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LOW-COST MEGAWATT RF POWER SOURCES FOR LINEAR ACCELERATORS TO 70 MHz AND ABOVE*

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Abstract

The new main RF amplifiers for the SuperHILAC are designed for high reliability, short repair-time, and low cost. Innovative use of copper-plated aluminum components cuts fabrication time, weight, and materials costs. The use of a simple, cylindrically loaded, $\lambda/2$ anode resonator is cost-effective and allows quick access to the tube when replacement is required. A high gain, neutralized, grounded cathode configuration simplifies the drive requirements. The EIMAC X2170 (8973) was chosen for proven reliability and low cost.

Introduction--Background

The SuperHILAC main RF amplifiers were originally designed around the RCA 6949 super power shielded gridtriode. This tube is very well mannered and easily achieves a stable gain of 18 to 20 db delivering the required 500-700 kW with 10-15 kW drive. The water-cooled beam former makes this tube extremely rugged and well-suited to driving "dirty" accelerator sparking type loads. However, in recent years, the RCA 6949 has become unavailable for tube replacement at any reasonable cost. Knowing that we would soon run out of suitable replacement tubes prompted us to begin design studies for a replacement amplifier.

Design Specifications

(1) The new design should use a tube of domestic manufacture and of reasonable cost, one that hopefully will remain in production for the remaining life of the SuperHILAC.
(2) The new amplifier cart must be mechanically and electrically compatible with the existing systems as they will be used interchangeably for several years while we use up our supply of RCA 6949's.
(3) The new design must provide increased reliability and maintainability over the existing system.

The EIMAC X2170/8973

The X2170 is the only serious contender in the power/frequency/price class. Although the X2170 is very cost-effective and exhibits very high gain, it has several very serious disadvantages when socketed for linear accelerator service, the first of which is its fragility. Since the X2170 is not a shielded grid design, it is therefore extremely prone to destruction from high-energy anode-to-screen grid arcing common in this service. At the SuperHILAC we have installed fast-acting crowbars to protect the tube from the stored RF energy in the main resonators as well as fast-modulator disconnects in the B+ line. As a backup, we have a shunt crowbar on the main DC bus. It is our hope that these crowbar circuits can be maintained in adequate working condition to protect the screen grid from destruction.

The second shortcoming is that, due to the tube's size and lack of internal shielding, it exhibits strong oscillations in the UHF region that are very difficult to eliminate.[1] The third, and probably the most serious problem, is the strong negative resistance characteristic of the control grid in the region between 100-300 volts positive. This is just in the region where the tube is producing near full output power. All solutions for this problem to date have severely reduced stage gain (grounded grid 13 db, reduced screen voltage and grid swamping 16-17 db).

SuperHILAC amplifier with 4CW25K driver.

The SuperHILAC Amplifier Design

The requirement for compatibility between the new and old amplifier types puts some very severe limitations on the amplifier design. The most serious is the requirement that the new amplifier be driven to full output from the existing drive chain. (In the case of the prestripper, this is about 15-20 kW maximum per tube.) This requires a stable gain of about 17 db, thus precluding the possibility of running the stage in grounded grid configuration.

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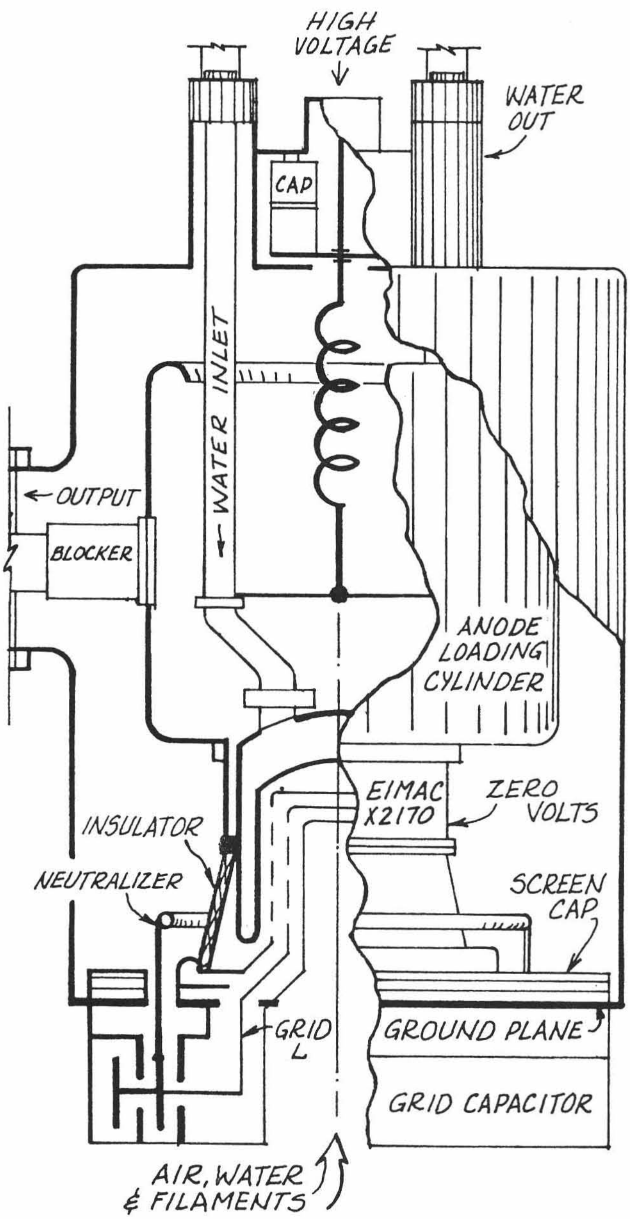
To meet these objectives, we have designed the amplifier as a conventional grounded cathode stage with λ/2 grid and anode sections. The anode resonator consists of a cylindrically-loaded coax with the blocking capacitor placed in the output transmission line. With this design, the voltages on all parts of the structure are low, the resonator is inexpensive and easy to fabricate, and the blocker is an off-the-shelf standard commercial unit.

