COMMISSIONING OF THE 2.2 KW, 476 MHZ SOLID STATE RF POWER SOURCE FOR THE LNLS BOOSTER SYNCHROTRON

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Abstract

A 2.2 kW, 476 MHz unconditionally stable solid state RF amplifier for CW operation has been built, tested, and is being used since July 2007 at LNLS. The amplifier, designed and developed in collaboration with Synchrotron SOLEIL, is made of 9 modules, each one containing one push-pull 290 W MOSFET equipped with an internal circulator and RF load. Low cost, reliability, linearity and high efficiency are the main features we aimed at for this device, which was developed for the Booster Injector. The amplifier technical characteristics and test results are presented.

INTRODUCTION – HISTORICAL OVERVIEW

At LNLS, the development of solid-state amplifiers began in 1999 during the design of the booster injector. The main reason for choosing solid-state technology, which had never been used before to provide power to storage ring RF cavities at UHF frequencies, was the encouragement we received from Mr. Ti Ruan, at that time, head of the LURE RF group. By the end of that year we built our first amplifier module, using the transistor VDMOS D1029UK from Semelab, whose datasheet shows 13 dB gain for 350 W output power at 175 MHz, but, after many tests, was used successfully in our prototype to amplify 476 MHz, reaching the output power record of 250 W, 10 dB gain and 60% efficiency. (Fig 1).

Still in 1999 we chose the quarter wave transformers as being the most adequate technology available in order to divide and combine powers in our amplifiers. This option came after we had built and tested 2 prototypes of 8 way Wilkinson hybrid combiners that, although had good performance as a splitter, presented rather limited performance as a combiner, besides being expensive and difficult to fabricate.

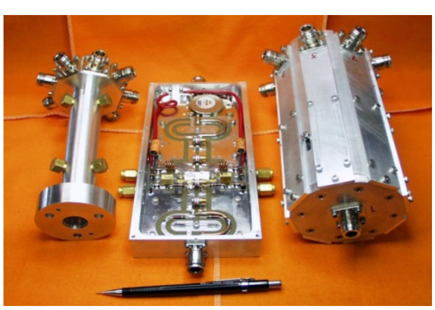

Figure 1: First Quarter-Wave Combiner, Amplifier Module, and Wilkinson Combiner

The LNLS Booster Synchrotron was installed and commissioned in July 2001 and the performance of the RF amplifier was quite satisfactory allowing significant improvement in the currents that could be accumulated in the storage ring[2]. The RF system installed at that time included only four amplifier modules (plus one pre-amplifier) and the final maximum output power was limited to around 900 W. This was a result of the difficulty in obtaining a reasonably large number of RF transistors presenting similar characteristics (e.g. phase advance, gain, etc) so that the resulting individual modules could be efficiently combined.

In July 2007, aiming to improve injection efficiency and thus reduce the injection time as well as thermal transients in machine and beamline components, a series of improvements was introduced in the booster, including the installation of a new solid-state amplifier, now ready to produce up to 2.2 kW [5].

NEW 2.2 KW AMPLIFIER

The new amplifier [fig 2] has 8 modules and a pre-amplifier..

Figure 2: 2.2 kW amplifier Installed in the Booster Injector

The assembly of this new amplifier was an opportunity to use components in their updated versions. For example, the combiner is our version 3, which now has fins for a better cooling and the inner side of the 8 inputs are welded (instead of screwed) to the output conductor. Taking into account energy efficiency, ease of maintenance and cost, we have changed the power source for the amplifiers from AC-DC to DC-DC converters. For the same reasons the power splitter is now a component built in microstrip, S11 = -26.3 dB, S21 = 9.05 dB.

This function was previously performed by a combiner installed in its inverted position.

For the control system we added the possibility of monitoring all transistor currents on line, which is a very important tool in order to check the individual performance of each amplifier module.

