New Power Amplifiers for 200 kW at 27 MHz

G.Hutter, G. Breitenberger, W.Gutowski, H.Valter, W.Hartmann GSI Darmstadt

O.Böhm, H.Seiler, W.Spitz, G.Zähringer Fritz Hüttinger Elektronik GmbH Freiburg

Abstract

Two 27 MHz amplifiers for a peak power of 200kW at a duty cycle of 10% and a repetition rate of 50 Hz were built by Fritz Hüttinger Elektronik GmbH Freiburg in a close collaboration with the UNILAC-RF-group of GSI. The amplifiers will be used for a planned high-current RFQ injector for the UNILAC and tests of a prototype RFQ. The main innovation of these amplifiers is that they require only one electron tube. The chosen tetrode provides more than 20 dB amplification in a grounded cathode circuit and deliveres 200 kW output power with a 2 kW solid state driver-amplifier. The amplifier design and circuitry, the measured electrical data, the free programmable control, the analog measurement equipment and the used special crowbar system of the anode power-supply are described.

Introduction

A High-Current Injector-extension is planned at the front end of the UNILAC at GSI, serving the synchrotron SIS with mA beams. After DC preaccelerating to about 2.5 keV/u a 27 MHz RFQ structure for 130 keV/u will be used for injection of high current beams into existing Wideröe structures. Two additional bunchers at 27 MHz will be needed for longitudinal phase space matching. Their request of rf peak power will be 120 kW, the same as for a prototype RFQ. The duty cycle will be less than 10% at a repetition rate of 50 Hz, which is equivalent to a pulse length up to 2 ms.

Amplifier Design

Since the UNILAC-RF-group has not the capacity, to built the needed amplifiers in parallel to the normal accelerator operation, a specification was prepared with the aim, to found a new generation of rf-amplifiers, comprising the following main features besides the parameters of table 1:

1. The amplifiers should use only one electron tube.
2. This tube should be one of the Siemens types RS1084CJ or RS2058CW, as these tubes are in satisfying operation in many amplifiers at GSI and CERN.
3. Since the above mentioned tubes are able to deliver more than the required power, the amplifiers should be able, to deliver 200 kW at 10% duty cycle, to guarantee a relaxed operation in the later application.
4. The driver should be a solid state 2kW amplifier, as the chosen tubes promised a gain of at least 20 dB in a grounded-cathode amplifier at 27 MHz.
5. The major control of each amplifier should be performed with a free programmable SIMATIC S115U.
6. The crowbar system should use a GSI invention.

Table 1

Center frequency	27.1 MHz
Bandwith (1 dB)	≥ 0.5 MHz
Pulse power	200 / 120 kW
Pulse duration	≤ 2 / 6 ms
Pulse repetition frequency	≤ 50 Hz
Peak input power	2.0 kW
Amplification	≥ 20 dB
Maximum harmonic level	< -30 dBc
Non-harmonic frequencies	< -60 dBc
Input connector	N-female
Output connector	42/98 GSI-type
Input impedance	50 Ohm
Input VSWR	≤ 1.2
Output impedadance	50 Ohm
Output VSWR	≤ 2.0
Mains suppply	3 x 380 V

Results

Fig.1 Two amplifiers installed in the UNILAC RF-Gallery

A slightly modified commercial 2 kW amplifier from Herfurth GmbH Hamburg could be used as driver, while the main contract was given to Fritz Hüttinger Elektronik GmbH Freiburg. Since it was the first amplifier of this size built by this company, a close collaboration took place all along the project with detailed specifications of many accelerator specific parts like analog electronics, crowbar system and pulse operation. Fig.1 shows the result of the one and a half year cooperation. The rf-cabinets of one amplifier with input- and output circuitry and an installed RS1084CJ are shown in Fig.2.

