A HIGH POWER RF SUPPLY FOR THE CHALK RIVER 100% DUTY FACTOR ALVAREZ LINAC

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Summary

The 3 MeV Alvarez tank of the Chalk River High Current Test Facility needs an rf source with a continuous power level of 400 kW at a frequency of 268 MHz. The amplifier chosen employs a RCA A15039 development UHF Triode operating in a grounded grid circuit and has a minimum power gain of 12. It is driven by a high gain RCA A2548 developmental tetrode. The low power stages are conventional.

A description of the application requirements and the final amplifier design will be given and our operating experience with this system outlined.

Introduction

The Alvarez linear accelerator section of the Chalk River High Current Test Facility is being constructed to study problems of high beam current accelerators under 100% duty factor operating conditions. The choice of operating parameters has been influenced by the availability of equipment and designs from the ING study[1]. The rf power supply described in this paper obtained its major components from a breadboard amplifier constructed for the ING development program[2].

Rf Power Supply Specifications

The Alvarez accelerator is a single tank; Table 1 lists its basic specifications[3].

TABLE 1

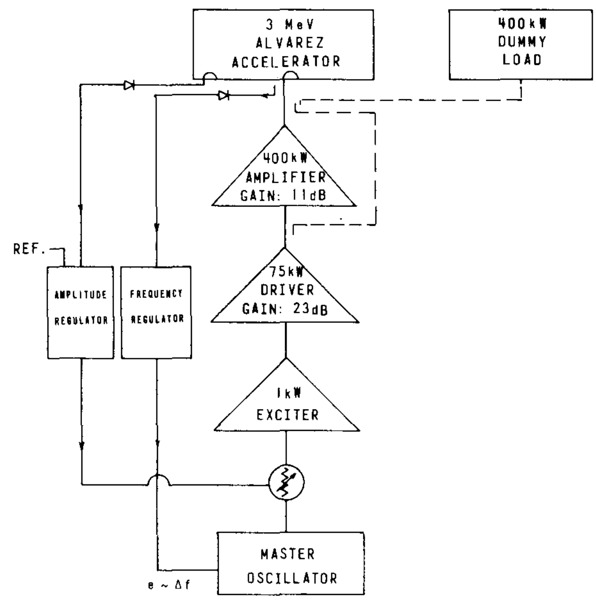
BASIC LINAC SPECIFICATIONS

Input Energy	750 keV
Output Energy	2.982 MeV
Frequency	268.3 MHz
Tank Diameter (inside)	71.11 cm
Tank Length (inside)	164.97 cm
No. of Cells	25
Rf Field (peak)	2 MV/m
Rf Power	
no beam	120 kW
with 50 mA beam	232 kW
with 100 mA beam	344 kW

It operates at 268.3 MHz and requires an excitation power of 120 kW to achieve the design axial field of 2 MV/m. The beam loading at the expected space charge limit of 50 mA is 112 kW. An rf power capability of 400 kW was chosen to provide suitable contingency.

Rf System Outline

A block diagram of the rf system is given in Fig. 1. Because the last stage is a triode in a grounded grid circuit, the gain is low and a large drive power must be provided. The lower power stages have somewhat higher gains but we still require many stages with the associated complexities of control and protection.



3 MeV ALVAREZ LINAC RF SYSTEM

FIGURE 1

The tube manufacturer recommends that the triode should not be operated with zero or very low drive power to avoid the possibility of a destructive parasitic oscillation, so for very low power outputs as for example initial rf conditioning of the Alvarez accelerator, the 75 kW amplifier can be connected directly to the accelerator. The final amplifier can be switched to a full power resistive load for test or adjustment.

Amplitude and frequency regulation systems are required for accelerator operation. A tuner has not been incorporated into the accelerator so the operating frequency will be made to follow the resonant frequency of the accelerator as it drifts because of rf heating. The expected shift in frequency of about 85 kHz can be handled readily by the frequency control system[4].