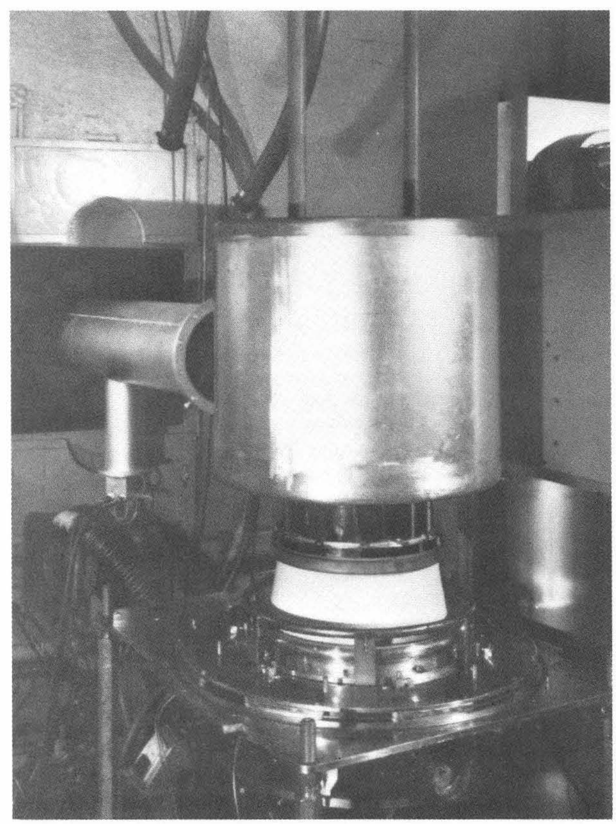
The screen bypass capacitor is a multiplate kapton-insulated subassembly, capacity about 65 nF. The neutralizing network penetrates the screen capacitor at six places. Spark gaps are mounted on the top surface to protect the insulation in the event of an anode/screen arc.



X2170 main amplifier simplified section view.

Grid Resonator

By far the most challenging task facing our group was the design of the grid resonator/neutralizer system. The input capacity is high, currents are high, and space is at a premium. As a cost-saving measure, we elected to use the shortened radial line that has proved so effective on the 6949 amplifier. This saved considerable space directly below the socket, and placed the 180° point directly under the edge of the screen flange. This made it very easy to merely penetrate the screen capacitor with six neutralizing tabs coupled to the lower end of the active anode by a corona ring. This produces a simple neutralizing system free of any parasitic modes near the operating frequency. Since the grid input impedance of this tube varies widely with level and tune, it is imperative to use heavy resistive swamping on the grid. In our case, this amounts to 20 kW worth of nichrome-on-alumina water-cooled resistors mounted radially around the grid contact ring. This gives a grid-to-ground resistance of ~12 ohm and a gain of ~18 db.



X2170 with outer resonator removed.

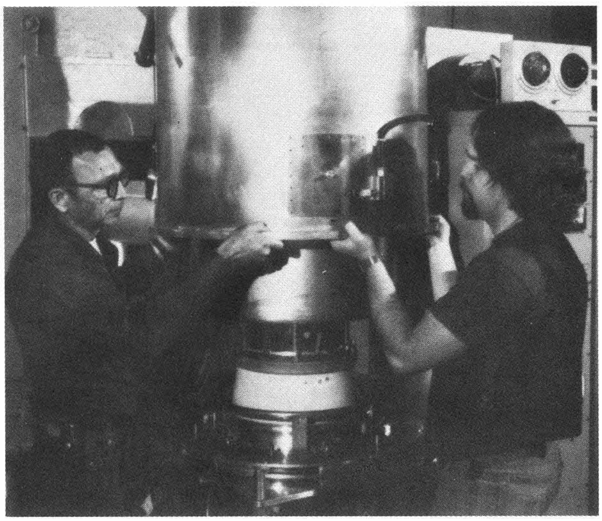
Tests

The prototype amplifier has been run up to a power level of about 700 kW. Sparking in the linac cavity prevented us from further increase in power. At full power, even under out-of-resonance or load-sparking conditions, no sparking was detected in the X2170 or its anode cavity.

