DESIGN OF A COMPACT RF PULSED POWER AMPLIFIER

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Abstract:

This paper describes the electrical and the mechanical design of a compact radio frequency power amplifier at 200 MHz employing coaxial line techniques extensively. There is no tuning element either in the anode circuit or in the control grid circuit. This makes the amplifier rather attractive for fixed frequency application and for bandwidth requirement not exceeding 5 % of the center frequency. Tetrode tube with grounded screen grid is considered for the design. A programme for developing a proto-type amplifier with a pulsed output power of 550 kW has been started.

Introduction:

The large peak power requirement for SNQ LINAC[1] in excess of 300 MW at 201.25 MHz demands very efficient radio frequency power amplifiers. With 640 single accelerating structures, it is possible to design modular power amplifiers which will produce 550 kW to power each accelerating structure. The general requirement for the accelerator is that the rf gain and dc-to-rf conversion efficiency be as high as possible and that the physical size and cost be minimised. Since the overall efficiency of the rf plant takes into account bias, heater power, cooling and rf drive, the choice of the active device plays an important role.

Design considerations:

i) Tube-selection: Although in principle both triodes and tetrodes can be employed in accelerators, the triode amplifier generally has a low rf gain of 10-13 dB whereas the tetrode has a gain between 16 to 20 dB. Hence a tetrode amplifier is favoured since the drive stage is simplified.

A beam power tetrode capable of producing 550 kW of output with thoriated tungsten needs approximately 2.7 kW of heater power. For a pulsed amplifier with low duty cycle (2.5% for SNQ), this heater power will lower the overall efficiency and also will contribute to higher operational cost. An oxide coated cathode will be a better choice since the heater power is only 700 Watts.

Since dc-to-rf conversion efficiency is a strong requirement for an efficient rf amplifier, tetrodes whith grid drive modulation are used. The permanent DC plate voltage can not be chosen as high as in the case of short pulse plate modulation. Also a high plate voltage will impose a voltage hold-off limits in the design of the resonator around the tube rather than inside the tube which is in vacuum. Since a DC voltage in excess of 30 kV begins the region of corona, a DC plate voltage in the neighbourhood of 20 kV will be ideally suited. This brings in the need to increase emission current. This requirement can be satisfied by enlarging the active tube geometry[2]. The tube designer is faced with two major problems when active system is increased namely sharp current maxima inside the tube or close to the socket giving rise to excessive heat and lowering the resonant frequency of the circumferential wave modes in the three interelectrode areas where the tube still has high mutual conductance to sustain oscillation.

ii) Cavity design: Figure 1 shows the cross section view of the cavity around the tube. This cavity for pulsed operation is an extrapolation of a cavity developed at CERN.

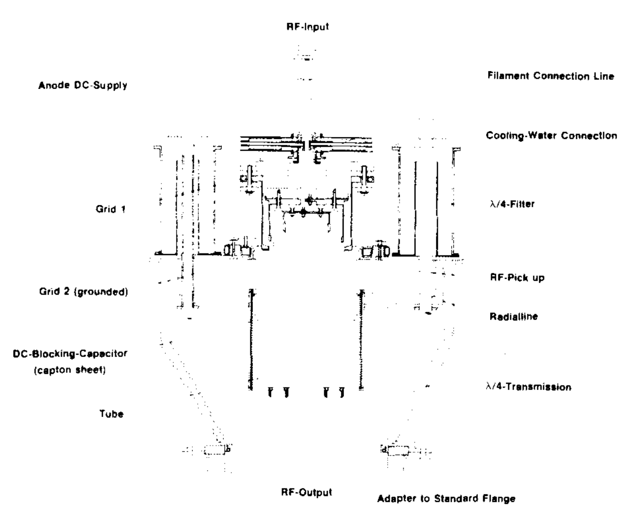

Fig. 1 Cross sectional view of amplifier

The screen is grounded both rf and DC wise, thus, simplifying the output circuit and provides excellent isolation between input and output circuit. The external plate circuit consists of a 30 Ω line, a λ/4 line of 3.3 Ω and a finally 10 Ω line to match to the output. However, any other output impedance can be chosen for a specific application. The different line lengths and impedances are optimised to match the inherently low impedance at the socket. Similar technique is applied to the grid circuit such that it is matched to a 50 Ω generator. The grid 1 - grid 2 is shorted with respect to rf by a λ/2 line and bypass capacitor. Both the DC plate voltage and filament power feeds are decoupled by λ/4 lines. An approximate equivalent circuit is shown in Figure 2.

