CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC – Note – 1192

HIGH POWER CONDITIONING OF X-BAND VARIABLE POWER SPLITTER ND PHASE SHIFTER

V. del Pozo Romano[1], H. Bursali[1], N. C. Lasheras[1], A. Grudiev, S. L. Pitman[1], I. Syratchev[1], M. Volpi[1,3] and C. Serpico[2]

[1]CERN, Geneva, Switzerland
[2]Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Italy
[3]University of Melbourne, Parkville, Australia

Abstract

The three X-band test facilities currently at CERN aim at qualifying CLIC structures prototypes but are also extensively used to qualify X-band components operation at high power. In order to upgrade one of the facilities from a single test line to a double test line facility, a high power variable splitter and variable phase shifter have been designed and manufactured at CERN. They have been power tested, first in a dedicated test and also in their final configuration, to ensure stable power operation before installing them together with an accelerating structure. In this paper, we broadly describe the RF and mechanical design, manufacturing and low power measurements agreement with simulations. We report the high power qualification of both components and their suitability to be used in existing and planned X-band facilities.

Presented at the 10th International Particle Accelerator Conference, Melbourne, Australia, 19-24 May 2019

Geneva, Switzerland
May 2019

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB064

HIGH POWER CONDITIONING OF X-BAND VARIABLE POWER SPLITTER AND PHASE SHIFTER

V. del Pozo Romano*, H. Bursali, N. C. Lasheras, A. Grudiev, S. L. Pitman, I. Syratchev, M. Volpi[1],
European Organisation for Nuclear Research (CERN), Geneva, Switzerland,
C. Serpico, Elettra-Sincrotrone Trieste S.C.p.A., Basovizza
[1] also at University of Melbourne, Parkville, Australia

Abstract

The three X-band test facilities currently at CERN aim at qualifying CLIC structures prototypes but are also extensively used to qualify X-band components operation at high power. In order to upgrade one of the facilities from a single test line to a double test line facility, a high power variable splitter and variable phase shifter have been designed and manufactured at CERN. They have been power tested, first in a dedicated test and also in their final configuration, to ensure stable power operation before installing them together with an accelerating structure. In this paper, we broadly describe the RF and mechanical design, manufacturing and low power measurements agreement with simulations. We report the high power qualification of both components and their suitability to be used in existing and planned X-band facilities.

INTRODUCTION

The design of the RF power splitter and phase shifter must satisfy the requirements of X-band RF technologies in particle accelerating structures. These requirements include high power level (up to 100 MW for short pulse length ([50-200] ns). The geometry of both components have been designed to have a compact size and large bandwidth. The surface field is also minimized to reduce possible RF breakdown in high-power use.

RF AND MECHANICAL DESIGN

Variable RF Power Splitter

The variable RF power splitter implements the concept of RF circular polariser (see Fig. 1), signals coming from the middle waveguides will excite modes with orthogonal polarization in the connected circular waveguide. The circular waveguide is terminated by a short circuit piston, which reflects both polarisations equally. The output power to ports 2 and 3 is adjusted by mechanically changing the position of the piston. The mechanical design shows the contact free piston and the upper flange where a step-motor is connected providing its precise movement [1].

RF Phase Shifter

The RF phase shifter design is also based on the concept of the RF circular polariser and a movable piston to change, in this case, the phase between the ports (see Fig. 2). The design is symmetric, thus, both ports can be used as either input or output. The RF phase variation is 20°/mm of piston displacement. When the piston comes closer to the circular waveguide transition the isolation deteriorates, so the minimum distance between the transition and the piston is limited to 20 mm to ensure good isolation with large bandwidth [2].

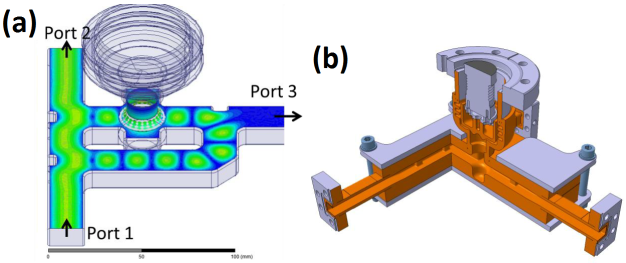

Figure 1: Variable RF splitter HFSS simulations (a) and general view of mechanical design (b).