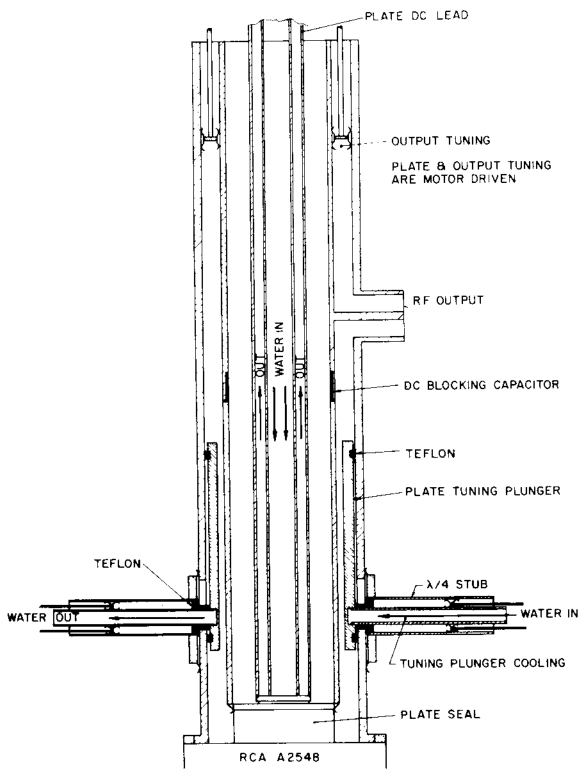
Oscillator-Exciter

The master oscillator is a General Radio Synthesizer because it can be programmed easily for frequency control. Its output, which is 22.361 MHz, (1/12 operating frequency) is raised in frequency and power by a series of multiplier and amplifier stages (comprising the "exciter" of Fig. 1) to a maximum power of 1 kW.

Tetrode Driver Stage

The driver stage uses an RCA A2548 high gain tetrode which is a developmental version of the 2041 used in radar service. The cooling has been increased from the standard 2041 to raise the plate dissipation limit from 20 to 55 kW thereby permitting a nominal output of 100 kW at 100% duty factor.

The tube has a single ended coaxial structure with a centrally located plate and rf terminals arranged so that the input and output resonators are mounted on opposite ends of the tube. Figure 2 is a simplified cross section of the coaxial 3/4 λ plate resonator. It is tuned by a combination of adjustments of a shorting plunger and a moveable tuning plunger λ/4 long. The latter is supported between the resonator walls by a pair of shorted λ/4 stubs. The shorting plunger strongly affects the output coupling and hence is used primarily for loading adjustments. Only the tuning plunger assembly is water cooled; the remainder of the structure is air cooled.



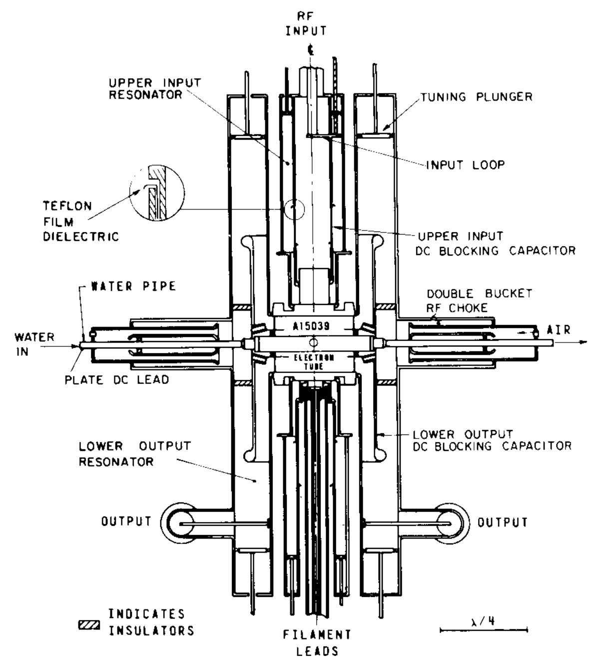
TETRODE PLATE RESONATOR

FIGURE 2

Triode Amplifier Stage

The final stage uses an RCA A15039 developmental triode which is electrically identical to the pulse type 2054 and similar to the 7835 used in many accelerator applications. The main differences from the 7835 are a double wound grid giving a higher amplification factor and better plate to cathode isolation, and improved cooling allowing a plate dissipation of 750 kW. The early breadboard installation had a power output goal of 1.2 MW and the tube itself is capable of this but the present installation is designed for only 400 kW.

