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TITLE: DEVELOPMENTS AND DIRECTIONS IN 200 MHz VERY HIGH POWER RF AT LAMPF

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DEVELOPMENTS AND DIRECTIONS
IN 200 MHZ VERY HIGH POWER RF AT LAMPF

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ABSTRACT

The Los Alamos Meson Physics Facility (LAMPF), is a linear particle accelerator a half-mile long. It produces an 800 million electron-volt hydrogen-ion beam at an average current of more than one milliamp.

The first RF section of the accelerator consists of four Alvarez drift-tube structures. Each of these structures is excited by an amplifier module at a frequency of 201.25 MHz. These amplifiers operate at a duty of 13 percent or more and at peak pulsed power levels of about 2.5 million watts.

The second RF accelerator section consists of forty-four side-coupled-cavity structures. Each of these is excited by an amplifier module at a frequency of 805 MHz. These amplifiers operate at a duty of up to 12 percent and at peak pulsed power levels of about 1.2 million watts.

The relatively high average beam current in the accelerator places a heavy demand upon components in the RF systems. The 201-MHz modules have always required a large share of maintenance efforts. In recent years, the four 201.25 MHz modules have been responsible for more than twice as much accelerator down-time as have the forty-four 805 MHz modules. This paper reviews recent, ongoing, and planned improvements in the 201-MHz systems.

The Burle Industries 7835 super power triode is used in the final power amplifiers of each of the 201-MHz modules. This tube has been modified for operation at LAMPF by the addition of Penning ion vacuum "pumps." This has enabled more effective tube conditioning and restarting. A calorimetry system of high accuracy is in development to monitor tube plate-power dissipation.

Conversion of the driver amplifier for the 7835 from "plate-pulse modulated" to "drive-modulated" operation is planned. Development of a data acquisition and diagnosis system is in progress. Conversion to solid-state RF components where possible,

modification of the Alvarez structure coaxial RF windows, replacement of the 7835 filament power supplies, and additional modifications to the 7835 tube are also under consideration.

1. ACCELERATOR CONSTRUCTION

The construction of LAMPF was proposed in 1962 and begun in 1968. In 1970 the first phase of construction was completed with the production of a proton beam at 5 million electron volts. A year later 100 million electron volts was achieved and the design energy of 800 million electron volts was attained the following year.

The facility was formally commissioned as the Clinton P. Anderson Meson Physics facility in 1972 in memory of the late Senator from New Mexico. An average beam current of one-half milliamp was achieved in 1978 and a current of one milliamp became routine after 1983.

The LAMPF accelerator was built in four principal sections: a very-low-energy electrostatic accelerator section (called the injector area), a low-energy RF accelerator section, a medium-energy RF accelerator section, and an experimental area. See Figure 1.1.

There are actually three electrostatic accelerators in the injector area. They are of the "Cockcroft-Walton" type and each contains its own hydrogen-ion source. These three accelerators all inject hydrogen-ion beams at 750 thousand electron volts into the low-energy RF accelerator. They may be operated simultaneously and their beams interleaved into the low-energy RF accelerator together.

The low-energy RF accelerator section operates at 201.25 MHz. It boosts the beam to 100 million electron volts for acceptance into the medium-energy RF accelerator section. See Figure 1.2. The low-energy accelerator consists of four resonant structures known as "Alvarez tanks." See Figure 1.3.

The medium-energy RF accelerator section operates at 805 MHz and boosts the beam to as much as 800 million electron volts for collision with targets in the experimental area. The forty-four accelerator segments of this section are of the "side-coupled-cavity" type. This structure was developed at Los Alamos for LAMPF and is now widely applied in similar applications.

2. ACCELERATOR OPERATION

LAMPF is unique in its high average particle flux, which reduces the time required to accomplish research objectives. Production of this high flux beam has placed an increasing demand upon the RF systems. During the initial years of operation, RF duties were in the six to eight percent range. After 1978, duty was increased about three-quarters of a percent each year in an effort to produce significantly higher beam flux.

201-MHz duty reached about thirteen percent during the 1984 run, then was decreased to about 11.5 percent from 1985 until the beginning of 1989 to reduce power costs. Concern about 7835 tubes caused a reduction of 201-MHz RF duty to about ten percent for the 1989 run, but the 201-MHz duty was increased to about eleven percent in 1990 and back to about twelve percent for 1991.

All of the systems of the complex were originally sized for operation at a maximum beam duty of twelve percent. This corresponds to a maximum design 201-MHz RF duty of about 14.4 percent. By performance standards for such facilities, this is extreme. In comparison, radar and accelerator facilities capable of comparable power levels generally operate in the range of one-tenth percent to two percent RF duty.

It is also notable that operation has been pushed so close to the original design limits. All of the LAMPF systems were sized with relatively narrow duty margins. The 201-MHz systems, particularly, have in recent years encountered problems related to the combined requirement for high peak RF power levels and high duty.

The performance of 7835 tubes in operation at LAMPF declined after about 1982. This decline appears to correlate with a combination of factors: an order of magnitude reduction in annual tube production levels due to the retirement of military systems; discontinuance of tube RF testing at the factory as a cost-reduction measure instituted by customers; and increased RF duty at LAMPF. Low-duty users of the tube have seen relatively minor changes in 7835 performance during the same period.

The effects of LAMPF high-duty operation have begun to be felt on other parts of the 201-MHz systems. Advancing system age is a factor as well. Recently problems have been encountered in maintaining the 7835 filament power supplies and the RF driver amplifiers. Efforts are underway to replenish low stocks of spare parts through custom manufacturing and to replace components and subsystems which have become difficult to buy or support.

The 201-MHz systems have always required about as much RF system maintenance time as all of the 805-MHz systems taken together. See Figure 2. However, the accumulating effects of 201-MHz problems in recent years is clear. Even though there are forty-four 805-MHz modules and only four 201-MHz modules at LAMPF, the 201-MHz systems have come to be responsible for more than twice the amount of accelerator down-time during operating periods.

3. 201-MHZ RF SYSTEMS

The 201.25-MHz RF systems are designated as RF modules one through four. See Figure 3.1. Modules two through four are identical and module one is very similar to them. Each RF module feeds a corresponding Alvarez accelerator tank. Module one is required to produce RF power at only about 400,000 watts peak. Modules two, three and four are each required to produce about 2.6 million watts peak.

The control requirements on the modules are stringent. During each RF pulse, the module output amplitude is to be automatically maintained within +/- one percent of the amplitude required. At the same time, the output phase is to be held constant to within +/- one degree of that required. It is anticipated that these requirements may have to be tightened still more in the future.

The accelerator must be a coherent structure so a single RF source signal is used to drive all of the RF modules. The source oscillator used is stable to one part in one hundred billion. Its signal is frequency multiplied to provide drive for the RF modules at 201.25 and 805 MHz.

The phase of the distributed source signal is adjusted at each module and then fed to a solid-state interface amplifier (IFA). See Figure 3.2. The signal from the IFA drives the intermediate power amplifier (IPA) which drives the final power amplifier (PA) of each module. The output power of each PA is adjusted for amplitude control.

The intermediate power amplifiers were originally designed and built by RCA. Each IPA contains a chain of three vacuum tubes: two Burle 7651 tetrodes and a Burle 4616 tetrode. See Figure 3.3. The first 7651 accepts pulsed RF input from the IFA at a level of about 25 watts. This stage is a common-cathode amplifier with pulsed bias and produces output RF at about 300 watts.

The second 7651 is a common-cathode stage with constant bias and boosts the RF signal to about 5,000 watts. The 4616 is a common-cathode, constant bias stage operated in class B with pulsed plate and screen supplies. It is used to produce pulsed RF at about 150,000 watts, though it can put out much more. All three stages of the IPA have resonant input and output tuners constructed in coaxial "cavity" form.

The input of the 4616 is coupled with a "paddle-type" variable capacitor to a water-cooled coaxial "de-Qing" load. Variation of coupling of drive to this load permits amplitude control of the 4616 output over a wide range. In this application, this assists in adjusting to PA input drive requirements. The two 7651 tubes are air-cooled and the 4616 tube is water-cooled. The 4616 DC plate supply is series switched by a pulse modulator employing an Eimac 4CW100,000 tetrode.

The final power amplifiers were originally designed and manufactured by Continental Electronics. See Figure 3.4. Each PA contains a single Burle 7835 triode as a common-grid amplifier with a cathode resistor to provide RF self-biasing. The amplifier is enclosed in a pressure tank containing dry air at about 40 PSI to assist in holding off high voltage.

Input and output impedance matching is accomplished by coaxial sliding-stub tuners. Blocking of the DC plate voltage is realized by quarter-wave sections of large-diameter, dielectric-filled coaxial line which nest around the tube and parts of the input and output tuners.

Chilled air is circulated through the PA to cool amplifier parts and to assist in cooling the 7835. The center conductor of the input tuner of the amplifier is water-cooled where it contacts the tube cathode. The 7835 also requires plate, grid and cathode/filament cooling water.

The 7835 DC supply is series switched by a pulse modulator employing two Eimac 4CW250,000 tetrodes. Amplitude control of the PA output is accomplished by plate modulation, that is, variation of the modulator voltage drop. The RF output of the amplifier is a nine-inch coaxial line which quickly tapers in an adapter section to a fourteen-inch line.

The 7835 triode is constructed in a double-ended coaxial configuration. See Figure 3.5. The large physical size of the tube, about 14 inches in diameter by about 17 inches tall, makes this configuration advantageous for operation at frequencies up to 400 MHz. It allows the active input and output regions of the tube to be centered on the standing voltage maxima of the input and output tuners.

Inside the tube, 96 thoriated tungsten filaments are arranged in a ring about the central tube core. Grid wires are wound on supports between each of the filaments. The plate ring is outside of the filament and grid assembly. The tube can operate class-B common-grid under a DC plate supply of up to 40,000 volts and can produce output RF at up to 7.5 million watts peak at low duty.

Peak plate current can be up to 300 amps. The tube filaments require about 6800 amps at about 3.6 volts during operation. At such high current, there is a drop of over a volt in the conductors between the filaments and their supplies. Plate cooling-water flow required is in the range of 100 to 160 gallons per minute, depending upon tube plate-power dissipation.

Because of its large size, if the 7835 is not operated under sufficient RF drive, oscillation at a frequency of about 1.2 GHz can occur within the tube itself. This requires that the tube be operated under a pulsed plate supply and in a drive saturated condition in any application.

4. RECENT 7835 TUBE MODIFICATIONS

In the last few years, several aspects of the 201-MHz systems have attracted interest as possible areas for improvement. Improvement of the mean time before failure (MTBF) of the 7835 tube at LAMPF is the principal area in which work has been done to date. This has been a difficult problem for several reasons. First, no other user of the tube has experienced problems comparable to those encountered at LAMPF so no external assistance is available.

Second, resources which could be devoted to work on this problem have been limited. To date, very little formal failure analysis of problems has been possible. The principal LAMPF problem is continuing failure of tube ceramic plate insulators during operation. About two tubes per year have been lost this way since 1988.

Third, a total of only three of these tubes are operated at full power at LAMPF for only a portion of each year. The effects of changes in operating procedures and tube modifications take a long time to evaluate. Modifications must also wait on proposal evaluation, purchasing, and manufacturing lead time.

Several initial moves were made about three years ago, but the first successful action was taken at the insistence of J. Doss of MP-8 at LAMPF. After some discussion, it was decided to have a small Penning ion vacuum gauge installed on all tubes ordered for delivery to LAMPF. It was intended that these devices should serve as diagnostic vacuum gauges on the tubes.

The Penning gauge operates by ionizing gas molecules in a fairly hard vacuum. The gas ions are caused to strike a metal target and are then frequently trapped by sputtering in the target or against the gauge enclosure walls. The resulting ion current is proportional to vacuum quality and is measured to provide a reading of that quality. That is, the device operates as a vacuum gauge.

A bonus provided by this type of gauge, however, is the trapping of many of the gauge ions. As a result, the device also functions as a vacuum pump and is now generally referred to as an ion vacuum pump rather than a gauge. Beginning in 1990, a miniature "ion pump" of the Varian "Vacion" type, a "vacion" pump in everyday usage, was installed on all 7835 tubes manufactured for LAMPF. See Figure 4.1.

Because the device was so small, it was expected that it would not provide any improvement in tube vacuum. However, as the modified tubes were delivered and put into operation, surprises were provided by the new diagnostic information made available. Peculiarities were found in the filament turn-on gas burst. See Figure 4.2. This burst is a transient period of poor tube vacuum which occurs when the tube filaments are turned on.

In the 7835s at LAMPF, the amplitude of this filament warm-up gas burst increases for the first few hundred tube operating hours. It seems to peak out after a few hundred additional hours of operation. Then it does not decrease appreciably for thousands of additional operating hours.