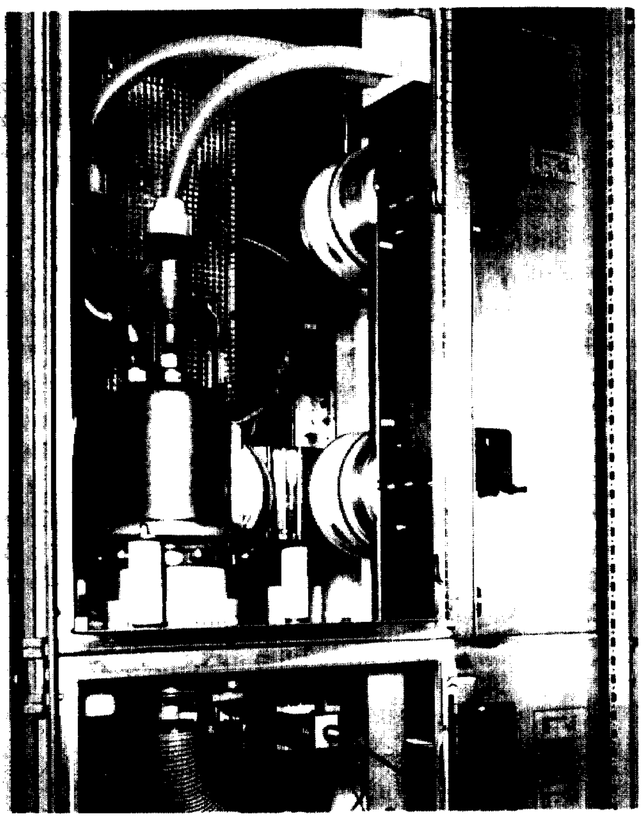

Fig.2 Input- and output rf cabinets

The block-diagram of the amplifier is shown in Fig.3

The input circuit of the cathode grounded amplifier is heavily loaded by a capacitively coupled air cooled 50 ohm, 600 W load. A variable vacuum capacitor (C1) in parallel and a variable series inductance (L1) ensure the frequency-tuning and impedance matching of the input.

The output circuit uses a fixed vacuum capacitor (C2) as an anode dc-blocker and two big variable vacuum capacitors (C3 + C4) for frequency tuning and impedance transformation. No neutralisation was necessary to keep the amplifier "quiet". Tests have been carried out with a matching of 50 ohm and with short- or open-circuit at the output.

Automatic HV-Ground Connectors ensure staff security if access to the rf-cabinets is necessary by short-circuiting the anode- and screen-grid voltage.

The anode voltage can be preselected in the range from 12 kV to 15 kV without load. The needed dc-pulse-power of about 300 kW is provided by a 3 phase 75 kVA HV-transformer and a capacitor-bank of 110 uF.

To ease the repair and maintanance of the rf-part and the anode power-supply, a mechanical disconnecting switch is installed, which allows power-supply tests with high voltage while the final stage is grounded.

In the analog electronic plug-in all electrode currents and voltages are monitored as well as drive- and output power and -voltage, anode circuit voltage, anode loss and input- and output matching. All pulsed currents and rf-signals are available averaged, sampled and as a video signal. Overshooting a preset limit of any of these signals creates a combined failure signal for analog re-regulation and an identifying digital stored error signal.

The free programmable control gives a comfortable access to all subsystems, main computer control and interlock signals. The personnel security interlock is built by hardware in parallel.

