DESIGN OF A VARIABLE X-BAND RF POWER SPLITTER

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Abstract

The design of the variable high RF power X-Band splitter is presented. The RF power division ratio is adjusted by mechanically changing the position of a special RF short circuit piston. The piston is mounted on a step-motor providing the precise linear movement. Throughout the design, special measures were taken to reduce the maximum electric field on the copper surface, as well as to maximise the frequency bandwidth of the device.

INTRODUCTION

High RF power X-band test stands for testing the normal conducting CLIC accelerating structures are now in operation at CERN. In general, these tests require a precise adjustment of the driving RF power level [1]. The RF splitter with arbitrary division ratio will be used to meet this need without changing the RF power provided by RF source itself. The RF splitter is a three port device, where one output port is connected to the DUT (Device Under Test) itself and the other is connected to the matched RF load, which absorbs the excessive RF power. The division of RF power between the two is adjusted by mechanically changing the position of a special RF short circuit piston (see Fig. 5 in [2]). The piston is an RF contact free device and is mounted to a step-motor providing the precise movement. Thus a continuous adjustment of the RF power is achieved.

PRINCIPLE OF OPERATION

The schematic of the splitter RF circuit is shown in Fig. 1. For the known parameters s_{ij} in the scattering matrix (1), the output power in each port y_n can be calculated using equation (2). Parameter ρ in equations (1 and 2) is the reflection from the RF short circuit piston.

The output power in the ports y_1, y_2 and y_3 depends on the RF phase of the reflection ρ. By controlling the position of the RF short circuit piston, this phase can be changed, thus the output power at ports 2 and 3 can be adjusted. In order to minimize the overall reflection, the RF splitter should be matched, thus y_1 should be equal to zero. Consequently s_{11} and s_{14} should be equal to zero as well, but not s_{41}, otherwise y_2 and y_3 will be de-coupled. This condition ($s_{14} \neq s_{41}$) breaks the symmetry of the RF circuit and makes matching of the device impossible.

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} \\ s_{21} & s_{22} & s_{23} & s_{24} \\ s_{31} & s_{32} & s_{33} & s_{34} \\ s_{41} & s_{42} & s_{43} & s_{44} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ \rho y_4 \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} s_{11} \\ s_{21} \\ s_{31} \end{pmatrix} + \begin{pmatrix} s_{14} \\ s_{24} \\ s_{34} \end{pmatrix} \frac{\rho s_{41}}{1 - \rho s_{44}} \quad (2)$$
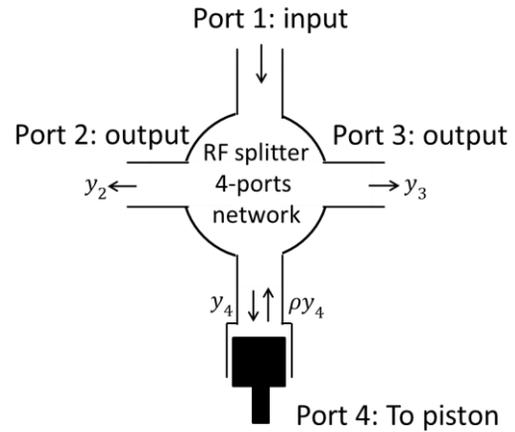

Figure 1: The 4 port network proposal for RF splitter.

The way to approach matching is to have a 5-port network where two ports are connected to the piston. It can be proven that a solution for the symmetric network exists in this case. A schematic of such a 5-port network is shown in Fig. 2. It uses 3 symmetric RF splitters to split the input port to 4 output branches. Each of the symmetric RF splitters is designed in a way that every port sees the combined impedance of the two others. The distance between the first and second symmetric RF splitter is a quarter-wavelength. According to transmission line theory, the total impedance seen by the input port is $\frac{1}{Z_2 + Z_4} + \frac{1}{Z_3 + Z_5}$, where Z_i is the impedance of each port by itself. As shown in Fig. 2, port 2 and 3 are output ports, thus $Z_2 = Z_3 = 1$. The RF short circuit pistons bring reactance, so that the values of Z_5 and Z_4 are purely imaginary. The input port will be matched if $Z_5 * Z_4 = 1$. That can be achieved by having 180 phase difference in reflection between the two short circuit pistons. The power division ratio is now determined only by the reflection phase of the pistons and can be varied from 0 to 1. This network design is very compact and has a broad frequency bandwidth. However, two synchronised short circuit pistons are needed, thus a certain complication of the mechanical design is unavoidable.
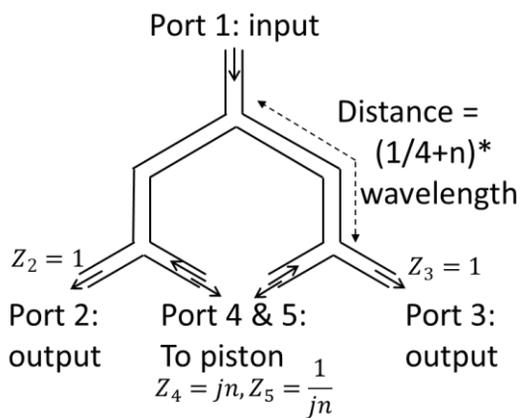
Figure 2: The 5 port network proposal for RF splitter.