It is reasonable to believe that the burst itself results from gas adsorbed to metal surfaces inside the tube. The gas is boiled off as the filaments heat up. A gas burst also occurs when RF is applied to the tube, which presumably heats additional internal tube surfaces. See Figure 4.3. But it is puzzling that much more gas evolves as tube aging proceeds.

When the tubes are first started, the bursts are relatively small and brief. It is more puzzling that the behavior persists for thousands of operating hours. After a start-up burst, the tube vacuum gradually improves to a level on the order of 10^{-5} torr, once the tube is over a few hundred hours old. But, even at several thousand hours of tube operation, the burst will occur whenever the tube is restarted.

Most puzzling, the burst makes its appearance unchanged even if a tube is operated under excellent vacuum for a period of days or weeks, then turned off only for seconds and restarted. As diagnostic data are accumulated, this pattern should become more explicable. It is fair to suspect that this operation is essentially normal under high duty requirement.

As additional operating experience and vacion current data became available, more remarkable results emerged. It was found that, in the general hurry to get back into service under normal operating conditions, it had previously been common practice at LAMPF to unknowingly operate these tubes in an excessively gassy condition.

Most surprising, it became apparent that the tubes would produce full power with little or no arcing at vacuum levels on the order of 10^{-4} torr. This capacity of the tube must be considered astounding. The effect on tube lifetime of this mode operation is difficult to quantify but could not be positive.

A new pattern for operation of these tubes was developed. The vacion "gauges" began to be used to pump the tubes down to operating vacuum more rapidly after turning the filaments back on. It was found that the new tube vacion "gauge" was an effective vacuum pump after all. See Figure 4.4.

This new pattern avoided operation of the tube at excessively poor vacuum. But it was probably shortening the useful life of the vacion gauge/pump by operating it in the poor vacuum condition instead. This kind of operation can cause a vacion pump to overheat and short out or at least to outgas. This abuse of the pumps was questionable but considered necessary under production conditions.

In response to concern about shortened vacion service life, although no vacion failures had been experienced, it was decided to have two of the vacion pumps installed on each tube instead of just one. This would enable extended "abusive" vacion pump operation, increase pumping speed and could be done for a nominal additional cost.

This modification of the 7835 tube has a unique appearance. However, several of these tubes have now been delivered and operated successfully. It is to be noted that no other user of the tube has decided to buy one of this type. At the same time, a search was initiated by R. DeHaven of MP-8 at LAMPF for a vacion pump which had a greater pumping capacity than the Varian type.

The volume available for installation of vacion pumps on the tube is severely limited. Also, it was determined that the diameter of the connecting tube could not be increased for improved gas conduction. A higher capacity pump would have a longer useful life on the tube, though it could not increase pumping speed. A pump no larger than the original but having a higher capacity was required.

An ion pump incorporating new technology recently developed by Perkin Elmer was found by W. Boedeker of MP-8. See Figure 4.5. These pumps include dual metal sputtering targets for better effectiveness on a variety of gases and incorporate more compact samarium-cobalt magnets.

The first two tubes manufactured with two Perkin Elmer pumps have been delivered, but neither has yet been operated. It should prove possible to operate the dual pumps simultaneously to shorten the time needed for tube conditioning. Alternating operation of the pumps should greatly reduce pump overheating in poor vacuum conditions.

5. 7835 TUBE CALORIMETRY

Development of a calorimetry system with which to monitor average power dissipation in the 7835 tube was begun recently. It is hoped that this system will be a useful tool in attempting to achieve higher RF duty and power in routine operation in the future. Also, the ability to continuously monitor tube performance with good accuracy will enhance understanding and control of normal system operation. It should eventually provide useful tube-failure information as well.

Tentative plans call for the 7835 plate cooling-water flow and temperature change to be monitored in each PA. See Figure 5.1. Initial tests have indicated that it may be necessary to monitor other cooling water supplies as well. A high-accuracy temperature difference thermometer using platinum resistive temperature detectors (RTDs) has been developed by A. Browman of MP-DO and L. Hasenack of MP-8 at LAMPF. See Figures 5.2 and 5.3.

This difference thermometer uses precision operational amplifiers to boost the difference in voltage drops across a pair of RTDs supplied by matched constant-current sources. Component values are selected so that a thermometer output of one volt DC corresponds to a RTD temperature difference of one degree Celsius.

The difference thermometer must be calibrated for the pair of RTDs used. Calibration is performed in stirred water baths monitored by precision mercury thermometers and has correlated to within 0.05 C. This calibration method has not yet been checked by a NIST traceable lab.

The 7835 plate-cooling-water temperature change under normal operating conditions in the LAMPF systems is about six degrees. The indications are that this difference thermometer design is accurate in these systems to within one percent. Using the thermometer alone, it is possible to see the approximately 30,000 watts of beam loading very well against the roughly 2.5 million watts of plate dissipation.

Installation and testing of flowmeters in the water systems, test of computer monitoring of flow and of temperature difference, and calculation of average dissipation are in progress under the direction of M. Parsons of MP-8 at LAMPF. The advertised accuracy of the flow meters is +/- one-half percent of the full-scale reading.

It is likely that some surprises and adjustments still lie ahead in development of a system with satisfactory accuracy. However, results to date promise that it will be possible to closely monitor and continuously record relatively small changes in RF system performance and clear up many puzzling details of system behavior. It is planned to push ahead on this project as rapidly as possible.

6. CURRENT DIRECTIONS

At present, discussion of and planning for a number of modifications to the 201-MHz systems is in progress. Improvement of the 7835 MTBF will continue to receive as much attention as possible. The potential cost savings are considerable. Further adjustments in tube operating procedures may evolve.

It is also hoped that it will be possible to pursue a detailed analysis of the LAMPF ceramic failure mechanism. 7835 ceramic failures have always been a problem at LAMPF though the situation has become much more serious recently. See Figure 6.1. It seems significant that no other user of the tube has experienced difficulty in this area.

A plan to further modify the 7835 tube is under consideration at this time. This proposal was developed by E. Robertson, on loan from the US Air Force to the Materials Science and Technology Division at LANL, and J. Eshleman of Burle Industries. See Figure 6.2. The tube plate and grid seals to the two outer ceramic insulators are made by means of single steel retaining rings on the outer surfaces of the four insulator edges.

It is proposed to modify the construction of the tube so that each seal will be made by means of a pair of rings, one on the inner ceramic surface and one on the outer. Definition of the proposal for this effort is in progress and it may be undertaken soon.

It appears that high-duty operation is primarily responsible for the LAMPF ceramic failure problem. The failure mechanism is suspected to be an excessively uneven heating of the ceramic material. Three possible sources of this heating have been suggested. First, localized light carbon deposits appear to be associated with the point of failure in at least two cases. It is possible that some resistive mechanism is heating the ceramic material in such areas.

The second possibility is that RF heating of some metal parts of the tube becomes excessive at high duty, and localized ceramic heating results. The third possibility, suggested by E. Meyer of the Accelerator Technology Division at LANL, is that the ceramic material might be experiencing x-ray induced electron avalanche. It has been established that some x-rays are incident on the insulators during operation of the tube. It is even possible that two or all three of these suspected heat sources is involved.

Another possible cause for the LAMPF 7835 ceramic failures is water from cooling system leaks contacting the tube during operation. There is excellent evidence that this has occurred on two occasions. Opinion is divided on whether this mechanism can be blamed for the full ceramic failure history. Another sore point has resulted from marking a number of tubes with temperature indicating paint in an effort to catch a record of ceramic heating. Several marked tubes have failed with a complete absence of high ceramic temperature indications.

All of the suspected mechanisms will be difficult, time-consuming, and expensive to test thoroughly. An initial analysis plan has been developed by E. Robertson. It is suggested that a state-of-the-art computer model of the insulator and seal structure be developed. The model would then be tested by strain gauge measurements during actual assembly of the seals at the factory. Iteration of the model would be performed if needed until its predictions could be used with confidence.

The model would then be used to find areas in the insulators where the material strength margins were narrow. These areas should correlate with the areas in which actual failures have occurred. Heat-transfer modelling could then be used to discover the locations and amounts of heating which would have to occur in order to exceed strength margins in the failure areas. It is hoped that it will be possible to begin work developing and testing the model this fall.

Another improvement which is needed in the 201-MHz systems is of serious concern but must be entirely deferred at this time. Each Alvarez accelerator tank is excited by means of a coupling loop driven by the corresponding RF PA output coaxial line. See Figure 6.3. Each coupling loop assembly includes a coaxial RF dielectric window to support the tank vacuum.

The original design for these assemblies planned dome-shaped windows which would extend into the tanks. This would have kept each loop on the air side of the vacuum barrier and precluded possible multipactoring problems. When difficulties were encountered, a compromise design was adopted which placed the vacuum barrier back toward the amplifier and left the loop in vacuum. Fortunately, no multipactoring appeared after this was done.

The original RF windows were to have been ceramic but the compromise windows were finally fabricated from Rexolite. It has turned out that the windows for each of the four tanks must be replaced at least once per year. The annual cost for this maintenance has attracted notice.

Furthermore, it appears that this problem is much more serious at high duty and high power. This situation must be corrected if operation at higher duty and power in the future is to be achieved. Development of a satisfactory window from a material such as high-purity alumina or possibly silicon nitride is needed.

It has been apparent for some time that much improvement is needed in the speed and accuracy with which 201-RF system problems can be diagnosed. Also, a complete and continuous record of the behavior of each RF module is needed. Work has been begun by M. Parsons to collect performance parameters for each RF module with an A/D data acquisition system. Initially, the data will be processed by the LAMPF central control computer (CCC).

Eventually, it is expected that the 201-MHz systems will be monitored primarily by a stand-alone computer such as a micro-vax. It should be possible, after accumulating some operating experience with the completed system, to develop algorithms which will rapidly diagnose RF-module problems which have been previously been difficult to identify. It should also be possible to employ off-the-shelf software to handle large quantities of data easily for more effective maintenance scheduling and analysis of failure trends.

The IPAs are another area requiring attention. They should be more reliable and easier to maintain if the plate pulsed supplies for the 4616 tubes are eliminated. The requirement for the present pulse modulators appears to arise principally from the fact that IPA and PA share a single DC high-voltage supply.

An effort to replace the IPA modulators with separate DC supply is planned. The results of initial tests by V. LoDestro of the LINAC Division at Brookhaven National Laboratory and of tests at LAMPF have been positive. It should also be beneficial to convert the first two stages of the IPA to solid-state amplifiers. V. LoDestro has also tested this concept with positive results at Brookhaven.

The higher duty requirement at LAMPF complicates this project. However, an effort to accomplish such a modification is under consideration. Also, the 7835-tube filament power supplies have now reached an age at which they demand an excessive amount of maintenance time. It is hoped that funding will be available to replace these units over the next few years.