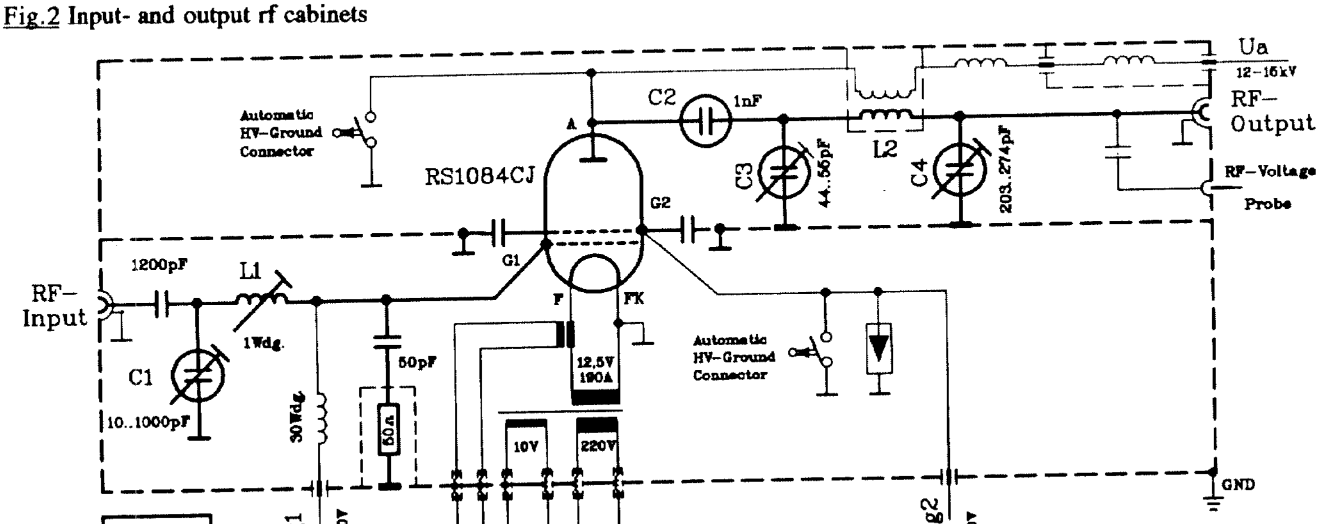

Fig. 3

The specified pulse power levels of 200 kW at 10 % duty cycle and 120 kW at 30 % duty cycle were reached with the data summarized in table 2.

Table 2

Acceptance Test Report Pulse Frequency 50 HZ ≙ 20 mS	short sign	Unit	200 kW 10 % duty cycle	120 kW 30 % duty cycle
Filament Voltage	Uf	V	12.1	12.1
Filament Current	If	A	175	175
Control-Grid Voltage	Ug1	V	264	357
Control-Grid Current ⎍	Ig1	mA	530	320
Anode Voltage	Ua	kV	13.6	13.6
Anode Current ⎍	Ia	A	22	12.4
Screen-Grid Voltage	Ug2	V	1350	1300
Screen-Grid Current ⎍	Ig2	mA	560	350
Drive Power forward ⎍	Pve	kW	1.26	0.9
Drive Power reverse ⎍	Pre	kW	<0.1	0.35
Output Power forward ⎍	Pve	kW	200	120
Output Power reverse ⎍	Pre	kW	<0.1	0
Uw reverse / Uw forward Input	r in	%	<10	4
Uw reverse / Uw forward Output	r out	%	<2	2
Caloric Power Measurement	Pth	kW	20.5	34.6
Water-Flew-Rate	Q	l/min	2200	2200
Temp. Difference Outlet-Inlet	ΔT	°C	8	13.5
Input Tuning L1		div	48	33.3
Input Tuning C1		div	20.9	23.1
Output Tuning C3		div	4.55	0.4
Output Tuning C4		div	20.55	17.9
Harmonic Suppression		dB	>35	38
Amplification		dB	22	21.2
Anode RF-Voltage ⎍	Ua~	kV	11.4	12
Anode dissipation ⎍	Qa	kW	120	60
Anode dissipation (Average)	$\overline{Qa}$	kW	12	18

Both amplifiers demonstrated their performance in a 24 hour test at full power on a dummy load without any problems.

Crowbar System

The anode power-supply needs a crowbar system for a quick discharge of the stored energy of about 12 kJoule of the capacitor-bank in the case of a tube failure or other short-circuits. The used device is a very sophisticated GSI developement. Its functional block diagram is shown in Fig.4.

An iron core L1, made from a special alloy, has four secondary windings L1.1 to L1.4 and as a primary winding L1.0 the cathode connecting cable of the anode power-supply which is fed isolated through the hole of the core.

