

NEW RF POWER SYSTEM FOR SUPERHILAC*

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Abstract

The upgraded rf system for the SuperHILAC is now operational using 9 new tetrode amplifiers. Each amplifier can produce in excess of 1Mw of 70 Mhz pulsed rf power. Ferrite is used to decouple the screen grid circuit and to absorb parasitic oscillations. This results in a very stable amplifier with reasonable gain. This system uses a common 6 Mw anode power supply and crowbar system. Overall system efficiency has been increased significantly. We project a 3 year payback on the equipment cost, realized from the power savings alone.

Introduction - Background

The SuperHILAC main RF amplifiers were originally designed around the RCA 6949 shielded grid triode. Several years ago when these tubes became unavailable, we started an upgrade program to replace all tubes with the EIMAC X2170/8973. A prototype amplifier was constructed in 1980 and initial tests were very promising, although control grid secondary emission remained a difficult problem.[1]

In 1983, for shakedown and evaluation, two new amplifiers with ferrite screen decoupling were installed on the prestripper. These replaced three existing triode amplifiers on the most difficult to drive accelerator cavity. Our experience with these tubes was very favorable.

Early in 1984 we started a full scale replacement of all amplifiers on the basis of payback from energy savings and better accelerator performance.

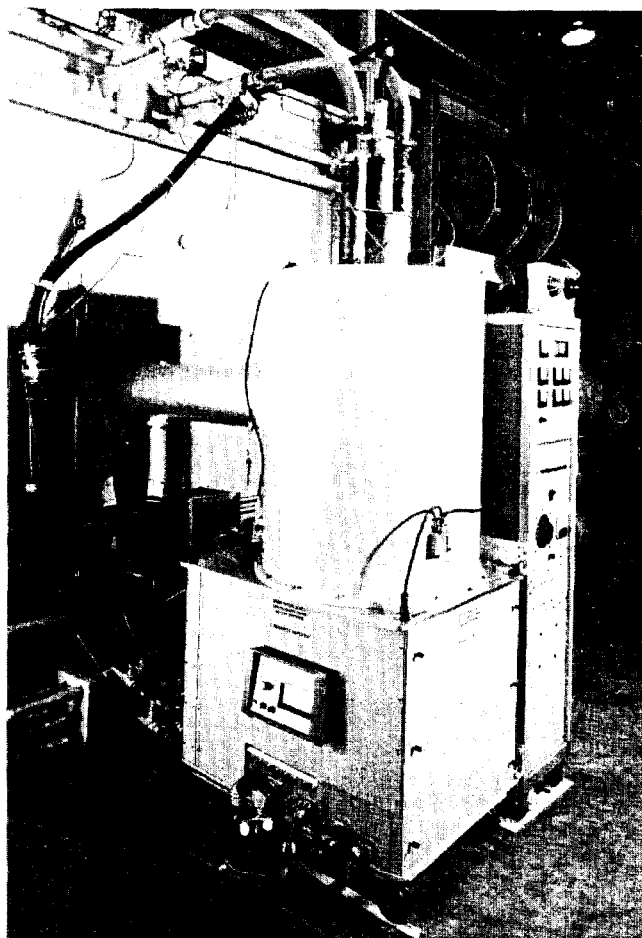
Ferrite Screen Grid Decoupling

In the original prototype design [1] the screen grid was bypassed directly to the cathode terminal. This provided maximum gain, but unfortunately with this connection we found it very difficult to stabilize the amplifier, especially when operating the control grid in the positive region. Secondary grid emission can, at times, be quite large in this tube, and the positive feedback produced causes severe instability in the amplifier. Traditional resistive grid swamping proved to be of limited value in this case since it was impossible to place an appropriate resistance at the required location.

It has been previously found at LBL, that if in large VHF tetrode amplifiers, the anode/screen grid, and cathode/control grid circuits are isolated from one another by a ferrite loaded cavity, that stability is much improved.[2] Since we were already using some ferrite loading below the screen deck to damp parasitic modes at 500 and 1000 MHz, we decided to increase the volume of this ferrite to also provide screen grid isolation at 70 MHz. Since the grid input capacity in this configuration is reduced to approximately half of its previous value (only the grid to cathode capacity is now effective for input tuning) the input circuit required rather extensive modification.