Reliability

With the RCA 6949, the most serious problem is high-current joint failure at the junction of tube and resonator. This invariably results in total destruction of the 6949 tube.

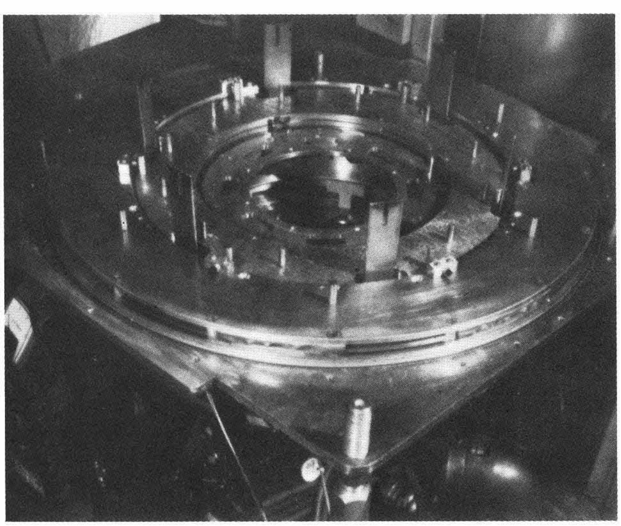
In the X2170 cavity, all high current joints are massively bolted and are additionally water- or air-cooled.



Amplifier with outer resonator partially removed.

Maintainability

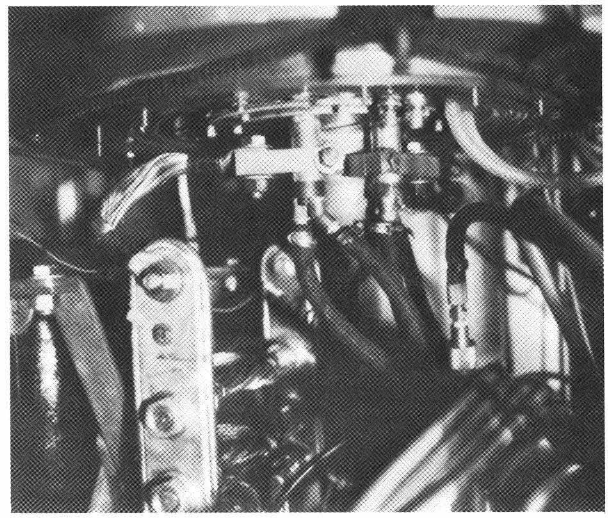
The X2170 cavity/amplifier is designed so that the tube or the entire cart may be changed in a fraction of the time required to change the RCA 6949. The main improvement is making the anode transmission time a quick disconnect unit and designing the X2170 resonator system so that the tube is installed into a socket rather than having the resonators built up around the tube.



Ground plane with screen capacitor.

Filament Power Supply

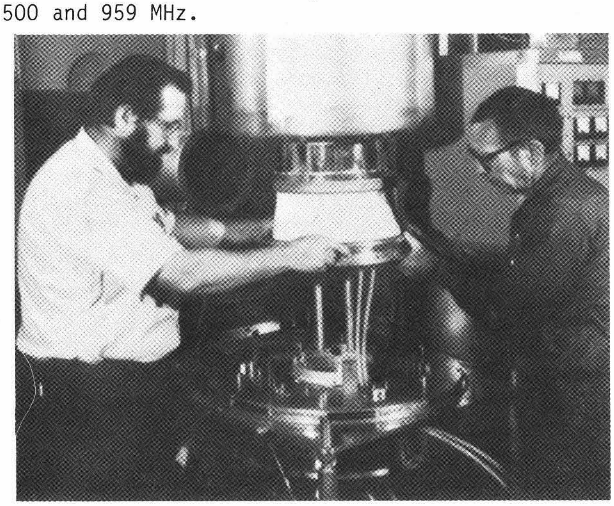
The filament is DC powered from a three-phase power supply. This scheme allows us to use our present filament induction regulator used on the 6949's. Also, since the filament voltage is almost 20 volts, it is advantageous to have DC excitation to prevent 60 Hz modulation of the output RF.



Tube base area showing filament connections and rectifiers.

Conclusion

The X2170 and its cavity have proven that they can provide the required power output and ease of maintenance. Considerable work remains to be done to fully stabilize the amplifier at partial drive levels and eliminate the parasitic oscillations at 500 and 959 MHz.



Removal of EIMAC X2170 with the inner resonator attached.

References

[1]K. H. Knobbe, Proc. IEEE Particle Accel. Conf., Washington, D.C. (1981) 3010.