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# MEDIUM POWER 352 MHZ SOLID STATE PULSED RF AMPLIFIERS FOR THE CERN LINAC4 PROJECT

J. Broere, J. Marques Balula, CERN, Geneva, Switzerland,  
Y. Gómez Martínez, UJF / CNRS-IN2P3 / INPG, LPSC, Grenoble, France  
M. Rossi, DB Elettronica Telecomunicazioni, Padova, Italy

## Abstract

Economic, modular and highly linear pulsed RF amplifiers have recently been developed to be used for the three buncher cavities in the CERN Linac4. The amplifiers are water-cooled and can provide up to 33 kW pulsed RF Power, 1.5 ms pulse length and 50 Hz repetition rate.

Furthermore a 60 kW unit is under construction to provide the required RF Power for the debuncher cavity. The concept is based on 1.2 kW RF power modules using the latest 6<sup>th</sup> generation LDMOS technology. For integration into the CERN control environment the amplifiers have an internal industrial controller, which will provide easy control and extended diagnostic functions. This paper describes the construction, performance, including linearity, phase stability and EMC compliance tests.

## INTRODUCTION

A new solid state pulsed RF amplifier has been recently developed in close collaboration between an Italian company specialized in RF broadcasting equipment, and now expanding in the scientific RF applications field, and the CERN Linac4 Project [1] supported by LPSC Grenoble. Two units out of five have been constructed and will be delivered to CERN early this autumn. Three of these amplifiers will be used to supply RF power to the buncher cavities in the Linac4 chopper line, and two units will power the debuncher cavity.

## AMPLIFIER DESIGN

The amplifiers have been designed with the following specifications

Table 1: Main Amplifier Specifications

Centre frequency	352.2 MHz
Output power	$\geq 33$ kW
Pulse Width	$\leq 1.5$ ms
Linearity (30 dB range)	$\leq 0.5$ dB / $\pm 2^\circ$
Rise and fall time (once amplifier ON)	$\leq 1$ $\mu$ s
Bandwidth (0.5 dB)	3.5 MHz
Repetition rate	50 Hz

The design is based on the NPX BLF578, a low-cost LDMOS transistor, with excellent power capabilities, ruggedness, which will withstand a sudden mismatch at

high power. The modules have been developed to deliver a peak power in excess of 1 kW (see Fig. 1)..

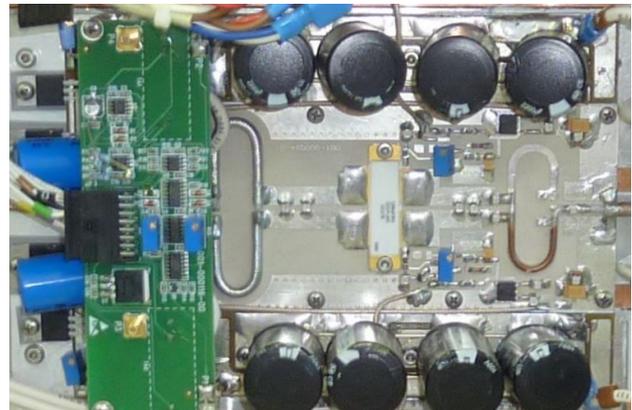


Figure 1: 1 kW amplifier module.

Eight modules are combined in one 19" unit with 4 modules (pallets) on top, and 4 underneath. Together they deliver more than 7 kW pulsed power, using 3 dB combiners, with very low insertion loss ( $< 0.1$  dB).



Figure 2: 7 kW amplifier unit.

To obtain the required linearity it was necessary to combine 5 units in one 19" rack.

Each rack has a depth of 110 cm to allow space for the RF combiners and the connections for the water cooling.

### COOLING

The amplifier is water-cooled and each 7 kW unit consists of a central cooling plate, with a copper cooling pipe to guarantee a constant temperature inside the amplifier unit, thus insuring gain and phase stability.

### POWER SUPPLY

A simple three-phase power supply has been chosen for this design. The distributed voltage is around 70 V, and the individual regulators of each 1 kW module series maintain the required DC voltage over the full power range and pulse width, thus insuring an extremely low pulse droop (< 0.3 dB).



Figure 3: Complete 33 kW unit.

### PERFORMANCE TEST AND LINEARITY

The amplifier was fully tested and the maximum RF obtainable power was > 33 kW.

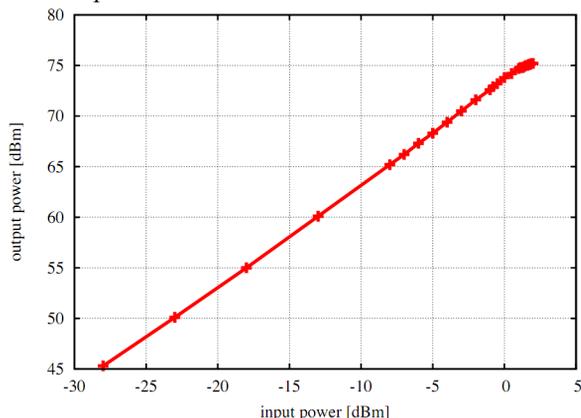


Figure 4: Output versus input power.

The power gain variation of the amplifier over a 30 dB dynamic range was maximum 0.5 dB (see Fig. 4 and 5).