ACKNOWLEDGMENTS

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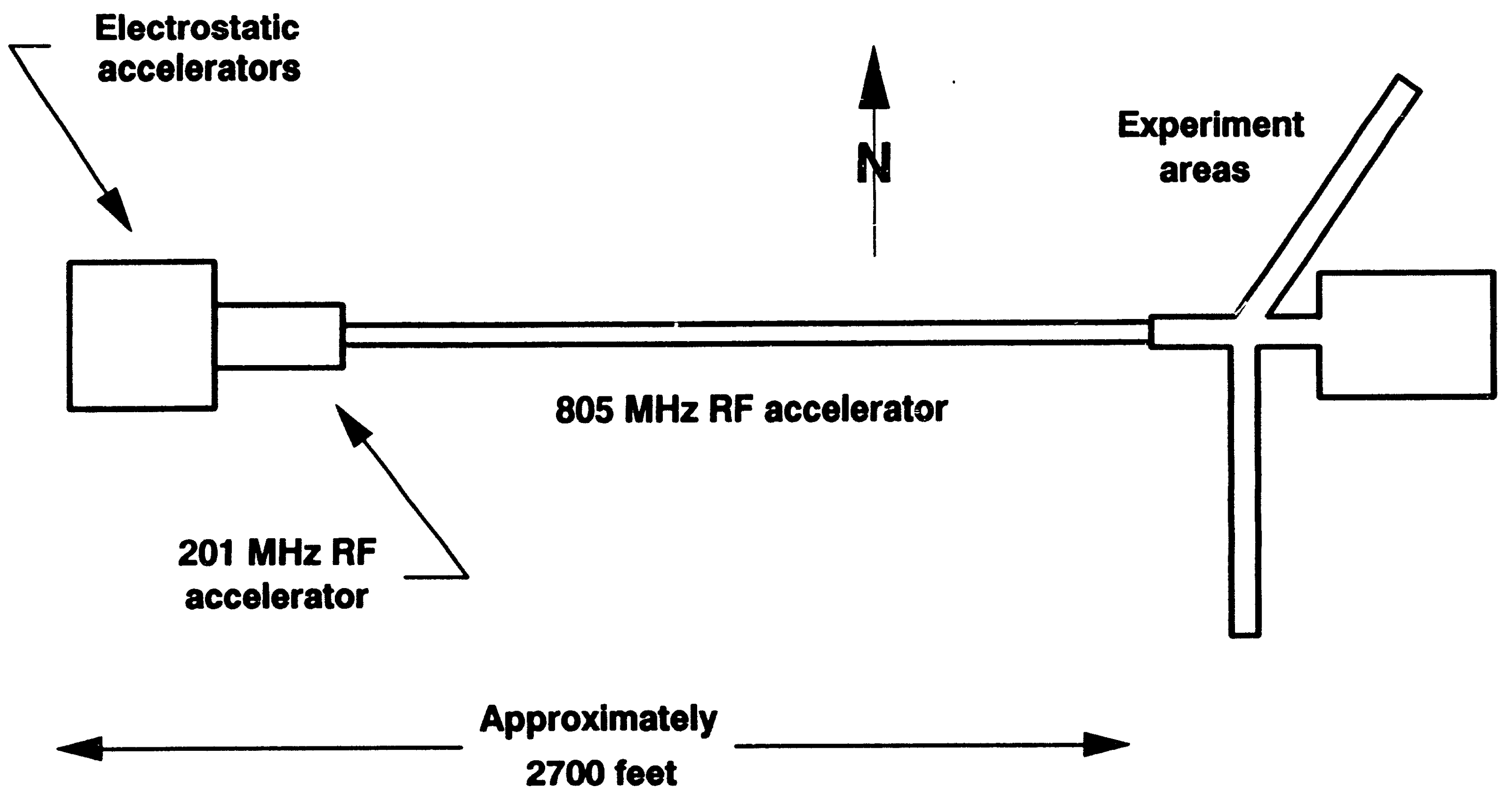


Figure 1.1 LAMPF accelerator facility

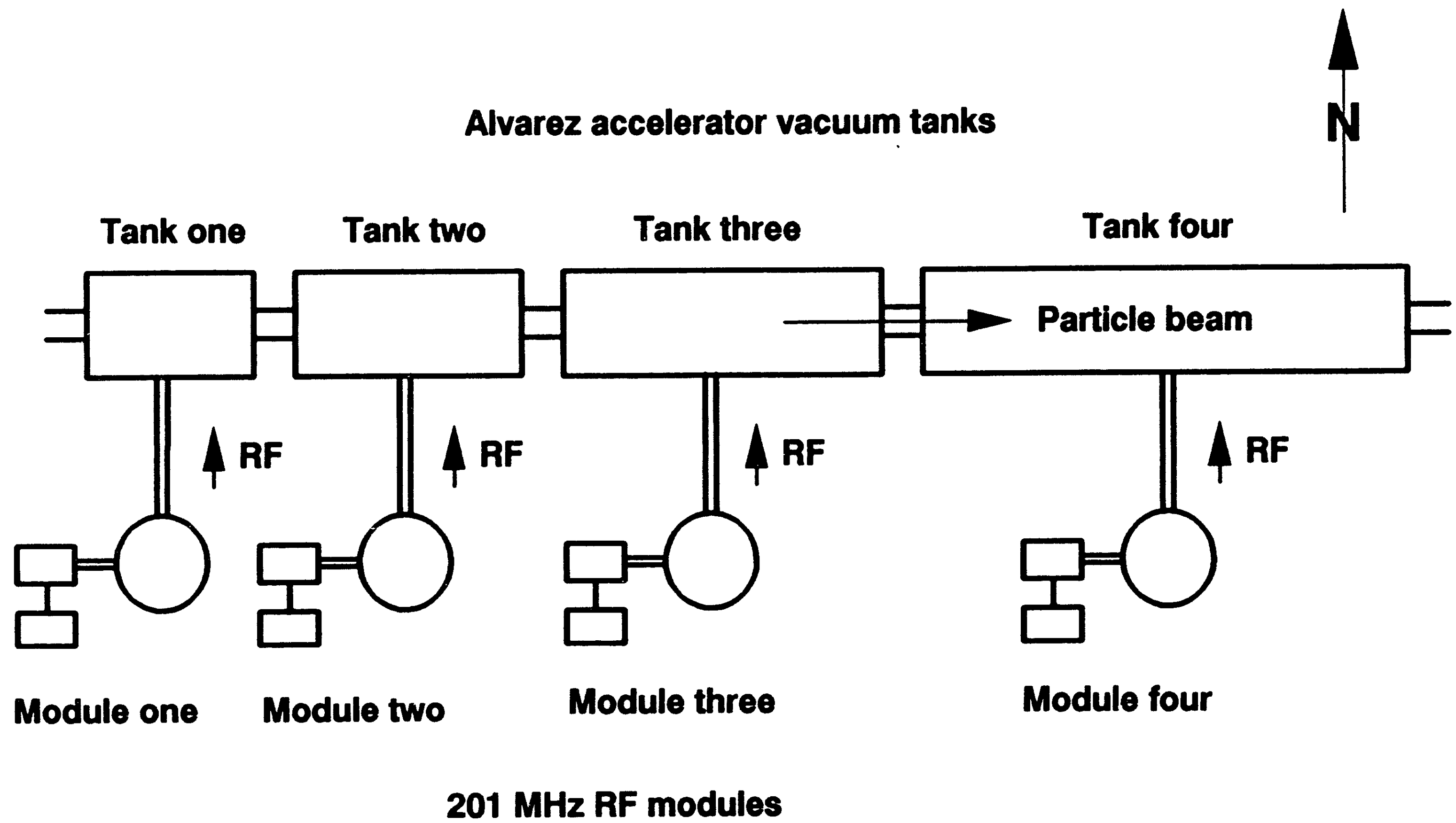


Figure 1.2 201 MHz accelerator section

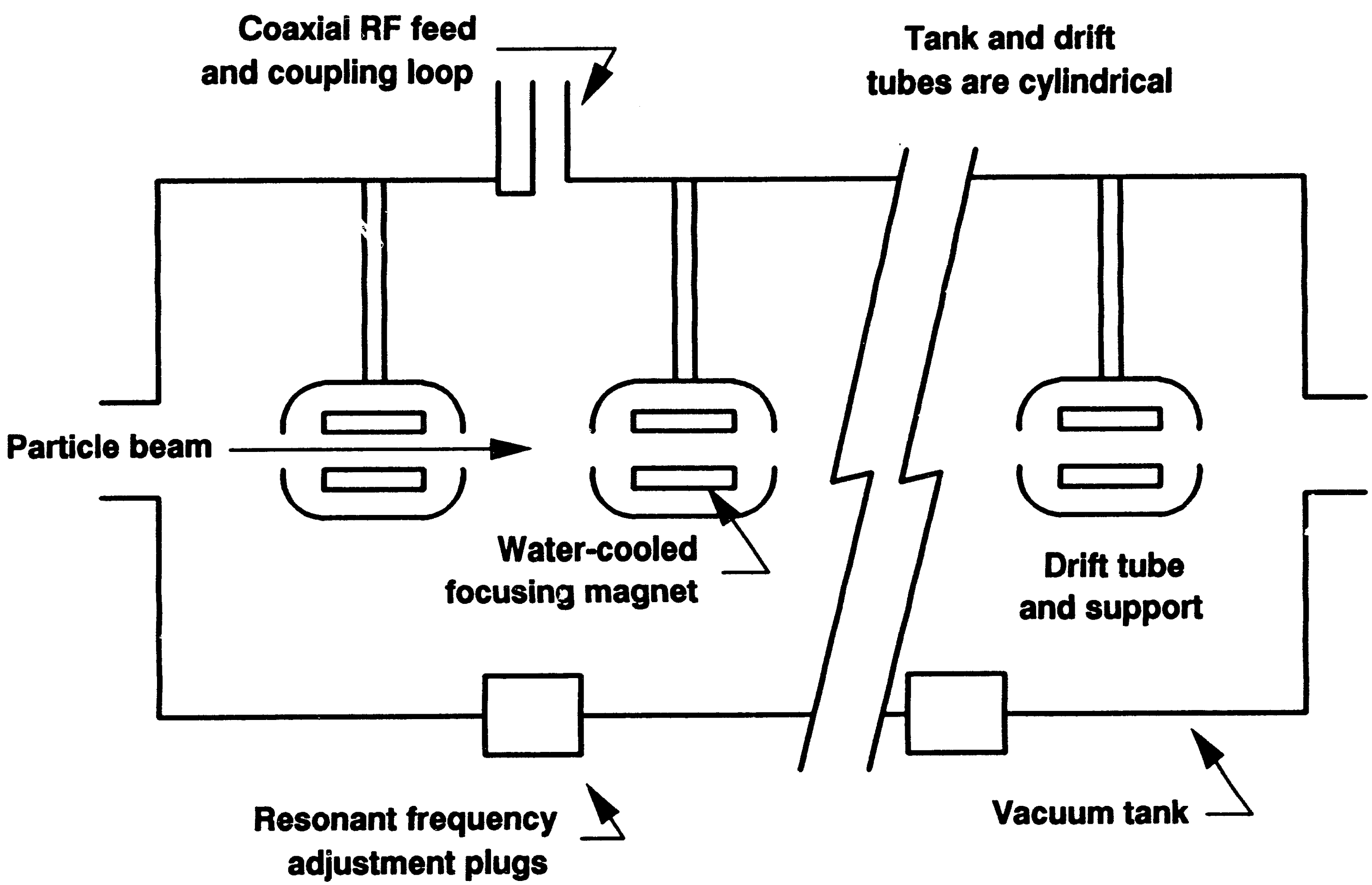
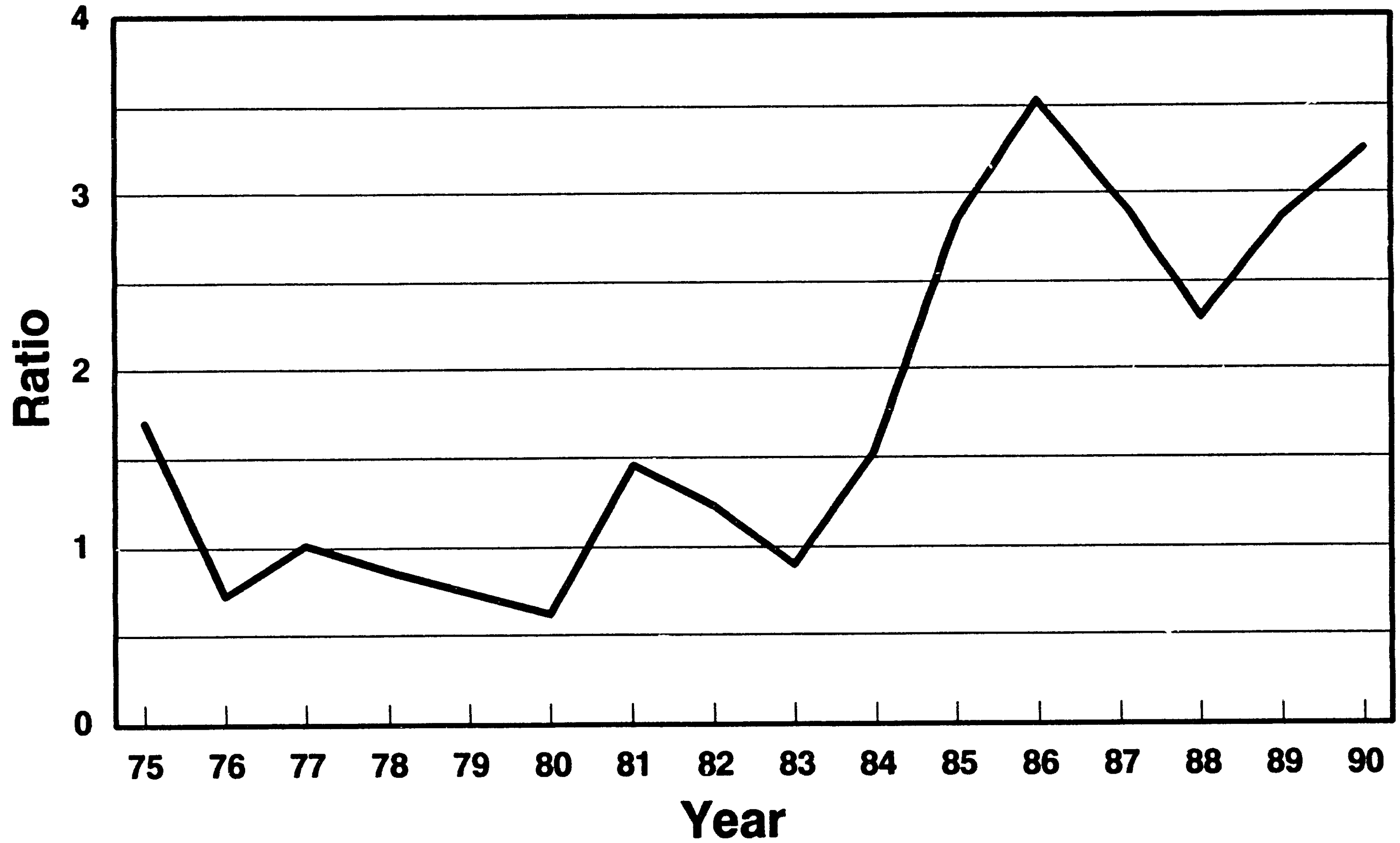