The system shown in Fig. 2 can be further simplified, if one port can accommodate two different waveguide modes, like two TE_{11} modes in a circular waveguide with orthogonal polarisations. In this case, only one short circuit piston can be used to reflect both modes. The RF circular polarizer (see Fig. 3) is a device, which can provide such mode merging [3]. Here, RF signals that are coming from left (port 4) and right (port 5) will excite modes with orthogonal polarization in the connected circular waveguide. The circular waveguide is terminated by the short circuit piston, which reflects both polarisations equally. Ports 4 and 5 are completely decoupled, so that the phase of reflected signals will be identical for both. This RF circular polarizer is used to substitute the two channels with short circuit pistons in the 5-port network shown in Fig. 2.
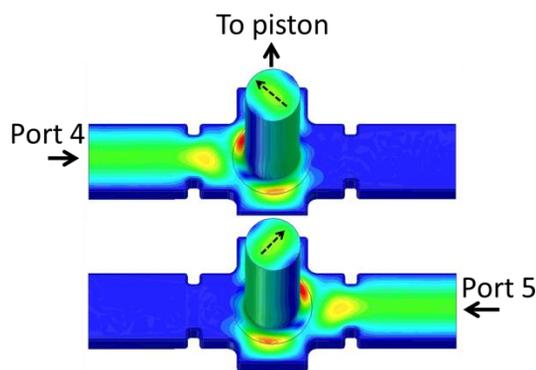

Figure 3: RF polarizer.

RF DESIGN AND OPTIMIZATION

Figure 4 shows the design of an RF variable splitter, which implements the concept of RF circular polariser. It is comprised of several waveguide-based components: three symmetrical splitters, two H-bends and the circular polarizer. All components are designed using WR90 waveguide transverse dimension (22.86 mm x 10.16mm) and the diameter of the circular waveguide is 18 mm. To provide the most compact design, as well as to maximize the frequency bandwidth, the distance between all components was minimised. This design was optimised using HFSS [4] (see Fig. 4(a)). The values of the output

RF power at each port versus the piston position are shown in Fig. 4(b). After carefully tuning of all components, the system achieved a good matching state where the maximum reflection is less than -35 dB. The bandwidth of the device varies between 180 MHz and 270 MHz depending on the division ratio between the two ports. For 100 MW peak RF power, the maximum surface field is 48 MV/m. This field level is considered safe for X-band RF pulses shorter than 2 microseconds.
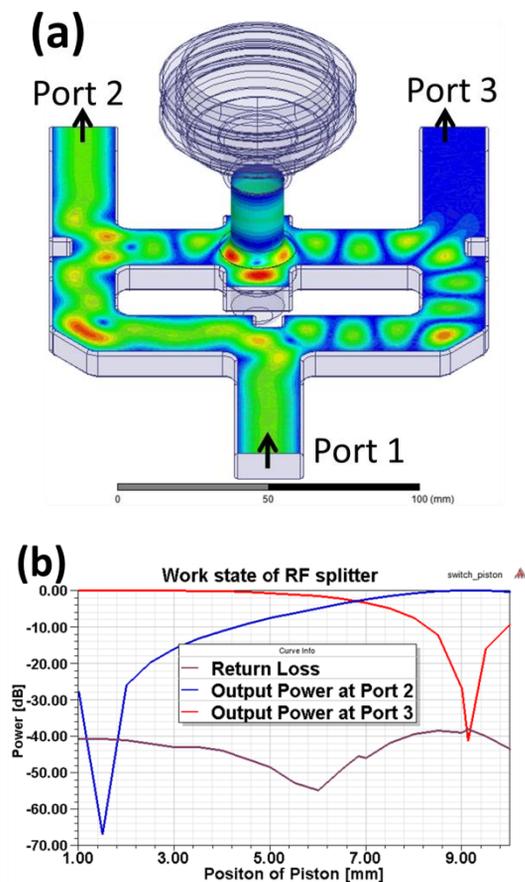

Figure 4: the RF splitter design using WR90 waveguide: (a) geometry; (b) power at each port versus position of the piston.

