

# HIGH POWER, SOLID-STATE RF AMPLIFIERS DEVELOPMENT FOR THE EURISOL PROTON DRIVER

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## Abstract

A 5 kW, 352 MHz solid-state RF Amplifier for the SPES and EURISOL projects has been built and extensively tested. High reliability and low cost are the main goals for this device, an evolution of a 2.5 kW unit that was previously developed at INFN Legnaro especially designed for operation with superconducting cavities in all matching conditions. The design and construction of two new 10 kW amplifiers of the same family, that can be coupled together to obtain a 20 kW unit, has recently started.

## THE 5 KW AMPLIFIER

### Description

A 2.5 kW prototype of RF Amplifier working at 352 MHz was built and successfully tested in 2002[1]. This prompted us to develop, following the same design scheme, a more powerful unit to cope with requirements of the SPES, 3 mA superconducting linac project. This accelerator required 352 MHz, 5 kW linear amplifiers able to work in CW mode with any matching conditions.

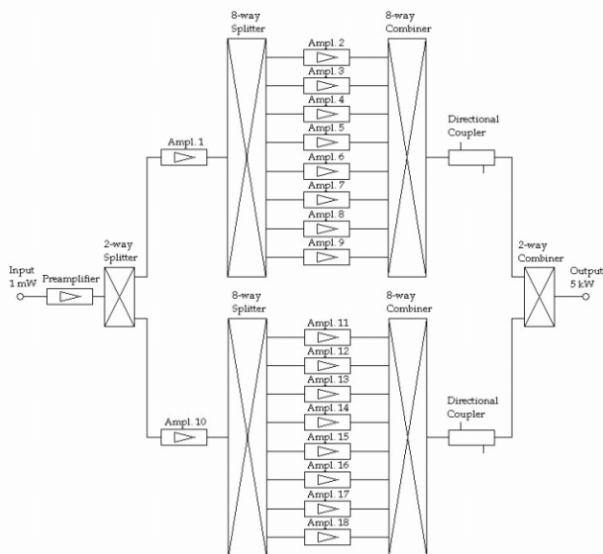


Figure 1: Block Diagram of the 5 kW Amplifier.

The basic structure consists of two 2.5 kW blocks. Each of them is formed by 9 solid-state modules, 8 of which are connected in parallel by means of an 8-way star-point power combiner, and the 9<sup>th</sup> one is used as a driver by means of an 8-way splitter. These 2 blocks are further connected in parallel by means of a 2-way input power splitter and a 2-way output power combiner.

A commercial preamplifier module has been used at input. The total gain of the whole amplifier is 68 dB.

The device is mounted inside one 19" rack and it is water cooled in order to save space (see Fig. 2).

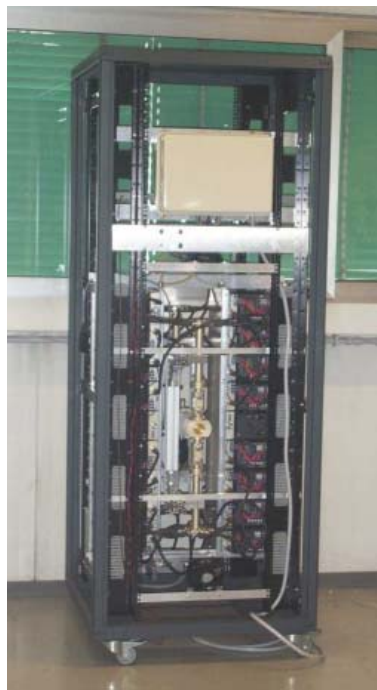


Figure 2: The 5 kW Amplifier.

### Components

Part of the components, as the 8-way splitter and the 8-way combiner, are of the same type used in the previous 2.5 kW version and have been described elsewhere [1]. The 330 W module itself is the same one designed at LNL except for some improvements concerning RF stability. The new 2-way power splitter and power combiner have been designed and built at LNL, as well as a new high power directional coupler with a coupling coefficient of 50 dB and directivity >30 dB (see Fig. 4).



Figure 3: Picture of the 5 kW, 2-way Power Combiner.

The preamplifier is a commercial, wide band module (even though wide band is not strictly required) made by

Ophir, with a gain of 44 dB and capable of 35 W in linear mode and 50 W at 1 dB compression.



