CACO: A CAVITY COMBINER FOR IOT AMPLIFIERS

B. Bravo, F. Mares, F. Perez, CELLS - ALBA, Spain
P. Sanchez, F4E, Spain
M. Langlois, ESRF, France

Abstract

The ALBA storage ring uses six room temperature cavities; each one fed by two 80kW IOTs amplifiers at 499.654 MHz. The power of the pair of transmitters is combined by a cavity combiner, CaCo. One of the design requirements of CaCo was that it continued working safely and with a good efficiency in the case of an IOT failure (asymmetrical mode). During the first asymmetric full power tests, in May 2010, with an active IOT and the other passive, the result was dramatic, the passive IOT broke in two parts after few hours of operation. This paper presents the experimental results and the electromagnetic field simulations of the asymmetrical operation mode of CaCo, i.e. one active IOT and the other passive, and analyze why the ceramic of the output tube of the passive IOT broke during the first performance of this mode. Also, it reports a possible solution to solve this problem.

INTRODUCTION

ALBA is a 3 GeV, 400 mA, 3rd generation Synchrotron Light Source in Cerdanyola, Barcelona, Spain. The RF System, formed out of six RF plants, provides 3.6 MV of accelerating voltage and restores up to 540 kW of power to the electron beam. One of the new developments included at the RF plants is CaCo: A cavity combiner to add the power of two 80 kW IOTs to produce the more than 150 kW needed for each DAMPY cavity, a normal conducting HOM damped cavity developed by BESSY and based in the EU design cavity [1].

CaCo is a three port device and is realized using a coupled pillbox cavity. The two inputs ports are coaxial 6 1/8" and the output port is coupled to a rectangular waveguide, see figure 1. All the design details and first test of this device are described in [2].

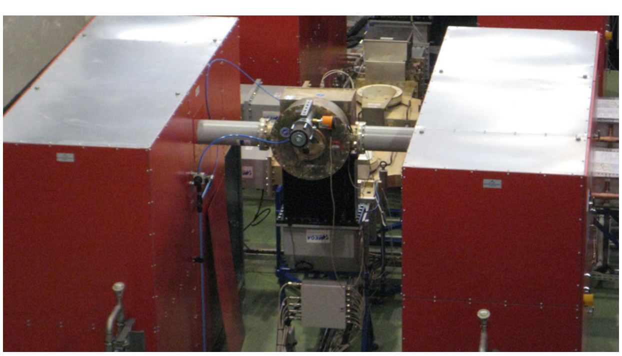

Figure 1: CaCo installed between two IOT's cabinets.

CACO HIGH POWER OPERATION: SYMMETRICAL MODE

In this mode the two active IOTs feed CaCo symmetrically. The two incidents waves from the IOTs are combined in CaCo and the resulting wave leaves by the rectangular waveguide.

Simulations and measurements show that the optimum performance of the CaCo as a combiner is depending on the right phase and amplitude of the two incident ways. Figure 2 shows a low power measurement example of a phase difference of 10º, which increase the reflections at the IOT ports from -50 dB up to -20 dB.

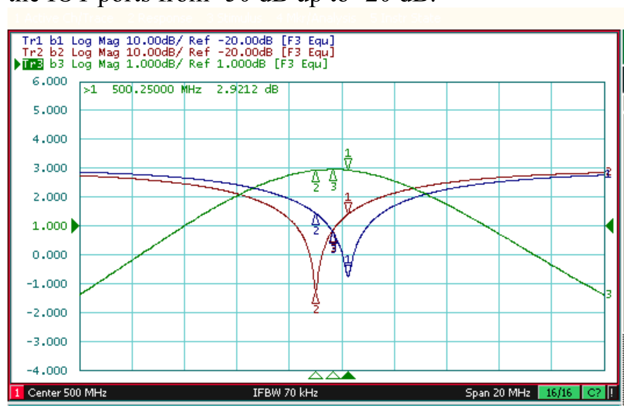

Figure 2: CaCo response with a 10º phase difference at the input ports.

In real operation the incident power of each IOT will include losses and phase delays due to the different IOTs behaviour but also due to connectors, cables and transitions. For this reason to make the performance of CaCo optimal we control the gain and the phase of each IOT via the Digital LLRF.

At high power a retuning of the CaCo via the plunger is also needed in order to optimize it for thermal effects.

Once both adjustments done, the reflected power at the IOTs ports was maintained always below 100 Watts, i.e. below -30 dB.

In routine operation, during cavity conditioning and during the ALBA storage ring commissioning, CaCo has performed reliably and without problems

CACO HIGH POWER OPERATION: ASYMMETRICAL MODE

In this mode of operation only one active IOT feeds the system and the other is keeping passive.

This mode is intended to cope with the situation when there is a fault in one IOT and we still operate the cavity. Adding extra redundancy to the overall RF system.

For this, CaCo is equipped with a second plunger that matches the RF circuit of the passive IOT to a short circuit, and allows full transmission of the active IOT.