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From the time this modified amplifier was first powered it proved to be extremely stable, even without neutralization. We were able, in only a few weeks time, to bring the peak output power up to almost 2 Mw.



AMPLIFIER WITH DRIVER

Power Testing

To enable us to perform off line power testing at full peak power we designed and fabricated a resonant load that quite closely approximated the characteristics of the Alvarez linac. A 300 mm diameter quarter wave line section with a 400 mm corona ball inside a one meter diameter outer conductor was used for the resonator. To lower the Q and provide the desired loss in the system we installed an electrolytic resistor between the center conductor and outer shield, radially at about the 100 Kv point in the coax. Potassium chromate solution was circulated in a closed loop system through the resistor and heat exchanger. By moving the tap point for the resistor up and down, and rotating the drive loop, we were able to change the loading conditions for the amplifier over a wide range of values.

During initial testing our average power was severely limited, by having only a small plate power

supply, to about 50 Kw. During our low (3-5%) duty factor tests we could quite easily produce 1.9 Mw peak power, measured at the electrolytic load. During these tests the plate power supply with only about 19 Kv limited the peak output power. The amplifier was very stable under all tuning conditions, and the gain was a reasonable 16-17 decibels.

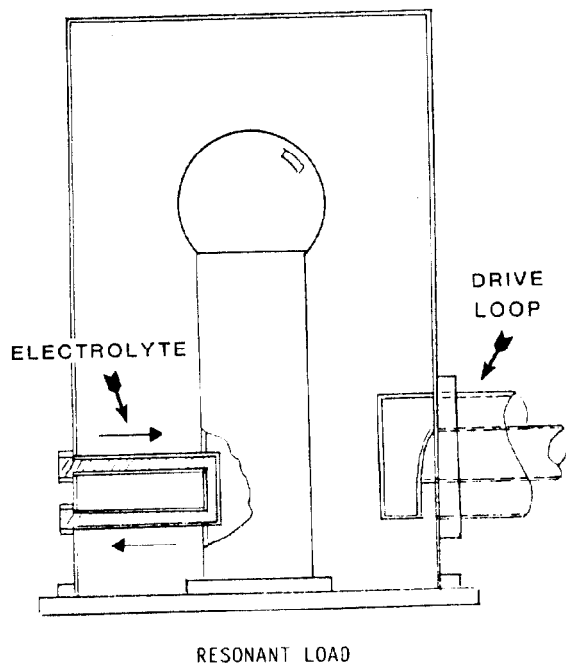
The existing driver, an Eimac 4CW25,000, was at near maximum output power for these high power tests, however, this was not felt to be a problem since the amplifier would operate at much lower peak power (500,700 Kw) when installed on the SuperHILAC.

In 1983 we installed 2 of the new amplifiers on the large prestripper cavity, in place of 3 RCA 6949 amplifiers. The performance of the new amplifiers exceeded our expectations, and we were able to permanently retire the 3rd amplifier location. At this time we connected the anode modulator to produce full output on a nonpulsed DC basis, as a test of amplifier stability.

