

# THE 101 MHZ AMPLIFIER SYSTEM OF THE NEW CERN LEAD INJECTOR

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## Abstract

The 101 MHz rf amplifiers for a RFQ, an IH-structure and two bunchers for the CERN Lead Injector were provided by GSI Darmstadt. The accelerating structures required amplifiers up to 400 kW while the bunchers needed about 2 kW, both with a pulse length of 1 ms at a repetition rate of 10 Hz. The special properties of the amplifiers, technical difficulties and their cure in respect of rf-circuits, output coupling, parasitic oscillations of the final stage and fulfillment of the new CE-Standards are reported. A second part of the report describes the low level rf-circuits which were built by CERN.

## 1 INTRODUCTION

The CERN LINAC 3 (Pb-Linac) consists of a RFQ, an IH-structure and two bunchers at 101,28 MHz and two IH-structures at 202,56 MHz [1].

The three IH-structures and the rf power for all 101 MHz cavities were supplied by GSI Darmstadt.

The 2.5 kW transistor amplifiers for buncher and de-buncher were specified at GSI and developed and delivered by Dressler as reported earlier[2].

This paper mainly describes the special features of the two 101 MHz / 400 kW amplifiers, and the low level rf-system. The amplifiers were specified in detail by GSI and CERN and ordered from BERTRONIX, Munich, while the work on the low level rf was done by the CERN PS RF-staff. Fig. 1 shows a picture of one of the 400 kW amplifiers installed at CERN while table 1 gives data at full power operation at BERTRONIX.



fig.1 One of the 400 kW amplifiers installed at CERN

CERN 400 KW 101.28 MHz	DRIVER STAGE	FINAL STAGE
Ufil / V	8.7	14.2
Ifil / A	107	172
Ug1 / V	130	200
Ig1 / mA	5	1600
Ua / kV	9	18
Ia / A	3.6	38
Ug2 / V	900	1150
Ig2 / mA	70	1200
Pforw / kW	19	400
Prefl / kW	0.4	3.5

table 1 Data for maximum output power

## 2 AMPLIFIER DESIGN

The 400 kW amplifiers consist of three rf-stages.

The predriver, a 400 W transistor amplifier, uses the Valvo transistors BLF278. It was built by Dressler[2] and adapted to the system by BERTRONIX.

The 20 kW driver is a new development of BERTRONIX. It is equipped with the new long-life Siemens tetrode RS2068CL. This tube has been developed for 20 kW FM-transmitters and is operated cathode driven with a kapton capacitor between g1 and g2. The output circuit is a coaxial  $\lambda/4$  resonator with a disk kapton dc-blocking capacitor around the anode. One characteristic of the amplifier design is that the coaxial resonators anode-g2 and g1-cathode are going straight down from the tube connector-rings, thus guaranteeing optimum access to the tube. The input-coupling and the input  $\lambda/4$  resonance can be adjusted as well as the output resonator's frequency and the mixed galvanic/inductive output-coupling by motordriven plungers with a digital position-readout.

The final 400 kW amplifier uses the same design except the g1-g2 circuit, built here by a short-circuited  $\lambda/2$  coax. The schematic design of this stage is shown in fig.2. The chosen Siemens tetrode RS2054SK is a very slim tube with long internal supports to its active system. Consequently, this results in a high inductance in the screengrid area of the output-resonator which made it nearly impossible to bring its resonance frequency to the required 101 MHz in a  $\lambda/4$  resonator.

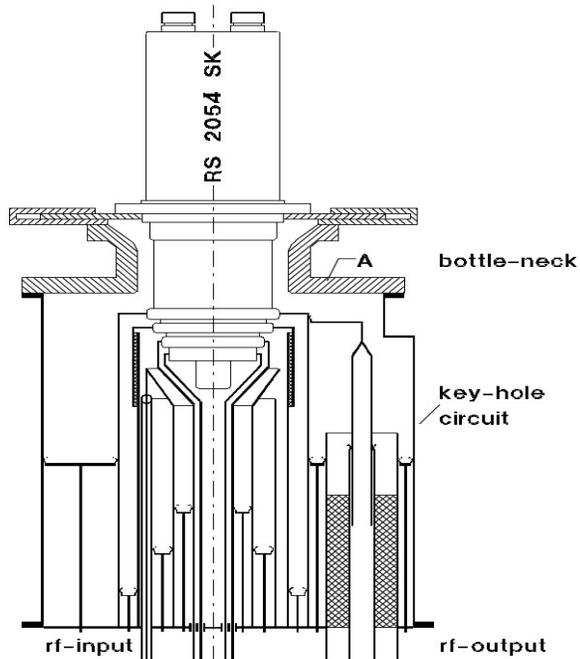


fig.2 Principal drawing of the final amplifier

The  $\lambda/4$  resonance of the anode-screengrid area of the tube itself, measured with a tin foil short-circuiting closely the anode-screengrid ceramic was already 135 MHz. So an extremely small space was left for sufficient output coupling and for the needed 20 kV bypass capacitor in the external part of the anode resonator at 101 MHz. For the shortest cylindrical coaxial circuit, a SuperCompact<sup>®</sup> simulation, made by GSI, gave a maximum frequency of 92 MHz. To reach the proper frequency with the required low loaded Q-factor of the anode circuit, three sophisticated measures had to be introduced to the amplifier design:

First, the output coupling was arranged partly penetrating the outer cylindrical wall of the anode circuit, which by that led to the shape given in fig.3.

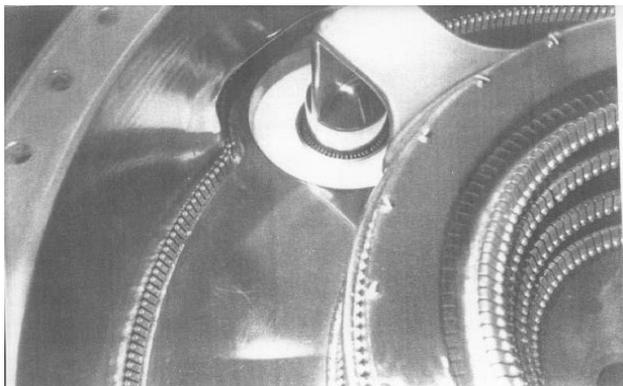


fig.3 Picture of the asymmetric output coupling

This so called key-hole circuit gives a characteristic impedance as low as possible with nevertheless good

voltage capability and effective coupling. Its disadvantage is the complicated and expensive production of the resonator-shape and the movable short-circuit-plane.

Second, another low impedance part was introduced into the anode circuit to increase the resonance frequency. This so called „bottle-neck“ is shown as part A in fig.2.. A SuperCompact<sup>®</sup> simulation of the anode resonator with this device gave the required frequency and agreed well with a model made out of aluminum-sheet-covered poly-foam. The  $\lambda/4$  resonance of the circuit simulation and the model-measurement was within 1%, while the calculated  $3/4 \lambda$  resonance of about 570 MHz was measured to be 590 MHz. The separation of the  $3/4 \lambda$  resonance from the third harmonic promised the low harmonic spectrum later reached in operation.

The third measure was a transformation of the  $50 \Omega$  load of the cavity (or a dummy load) to about  $25 \Omega$  at the output-coupling-loop by adjusting the location of a polyethylene filled part of the output coaxline.

### 3 POWER-SUPPLIES

All the controllable output power supplies for the two tetrodes, filament, g1, anode and g2 were built using primary variable-ratio transformers. Apart from the high-current filament transformers and the anode power-part, all other supplies were housed in modular plug-in units. The g1 voltages of driver and final stage are switched between two sources from a C working point to A/A-B during the rf-pulse by a high voltage power-mosfet transistor, while another one acts as an electronic load for the g1-current.

The crowbar system of the anode supplies is a modified fail-save GSI development which fires the ignitron at a preset anode-current without any electronic-circuit[3].

### 4 CONTROL AND MEASUREMENT EQUIPMENT

A programmable SIMATIC (SPS 105U) controls all the necessary command, status and interlock signals with 320 possible inputs and outputs. It stores all errors and also acts as an interface to the CERN remote-control.

A local alphanumeric read-out (COROS), connected to the SIMATIC, gives the present status and the last error-codes and can be used for statistic records.

The main-software for the SIMATIC was written by GSI while the COROS program was provided by BERTRONIX.

The transmission of more than 20 analogue signals is made via optical-fiber, digitized with a sampling rate of 250 kHz, to a separate plug-in, where video signals of all pulsed currents and rf-powers are provided.

This plug-in also limits all directly measured and derived values to their allowed levels, partly by analog feedback to the amplitude-regulator, partly by a reduction of the pulse-length and with the help of the SIMATIC.

## 5 PARASITIC MODES AND EMC

One main problem was to get rid of a parasitic mode at 1050 MHz, which the RS2054SK produced in the final stage's geometry. It was probably the „bottle-neck“, facing closely the anode-screengrid-ceramic which prohibited sufficient radiation out of the tube at this frequency. By this the Q-value of an internal circumference resonance increased, producing self oscillations at higher anode dc-currents, especially, when the tube was pulsed to the A-working point without rf-drive. About twenty different measures were tried to damp these oscillations. Resonant loaded loops were integrated in the anode circuit, the „bottle-neck“ was partly filled with ferrites, using the design of an earlier GSI-patent (fig.4), ferrites were located between  $g_1$  and  $g_2$  and polyethylene rings with different ferrite mixtures were mounted between anode-ceramic and the „bottle-neck“ at different distances. One of the last measures produced the highest damping and together with a timed dc-gridpulse in relation to the rf-drive, trouble-free operation was obtained.