High power operation

During the single IOT's commissioning, it was decided to use this mode of operation to speed up the commissioning of the twelve IOTs of the Storage Ring.

The CaCo plunger was set to asymmetrical mode (fully moved in) and the shutter of the waveguide was closed, so that the power of one single IOT was passing CaCo, then through the circulator to the short cut created by the shutter to return again via the circulator to the load. Thus requiring not dismounting of coaxial neither waveguide components.

The first try was performed the first week of May 2010. The transmitters Tx07 and Tx08 were tuned al low power separately and afterwards were connected to the corresponding CaCo.

Commissioning at high power of Tx08 was done without major problems up to 75 kW. Tx07 was kept off during this operation.

Switching to the operation of Tx07, there was an arc trip just two minutes after switching on the high voltage. Attempts to switch it on again were without success and indication was that the IOT has lost the vacuum.

Dismounting the IOT from the carriage it was discovered that the ceramic was broken in three parts, see figure 3.

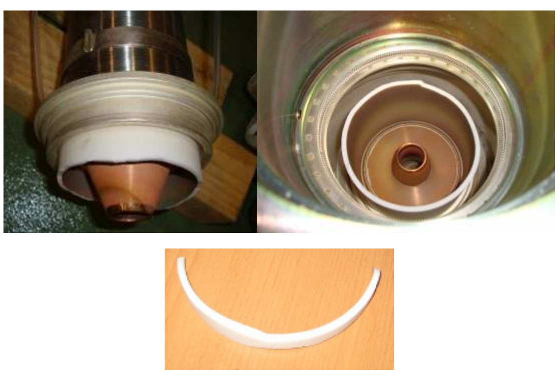

Figure 3: Broken IOT in three parts.

Electromagnetic simulations

The aim of this part is to understand why the ceramic of the passive IOT broke. For this purpose it is important to analyze the backgrounds of this project and how does the asymmetrical mode work.

First of all, if no passive IOT were present, the power will transfer from the active IOT, through a 6 1/8" coaxial waveguide, to CaCo. In the resonator is formed a standing wave that couples to port 2 and port 3, because those two ports are matching networks. The incoming wave is divided and only half of the power leaves port 3, the other half goes towards the other IOT port, figure 4.

Characterising the passive IOT by measuring the impedance with a network analyser it results that it behaves as a short circuit.

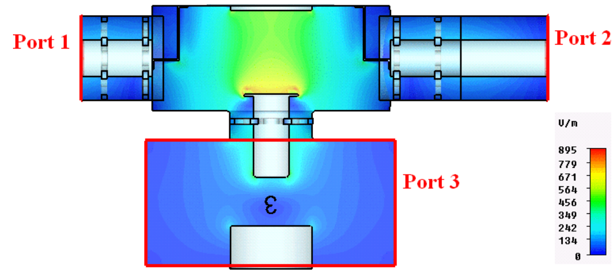

Figure 4: CaCo power flow.

So, when the passive IOT is present it is like a short circuit is placed at this port, so that in the passive arm a standing wave is created that interferes with the one of CaCo. As a result of this interference, the standing wave of the resonator couples to port 3 and not to port 2. All power goes towards the cavity.

During the real operation of the asymmetrical mode at ALBA it was not detected any incident power to the passive IOT, the measurements showed all the incident power was delivered to the cavities, confirming the previous analysis. So, if there was not power flow towards the passive IOT, how could the ceramic break?

To understand it, a simulation of the whole system was performed. The simulation shows that a standing wave is created in the passive arm. As a consequence of this a large voltage is created in the gap of the passive IOT. See figure 5.

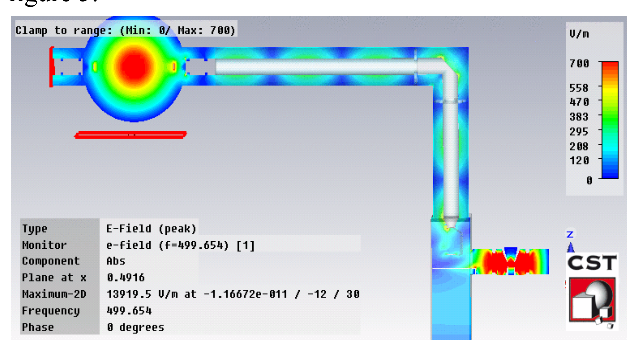

Figure 5: Simulation of the standing wave in the passive IOT arm.

This high voltage at the ceramic will create sparks and without any cooling system (it was disconnected since it was in passive operation) it provokes a huge thermal stress in the ceramic, weakening it and at some point, breaking it.

PROPOSAL OF A SOLUTION: CoStub

The requirements for a possible solution are: short circuit the coaxial waveguide before the passive IOT, has to be compatible with the current design, have a good high power performance and do not perturb the system when it works in the symmetrical mode.

Taking into account all the requirements it was proposed to use stubs tuner. The numbers of the stubs, the shape, the length and width of the stubs, the position of the stubs along the coaxial waveguide, the distance between the stubs have been optimized for a good performance in both symmetrical and asymmetrical mode. This device was named CoStub (coaxial stub).