Figure 1.3 Alvarez tank accelerator structure

Figure 2 Ratio of unscheduled downtime
201 MHz RF systems versus 805 MHz systems



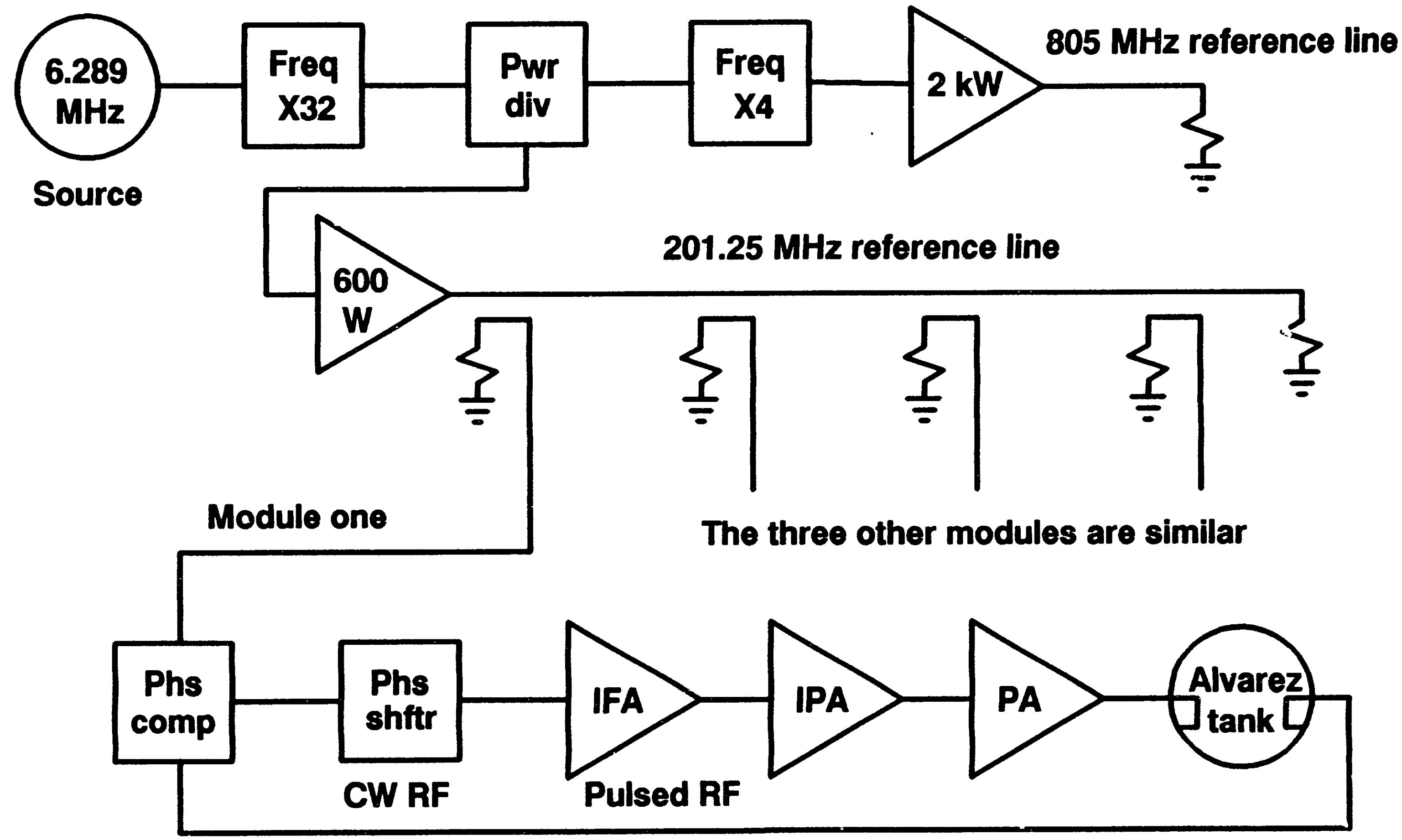


Figure 3.1 201 MHz RF system

After R. DeHaven

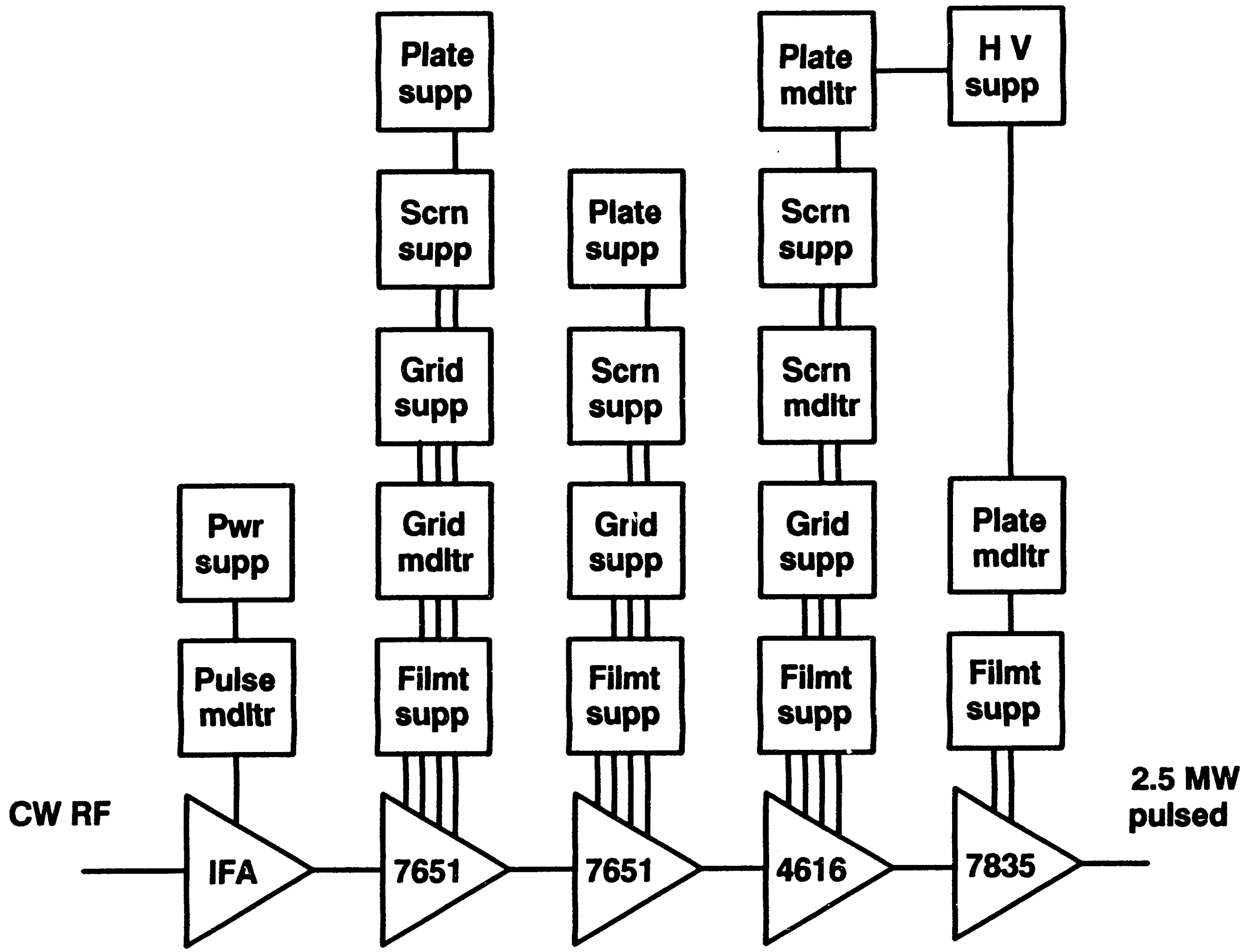


Figure 3.2 201 MHz amplifier chain

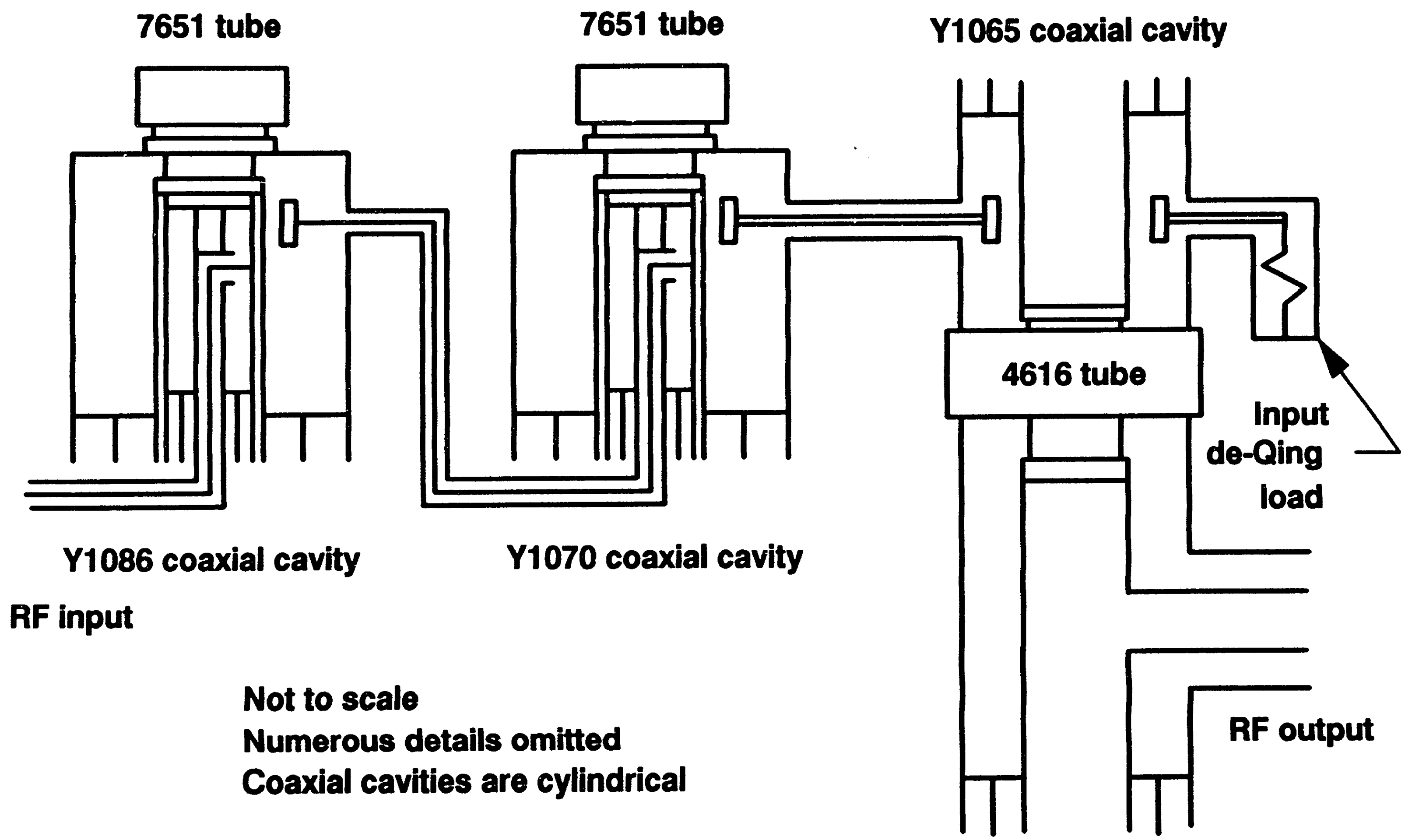