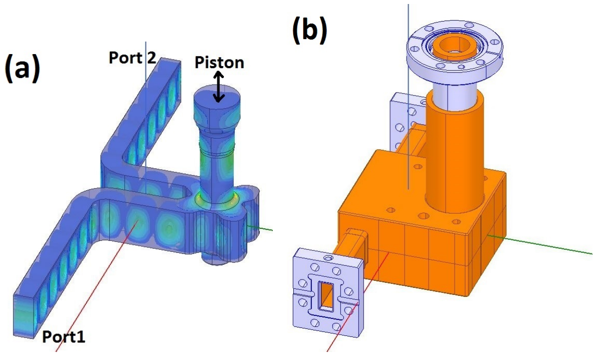

Figure 2: Phase shifter HFSS simulations (a) and general view of mechanical design (b).

LOW POWER MEASUREMENTS

After manufacturing of both components and their respective pistons, a step-motor was mounted in each of them (see Fig. 3) and they were ready for low power testing with the VNA. Results from these measurements have been compared with simulations.

Variable RF Power Splitter

Port 1 was used as the input so the transmission coefficients in Figure 4 correspond to S21 and S31 parameters in a 4-port VNA. Open and close refer to the position of the piston allowing all power (open) through that port or

---

* veronica.del.pozo.romano@cern.ch

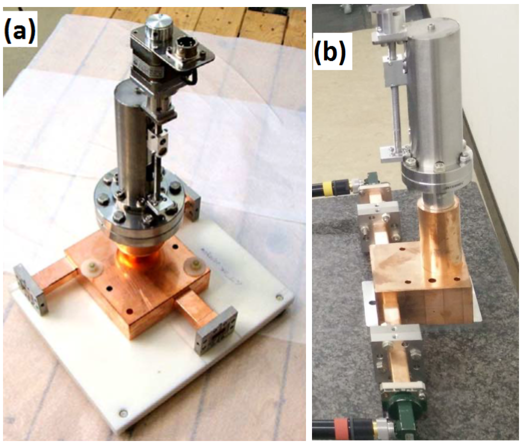

Figure 3: Step-motor installed in manufactured variable RF splitter (a) and RF phase shifter (b).

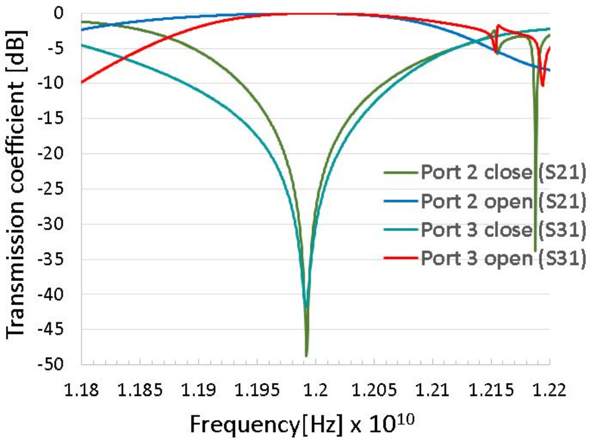

Figure 4: Rf splitter transmission coefficients measured with VNA.

none (close). Figure 5 shows the same coefficients plus the return loss (S11) at different positions of the piston. VNA measurements are very close to simulation results [1], the return loss is higher in reality than on the simulations but still well below -30 dB.

The phase was measured as well, showing that it changed when moving the piston (see Fig. 6); therefore, a phase shifter was needed after one of the ports of the power splitter to compensate for this variation.

RF Phase Shifter

Before connecting the motor, simulations and measurements were done with a short connector installed instead of the step-motor. Results showed that the reflection coefficient differs significantly from the simulated (-40 dB) and reaches -30 dB at the operating frequency (11.992 GHz).

With the motor installed new measurements were done at different piston positions (see Fig. 7). Again, results differed from simulations and specially for the reflection coefficient, which was quite high (>-25 dB) at some piston positions. Using these coefficients as a reference, we established an operating range of 17 mm around the lower dissipation areas which corresponded to a phase shift of 360°.

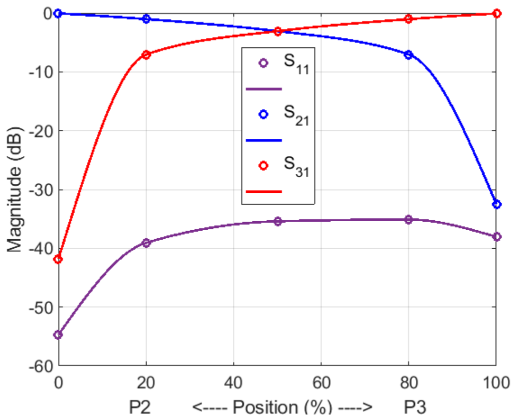

Figure 5: RF power splitter S-parameters vs. piston position measured with VNA.