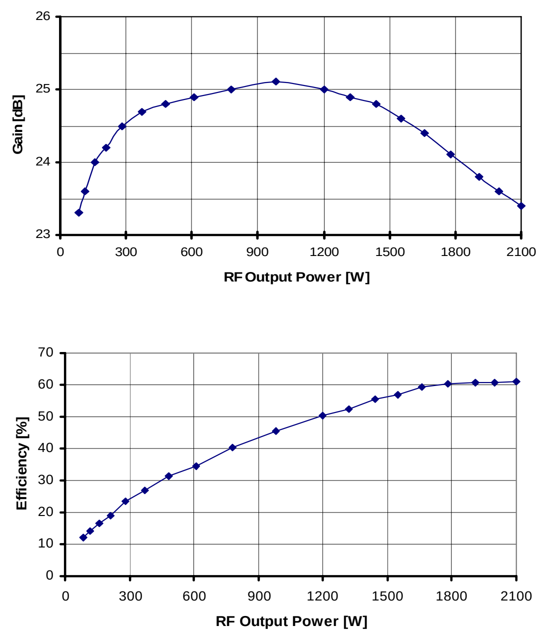

Figure 3: Gain and Efficiency at 2.1 kW

NEW 300W AMPLIFIER MODULES

The main modifications adopted as improvements to the new modules, in order to obtain high output power, small phase differences, high gain and unconditionally stable operation, were:

- • Employ the new transistors LDMOS type LR301, version 4 from Polyfet [datasheet], instead of VDMOS type D1029UK from Semelab, mounted over a copper slug in the aluminium box.
- • Use a very narrow band Circulator model VBE 1232 from Valvo, customized for operation at 476 MHz, instead of circulator type 0048CAD from NOVA with a comb filter installed in parallel with the input.

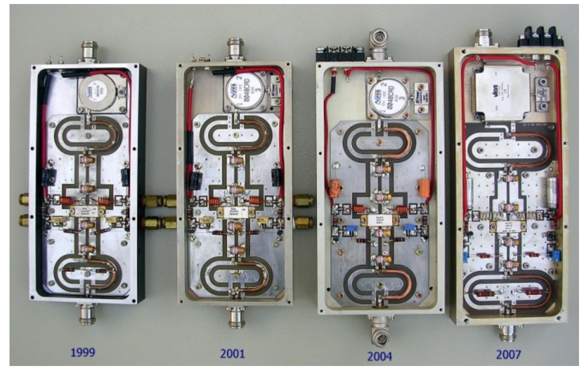

Figure 4: Amplifiers Modules Prototypes 1999 ~2007.

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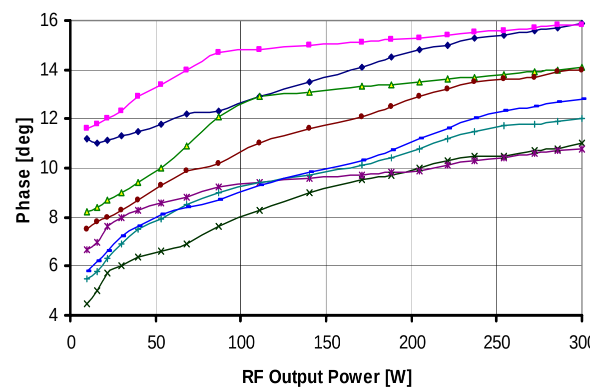

Figure 5: Phase Advance Spread of the 8 modules combined

COMMISSIONING RESULTS

During the long duration tests at full power, after 51 hours of uninterrupted operation, a decrease of the total gain from 25 dB to 24.3 dB was noticed; such difference in the gain indicated that one of the modules had failed. The verification of the transistor current consumed by each module, pointed out which one had failed. The module was replaced and in a few minutes the amplifier was operating again. The reason of the failure was a problem with the solder between the input terminal of the circulator and the PCB. (Fig 6).

The installation of the 2.2 kW amplifier at the booster injector and the tests without electron beam into the cavity took around 9 hours, so that in the same day it could be used successfully in several injection tests.