**Figure 3.3 201 MHz intermediate power amplifier
RCA Y-1068C 200 MHz amplifier**

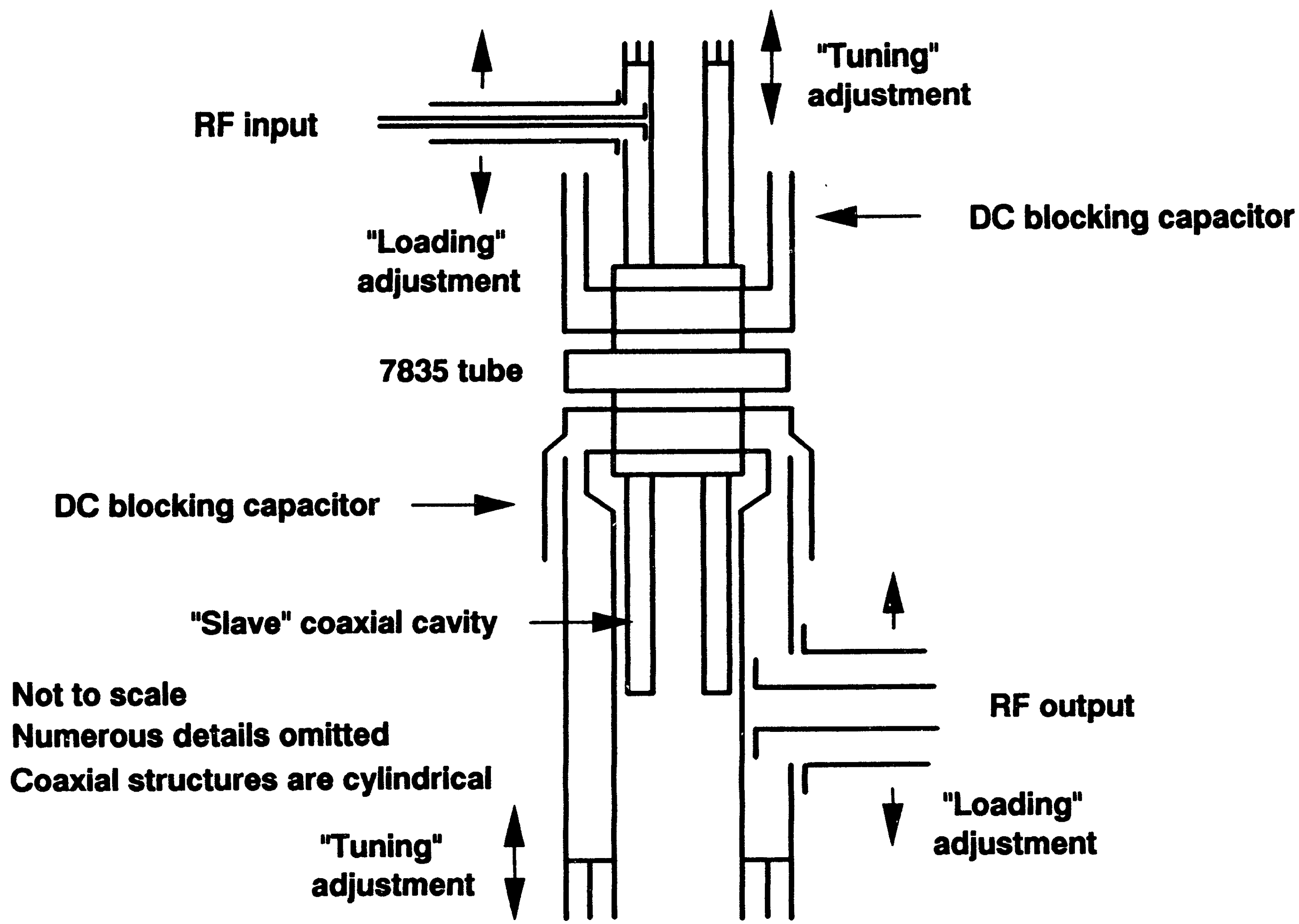


Figure 3.4 201 MHz final power amplifier
Continental 200 MHz amplifier

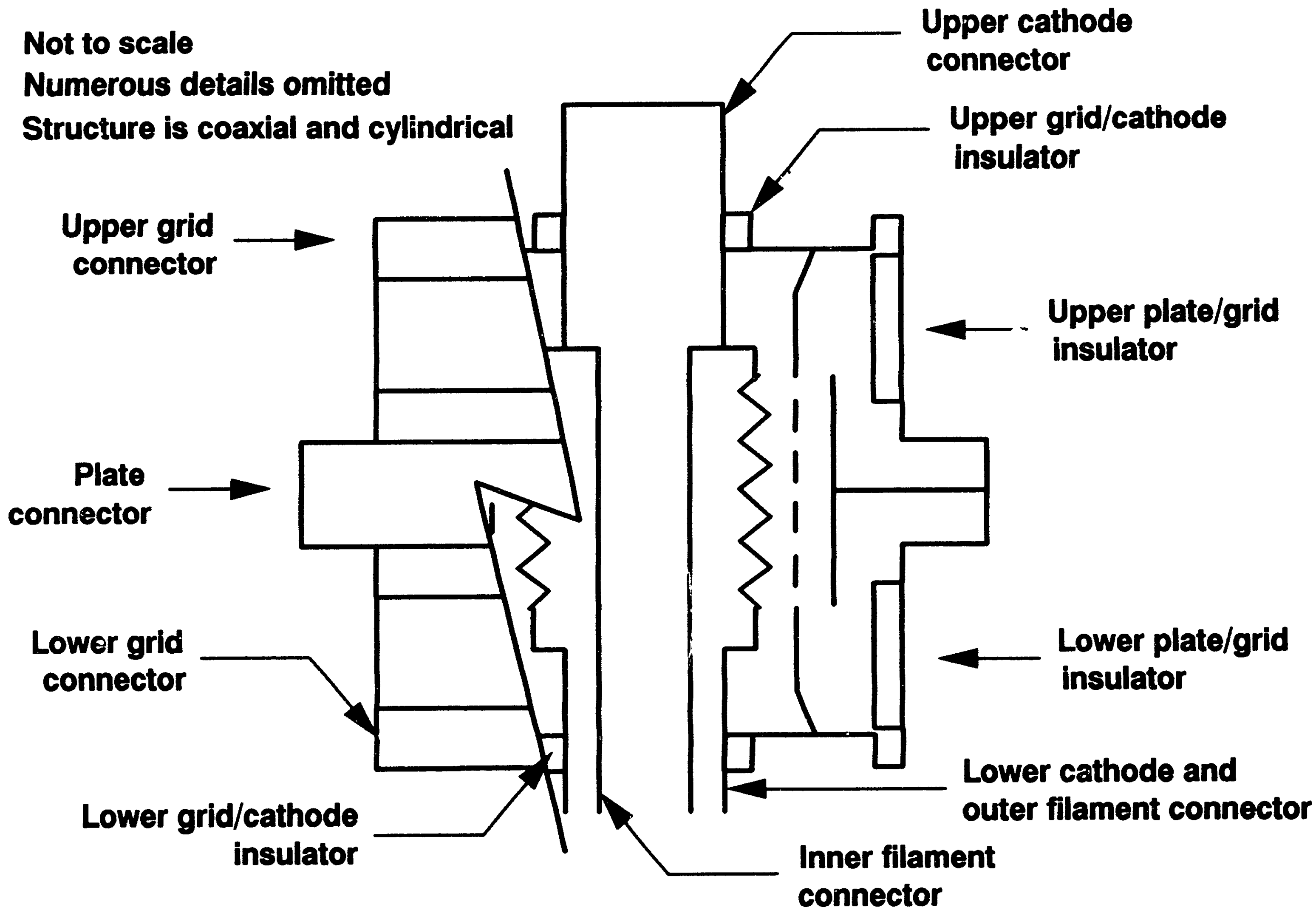


Figure 3.5 Burle 7835 triode

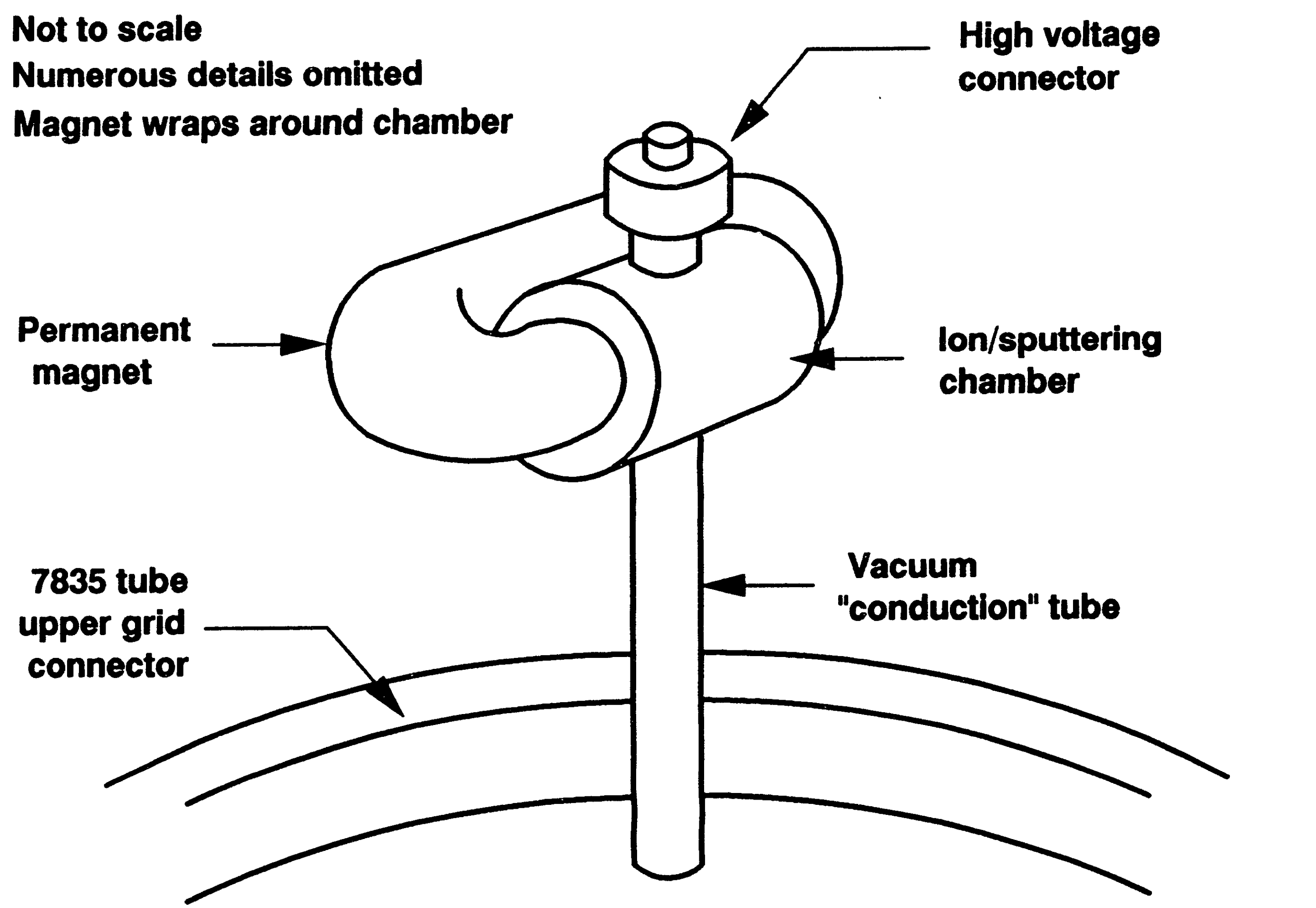


