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L-10 Accelerating Station

W. Frey

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

Accelerator Division
Technical Note

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L-10 Accelerating Station

W. Frey, M. Plotkin, R. Sanders, J. Tuozzolo

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The Heavy Ion (HI) accelerating station (cavity) at L-10 is a modified AGS pre-conversion cavity. The pre-conversion cavities for HI acceleration.

Initial Measurements

A small test program verified the feasibility of modification of the pre-conversion cavity. Small ferrite cores (approximately 3 cm. O.D. torroids) were tested at low signal levels. A 30 kW Gates transmitter was modified to drive the pre-conversion cavity at high power levels. Tests were made at the 2.1 and 10 kW levels corresponding to 1.6 and 3.3 kV peak gap voltage respectively. Cavity dissipation data was extrapolated to 76 kW at the 8.5 kV operational design gap voltage. These tests verified operation over the 0.5 to 2.5 MHz frequency range, with 4750 pF tuning capacitance/gap. Cavity dissipation data was extrapolated to 110 kW at the 8.5 kV operational design gap volts.

Starting with an initial current of about 50 μA at 500 KHz, approximately 3000 A of saturating current was required to tune the cavity to 2.5 MHz with 4750 pF/gap.

Cavity Modifications

Electrical Modifications

Lowering the cavity operating frequency and increasing the frequency sweep range required both electrical and mechanical modifications. Additional capacitors had to be added to each resonator to achieve a resonant frequency below 500 KHz without ferrite saturating bias current. The higher RF flux densities in the ferrite cores, and higher tuning currents required improved cooling and current carrying capabilities.

A. RF Modifications

1. Tuning Capacitors

Four 1000 pF and one 750 pF vacuum capacitors are used to tune each accelerating gap. Two 1000 pF capacitors are mounted on the aisle side of the cavity, while the other two 1000 pF and the 750 pf capacitor are mounted on the inside or catwalk side of the cavity. Figure 2 is sketch of the capacitor mounting.

2. Bi-Filar Tuning Current RFC's

The original cavity used bi-filar inductors to prevent RF leakage into the turning power supply. The RFC was several tuners of welding cable wound bi-filar to form a RF choke. The RFC was mounted under the cavity inside the support frame. Due to the increased tuning current, three times the capability. The second RFC is also mounted under the cavity inside the support frame. Figure 3 illustrates the interconnection of the RFC's.

3. RF Bypass

The bypass capacitors C3 of Figure 1 is an assembly of many 0.1 μF capacitors in parallel. In the pre-conversion cavities this assembly was only on the top half of the cavity at the center bias current feed point. Additional assemblies were constructed and place on the bottom half to improve RF bypassing at the lower frequencies and to obtain the proper circulating current distribution in the resonator/cavity structure.

4. Gap Shorting Relays

Vacuum relays are used to short the accelerating gaps of the HI cavity when no RF drive power is applied. This will reduce any possible interaction of the cavity with the circulating beam. Figure 4 is a schematic diagram of the shorting relay assembly.

B. DC Anode Power

The dc anode power (8 kVdc) for the output tubes of the power amplifier is routed through the cavity. Normally the anode supply for the output tubes in a push-pull amplifier is supplies through a center-tapped transformer or RF chokes, as shown dotted in Figure 5.

It is extremely difficult to construct a high-power wide-bandwidth (0.5 to 2.5 MHz) transformer or choke. Instead we make use of the voltage distribution characteristics of a shorted $\lambda/4$ transmission line resonator, illustrated in Figure 6. Since there is no RF voltage at the shorted end of the cavity, we bring the anode lead in at this end and run it down along the center-conductor/beam pipe, then out the "ears" at the gap to the anode side of the coupling capacitors. Figure 7 illustrates the anode supply feed.

Mechanical Modifications to Cavity

A. Buss

Due to the increased tuning (saturating) current and the circulating RF current at 2.5 MHz (over 600 A), the original sheet metal buss (1/4" x 1" copper) of the cavity was replaced with water-cooled buss. A small water flow (0.5 gpm) is required to keep the new buss cool at 4000 A.

The original clamp connections ("ears") that connected the flanges of the insulating gap to the buss were replaced with water cooled "ears" of larger cross section and clamping area.

B. Ferrite Cooling

The original cooling plates between the ferrite rings were retained. However, the cooling manifold was changed to improved the cooling capability of the plates. The previous series arrangement of water flow through the plates was changed to a parallel arrangement. The new cooling manifold is located on the aisle side of the cavity support frame. A flow of 20 gpm is required to keep the ferrite temperature in the normal range with full RF power (>110 kW) into the cavity.