The overall transverse dimension of the device shown in Fig. 4 is about 160 mm. The second, even more compact generation with a different topology of the variable splitter is shown in Fig. 5. It is as small as 100 mm across the long side. In this modification, a waveguide cross-section of 20 mm x 12 mm was used. The maximum reflection in this design is less than -40 dB for any piston position. The bandwidth is between 370 MHz and 280 MHz depending on the division ratio. This is about 30% wider compared to the design shown in Fig. 4. For 100 MW RF peak power, the maximum electric field is 50 MV/m. The mechanical design of the variable splitter has been completed (see Fig. 6) and the fabrication has started.
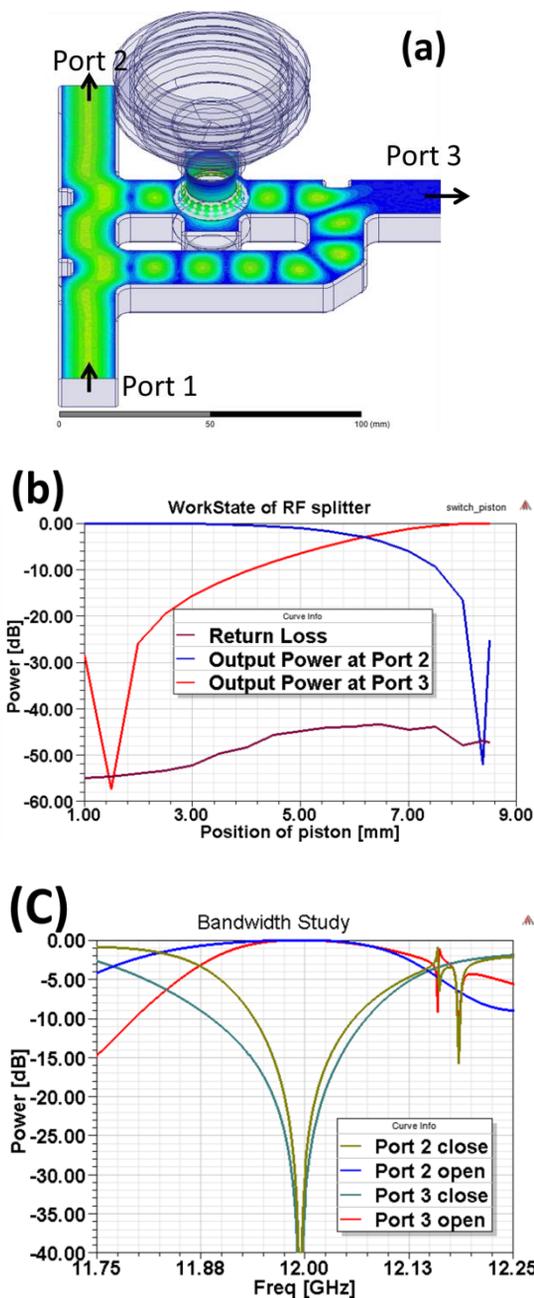
Figure 6: Mechanical design of the variable RF splitter.

CONCLUSION

An X-band RF splitter with arbitrary division ratio was designed. The design uses waveguide-based components including RF splitters, H-bends and the RF polarizer. It was carefully tuned to provide a compact, low reflection, large bandwidth and low surface field design. Fabrication has started and once completed and tested the installation in the CERN X-band test stands is foreseen.

REFERENCES

[1] N. Catalan-Lasheras et al., WEPME016, Proc. of IPAC'14, Dresden, Germany (2014); http://www.JACoW.org

[2] I. Syratchev et al., WEPE026, Proc. of IPAC'10, Kyoto, Japan (2010); http://www.JACoW.org

[3] Alessandro Navarrini and Richard L. Plambeck, IEEE Trans. Microw. Theory Tech. **54**(1) 272 (2006).

[4] Ansys HFSS; http://www.ansys.com

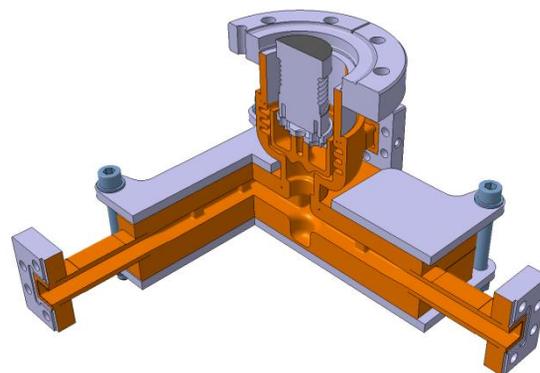Figure 5: RF splitter design using 20 mm x 12 mm waveguide: (a) geometry; (b) power obtained at each port versus position of piston; (c) bandwidth plots.