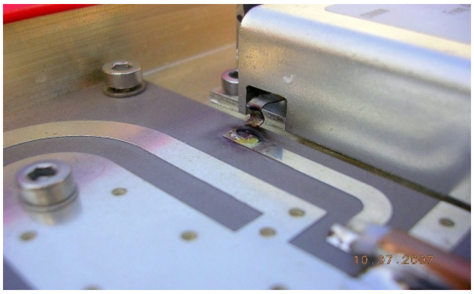

Figure 6: Failure during tests

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The next day, while making adjustments to the amplitude loop, accidentally, the circuit that controls the variable attenuator and the PIN switch for protection of reflected power, released itself from an extension card, causing an overdrive of 38 W during 15 seconds to the 8 modules combined inputs. The result was that 4 modules failed having had their transistors damaged.

In order to avoid definitively any possibility of such disastrous occurrence, some technical changes were added to the Booster RF system hardware. The four damaged 300W amplifiers modules were replaced with their spare parts and the 2.2 kW amplifier has been working without any failure since July/2007.

The transistors used to repair the damaged modules were from the same lot of parts of the ones that had failed. The exchange service was easy and even without any re-adjustment in the input or output matching circuits, if considering the parameters output power, gain, phase advance and stability factor, the modules presented exactly the same performance they had before the failures.

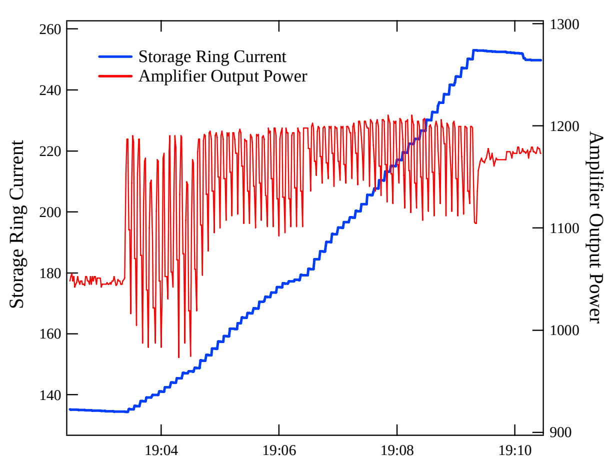

Figure 7: Booster synchrotron energy ramp versus amplifier output power.

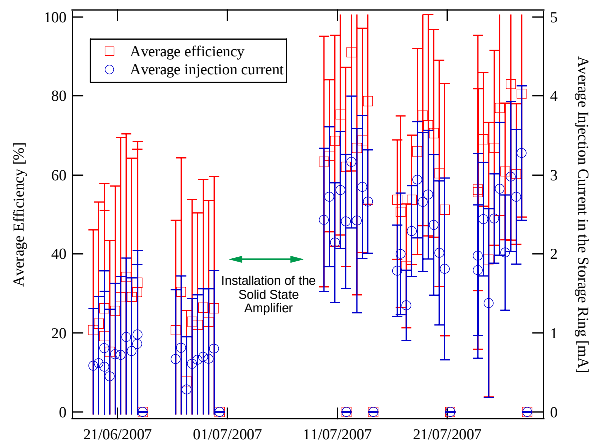

Figure 8: Injection average efficiency and average injection current after 2.2 kW amplifier.

CONCLUSIONS

The development of solid state RF power amplifiers for accelerator applications at LNLS has allowed the implementation of significant improvements to the performance of the LNLS light source injector complex. The amplifier modules developed have demonstrated high efficiency and reliability under real operating conditions in an electron accelerator. These excellent results have led us to consider expanding the same concept to much higher power, in a way similar to what has been done at SOLEIL, but at higher frequencies. In fact, LNLS is currently designing two 50 kW solid state RF plants aimed at replacing the existing klystron tubes in the LNLS storage ring. We expect this new system to be working in 2009.

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