A New Generation of Solid State Amplifiers for Accelerators

G.Hutter, W.Gutowski, W.Hartmann
GSI, Gesellschaft für Schwerionenforschung mbH
P.O. Box 110 552, D-64220 Darmstadt, Germany
U.Hansen, E.Gerards, N.Hartwich
Dressler HF-Technik GmbH Werther Straße 14-16 D 52224 Stolberg

Abstract:

An inexpensive modular solid state amplifier design using power MOSFETS was developed which allows power generation in the range of a few watts to 5 kW at frequencies from 10 MHz to 220 MHz at various duty cycles from 0.1% to cw operation. The advantages of the system are: 3 dB bandwidth of about 20% of the center frequency, full protection against any load mismatch, high slew rates, standardized programmable controls (SIMATIC S5), a sophisticated measurement- and self protection electronic board and conformance with the newest European EMC standards. The performances of two different amplifier types are reported, one with 2.3 kW, 60% duty cycle at 108.4 MHz and another with 2.5 kW, 1% duty cycle at 101 MHz.

1. INTRODUCTION

A new generation of solid state linear RF amplifiers has been designed for the specific environmental conditions of a linac in a close co-operation of a company experienced in VHF and UHF power amplifier design for industrial application, Dressler HF-Technik GmbH, and the UNILAC RF-group of GSI.

In a first common project, four amplifiers for bunchers of the HLI injector [1] of the UNILAC were built, actually followed by three amplifiers for the new Lead Injector of CERN [2], which just comes to operation, and for which GSI supports the 101 MHz RF power amplifiers for rebuncher, debuncher, a RFQ and an IH-structure

2. AMPLIFIERS REALIZED

In Table 1) the main data of the amplifiers built for the HLI of GSI are given.

Center Frequency	108.4 MHz
Bandwidth	20 MHz
Pulse Power	2.3 kW
Duty Cycle	60 %
Linearity	0.7 dB
Harmonics	<-40 dBc
Control	Internal Logic + External SIMATIC
Gemini Transistors	8 x 300W BLF278

Table 1) Relevant Parameters DRA 108-2K3

The front panel of the 2.3 kW 108 MHz amplifiers for GSI.is shown in Fig. 1)

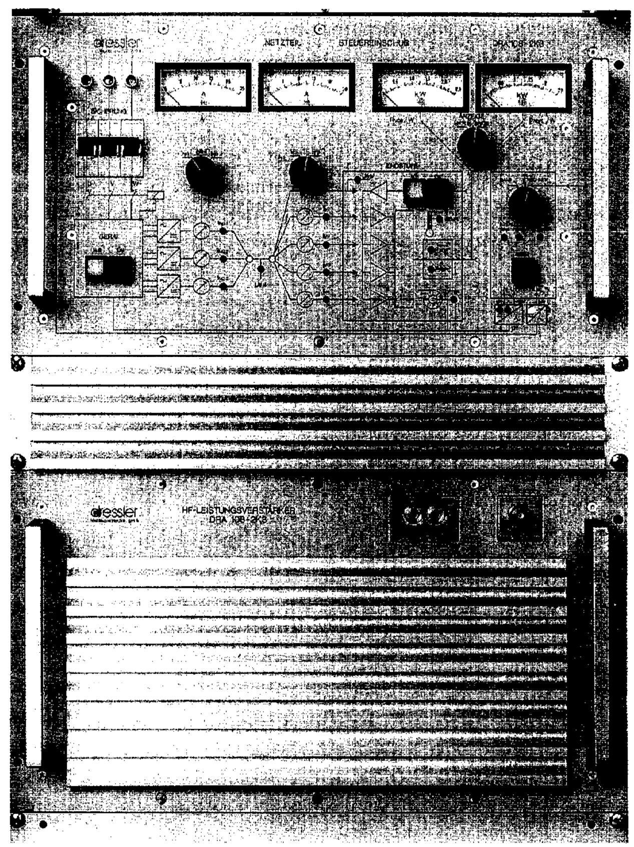

Fig. 1) Amplifier DRA 108-2K3 for GSI
(Photo A.Zschau, GSI)

In Table 2) the main data achieved with the amplifiers for CERN are given.