The ferrite rings were unstacked and cleaned. New thermal grease was applied to the rings when they were restacked. The new grease will ensure proper thermal conductivity from the rings to the cooling plates.

C. Thermal Testing

An infra-red camera was used to scan for hot spots in the tuning buss and cavity connections after running for several hours at 3000 A continuous. Only minor hot spots were detected, showing minimal rise over ambient.

The cavity was operated with full RF power for several hours without detecting thermal run-away.

Operational and Test Results

Calculations were made for medium weight ions, such as oxygen, sulfur, and silicon, with injection energies of 7 to 8 MeV/nucleon. These calculations determined that the AGS flux densities of approximately 100 gauss, and ramped at a low $\dot{B}$ rate (typically 1225 gauss/sec) with a total accelerating voltage of 17 kV (8.5 kV/gap--two gaps).

Ferrite permeability increases with increasing gap voltage at the low frequency end of the sweep range (low dc saturating bias), and decreases as the frequency increases (increase of dc saturation bias). The fires thoughts about a constant frequency, and increase frequency at constant gap voltage. This approach should keep their opposite effect on the bias tuning separate. However, these plans were quickly changed during system testing as described below.

The cavity was initially tested CW at gap voltages up to 4 kV peak across the operating frequency band. Above 4 kV the cavity was pulsed to keep the average ferrite dissipation at a safe level. The cavity was originally given an average power rating of 15 kW. During testing for the AGS conversion "interim cavity" G. Rakowsky found that the onset of thermal run-away occurred at approximately 30 kW, or a power density of 0.278 watts/cm^3. It as felt that 25 kW average power would be a sage operating limit for the heavy ion RF system. Above 4 kV gap voltage, the cavity was tested at a 5% duty cycle. Peak powers were measured using a Pearson current transformer and Tektronix high voltage probes. Average powers were too low to make accurate calorimeter measurements.

Ferrite power dissipation was higher than predicted earlier. The RF power amplifier was designed to deliver a conservative 110 kW CW. At the low frequency end of the passband, the power amplifier saturated at 8 kV gap voltage. The ferrite dissipation was over 230 kW (2.12 W/cm^3). Power measurements were made at various frequencies and gap voltages, and families of ferrite dissipation curves were plotted to find a safe operating curve for the cavity.

Applicable Documents

Tech. Notes

AGSCD-2 "Re-evaluation of Ferrite Cooling in RF Cavities", G. Rakowsky, 5 October 1965.

Drawings

D06-M1216-5 Ferrite Cavity Installation
D06-E485 LFRF Relay Control Schematic Diagram.