Figure 6 shows the result of the simulation of the whole system after the optimisation process. CoStub stops the wave that travel through the passive arm, this way the passive IOT is protected.

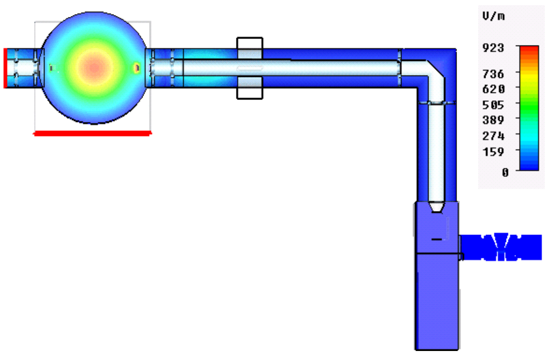

Figure 6: Simulation of the CoStub performance.

The two factors that can limit the stub performance or lead to its damage at high power are: the power dissipated by the stubs and the electric breakdown.

The calculated power dissipated by the stubs is 10 W which is quite low, therefore it is not necessary a cooling system for a good performance of the stubs. The maximum electric field magnitude around the stubs (scaled for 80000 RMS) is 14000 V/m, which is lower than the electric field magnitude breakdown, so it is ensured that the stubs will have a good high power performance, this means that they do not cause sparks and overheating.

The final design implementation and the cross section of the CoStub are shown in the figure 7 and 8.

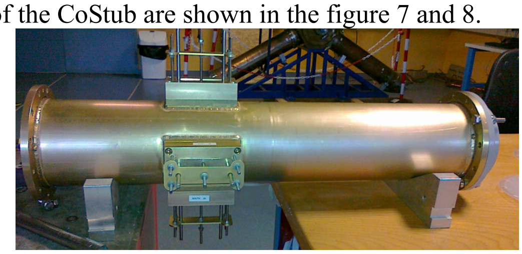

Figure 7: Picture of the CoStub to short cut the coaxial line of the IOT arms.

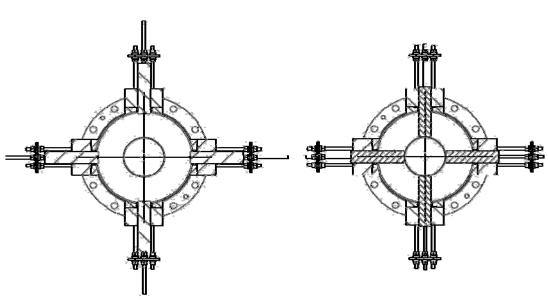

Figure 8: Cross section of the CoStub in symmetrical (left) and asymmetrical (right) modes.

Low and high power measurements of CoStub

CoStub was assembled on the CaCo and tests were carried out with network analyzer to determine the S-parameters. All the electrical parameters were found satisfactory, figure 9.

The prototype was tested for high power. The passive arm was connected to a power meter. The power in the active IOT was increased till 30 kW, the power meter measured less than 0.2 Watt in very good agreement with the simulations. No sparking, overheating neither RF leaks were observed. The results were according to the expectations.

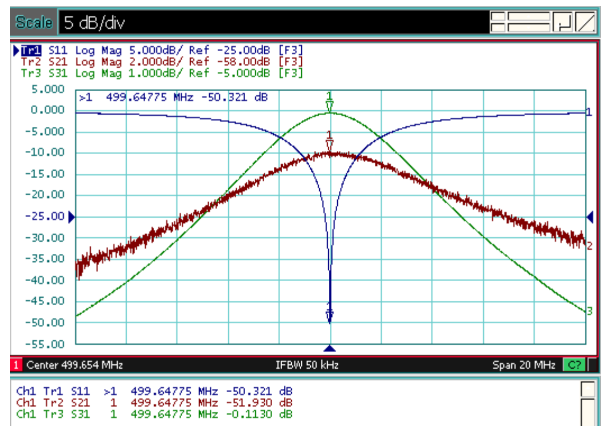

Figure 9: CoStub S-parameters showing complete isolation of the passive IOT.

CONCLUSION

The two possible operation modes of CaCo at high power have been tested. The symmetrical mode works properly and without presenting any problem. But in the asymmetrical mode a standing wave is created between the passive IOT and Caco, provoking a large voltage in the gap of the passive IOT that broke the ceramic. A new device, CoStub (coaxial stub), to short circuit the coaxial waveguide of the passive arm and protects the passive IOT is proposed and under test.

REFERENCES

[1] M.Langlois, M.Cornelis, F.Perez and D.Einfeld: RF measurements on variations of the 500 MHz Aba Dampy cavity. September 2008.

[2] F.Perez, B.Baricevic, P.Sanchez and D. Einfeld, M.Langlois: High power cavity combiner for RF amplifiers. September 2006.

[3] Thomson Broadcast and Multimedia AG: IOT SN 611024 Fail report Rev.4. May 2010.