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A RADIO FREQUENCY SYSTEM FOR EXPERIMENTS WITH THE FFAG ELECTRON MODEL

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ABSTRACT: A frequency modulated oscillator using ferroelectric capacitors has been constructed for rf experiments with the FFAG electron model. The system gives about 50 peak rf volts and a frequency swing from 65 to 75 Mc on the 150 $\mu\mu f$ vacuum tank gap. Closely spaced frequency modulated rf pulses, up to four or five per millisecond, are available for rf beam stacking and other experiments.

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Introduction:

In order to study rf acceleration questions in FFAG accelerators, and in particular to test experimentally the rf theory of Symon and Sessler[1], an rf system has been constructed and put in operation on the radial sector FFAG electron model[2]. The following report describes this rf system. An accompanying report[3] discusses the rf experiments that have been performed.

A. General Description

Electrons in the FFAG model are accelerated over a frequency range of about 2 to 1; they are injected with a frequency of 38 Mc and reach the target with a frequency of 74 Mc. The accelerator was originally designed for betatron type acceleration and no provisions had been made for applying rf. Since a number of interesting rf experiments could be performed without the necessity of the full 2 to 1 frequency modulation, by using betatron acceleration part way, an rf system was constructed which could modulate over a much smaller range. With this smaller range the system could be built rapidly using known techniques.

Frequency modulation can be obtained with the use of ferroelectric (barium titanate) capacitors in the resonant circuit of an rf oscillator. Varying a DC polarizing voltage on the capacitors changes their capacity: changes of a factor of 4 to 10 have been measured. Rf voltage on the capacitors reduces this factor. The fixed circuit capacity and the rather low Q (50 or so) also reduce the frequency range obtainable. The above system has been used successfully on the University

[1] MURA-106

[2] MURA-219

[3] MURA-255

of Michigan synchrotron to change the frequency of the rf cavity from 27 to 32 Mc and is also employed here.

The FFAG model is constructed with no space for an rf cavity. Drift tubes inside the aluminum vacuum tank (vertical aperture 1") would have a large capacity to the tank as well as decreasing the vertical aperture available for the beam. A third alternative, and the one used, is to apply rf directly across one of the 2mm insulated gaps between the halves of the vacuum tank. The vacuum tank and an insulated gap are seen in Fig. 1, a photograph of the machine with one magnet removed. Figure 2 is a schematic drawing of the method of applying the rf to the vacuum tank and Fig. 3 shows photographs of the oscillator coupled to the tank. The opposite gap is rf short circuited and the tank looks like an inductance of order 1 μh with reactance considerably larger than that of the insulated gap. The latter, because of the flanges, looks like a large capacitance, of order 150 $\mu\mu$f. Since the tank is a good antenna, its Q is quite low. Fortunately, the experiments require only a small rf voltage so the oscillator is weakly coupled to the tank gap with a small capacitor. 50 peak volts of rf are available on the gap and it has been possible to frequency modulate over a range of 10 Mc, going from 38 to 48 Mc or from 65 to 75 Mc. The applied rf voltage is constant only over about 5 Mc of the range. Most of the rf experiments are done with only a 1 or 2 Mc sweep.

Some of the rf experiments require a number of repetitions of the frequency modulation cycle. Since the lifetime of the electron beam, coasting at 300 kv after betatron acceleration, is of order 1 millisecond at 10^{-6} mm of Hg, the period of one rf cycle must be quite short, two to three hundred μsec. Some rf pulses and their beat frequency patterns are shown in Fig. 4.

B. Frequency Modulated Power Oscillator

The circuit diagram of the rf oscillator with ferroelectric capacitors is shown in Fig. 5. It is a Colpitts type oscillator, run class C with grounded grid. The fraction of output voltage fed back to the grid is determined by the tube plate-cathode capacitance and a variable grid-cathode capacitance. The frequency range and output voltage are limited in this circuit primarily by the large capacitance and radiation loss of the tank.

A number of suitable ferroelectric capacitors are commercially available. Stock items are Sprague 5HK-D and Centralab DD3 series, the lowest values being 1000 $\mu\mu$f. Sprague has test samples in the range of 200 - 400 $\mu\mu$f unpolarized. The largest capacity change, a factor of 10, was obtained with 1000 $\mu\mu$f samples of type K6000 from Centralab. The Q of these ferroelectrics is a function of material, frequency, and polarization, varying from 25 up to 75. About 4 KV of polarizing voltage usually produces most of the capacity change.