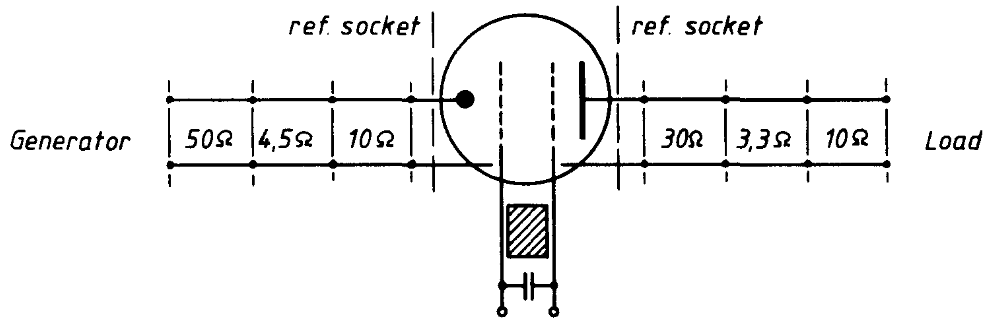

Fig. 2 Equivalent circuit of the amplifier

The DC blocker for the plate voltage are made of several capton sheets placed between the double plates of the anode disc. The immediate vicinity (30 Ω impedance section) allows to install damping loops for higher harmonics. Longitudinal slots are cut in the outer conductor to prevent the current flow of circumferential modes. Also ferrite absorbers are used in the anode ring to suppress spurious oscillation.

Due to the fact that inside the matching sections only little energy will be stored the cavity is a broadband device. Therefore no tuning elements are needed in the plate or in the grid circuit. Nevertheless there is a tuning element provided in the area near the socket which can be incorporated easily. For reasons of high efficiency a fine tuning of the resistive matching can be obtained by adjusting the plate current.

iii) Other considerations: The cavity around the tube, generally known as "Topfkreis" is made of aluminium with silver plating.

Both water and air cooling is provided in the "Topfkreis". The socket is well cooled since this is the region of maximum rf current. The unique design of the Topfkreis allows water cooling pipes (polythene) for plate to be coiled around the plate and be located in a rf free region.

iv) Amplifier design: The amplifier is designed as class B grounded grid operation capable of producing 550 kW pulsed output. The approximate DC and rf parameters of the amplifiers is listed in Table 1. Although a shunt impedance of 240 Ω and an assumed output capacity of 40 pF would produce a 3 dB bandwidth of 16 MHz, in reality the transformations through transmission lines will result in narrower bandwidth. The bandwidth requirement is tightly coupled to the control system and a 3 dB bandwidth of a few megahertz is often adequate for the purpose. Figure 3 is the photograph of such an prototype amplifier[3] made at CERN producing 125 kW of pulse power.

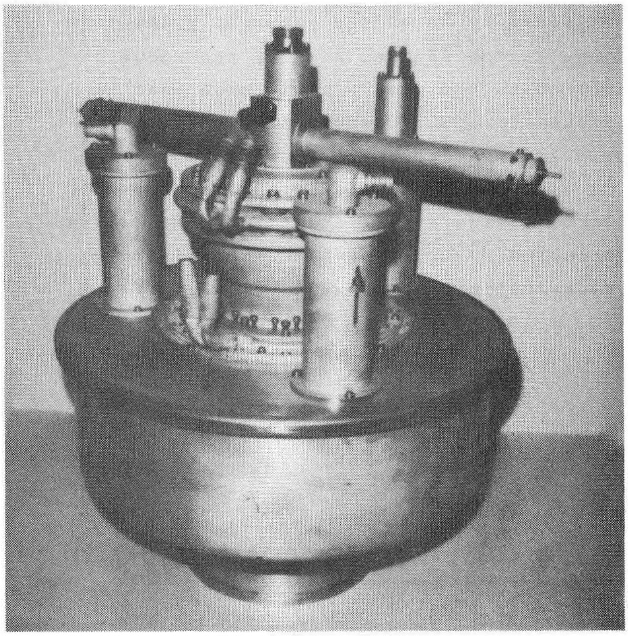

Fig. 3 Photograph of "Topfkreis"

Discussion:

The amplifier which is described in this paper is presently under design consideration. The prototype tube which will meet the DC operating points and rf values are in the process of precurrement from different manufacturers. A careful design of the Topfkreis is needed such that voltage hold-off is not exceeded and rf current peaks are minimised.

The design outlined has one significant drawback, i.e. the tube is poorly accessible for a quick replacement. This does not pose a problem for the SNQ since a failed amplifier unit will be replaced completely and the faulty unit to be serviced at a later time.

Future attempts will be made to combine the driver amplifier with the power amplifier such that a compact amplifier module (with gain of 40 dB) can be built requiring very little drive power. This will also result in low cost of the rf plant since rigid coaxial feeder lines in the drive circuit can be avoided.

References:

1 SNQ Report 1983.

2 K.H. Knobbe and D. Böhne, "A megawatt rf source at 108 MHz", IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981, pp. 3010-3011.

3 H.P. Kindermann, private communication.

Table 1 Amplifier parameters

Typical ratings, grid pulsed rf-amplifier

Plate Voltage	20	KV
Screen Voltage	1,5	KV
Bias Supply	-300	V
DC Plate Current	40	A
Anode Dissipation	20	KW
Frequency of Operation	201,25	MHz
Pulse Width	250	μs
Pulse Repetition Rate	100	Hz
Peak Plate Current	69	A
Peak Plate Voltage	16	KV
Useful Peak Power Output	550	KW
Plate Effective Shunt Impedance	240	Ω
Grid Drive Power	8	KW
Power Gain	18	dB
RF-Efficiency	69	%