HIGH POWER (35 KW AND 190 KW) 352 MHZ SOLID STATE AMPLIFIERS FOR SYNCHROTRON SOLEIL

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Abstract

In the SOLEIL storage ring, two cryomodules, each containing a pair of superconducting cavities will provide the maximum power of 600 kW, required at the nominal energy of 2.75 GeV with the full beam current of 500 mA and all the insertion devices. Each of the four cavities will be powered with a 190 kW solid state amplifier consisting in a combination of 315 W elementary modules (about 750 modules per amplifier). The amplifier modules, based on a technology developed in house, with MOSFET transistor, integrated circulator and individual power supply, will be fabricated in the industry. In the Booster, a 35 kW solid state amplifier (147 modules) will power a 5-cell copper cavity of the LEP type. The status and the test results of the different parts of the equipment are reported in this paper.

INTRODUCTION

At LURE-Orsay, a program of R&D on solid state amplifiers started ~ 12 years ago. Solid state amplifiers operating at 100 MHz - 1.8 kW and 500 MHz - 1.5 kW were realised and operated on the SUPER-ACO ring. From their commissioning in 1997 until the LURE shutdown in December 2003, they run without a single failure whilst the tetrodes, which were used previously, had to be replaced periodically [1].

When the SOLEIL design phase started in the mid 1990s, it was naturally proposed to benefit from the experience acquired in that domain. The development of a 352 MHz - 2.5 kW prototype was launched with the goal to validate both the 330 W amplifier module design and the power combination scheme. The successful results [2] led to the decision of applying this technology for the SOLEIL Booster (BO) amplifier and the fabrication of a 352 MHz - 35 kW CW power plant was launched. It shall power a 5-cell copper cavity of the CERN LEP type that will provide up to 0.8 MV of accelerating RF voltage with 20 kW of power (~ 15 kW dissipated in the cavity walls and 5 kW delivered to the beam) [3].

In synergy with the LURE projects, two other 2.5 kW amplifiers were built, following the same approach, one at 352 MHz for LNL [4] and another one at 476 MHz for LNLS, the Brazilian light source, where it is reliably operated since several years [5].

In the mean time, investigations started about the design of the RF system for the SOLEIL storage ring (SR). Two cryomodules, each housing a pair of 352 MHz superconducting cavities shall transfer up to 575 kW of RF power to the electron beam [3,6,7].

Different possible alternatives for the RF power sources were considered in terms of modularity and technology, with vacuum tubes (Klystron, IOT, Diacrode) and the solid state version. The absence of commercially available vacuum tubes at 352 MHz in the 180 - 400 kW power range, led us to select the solid state technology with 4 power plants (one per cavity), each capable of providing up to 190 kW CW [8]. Although it is quite innovative in this power range, the choice of the solid state technology presents significant advantages: high modularity with associated redundancy and flexibility, elimination of the HV and of the high power circulator, simpler start-up procedures and operation control, no need for periodical replacement, low operational costs (no costly spare parts). For the SOLEIL case, the total investment cost is lower than the solutions with vacuum tubes and one can profit of the existing in house expertise.

In the following sections, the design of the solid state amplifiers for the SOLEIL BO and SR are described; the test results of the former, the status and schedule of the latter are reported.

BO 35 KW SOLID STATE AMPLIFIER

Design of the 330 W Amplifier Module

The amplifier module (Figure 1) includes one push-pull VDMOS, type D1029UK05, from SEMELAB. Tests on many samples pointed out that this device, selected from D1029UK with guaranteed gain of 13 dB, for 350 W at 175 MHz and 28 VDC, could reliably operate with a gain larger than 11 dB, for 330 W at 352 MHz and 30 VDC.

A circulator from VALVO with a 500 W - 50 Ω RF termination is integrated in each module to protect the transistors from excess of reflected power. This component is essential for ensuring unconditionally stable conditions. The input and output circuits are matched thanks to two pairs of adjustable trimmer capacitors.