Figure 4: Picture of 5 kW Directional Coupler.

A microcontroller system (FieldPoint - National Instruments) with A/D converter modules is mounted in the amplifier in order to perform data acquisition, control and communication with external computers.



Figure 5: Picture of the control system.

### Construction and testing

Care has been taken in choosing and mounting modules with compatible characteristics, in order to minimize the differences in gain and phase of the modules that are connected in parallel.

The amplifier testing included power sweep tests, in order to take the power vs. gain curve, and 1-2 weeks long tests both in matched output condition and in shorted output condition in order to verify the long term behaviour with full power reflection.

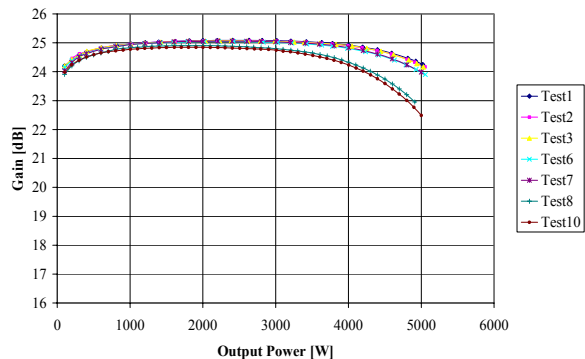


Figure 6: Gain characteristic.

The measured data, at the beginning, showed a very linear characteristic with a low gain compression until the maximum power. After the long tests, however, a gain drop of about 1.75 dB was observed at maximum power,

while at medium and low power the degradation was much less pronounced (Fig.6).

Examining the DC supply current data of the modules, we could point out that they exceeded the maximum allowed value of 9 A in part of the modules. Long operation at 100% output power might have caused an excess of heat, and degradation of the transistors. As it can be seen in Fig. 7, below 4 kW all supply current values are below the 9 A limit, while at 5 kW and at 4.5 kW part of the modules exceed it.

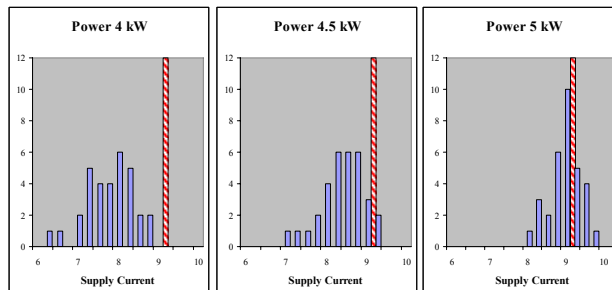


Figure 7: Histograms of the supply currents.

The current distribution at 4 kW is anyhow rather wide (from 6 up to 9 Ampere), meaning that a few modules work at their maximum power limit while others work much below their possibilities.

This implies a rather wide spread of the characteristics of this particular type of MOSFET (Semelab D1029UK); better performance could be obtained by using only selected components. Safe, long time CW operation, in these conditions, should not exceed 80% of the maximum power, while up to 100% of the power could be reached for short periods without harm. This problem can be overcome by using a set of MOSFETs with more uniform characteristics. Several tests have been done with modules using different transistors (LDMOS Polyfet LR301) with more uniform behavior and higher gain. Although good performance could be obtained [2], a high number of transistor failures occurred as well.

The technology of these transistors is continuously improving, and elimination of the undesirable characteristics is expected in a short time.

## THE 10 KW AMPLIFIER

### Description

A new project for two 10 kW, 352 MHz amplifier prototypes has started in December 2005, in the EURISOL Task 8 framework. In this case, 4 blocks of 2.5 kW are necessary for a total number of 36 modules in each unit.

To preserve compactness, the amplifier will be still water cooled, with all modules mounted on two aluminium cooling bars. All components will be placed in order to obtain easy assembly of the complete amplifier in one rack 2 m tall, 0.6 m wide and 0.8 m deep. A block diagram is shown in Fig.8.