The tube is a double ended coaxial structure and requires dual resonators arranged concentrically as shown in the simplified cross section of Fig. 3.



A15039 TRIODE AMPLIFIER STRUCTURE

Figure 3

The resonators are (3/2)λ total length including the tube. The input resonator has an enlargement of the outer wall diameter to accommodate tuning plungers. All of the tuning plungers are fitted with finger stock wall contacts and are driven electrically as a pair so that the upper and lower halves of each resonator are adjusted equally. All of the resonator walls and the tuning plungers are water cooled except the outer wall of the output resonator which has an adequate radiating surface.

Dc isolation is provided by λ/4 coaxial capacitors (solid dielectric insulation for the input and air for the output) placed in the resonator wall at a current minimum, λ/4 from the tuning plunger short. Although the input blocking capacitor has a low characteristic impedance (0.4 ohms), it does allow some rf leakage at the filament lead penetration on the lower resonator but this has not proved troublesome. The output blocking capacitor consists of two copper buckets bolted at the high current end to the tube plate terminal. The bead enlargement at the open end has been shaped to withstand the combined dc and rf voltage stress.

Water cooling for the plate enters and leaves by four radial copper tubes which are fitted with "double bucket" rf chokes to isolate the rf voltage on the plate. The blocking capacitors alone do not prevent all rf leakage because the open end of the capacitors is not exactly at the current minimum, and this minimum is not zero, so careful tuning of the rf chokes is essential. These assemblies also carry plate dc power and cooling air for the alumina plate-to-grid insulators of the tube.

The input loop on the upper resonator is made adjustable by extending the centre conductor of the input coaxial line with a telescopic joint to the three arms of the loop which pass through axial slots in the inner resonator wall and connect to the outer wall with sliding contacts. For output coupling, two fixed taps are made to the inner wall of the lower resonator to avoid exciting a circumferential mode. These are connected to two 100 ohm coaxial lines which are joined at a tee junction to a 50 ohm, 23.3 cm diameter output transmission line. Both the taps and their continuations, the 100 ohm line centre conductors, are water cooled.

Plate Power Supplies

Plate dc power for the triode is supplied by two parallel connected 20 kV - 40 A general purpose power supplies located in an adjacent building about 75 metres away. Because these supplies must be shared with other experiments, they are equipped with facilities for interconnection with one of several control and terminal stations. Hence they have independent short circuit protection consisting of vacuum switches that disconnect the transformer primary windings and short the output terminals within the first half-cycle following detection of an external short. Other features that contribute to their ability to withstand tube arcs and crowbar short circuit fault currents include air core primary reactors to limit short circuit fault current to 5.5 times full load current, and thyrite resistors and lightning arrestors for filter choke and rectifier bank protection.

Voltage control is accomplished by off-load wye-delta switching of the transformer primary and continuous adjustment of primary voltage by a 30 percent range induction regulator.

The supply for the tetrode amplifier is similar but with a reduced rating and a continuous 75 percent range voltage control.

Crowbar Protection

Electronic crowbars for protecting the tetrode and triode tubes from internal arcs and shorts use the GL-37248 ignitron as the switch tube in a circuit that limits the growth of fault current to 110 A/μs and fires the ignitron in about 1 μs[5]. The energy stored in the filter capacitors of the two parallel connected power supplies is 2 kJ at 13 kV but if a tube arc develops, less than 0.05 J will be delivered to the arc. Crowbar effectiveness is measured by a 0.025 mm aluminum foil test in air[6].