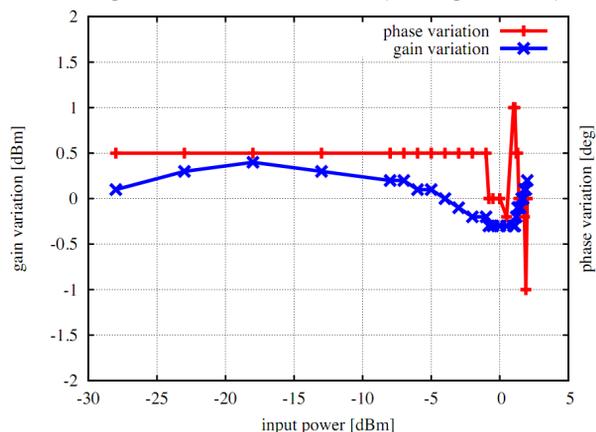


Figure 5: Phase and amplitude gain variation.

The phase linearity was measured between input and output. The maximum phase deviation measured was <math>\pm 0.8^\circ</math> (see Fig. 5) and is well within the required specifications, which will make the integration of this amplifier in a closed loop regulated RF system straightforward.

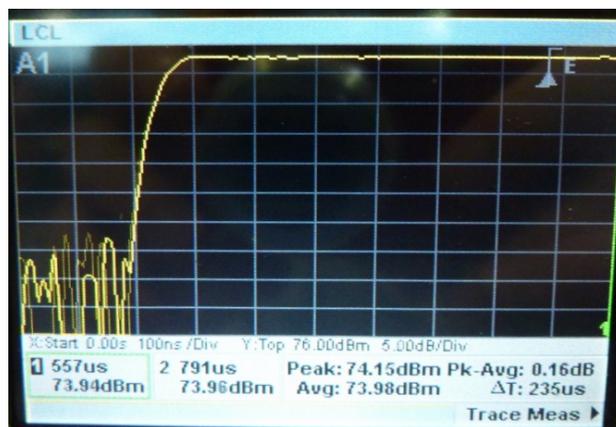


Figure 6: Rise time: 100 ns per division, 5 dB per division.

The rise and fall time between 5 and 95% of the full RF power was measured and were found to be < 100 ns, again well within the specifications.

### INTERLOCKS AND CONTROL INTERFACE

The amplifier must be both locally and remotely controllable via the control interface. The settings, measurements and alarms of malfunctioning are accessible via the CERN control system tools based on FESA and via industrial SCADA. Each RF power module of 7 kW has its own fast electronic interlock circuits, sample and hold circuits, RF measurement system and timing circuits for synchronization. These signals are

connected to the PLC of the amplifier by an internal bus RS485 using a device specific protocol. The internal PLC of the amplifier is the master for the internal control, it manages the received commands, the functioning of all the components, the local display and local control. In total there are 5 commands, 40 status values and 60 measured values, all 15 bits signed. The interface is realized with a dedicated industrial controller, which communicates on one side via Profibus (RS485) with the controller of each amplifier (up to 32 amplifiers maximum) and on the other side via Ethernet with the IEPLC protocol of the middleware FESA server of the CERN accelerator control system and is therefore perfectly adapted to be integrated.

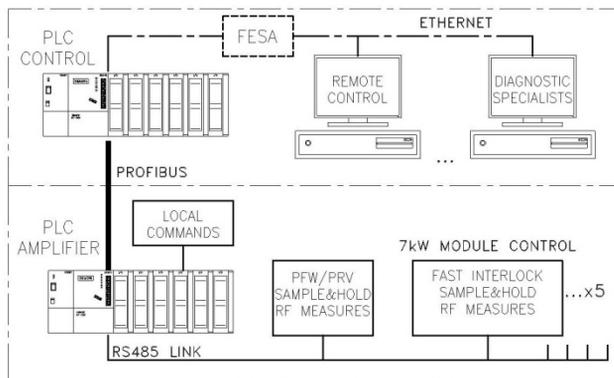


Figure 7: Control Interface.

## EMC/EMI

The amplifiers will be installed in the Linac4 surface building. The construction of this building is not designed to provide substantial RF shielding, and is situated rather close to the outer boundary of the CERN Meyrin site. Furthermore the amplifiers will share the room space with other users. For this reason the amplifiers have been specified to comply with strict RF emission norms, IEC 61000-6-2 and IEC 61000-6-4. Initial tests showed that additional RF shielding had to be installed. During further tests in August 2011 the limits as defined in the norms have been achieved. The emission values obtained are in the order of  $47 \mu\text{V/m}$  at 10 m distance.

## DEBUNCHER AMPLIFIER

The debuncher cavity which will be installed in the Linac4 transfer line to the Booster will receive a phase modulation of  $0-110^\circ$  and back to  $0^\circ$  within  $40 \mu\text{s}$ . This phase modulation will charge the RF amplifier heavily as shown in [2].

The fourth and fifth amplifier will be combined into one 60 kW unit and is foreseen to provide the RF power for the debuncher cavity via a high power circulator. The control for the amplifiers as one unit is foreseen in the internal control units of each amplifier.

## CONCLUSION

It is now possible to construct a high power and high performance solid stated pulsed RF amplifier in one 19" rack.

This very cost effective design opens up the way for other pulsed RF power amplifiers, in a large frequency range. Furthermore this design allows in a simple way the combination of two units to obtain a fully functional 60 kW, whilst maintaining a simple remote control as for one complete unit.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] M. Vretenar et al., The Linac4 Project at CERN, IPAC 2011, San Sebastian, Spain.
- [2] J. Tuckmantel, Power Overhead in the LINAC4 Debuncher Cavity, sLHC-Project-Note-0033