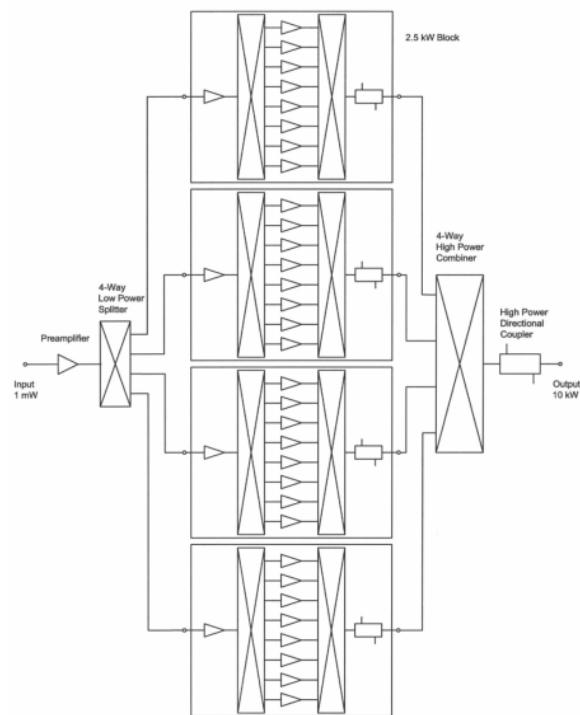


Figure 8: Block diagram of the 10 kW Amplifier.

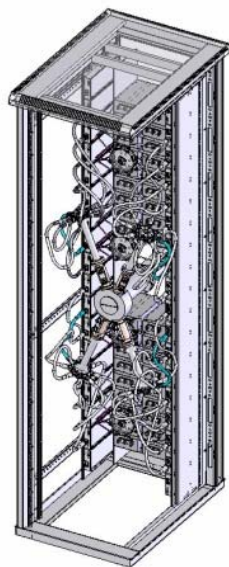


Figure 9: A possible layout of the 10 kW Amplifier.

### Components

The usual 330 W modules have been upgraded with the most recent improvements; in particular a new MOSFET will be used delivered by Semelab (DMD1029A) with an increased power gain and free from toxic Beryllium compounds. The use of selected semiconductors has been planned, in order to reduce the dispersion of the

characteristics. Samples have already been tested with good results.

Most of the design of the 2.5 kW amplifier components [1] can be used. However, a new 4-way high power combiner had to be developed. One prototype has already been built, showing a very good agreement with simulations performed with the CST Microwave Studio electromagnetic simulation software.

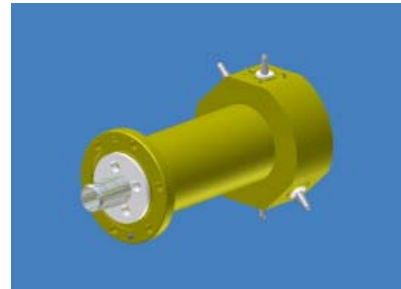


Figure 10: The new 10 kW, 4-way power combiner.

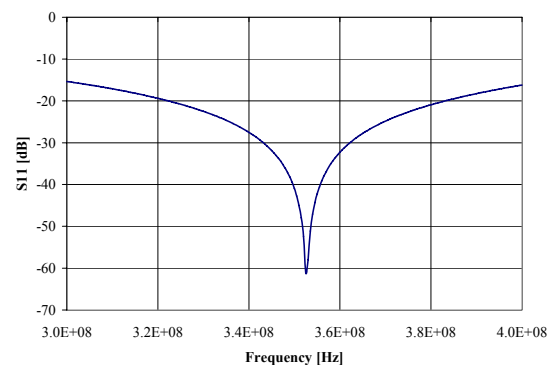


Figure 11: Measured characteristic of the new 10 kW, 4-way power combiner.

A new high power directional coupler has been designed as well and it is under construction.

A new data acquisition, control and communication system will be mounted with an increased number of channels.

The completion of two 10 kW units is foreseen for the end of 2006.

### REFERENCES

- [1] F. Scarpa, A. Facco, V. Zviagintsev, Z. Lipeng, "A 2.5 kW, Low Cost 352 MHz Solid State Amplifier for CW and Pulsed Operation", EPAC'02, Paris, July 2002, p. 2314.
- [2] F. Scarpa, A. Facco, "Progress in High Power RF Amplifiers development at LNL", LNL Annual Report 2004, LNL-INFN(REP) 204/05