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L-10 TECH NOTE

FIGURE 1

CROSS SECTION OF FERRITE LOADED ACCELERATING CAVITY

ARROWS SHOW DIRECTION OF DC SATURATING CURRENT OPPOSITELY DIRECTED IN THE TWO HALVES

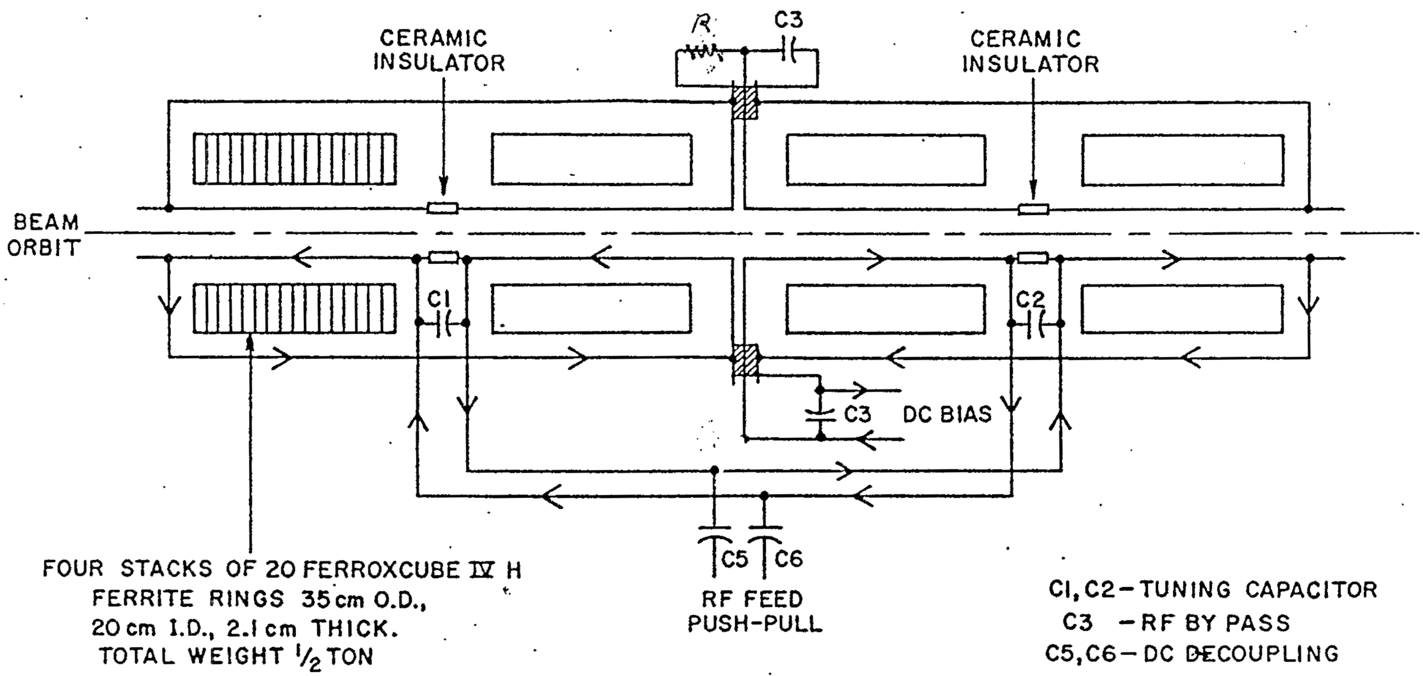
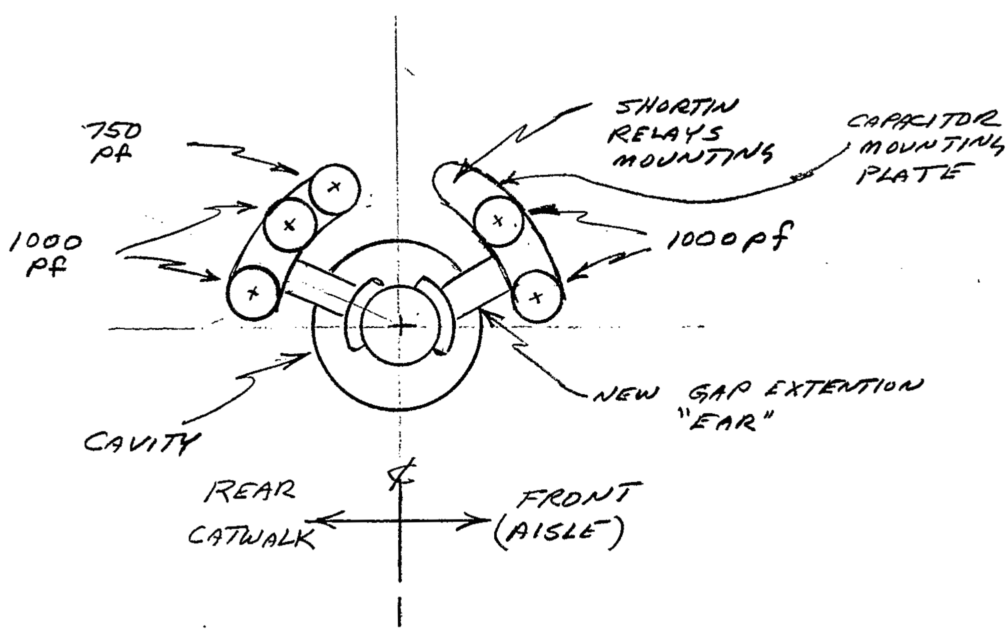
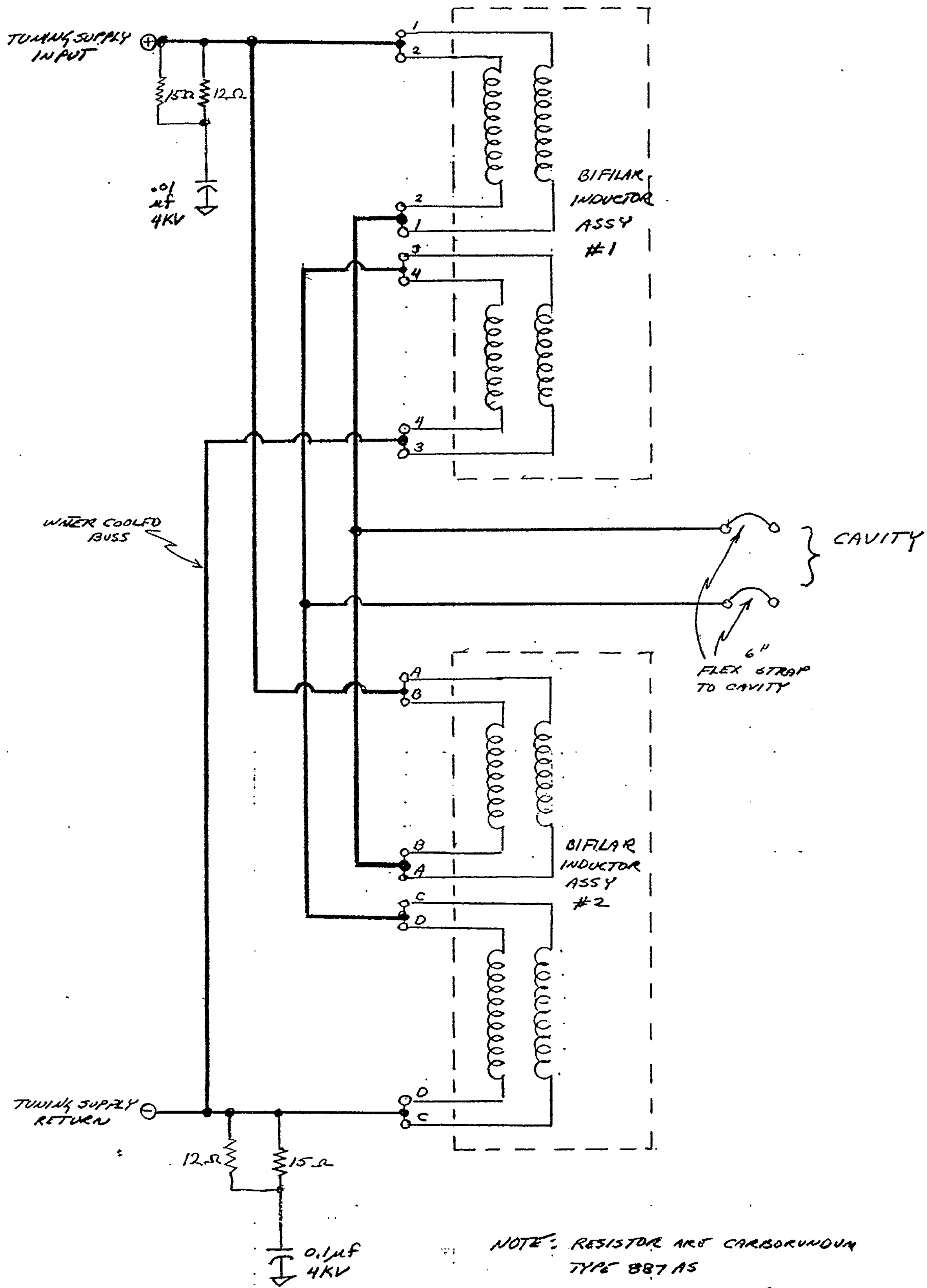