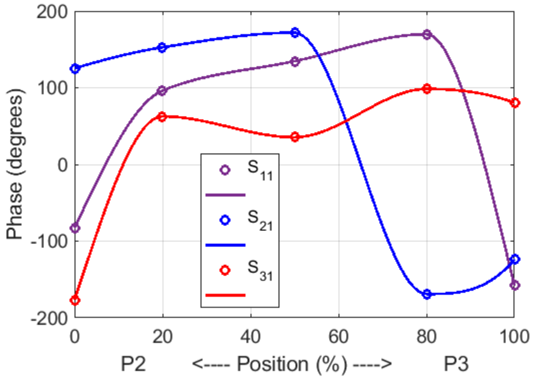

Figure 6: RF splitter phase variation vs. piston position measured with VNA.

HIGH POWER QUALIFICATION

Before installing these components together in their final configuration in Xbox2, they were high power tested separately in Xbox3, which allows the simultaneous test of two DUTs with different conditioning specifications at high power and high repetition rate [3,4]. Phase shifter input was connected after the pulse compressor and a high power load was connected to its output [5]. In the case of the power splitter, two loads were connected to its outputs (see Fig. 8), a high power load and a 3D printed spiral load already conditioned at CERN [6].

After a month of conditioning, the phase shifter was still struggling at a couple of megawatts while the power splitter had reached 15 MW. Even though the two test lines can have independent pulse and power configuration, the lines are still communicated and it was found that a big difference in power led to leakage from one line to the other; therefore, the phase shifter was actually seeing more power than a couple of megawatts. From that moment on, both lines were kept at a similar power level.

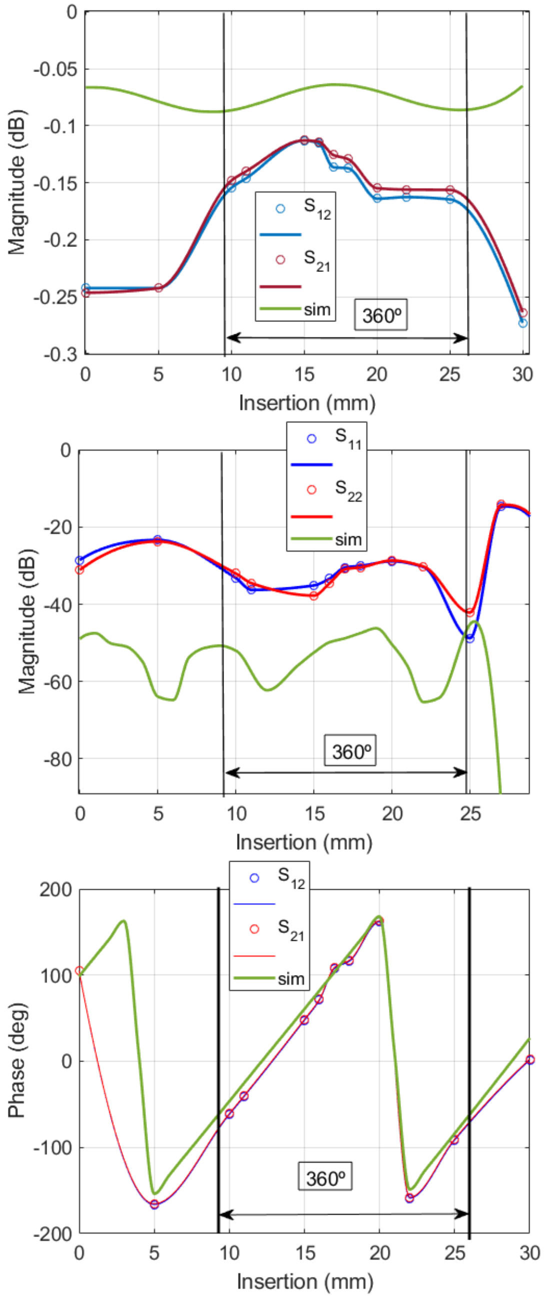

Figure 7: RF phase shifter transmission coeff. (top) reflection coeff. (middle) and transmission phase variation (bottom) vs. piston position from measurements and simulation.

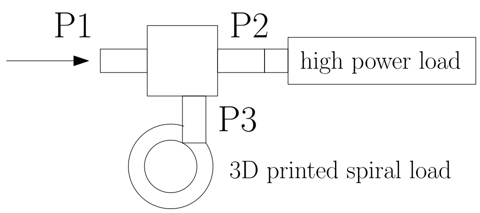

Figure 8: Schematic of the power splitter installation.