Center Frequency	101.28 MHz
Bandwidth	20 MHz
Pulse Power	2.5 kW
Duty Cycle	3 %
Linearity	0.5 dB
Harmonics	<-40 dBc
Control	Internal Logic + Internal SIMATIC
Gemini Transistors	16 x 300W BLF278

Table 2) Relevant Parameters LPPA-10025

An open amplifier for 2.5 kW at 101 MHz for the CERN Pb Linac is shown in Fig. 2). In the front panel one can see the integrated small SIMATIC free programmable control.

As the average power in the CERN application will be less or equal to 25 Watt, the complete amplifier could be realized in one 19" plug in unit.

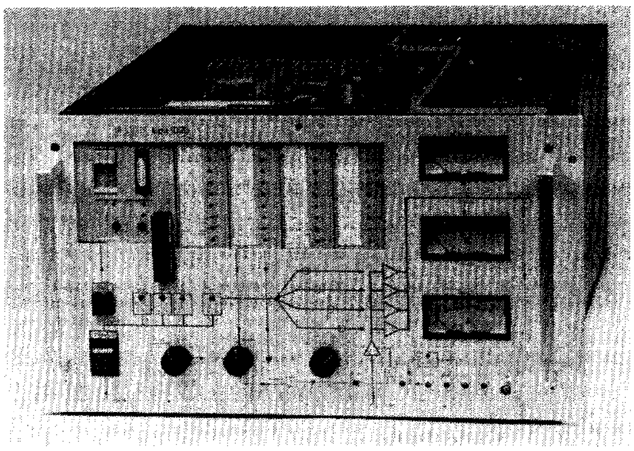

Fig. 2) Amplifier LPPA-10025 for CERN
(Photo Dressler)

3. BASIC AMPLIFIER DESIGN

All the amplifiers described here have been built using the same kind of "RF power module", but adapting the number of the modules as well as the kind of the power supplies, the cooling and the controls to the special needs.

For example, the power supplies of the amplifiers for GSI are of a switched mode technique, while the CERN amplifiers only need a standard linear regulated power supply, as the high pulse power here is delivered by big capacitor banks. While the cooling of the 60% duty cycle GSI amplifiers requires special very efficient custom tailored cooling brackets out of copper, the 1% CERN amplifiers only need standard devices.

The heart of the amplifiers however, the RF power module, is the same for both amplifier types. Each module consists of two 300 Watt MOSFETS in a Gemini package of the type BLF278. Each Gemini package with its two internal MOSFET transistors is assembled together with transmission line transformers at the input and output to form a so called "amplifier cell" which works in a broad band push pull operation.

The typical frequency range which can be achieved with such a basic amplifier cell is 50 MHz - 150 MHz, respectively 150 MHz - 220 MHz.

Compared to standard narrow band techniques using striplines together with impedance matching networks, the wide band design with transmission line transformers used here ensures a remarkable higher stability against mismatch conditions and unwanted and destructive self oscillations especially at low frequencies,

The large possible bandwidth of 100 MHz is reduced to 20 MHz due to a network compensating the capacitive losses inside the power MOSFET and increasing the efficiency and the power output by more than 15%.

Two of these 300 Watt amplifier cells are combined by powersplitters and -combiners of the Wilkinson type to form a power module with a power output capability of 600 Watts. For best reliability and ruggedness, 8 of these modules are combined to deliver the specified 2.5 kW output for the CERN amplifiers, loading each module only with 320 Watt peak power. This conservative rating, together with all the power splitters, -combiners and termination resistors associated, makes the final amplifiers performing extremely reliable.

Contrary to narrow band amplifiers, the length of the feeder cable from the amplifier to the cavity is uncritical, as the amplifier accepts the reflected power during the filling time of the cavity at all possible phase angles, as there are no additional resonances with a high Q in its output circuit.