Figure 4.1 Varian-type miniature Penning ion pump

Figure 4.2 Evolution of 7835 gas
7835 number N48R4

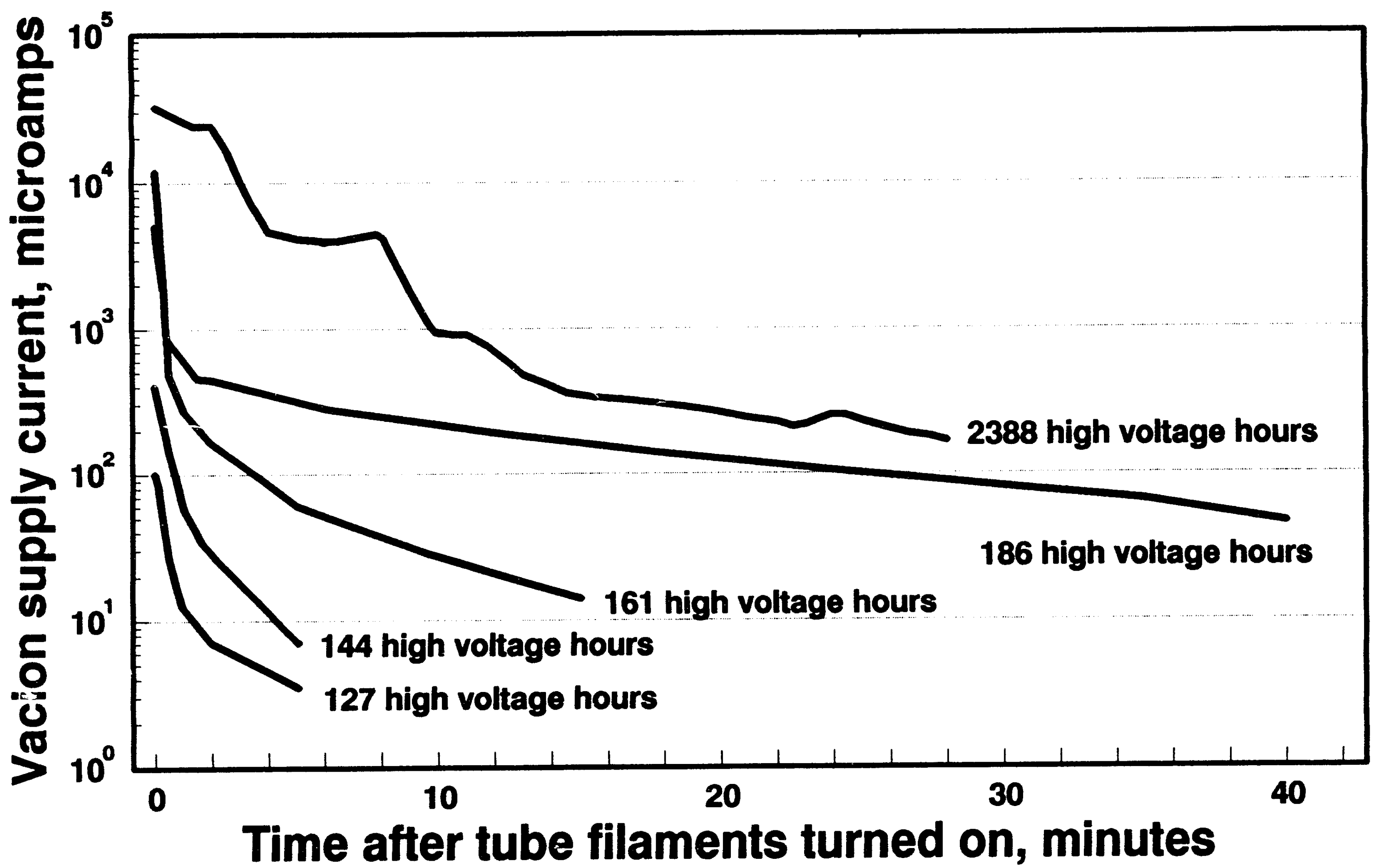


Figure 4.3 Restarting a 7835 under operational conditions
7835 number N48R4, 7/10/90, 2388 high voltage hours

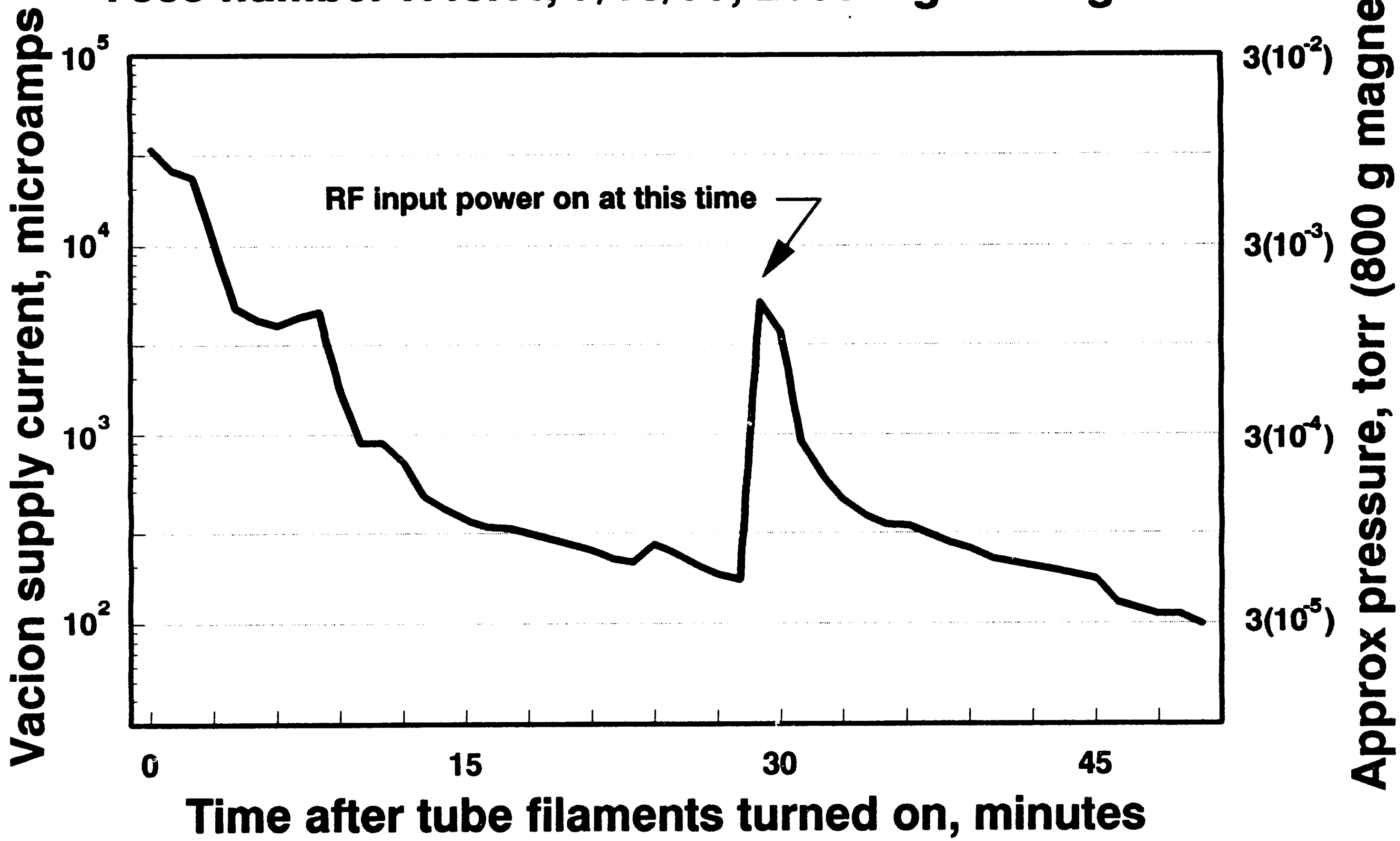
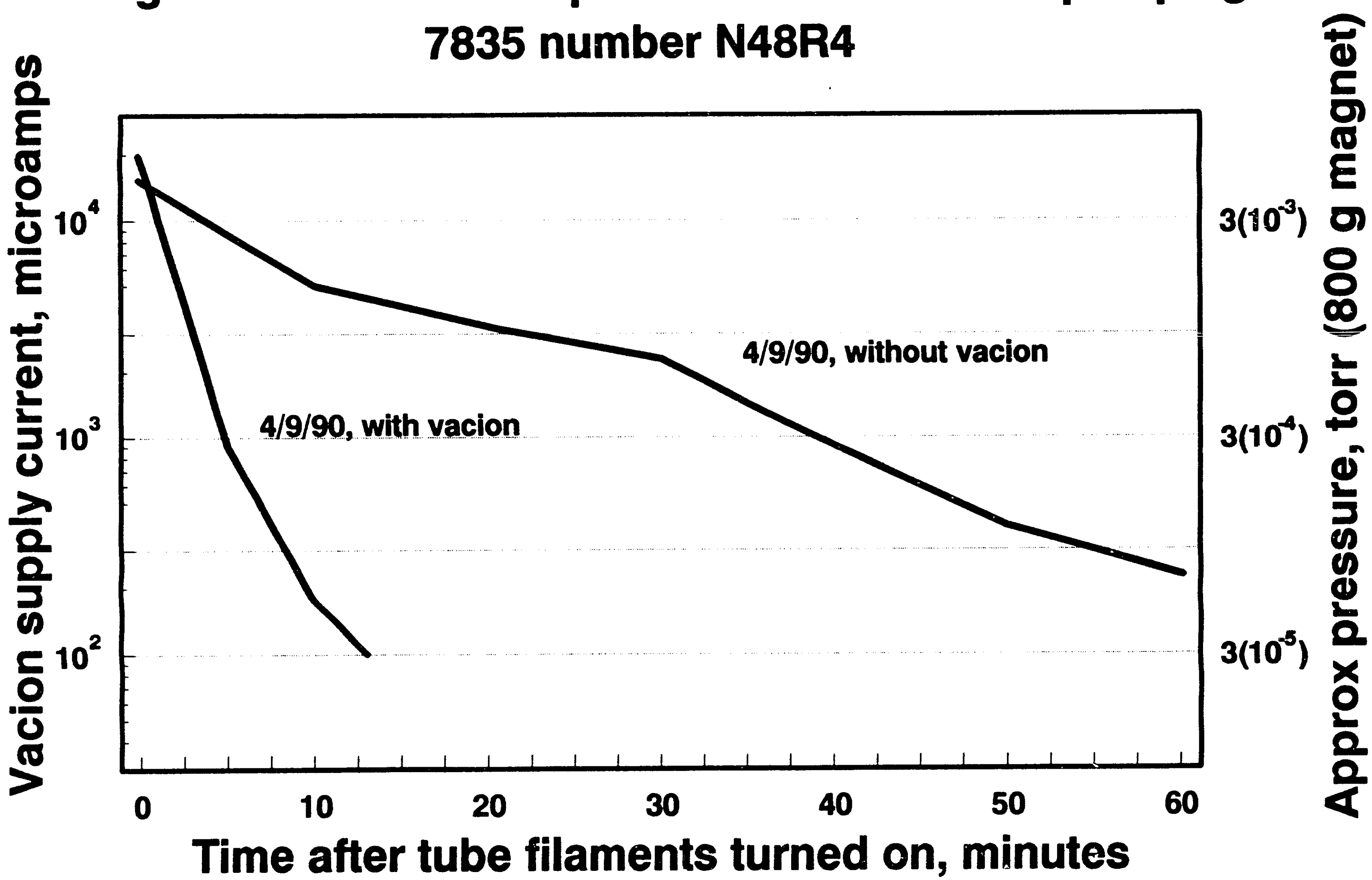