FIGURE 2 TUNING CAPACITOR MOUNTING





NOTE: RESISTOR ARE CARBORUNDUM TYPE 887 AS
CAPACITOR IS SANGAMO

FIGURE 3

TUNING CURRENT CONNECTIONS

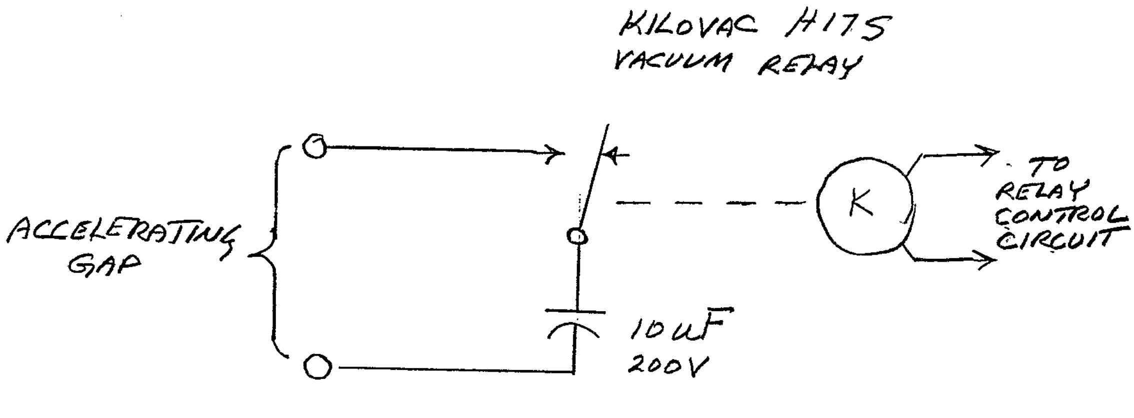