The core itself is premagnetized by a DC current through the winding L1.3, for example selected with R1 to 200 ampere-turns. If the current in the cathode cable exceeds 200 A, the core is driven out of saturation and acts as a transformer. A high voltage is generated by this on L1.1 which fires the ignitron V5. The winding L1.4 has three functions. At a normal switch off of the anode supply, the stored energy of C1 is discharged over the thyristor V2, the limiting resistor R3 and L1.4, firing the ignitron soon after the normal disconnection of the mains. It functions in a similar way if a breakdown of the mains occures. In this case relay K3 fires the thyristor V2 with the stored energy of C2. Finally, an alarm signal is generated by V3,V4 and R4 which indicates that the crowbar was fired.The winding L1.2 is used only in smaller power supplies, where one primary winding is not sufficient for proper operation. The inductance L2 keeps the high voltage, produced in L1.3, away from the DC supply. Relay K1 monitors the proper DC presaturation current.

The above discribed crowbar system replaced all the old shunt-triggered crowbar systems of the UNILAC and is now in satisfying operation in 60 powersupplies at GSI.

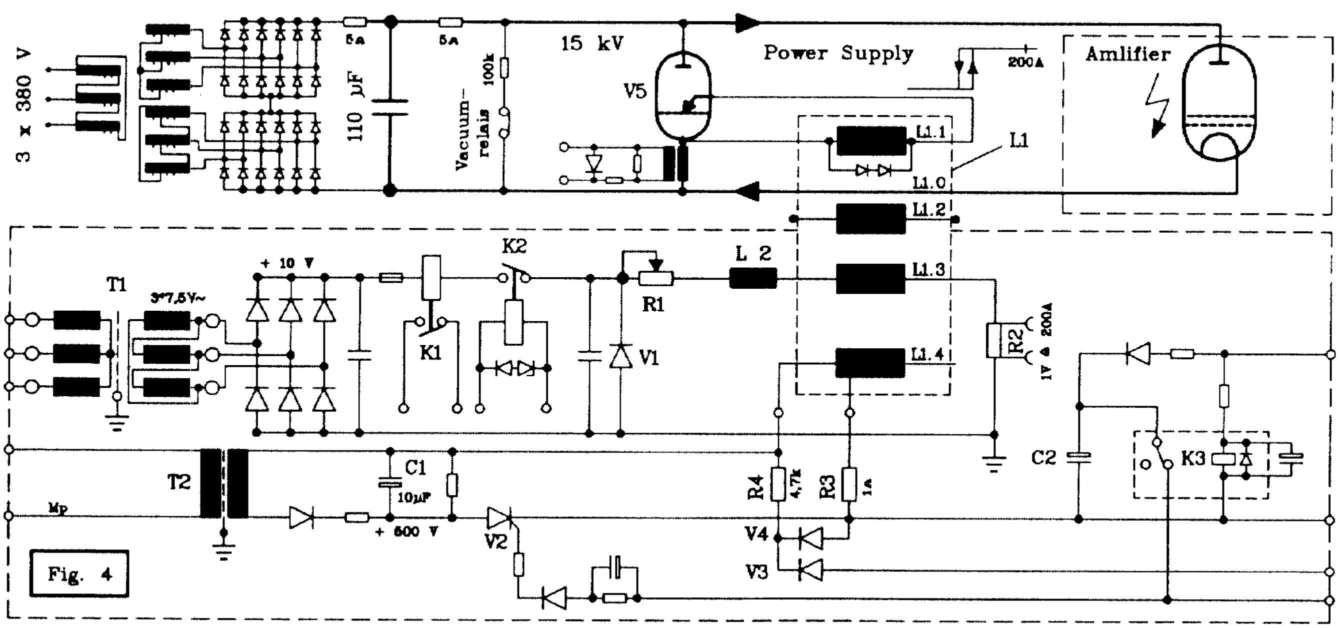

Fig. 4