Figure 4.4 Vacuum improvement with vacion pumping
7835 number N48R4



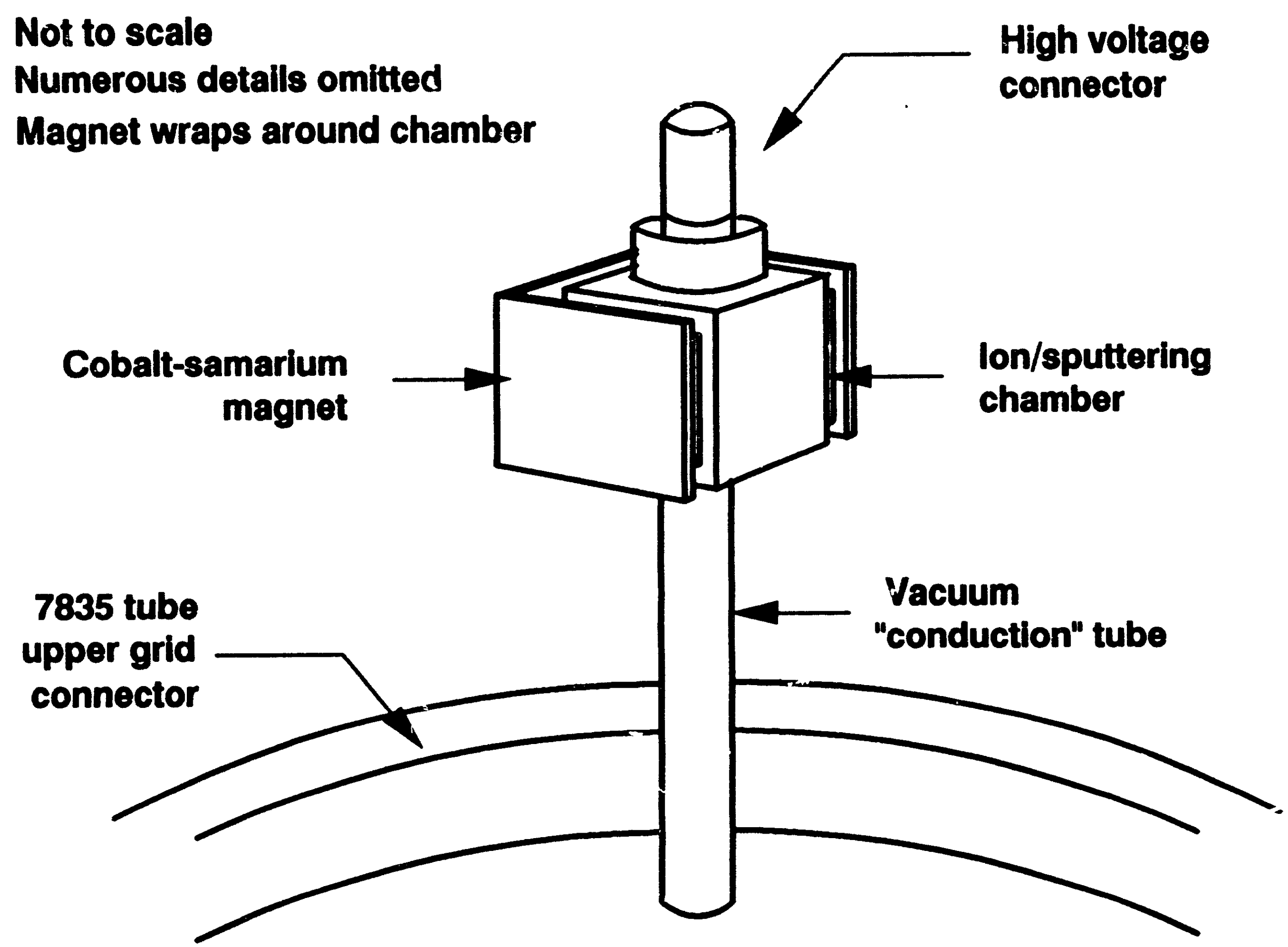


Figure 4.5 Perkin Elmer miniature ion pump

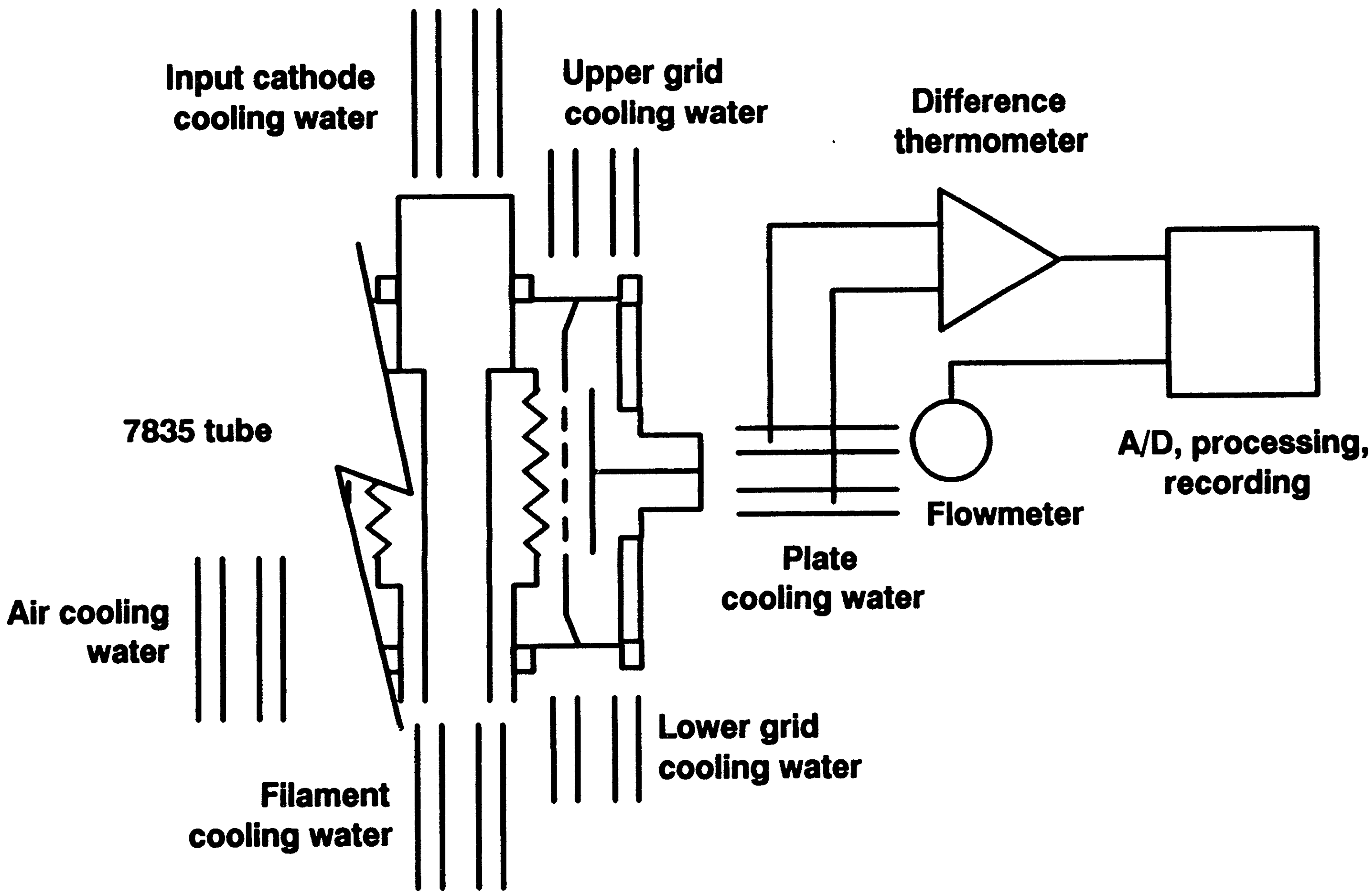


Figure 5.1 Tentative 7835 plate calorimetry system

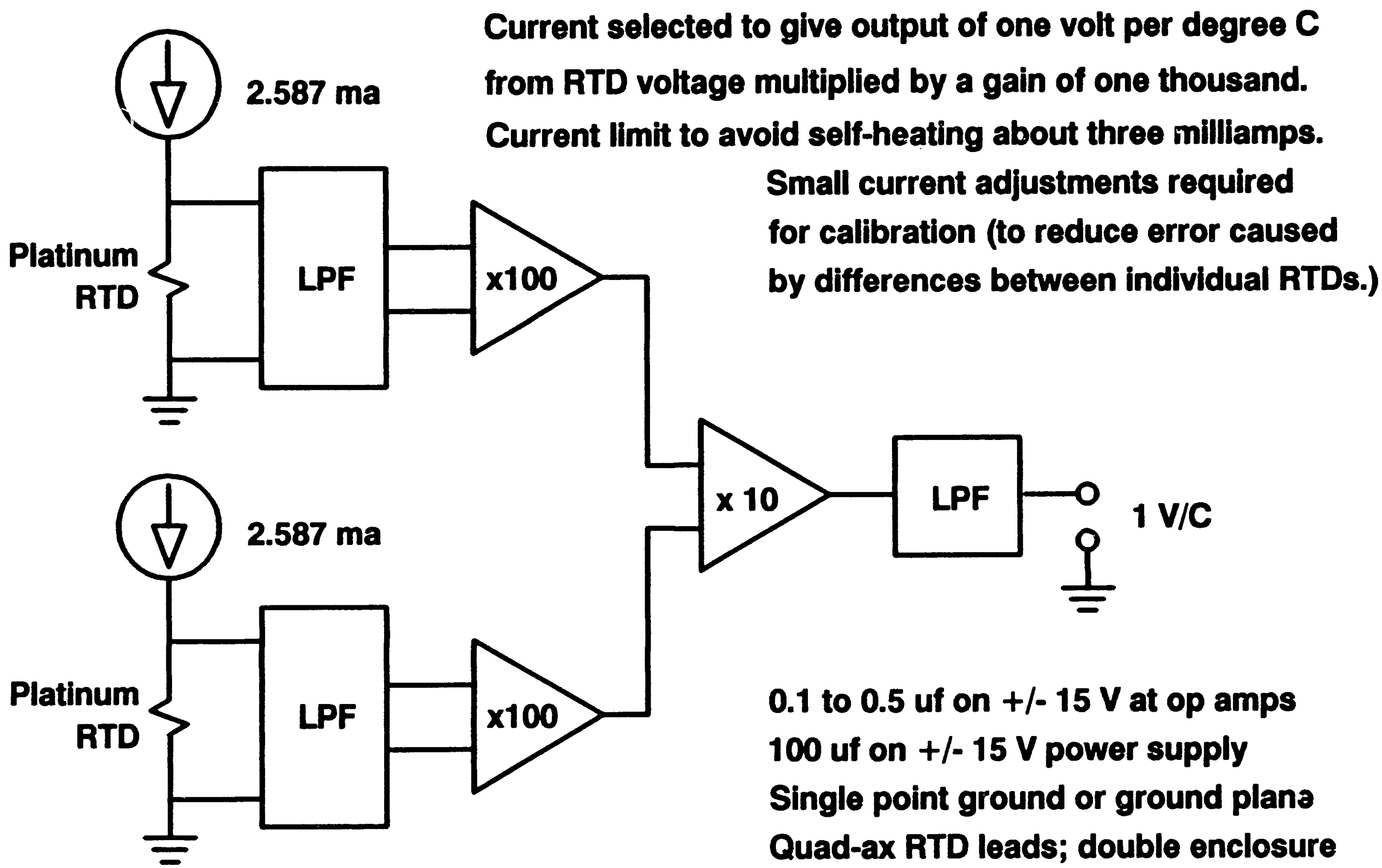


Figure 5.2 Temperature difference thermometer

After A. Browman

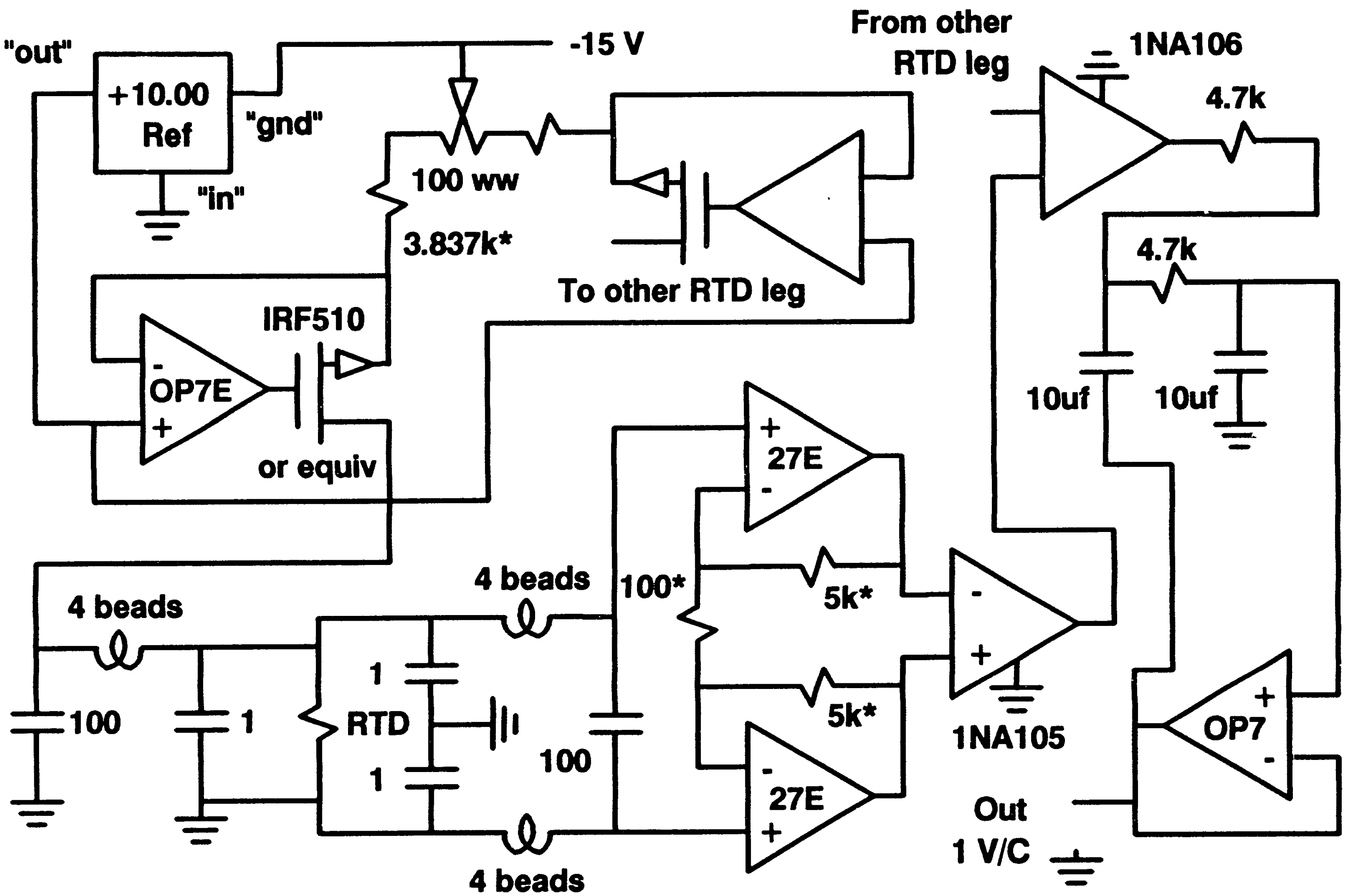
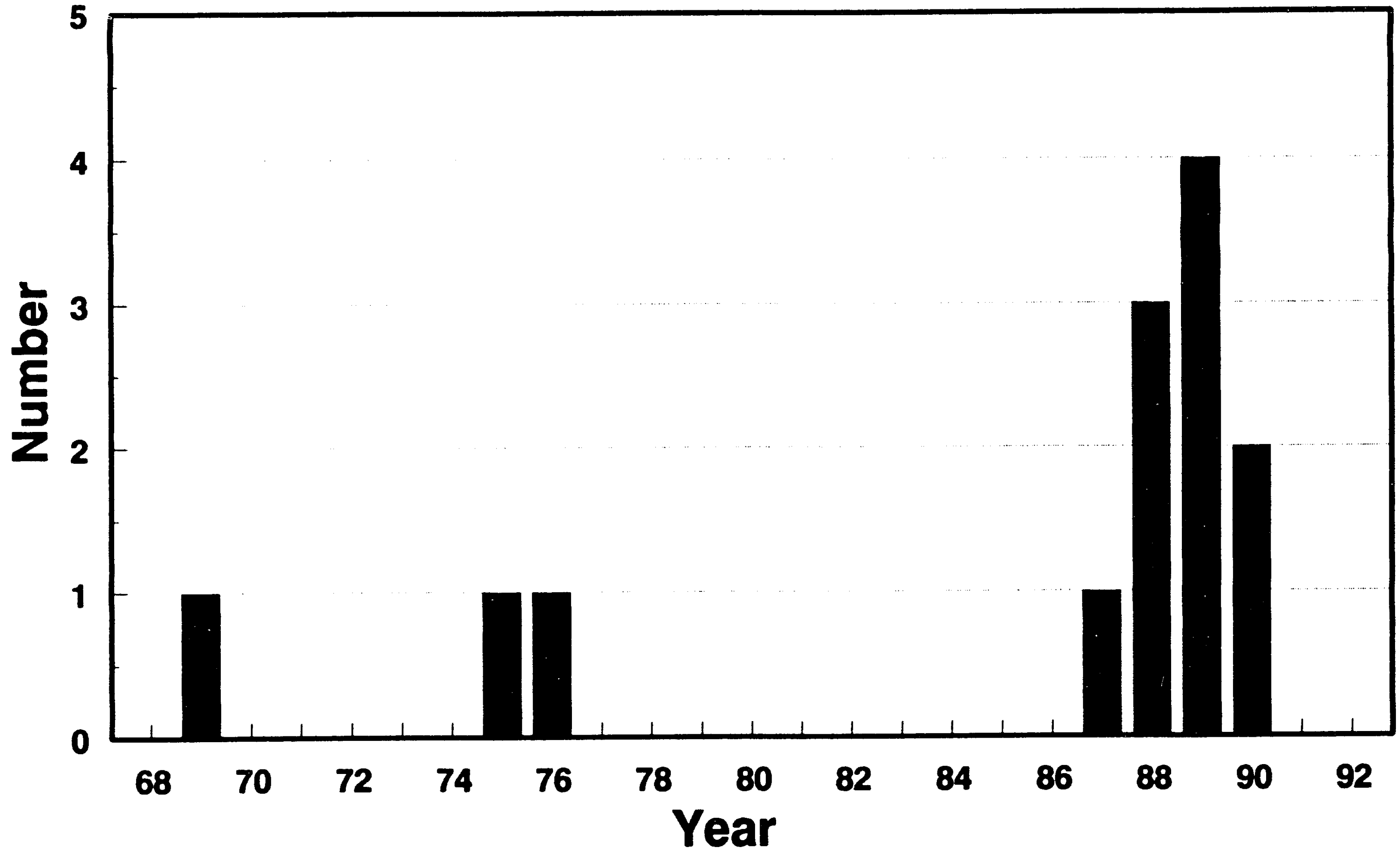