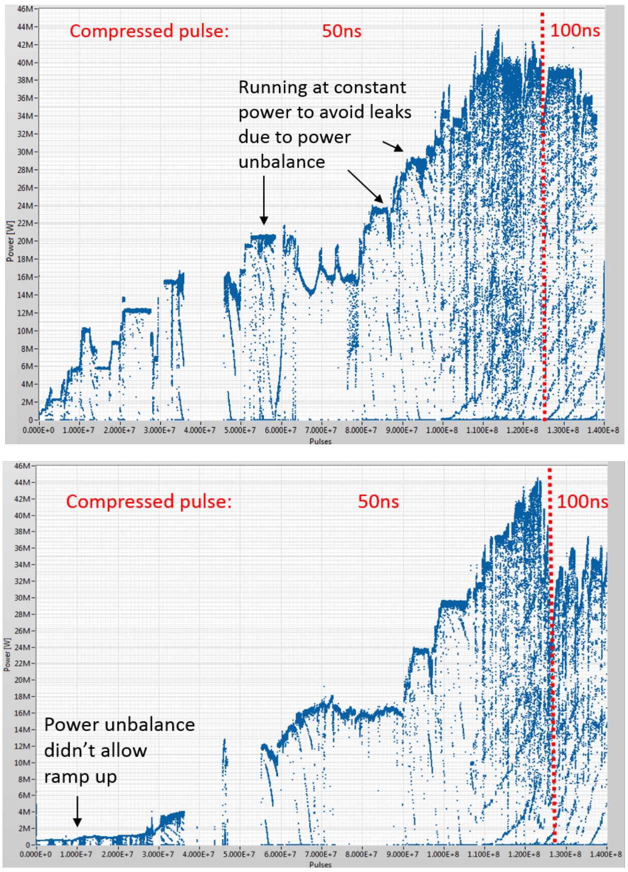

Figure 9: Conditioning plots: Peak power in MW vs. number of pulses for power splitter (top) and phase shifter (bottom).

Table 1: Max. Peak Power and Average Lower Levels Reached at 50 Hz Repetition Rate

Pulse width	***Phase Shifter*** *Max. peak*	*Average*	***Power Splitter*** *Max. peak*	*Average*
50 ns	44 MW	110 W	43 MW	108 W
100 ns	37 MW	185 W	41 MW	205 W

Three different positions of the pistons were tested for both components. The starting compressed pulse width was 50 ns and was later increased to 100 ns (see Fig. 9). Even if the repetition rate capability of the Xbox3 is 400 Hz, we chose to run at 50 Hz to limit the average power seen by the piston and match the intended use of these components in Xbox2. The maximum peak power levels reached is summarize in table 1. At higher pulse length the maximum peak power available from the klystrons is lower, keeping the same average power. The test stopped due to a klystron instability problem that forced the replacement of the klystron.

After a successful high power test, both the power splitter and the phase shifter were ready for installation together in Xbox2 for testing a superstructure, but before installing the structure a couple of loads were installed to perform conditioning of the complete line. Testing is still ongoing.

CONCLUSION AND FUTURE WORK

A high power phase shifter and a variable power splitter have been designed, manufactured and tested at CERN. They will be used in the upgrade of Xbox2 from a one line to a two lines test bench, that will allow testing a superstructure. They have been validated both in low power and high power individually.

REFERENCES

[1] H. Zha, I. Syratchev, D. Gudkov, and A. Grudiev, "Design of a Variable X-band Power Splitter", *Proc. of IPAC'15*, Richmond, VA, USA, May 2015.

[2] A. Grudiev, "Design of Compact High Power RF Components", *CLIC-Note-1067*, CERN, Geneva, Switzerland, May 2016.

[3] N. Catalan Lasheras *et al.*, "Commissioning of XBox-3: A very high capacity X-band test stand", in *Proc. of 28th Linear Accelerator Conference*, East Lansing, Michigan, Sept. 2016.

[4] M. Volpi *et al.*, "High power and high repetition rate X-band power source using multiple klystrons", *Proc. of IPAC'18*, Vancouver, Canada, May 2018.

[5] M. Filippova, V. Soldatov, A. Solodko, G. Riddone, and I. Syratchev, "Engineering design and fabrication of X-Band components", *Proc. of IPAC'11*, San Sebastian, Spain, Sept. 2011.

[6] N. Catalan Lasheras *et al.*, "High Power Conditioning of X-band RF Components", *Proc. of IPAC'18*, Vancouver, Canada, May 2018.