FIGURE 4 GAP SHORTING RELAY CIRCUIT

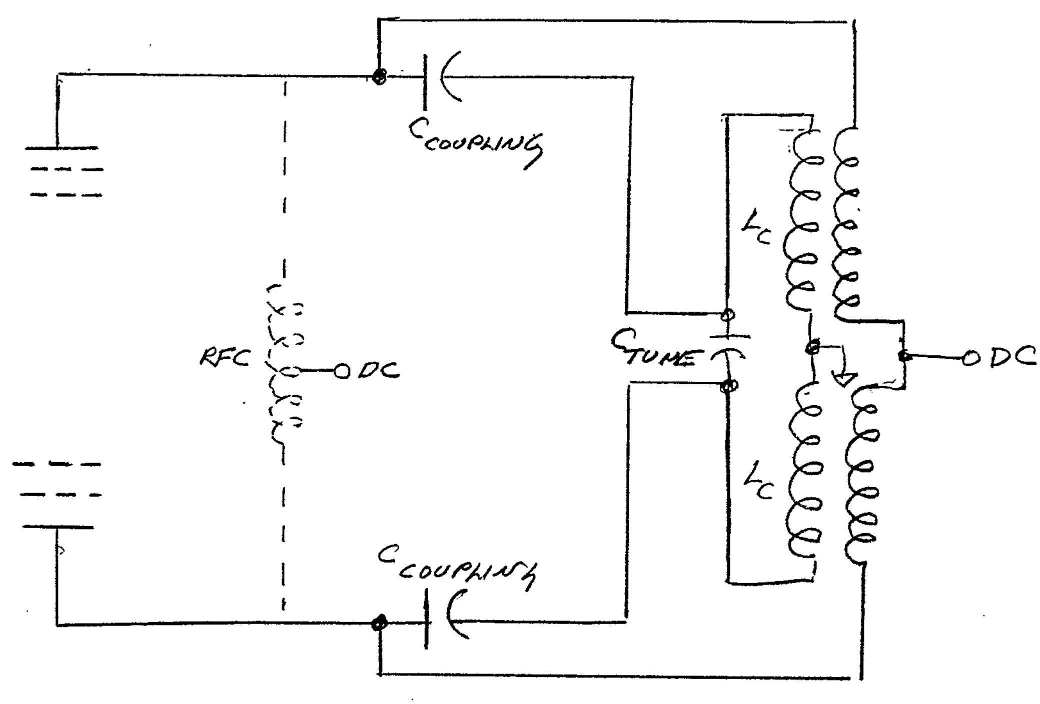
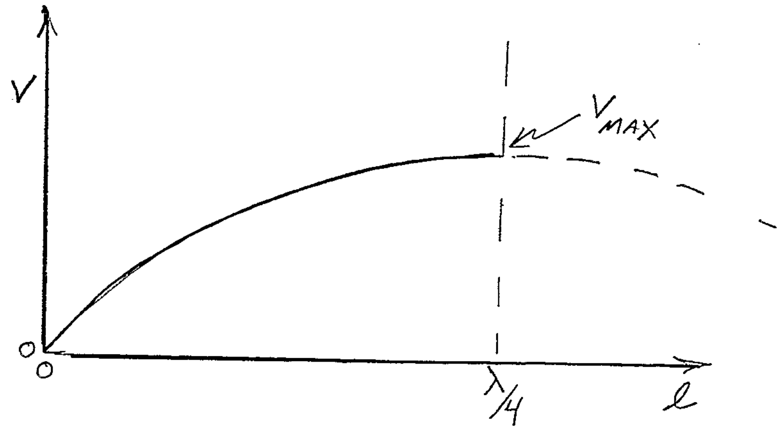
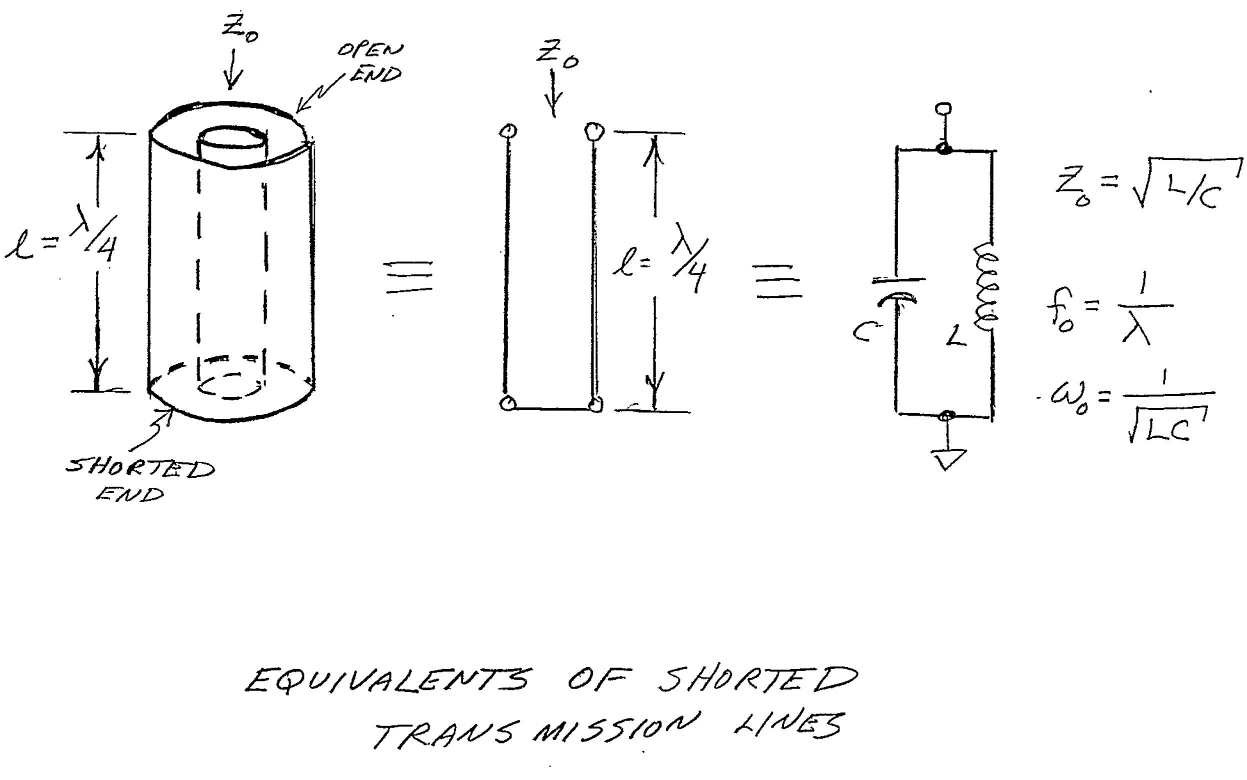


