaka and H. Matsumoto, "Development of C-band RF pulse compression system for e+e- linear collider," Proceedings of the 1997 Particle Accelerator Conference (Cat. No.97CH36167), Vancouver, BC, 1997, pp. 455-457 vol.1.

[4] I. Syratchev, Variable high power RF splitter and RF phase shifter for CLIC. No. CERN-OPEN-2003-005. 2003.

[5] O. A. Ivanov, V. A. Isaev, M. A. Lobaev, A. L. Vikharev, and J. L. Hirshfield et al. High power microwave switch employing electron beam triggering with application to active RF pulse compressors. Phys. Rev. ST Accel. Beams 14, 061301 (2011).

[6] Fumihiko Tamura and Sami G. Tantawi. Development of high power X-band semiconductor microwave switch for pulse compression systems of future linear colliders. Phys. Rev. ST Accel. Beams 5, 062001. (2002).

[7] Zhuang, Leimeng, et al. "Photonic high-bandwidth RF splitter with arbitrary amplitude and phase offset." IEEE Photonics Technology Letters 26.21 (2014): 2122-2125.

[8] Reichel, Kimberly S., Rajind Mendis, and Daniel M. Mittleman. "A Broadband Terahertz Waveguide T-Junction Variable Power Splitter." Scientific Reports 6 (2016): 28925. PMC. Web. 21 Dec. 2016.

[9] C. Chang, S. Tantawi, S. Church, J. Neilson, and P. V. Larkoski, Novel compact waveguide dual circular polarizer, Prog. Electromagn. Res. 136, 1 (2013).