Operating Experience

Tetrode Amplifier

The tetrode amplifier has been in service for several years with both resistive and resonant loads. It has been used extensively to condition and run a 1.1 m Alvarez test tank up to a power level of 55 kW[3]. Table 2 lists data from one of a more recent series of runs into a resistive load in which an output of 70 kW was reached at an efficiency of about 63%. Maximum permissible values shown in parentheses indicate the tube was operating well within its limits.

TABLE 2

A2548 TETRODE AMPLIFIER TYPICAL OPERATING CONDITIONS

Grid Drive Power	kW	0.37
Grid Bias Voltage	V	-195 (-300)
Grid Current	A	0.24 (1)
Screen Voltage	V	1245 (1500)
Screent Current	A	0.72 (1)
Plate Voltage	kV	12.0 (15)
Plate Current	A	9.4 (11)
Power Output	kW	70.8
Plate Efficiency		62.7
Power Gain		190
		22.8 dB

Triode Amplifier

The triode amplifier has been assembled, controls and protective circuits tested and high power commissioning has just started. In the breadboard setup, the tube achieved power outputs of up to 350 kW but these levels could not be sustained for longer than a few seconds because of excessive internal gas. The tube has been rebuilt by the manufacturer to correct this problem. Factory tests were conducted on the rebuilt tube under pulse conditions at 400 MHz. The tube delivered a peak output of 3.94 MW with 190 kW drive at 30.5 kV plate voltage and an efficiency of 49%. Of more interest for our application is their data at 13 kV in Table 3, which shows the performance for class B operation at two values of drive power, the minimum permissible and the value expected to produce 400 kW in our amplifier. The gain for both is much greater than originally estimated by the manufacturer and if performance at 268 MHz proves to be similar such gains may cause some inconvenience in control over the full range of beam current because the output power at minimum permissible drive will be too high.

In our own high power tests at 100% duty factor we have operated into a resistive load up to 210 kW (measured calorimetrically). Initial performance data of the completed amplifier stage shown in Table 4 are taken from two runs during rf conditioning of the tube. For these initial tests a large fixed bias of close to cut-off value for a 10 kV plate voltage was applied as a precautionary measure. Although the bias voltage is greater and the plate voltage is lower than those of the RCA tests described earlier, the power gain at the minimum permissible drive of 10 kW is large and possibly will match the RCA value at their operating conditions.

TABLE 3

A15039 TRIODE OPERATING CONDITIONS AT 13 kV
(400 MHz 0.07 duty factor)

Grid Drive Power	kW	10	35
Grid Bias Voltage	V	14	22
Grid Current	A	62	100
Plate Voltage	kV	13	13
Plate Current	A	61	100
Power Output	kW	252	628
Power Gain		25 (13.9 dB)	19 (12.8 dB)

TABLE 4

A15039 TRIODE AMPLIFIER TYPICAL OPERATING
CONDITIONS (268.3 MHz)

Grid Drive Power	kW	10	12.2
Grid Bias Voltage	V	40	42
Grid Current	A	26.5	33
Plate Voltage	kV	10.8	12.5
Plate Current	A	22	27
Power Output	kW	150	210
Power Gain		15 (11.7 dB)	17 (12.4 dB)
Efficiency	%	63	62

Conclusion

While amplifier performance has yet to be explored over a wide range of operating conditions, the initial conditioning runs have provided useful information. For instance, the amplifier can deliver an output power of 210 kW, which should be sufficient to excite the Alvarez tank and to accelerate a 40 mA beam. Much of the operation to date has been at a substantial output power and with runs of several hours length during which the rf structure has performed well and thermal problems have not been encountered . We are optimistic therefore, that the amplifier will meet our power objective of 400 kW.

Acknowledgement

We wish to acknowledge the work of Professor F. Konopasek, Physics Department, University of Manitoba, who designed and constructed the exciter and tetrode driver systems part of which has been used in this present installation.

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