Figure 5.3 Temperature difference thermometer schematic

After A. Browman

* resistors 0.01 %; 100 uf tan; 1 nf RF.

Figure 6.1 Ceramic plate insulator failures at LAMPF 7835 electron tubes by manufacturing date



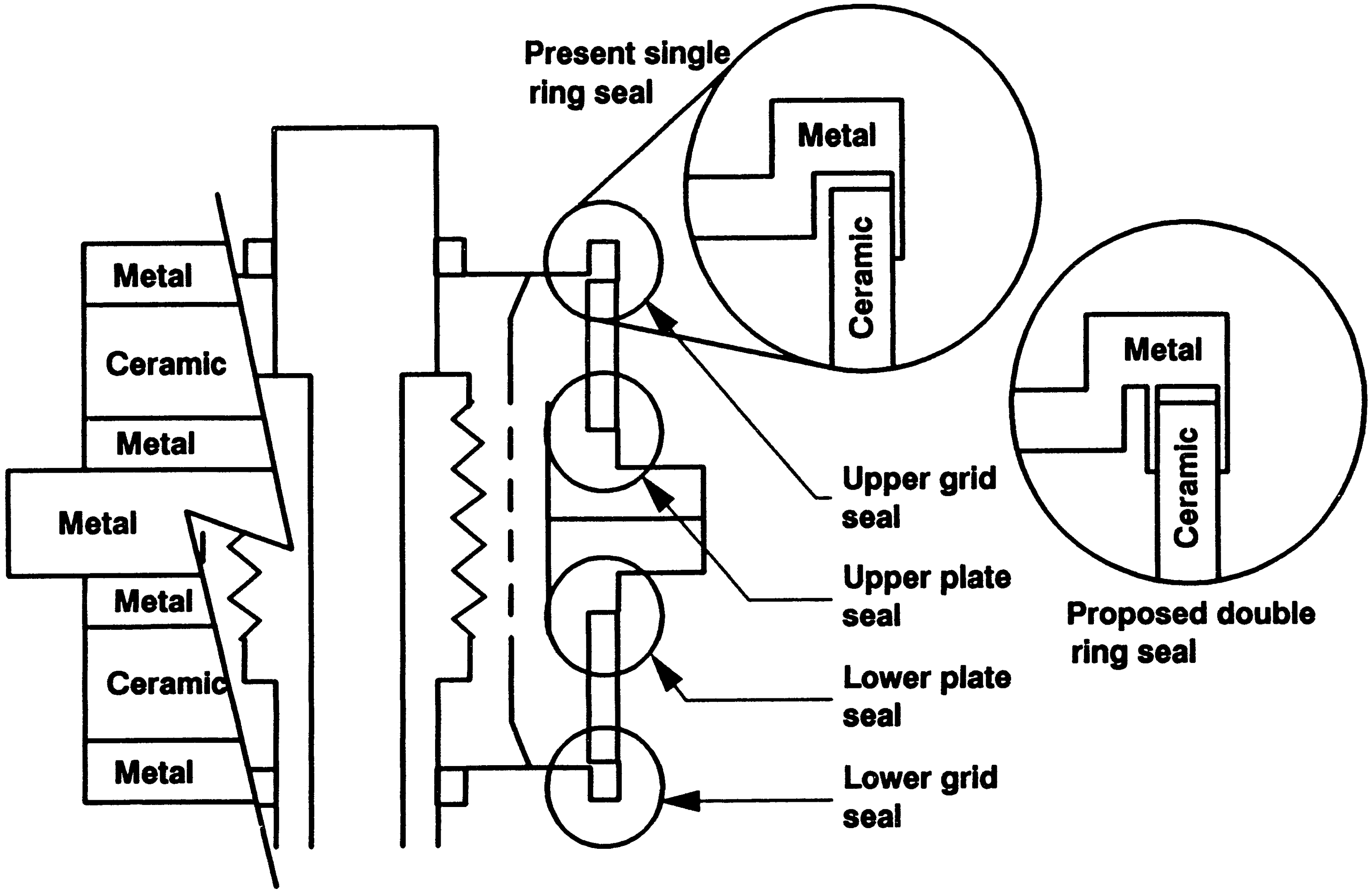


Figure 6.2 Present and proposed 7835 insulator seals

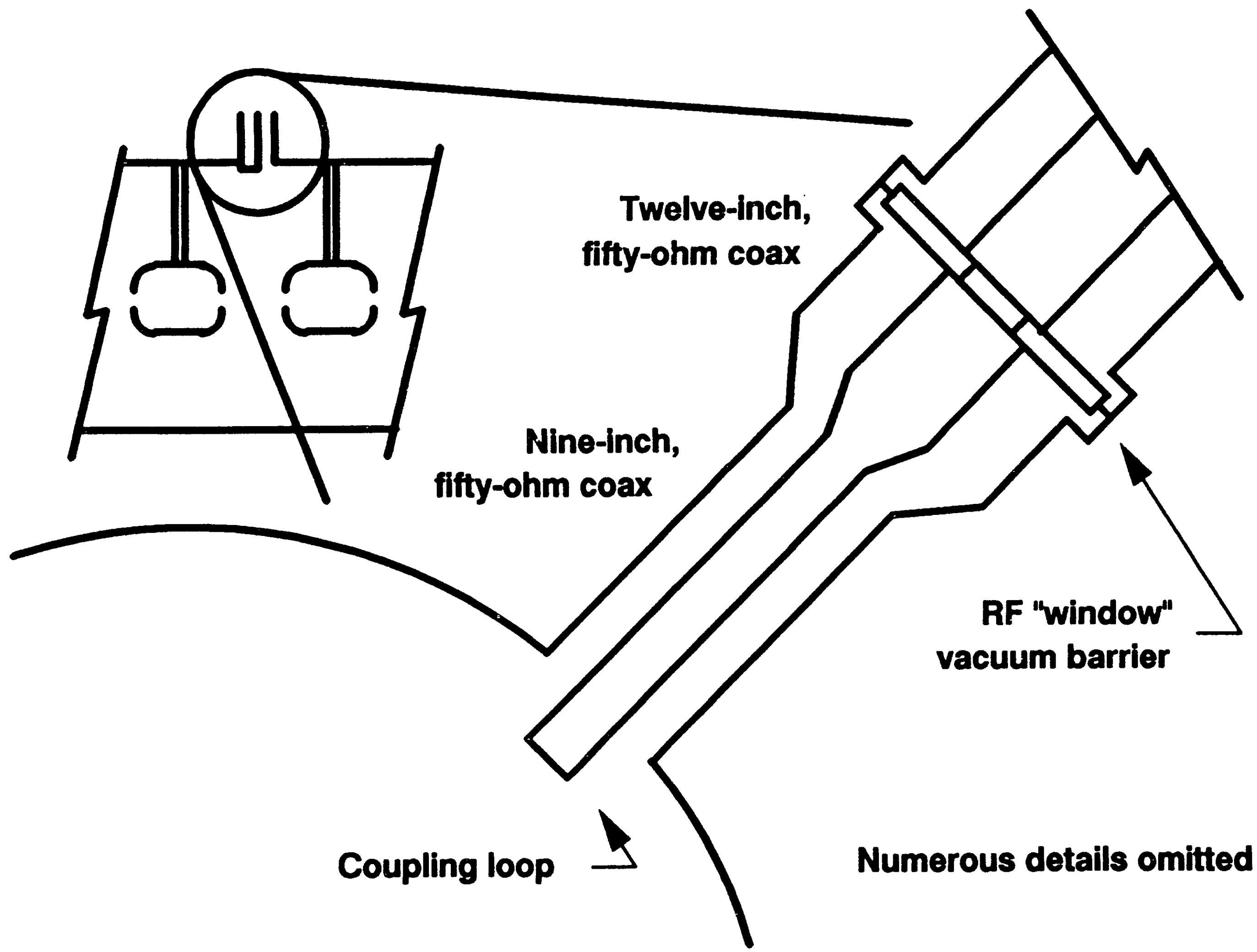


Figure 6.3 Alvarez tank feed loop and vacuum window

END

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10/25/91