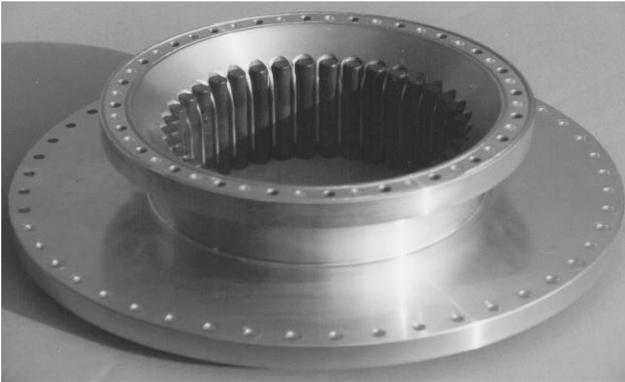


fig.4 Ferrite loaded „bottle-neck“

As these procedures were very time consuming, the rf-radiation of the amplifier in respect of the new EMC-standards was measured in parallel. The limits of the allowed radiation levels were reduced by about 20 dB during the project lifetime. Standard EMC-racks were no longer sufficient. Many parts had to be connected by additionally welding and sealing. Also the anode-voltage filter of the final stage had to be redesigned to meet the new requirements besides several smaller improvements. The final result regarding EMC was that measurements, done by an external „competent body“ could not identify the radiation of the amplifier at 10 meter distance from the building at a total distance of about 16 meters.

## 6 TEMPORARY LOAN AMPLIFIERS BY GSI

All the described additional necessary work led to a significant delivery delay. To avoid an unacceptable delay to the beginning of the operation of the otherwise completed LINAC 3, GSI provided temporarily two amplifier-chains

from 108.4 MHz UNILAC single-gap-cavities, modified to 101.28 MHz. Along with modified driver- and final-anode-power supplies these units were sent to CERN within about three months. They were assembled by CERN and GSI personnel and operated satisfactorily until the last BERTRONIX amplifier was installed and all spare units of the new amplifiers were tested successfully.

## 7 LOW LEVEL RF AND CONTROL CIRCUITS

The low level rf was based on the existing system of the CERN LINAC 2, modified for 101 MHz (fig. 5).

The fundamental frequency of 101.28 MHz is distributed by equal length, minimum phase drift coaxial cable to the low level equipment of each rf chain. The return tank signal is carried by the same type and length of cable to keep temperature dependence as low as possible (calculated phase drift for the linac length has been estimated as  $< 0.1^\circ$  per  $^\circ\text{C}$ ). The very stringent  $0.3^\circ$  phase-stability specification imposed by the use of the IH structures required the development of a new high- resolution electronic phase shifter in the reference line of each rf chain. The final design is adjustable in  $0.1^\circ$  steps and has an overall stability of  $< 0.3^\circ$ .

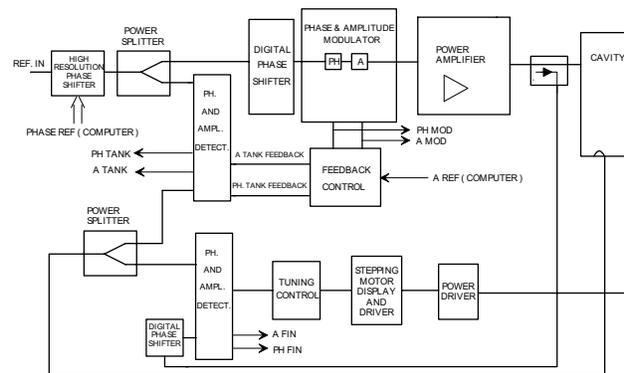


fig 5. RF control layout

Each amplifier chain is remotely controlled by means of a local G64 rf chassis linked to a VME Device Stub Controller. This chassis contains analogue and digital interface cards and also some local intelligence. Its main functions are to supply and acquire the cavity reference voltage, its reference phase and to interface to the SIMATIC SPS 105U. Additional sampled analogue signals allow the rf performance of each amplifier stage to be monitored. This immediately highlights any performance degradation due to failing tubes etc..

## REFERENCES

- [1] H.D.Haseroth, Pb Injector at CERN, LINAC96 pp. 283-287
- [2] G.Hutter et.al., A New Generation of Solid State Amplifiers for Accelerators, EPAC 94 pp.1909-1911
- [3] G.Hutter et.al. New Power Amplifiers for 200 kW at 27 MHz, EPAC 92, pp.1203-1205