C. Control Circuits

A block diagram of the control circuits for the oscillator is shown in Fig. 6. The circuits are designed to produce the rapid sequence of rf pulses indicated in Fig. 4. An input pulse, delayed from injection, generates a series of trigger pulses for a few milliseconds; each of these triggers fires the hydrogen thyratron, a 5C22. The 5C22 circuit is shown in Fig. 7a. The ferroelectric capacitors, connected in parallel for the polarizing voltage, are at the supply voltage until the 5C22 fires. The circuit then starts to ring, with period and damping determined by the RLC circuit parameters. L is chosen to make the oscillation rapid, a few microseconds period, and R to make the damping short of critical so that a negative voltage appears across the thyratron after one half an oscillation, turning it off. The voltage on the tube must be negative for at least 10 μsec, the deionization time of the hydrogen thyratron. The ferroelectric capacitors then are recharged to the supply voltage through a resistor. The voltage on the capacitors is not quite an exponential because of the change of capacity. The rate of change of voltage, and hence the rate of frequency modulation, can be varied by changing the charging resistor or the supply voltage. A bias voltage V_b is available to minimize the time spent recharging to the voltage corresponding to the turn on frequency of the oscillator. A sketch of the voltage applied to the ferroelectric capacitors appears in Fig. 7b. To make sure that the turn on frequency of the oscillator is reproducible, the start of the gate pulse going to the 829B screen is determined by a discriminator, which fires when the capacitor voltage reaches a set value.

The peak voltage of the applied rf is picked up by a diode detector across the gap and presented on an oscilloscope, along with a beat signal between the rf and a constant frequency generator, as shown in Fig. 4. The rf turns on rapidly with a rise time of one to two μsec, and the turn on frequency of the oscillator appears reproducible within a few kc, the accuracy of this measuring technique.

I wish to thank D. Ford for his help in constructing the circuits, and I want to express my appreciation to G. Edict of the University of Michigan synchrotron project and members of the MURA technical group for many helpful suggestions.

FIGURE CAPTIONS

Fig. 1. Photograph of the electron model with one magnet removed, showing vacuum tank and the insulated gap.

Fig. 2. Schematic drawing of the method of applying rf to the vacuum tank.

Fig. 3. Photographs of the oscillator coupled to the vacuum tank.

Fig. 4. Oscilloscope photographs of rf pulses.

a. Pulse from a diode detector on the rf gap. The time scale is 50 μsec/cm. The maximum voltage is about 45 volts.

b. Beat frequency patterns of the above rf pulse with a signal generator. The signal generator is set at about 72.5, 73.0, and 73.5 Mc on the different traces.

c. and d. Detector signal and beat frequency pattern from a group of rf pulses. The time scale here is 200 μsec/cm.

Fig. 5. Frequency modulated power oscillator circuit.

Fig. 6. Block diagram of control circuits for rapid pulsing the frequency modulated oscillator.

Fig. 7 a Circuit for generating the high voltage polarizing pulse for the ferroelectric capacitors.

b. Voltage on the capacitors as a function of time.