Energy Savings

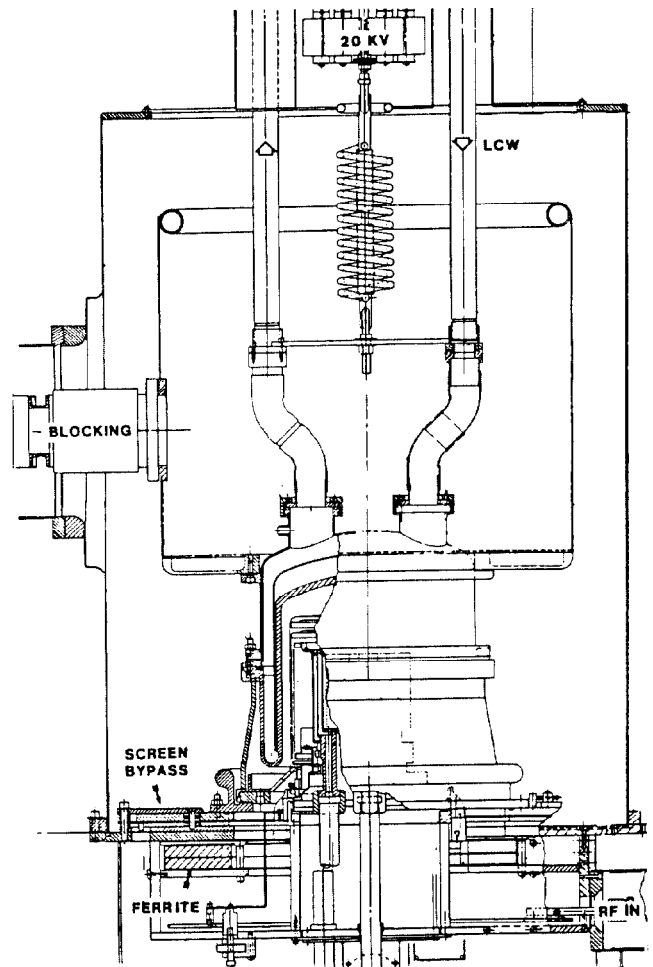
Our original plan was to replace the RCA amplifiers, with the new tetrode amplifiers, one at a time as they failed. It soon became obvious, however, that we would not require the anode series modulators with the new system, and they could be bypassed as soon as all of the triode tubes were replaced with the tetrodes. The series modulators drop a minimum of about 5 to 7 Kv and require over 100 Kw of auxiliary power. We calculated that we could save sufficient energy by eliminating the modulators, to amortize, in less than 3 years, the total cost of building and installing all 9 new amplifiers. This high cost to benefit ratio qualified us for immediate funding under the Department of Energy's, In-house Energy Management program. In order to reach our goal of eliminating the energy wasting modulators as soon as possible, we elected to fabricate and install all new amplifiers simultaneously.

By closely tracking costs and project milestones, we were able to complete the project easily within the 18 month schedule and \$920K budget.



Fault Management

We were quite concerned about the ability of our single large anode power supply to do severe damage to the relatively fragile tetrodes, especially without the extra safety factor provided by the series modulators. We started an engineering program to re-evaluate our crowbar and fault monitoring system. Now in addition to the original doubly redundant ignitron crowbar, and rf resonator crowbar, we have installed a series current-limiting resistor and a fast-acting high-voltage fuse.



AMPLIFIER CROSS SECTION

We designed and installed a microcomputer fault monitor and analysis system that, on each crowbar initiation, checks for proper operation of all systems, and prints out a status report for the maintenance personnel. We have also installed, in the control room, a transient digitizer system that is used to record all pertinent signals from an individual amplifier, and display a pre- and post-trigger record for fault analysis. These systems give us the ability to rapidly analyze, and repair, any malfunction in our crucial fault diverting systems.

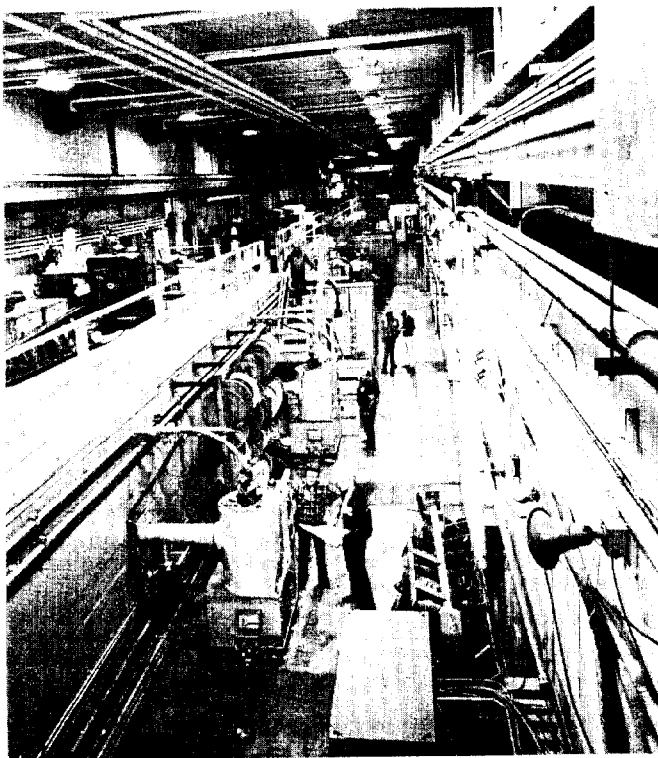
Problems

In most high power rf systems the majority of problems relate to unwanted oscillations and high current joint failures. Our experience on the X2170 project was not unusual in this respect.