The complete modules, manufactured and tested by RFPA according to the SOLEIL specifications, reached the expected performance : 10 dB < Gain < 11.5 dB, phase dispersion < 15°, input matching > 30 dB at 330 W and K (stability margin factor) > 8 dB at 1.4 A.

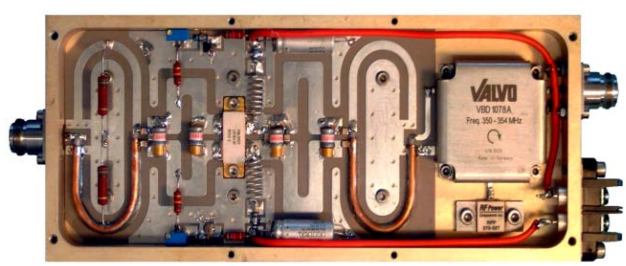

Figure 1: 330 W amplifier module.

Each module has its own power supply board (figure 2), based on a 600 W - 300 VDC / 28 VDC converter from INVENSYS LAMBDA.

Figure 2: Power supply board.

Amplifier Power Combination and Assembly

The power combination scheme for one half of the BO amplifier is described in figure 3; the complete plant is made of two such units. The 40 W input power is amplified by the 1st stage module the output of which is split into 8 and re-amplified, twice, leading to 64 times 330 W which are re-combined per 8 in two stages, 2.5 kW and 20 kW. That leads to a total of 146 modules (+ 1 "stand-by") for the complete amplifier.

Each 2.5 kW branch as well as the 40 kW output are equipped with monitoring bi-directional couplers. All splitters, combiners and couplers were designed in house with HFSS computations and tests on prototypes. The final fabrication of the mechanical parts was sub-contracted to LNLS while the assembling and tests were also performed in house. Amplifier components and complete assembly are shown in figure 4.

The modules and converters are mounted on each side of dissipaters, made of water-cooled Aluminium plates.

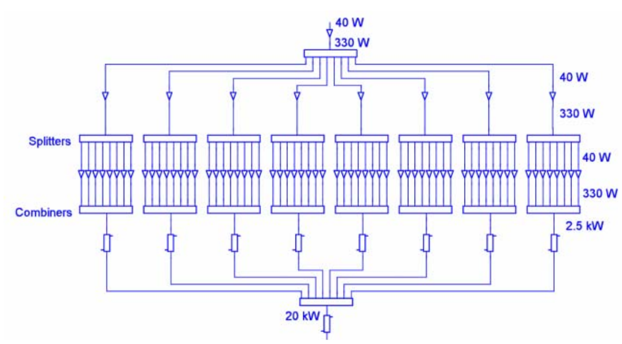

Figure 3 : Power combination (1/2 BO amplifier).

Power Tests

The 2.5 kW units were first tested individually and amongst the 147 modules, only 3 showed minor problems that could be fixed rapidly. After all units have been tested up to 2.5 kW they were combined together. The first day of operation, 35 kW was delivered into a dummy load, with transistor currents below 8.6 A, that is far from their limit. The measured global efficiency of 50% (including circulators and DC/DC converters) is comparable to other types of amplifier. Over the useful range, 1 - 25 kW, the phase and gain changes vs power are 10° and 2.5 dB. Following the successful results of the first day operation, a long test run was launched and, after about 500 hours of continuous operation at 30 kW CW without the least fault interlock, no performance degradation was noticed. Two weeks ago, the amplifier was used for conditioning the BO cavity up to 30 kW.