4. NEW METHODS FOR PULSE SHAPING

In pulsed operation, power MOSFETS show a thermal time constant of typical 2-3 ms, in which the transistors change their gain. The kind of the change depends on the RF level. At low levels, the output power increases, at high levels it decreases during this time.

A newly developed bias correction circuit allows a pulse shape correction for a flat response at all power levels. In addition, the rise time of the pulse can be adjusted from a few us to about 100 us, to find the best shape of the pulse for the cavity filling time, depending whether a cavity tends to multipactoring and needs a steep slope with high reflected power to the amplifier or not.

The bias control also allows a compensation of output degradation due to a voltage drop of the capacitor banks of the power supply

5. RELIABILITY, SELF-PROTECTION and CONTROLS

A maximum in reliability and trouble free operation was reached by the following items:
-Huge reserve in output power
-High immunity against any mismatch conditions
-Ruggedness against RF fed back from the cavity
-Linear operation to minimize phase variations over power and to ease amplitude- and phase-regulation
-Full self protection with sensors for all DC voltages and currents and forward and reverse RF voltages
-Standardized free programmable control
-Conformance with the actual EMC-standards
-Self explaining local operation and status signals
-Stored Indication of all possible errors
-No total disconnection under fault condition

The amplifiers installed at GSI showed a very good reliability. Although the cavities had hard multipactor-levels during a long time at the beginning of operation, the amplifiers did not fail.

The amplifiers for CERN were tested with complex loads around the Smith Chart as well as with a disconnection of the output cable under full power. They reduced their power under the total mismatch but continued normal operation after reconnection of the cable without the need of a reset.

The basic amplifier cell with the BLF278 meanwhile has proven its reliability also under hard industrial conditions in more than a thousand modules built for the excitation of plasma loads and CO2 lasers.

6. EMC / EMI

The main problem to fulfill the German VDE 0871 with the amplifiers delivered for GSI has been to get rid of the 100 kHz of the switched power supplies on the mains, which had been demanded earlier by the so called "Störgrad N" (Now A / B). Custom made filters had to be additionally introduced to the amplifiers. Compared to the necessary work for this part of the specification, the RF-radiation acceptance test was easy achieved, as the old limits of 1992 had to be met.

At the time of the construction of the CERN amplifiers, the limit of the radiated field strength as allowed was drastically reduced to 30 dBuV/m, measured in a distance of 30 meters by the newest IEC-801/3 standards and the VDE 0871/B regulations.

A special RF-cabinet inside the 19" plug in has been built, with high quality filters for all signal cables surpassing, but even if all the design has been made to fulfill the EMC regulation, many additional shielding had to be introduced until it passed the final examination.

The result achieved at last was that inside a building the electric field strength of normal broadcast stations in the VHF range was as high as the signal from the amplifier in a 6 meter distance while the magnetic field signal of the amplifier was negligible. The maximum of the remaining leakage, found with a small RF-pickup-probe, was caused by a surface wave on the output RF line, which was additionally reduced by a better contact of the output N-connector.

7. CONCLUSION

A modular new generation of power amplifiers has been developed, which fulfils the special demands of pulsed operation for accelerators with different duty cycles from 1% to 60% in a most cost-effective manner, based on an proven industrial RF power module.

The modularity allows the realization of RF amplifiers up to 5 kW at 10 - 220 MHz from short pulses to cw operation with only minor modifications to the system.

The amplifiers built for GSI and CERN demonstrate a very satisfying performance and reliability and meet all of the high standards of the specifications.

Additionally to the above described amplifiers, three amplifiers with 1 kW pulse power, 1% duty cycle at 202 MHz where meanwhile delivered to CERN as amplifiers for a phase reference line of the Pb-Linac.

8. ACKNOWLEDGEMENT

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2 N.Angert et al., CERN Heavy - Ion Facility Design Report, CERN 93-01