After our first two amplifiers had been in service for approximately one year (about 6000 hours) we dismantled them for an inspection. To our horror we found several potentially serious problems. The anode to water jacket joint and O-ring were badly burned. We determined that the O-ring groove was undersized and the ring over-filled it, precluding a metallic contact between the resonator and tube. It was also found that there was paint in this rf joint that must be removed before the tube is put in service. The fix for this problem on pre-1985 tubes is to put a copper shim in the space outside the O-ring to provide solid metallic contact between the two flanges. On current production tubes this problem is solved by redesign of the O-ring groove.

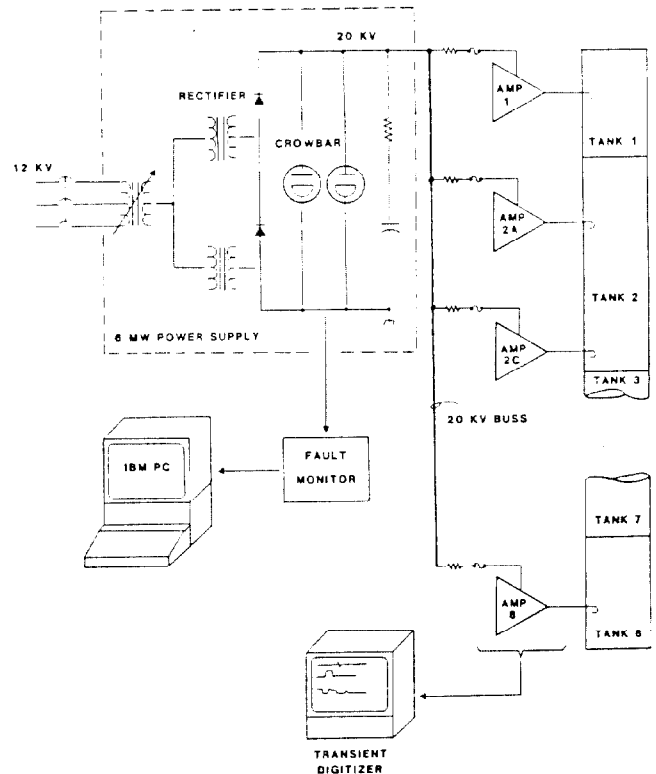
On further disassembly we encountered a second and potentially more serious problem. The cathode contact ring was badly pitted under each contact finger. This is a fairly fragile area with tube vacuum behind the relatively thin contact ring. The problem here is the high current flowing to the point contacts of the fingers on the magnetic kovar contact ring. Since up to 1/2 of the ring thickness had been destroyed, we elected to heavily silver plate these damaged bases, and also the new, tube bases. We redesigned the cathode connection to increase the finger contact pressure, and with the silver to silver contacts, have had no further failures.

The last problem encountered is in the screen grid to screen corona ring joint. On any factory new tubes this ring must be removed and the contact surfaces cleaned, then reassembled with Penatrox compound in the joint area, and the bolts tightened to the maximum factory specified torque. On 5 tubes without this treatment and only a short time in service, all showed damage, some quite serious, between the nickel and aluminum surfaces. The 2 tubes with 6000 hours each, and with Penatrox in the joint areas, showed no damage whatsoever.



ACCELERATOR GENERAL VIEW

During our debugging phase the engineers at EIMAC were extremely helpful, and very quick in their response to our needs. The fixes to all the identified problems have been incorporated into their current production, and several internal improvements to the tube have been made as well. The 1985 EIMAC 8973 is a rugged and well manufactured tube, and definitely superior to the original X-2170 we started with in 1978.



SYSTEM BLOCK

Conclusion

The system at the SuperHILAC is now fully operational with 9 amplifiers directly connected to a single large (6Mw) anode power supply. This system has proven to be reliable in operation, with very short mean time to repair failures, and can produce well over 10 Mw of long pulse rf. This system was completed on a tight 18 month time schedule, and remained well within our budgeted cost.

Our next major task in the upgrade schedule will be to redesign the class C intermediate power amplifiers, and the low level drive chains for linear service, and move the amplitude regulation control loops from the driver screen grid modulators, to the low level rf control system.

References

- [1] J. Fugitt, Proc. Linear Accelerator Conf., Santa Fe, Nm, 1981, pp. 287
- [2] A. Faltens, PEP 78 Mhz RF Development (LBL Memo.)