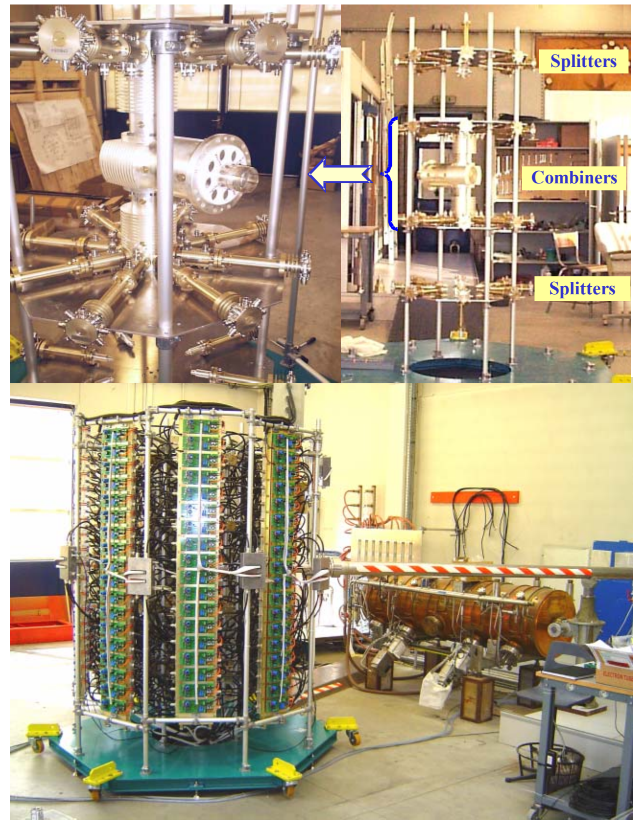

Figure 4 : BO amplifier assembly.

Control System

Figure 5 shows a schematic diagram of the BO RF control system. The 292 transistor currents and 32 RF powers (incident and reflected at the 2.5 kW stage) are permanently monitored by a µcontroller through a multiplexing system.

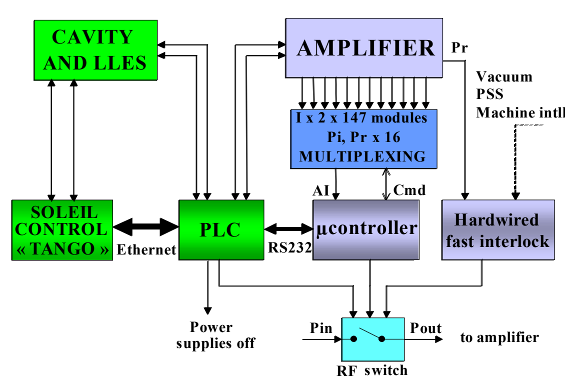

Figure 5 : Booster RF control system.

The reflected power at the output of the amplifier, the cavity vacuum, the personal and machine safety are interlocked by a fast hardwired system. All the other "slow interlocks" from the amplifier, cavity and LLES (Low Level Electronic System comprising the frequency, phase and amplitude control loops) are monitored by a PLC, linked to the µcontroller via a RS232 bus and to the SOLEIL control system via Ethernet. In case of fault the RF power can be stopped by acting on the RF switch located in the amplifier drive chain and/or switching off the power supplies.

SR 190 KW SOLID STATE AMPLIFIERS

For the RF power source of the SR, the possible solutions in term of modularity and technology were investigated. It was decided to power each of the four cavities with one 190 kW solid state amplifier.

Design

A schematic view of the SR 190 kW amplifier is shown in figure 6. It is based on the same principle as the BO one, extended to 4 units of 50 kW. One of the main change as compared to the BO is the use of a new type of MOSFET, a LDMOS LR301 from POLYFET which can achieve better performance than the VDMOS D1029UK. The higher gain of these transistors (14 dB) led us to optimise the power combination scheme in a different way, using a total of 682 modules for the 190 kW amplifier (figure 7). However, in order to improve the reliability, 42 modules in "stand-by" were added.