FIGURE 5 SCHEMATIC DIAGRAM OF ANODE SUPPLY CONNECTION

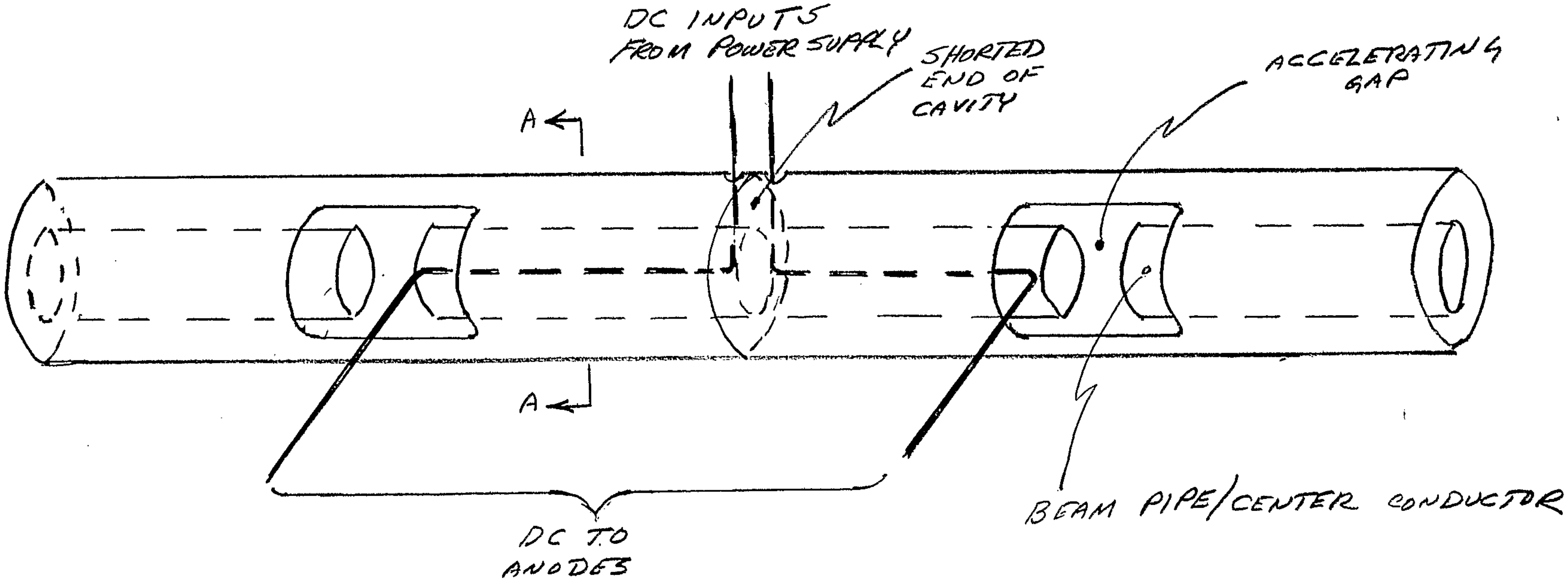


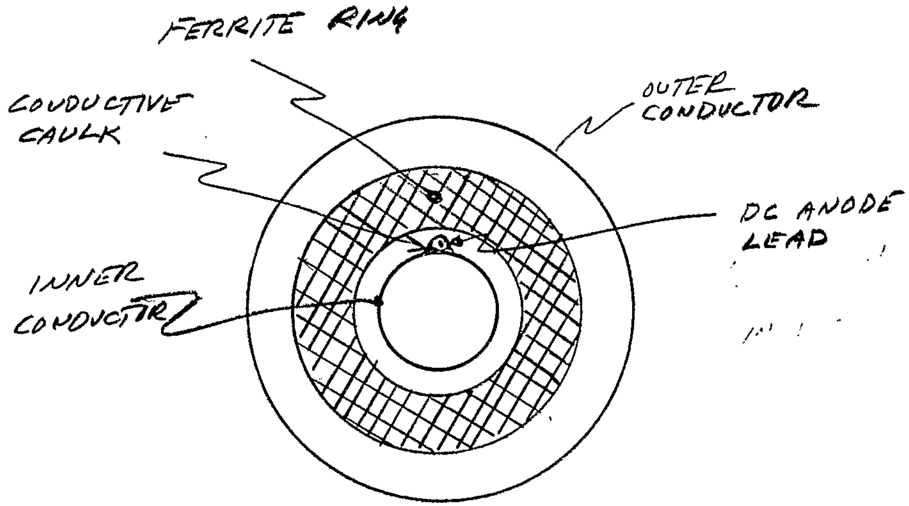
VOLTAGE DISTRIBUTION ON A SHORTED TRANSMISSION LINE



EQUIVALENTS OF SHORTED TRANSMISSION LINES

FIGURE 6





CROSS SECTION AA
ILLUS

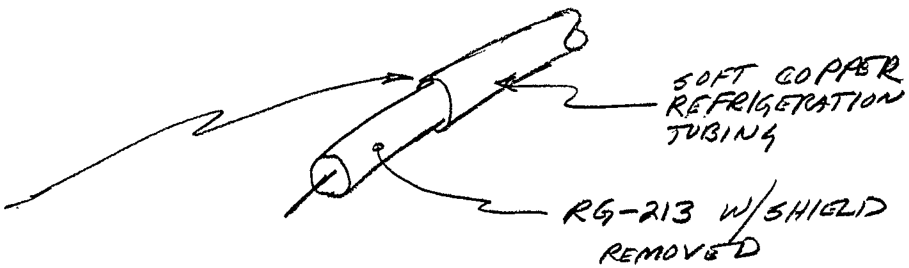
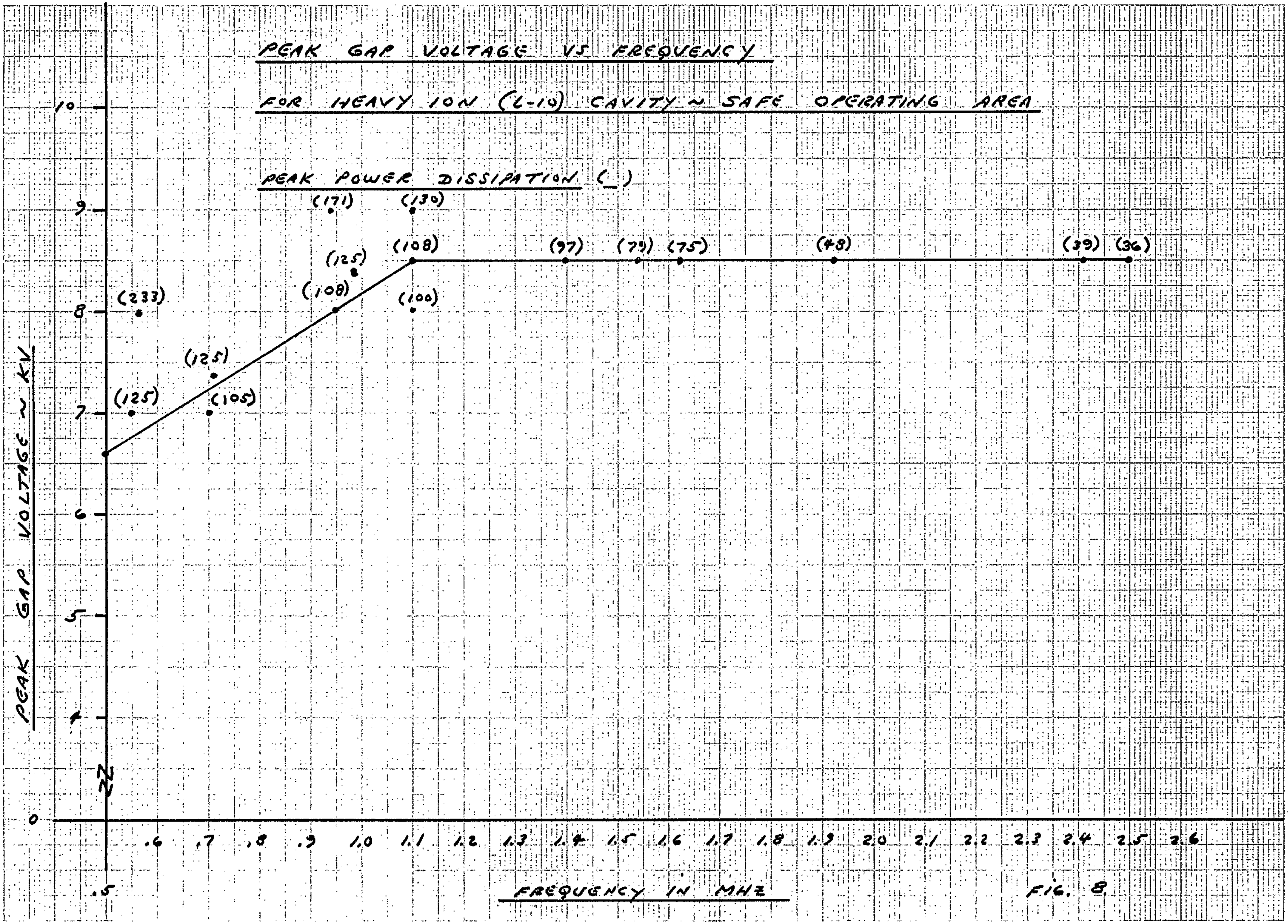


FIGURE 7

D.C. ANODE SUPPLY


PEAK GAP VOLTAGE VS FREQUENCY
FOR HEAVY ION (L-14) CAVITY ~ SAFE OPERATING AREA
PEAK POWER DISSIPATION ( )
PEAK GAP VOLTAGE ~ KV
FREQUENCY IN MHZ
(171)
(130)
(108)
(97)
(79)
(75)
(48)
(39)
(36)
(125)
(108)
(100)
(233)
(125)
(125)
(105)
10
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1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
FIG. 8