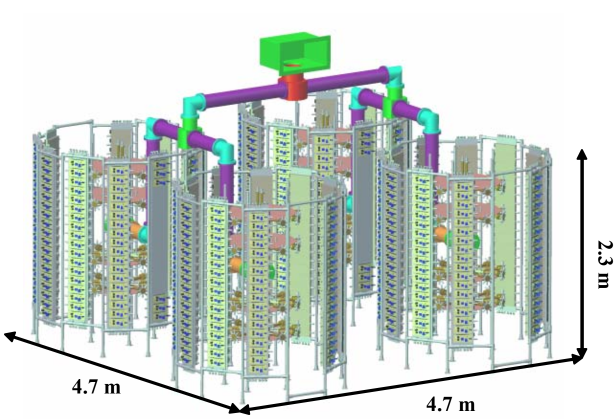

Figure 6 : Schematic view of the SR 190 kW amplifier.

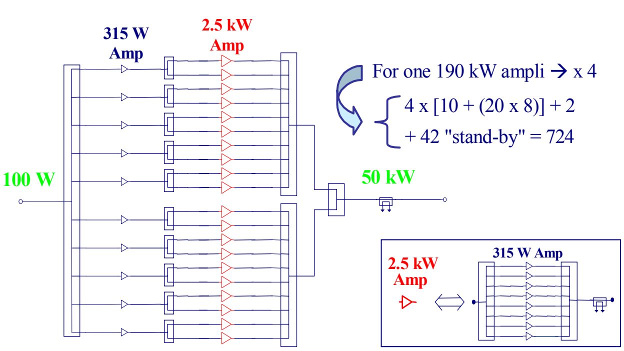

Figure 7 : Power combination scheme for a 50 kW unit.

The complete family of power combiners is shown in figure 8-a. The 10, 8 and 2-way power splitters are built with micro-strip circuits (figure 8-b) making them more compact and cheaper than with coaxial lines.

As another upgrade, the insertion of a Cu slug through the Al case of the modules, at the transistor location will significantly improve the heat transfer (computer simulations show a 15° temperature drop).

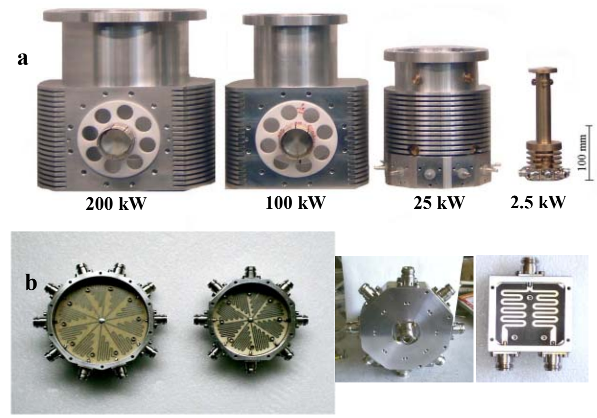

Figure 8 : Prototypes of power combiners and splitters.

The manufacturing and tests of the amplifier modules, of the power combiners and splitters were subcontracted to BBEF Electronics (Beijing). It is planned to test a first 50 kW unit before the end of 2004 and then have two complete 190 kW amplifiers operational for the start of the SOLEIL SR commissioning in May 2005.

CONCLUSION

The required RF power for the SOLEIL BO and SR will be provided using solid state amplifiers (1 x 35 kW and 4 x 190 kW). They consist in a combination of large number of 330 W amplifier modules (1 x 147 and 4 x 724), based on a design developed in house, with MOSFET transistor, integrated circulator and individual power supply. The 35 kW amplifier for the Booster is operational, whilst the manufacturing of the SR components is on going. Although quite innovative for the required power range, this technology is very attractive and offers significant advantages as compared to vacuum tubes. The successful results of the BO amplifier reinforce our confidence for the SR amplifiers.

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REFERENCES

[1] T. Ruan et al, EPAC98, p. 1811.
[2] T. Ruan et al, 7th ESLS RF meeting, Berlin, 1999.
[3] M-P. Level et al, PAC03, p. 229.
[4] F. Scarpa et al, EPAC02, p. 2314.
[5] C. Pardine et al, PAC01, p. 1011.
[6] P. Marchand, MOYCH03, these proceedings.
[7] P. Bosland et al, THPKF028, these proceedings.
[8] P. Marchand, SOLEIL internal note, MAC, Feb. 2003.