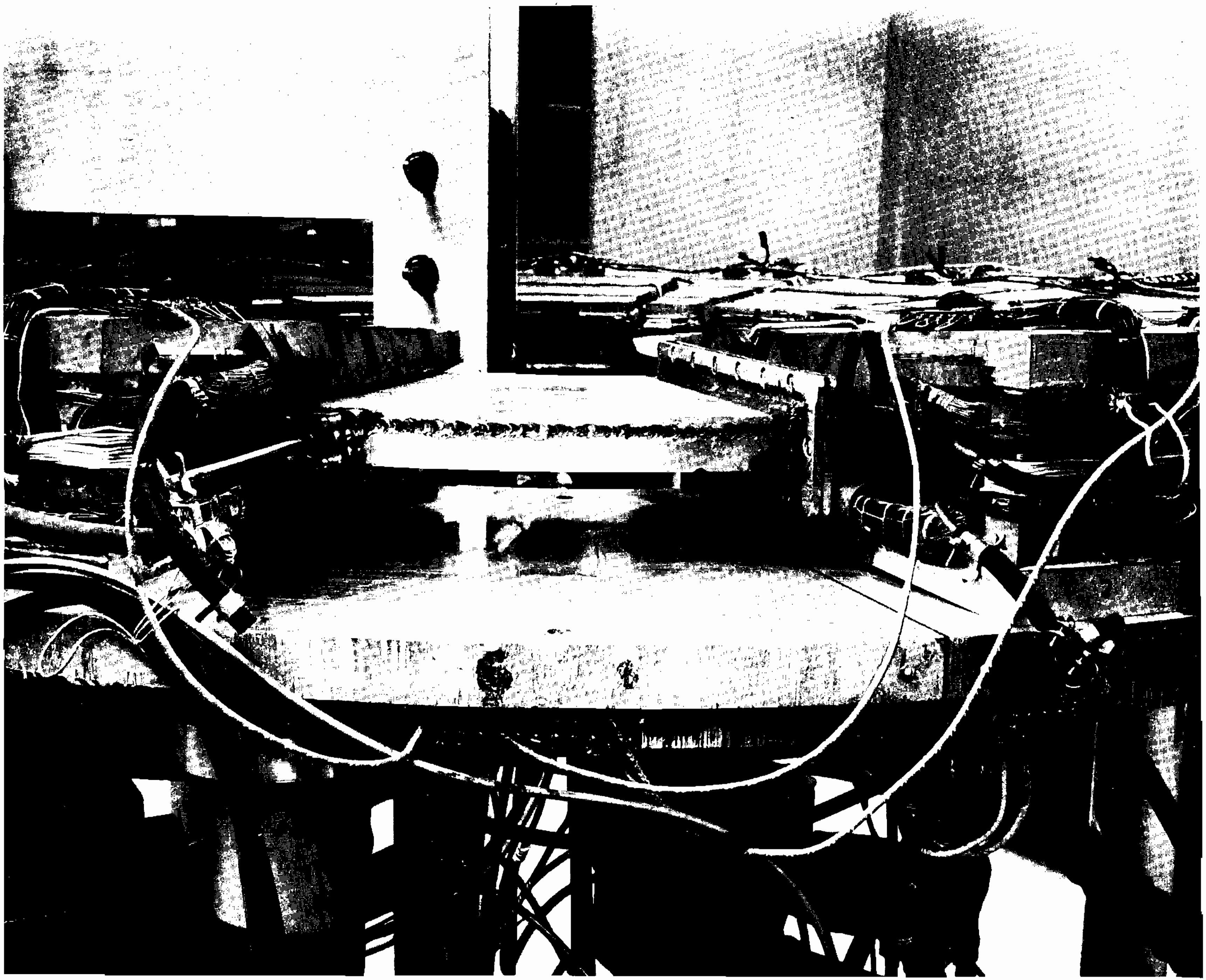


Fig. 1

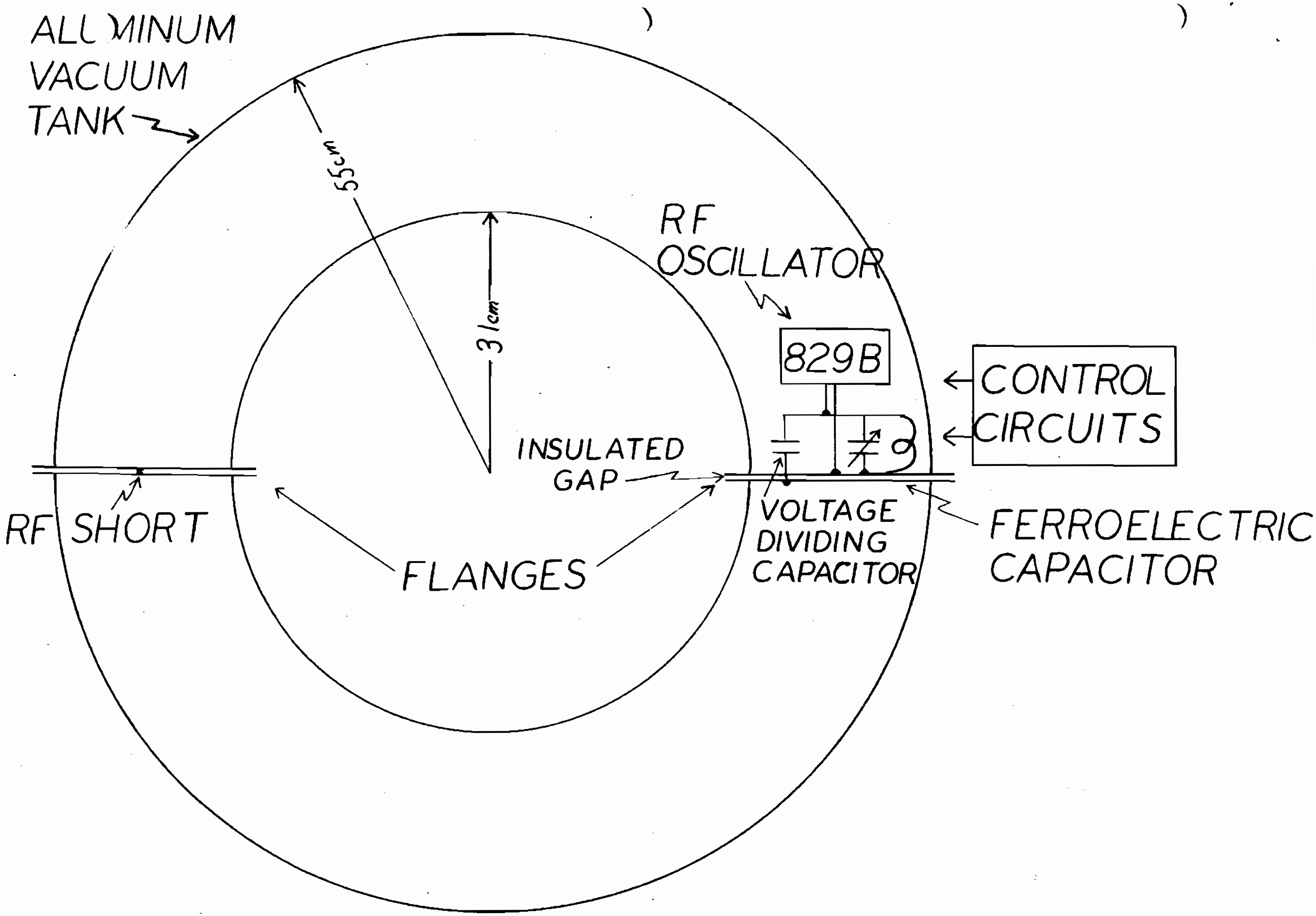
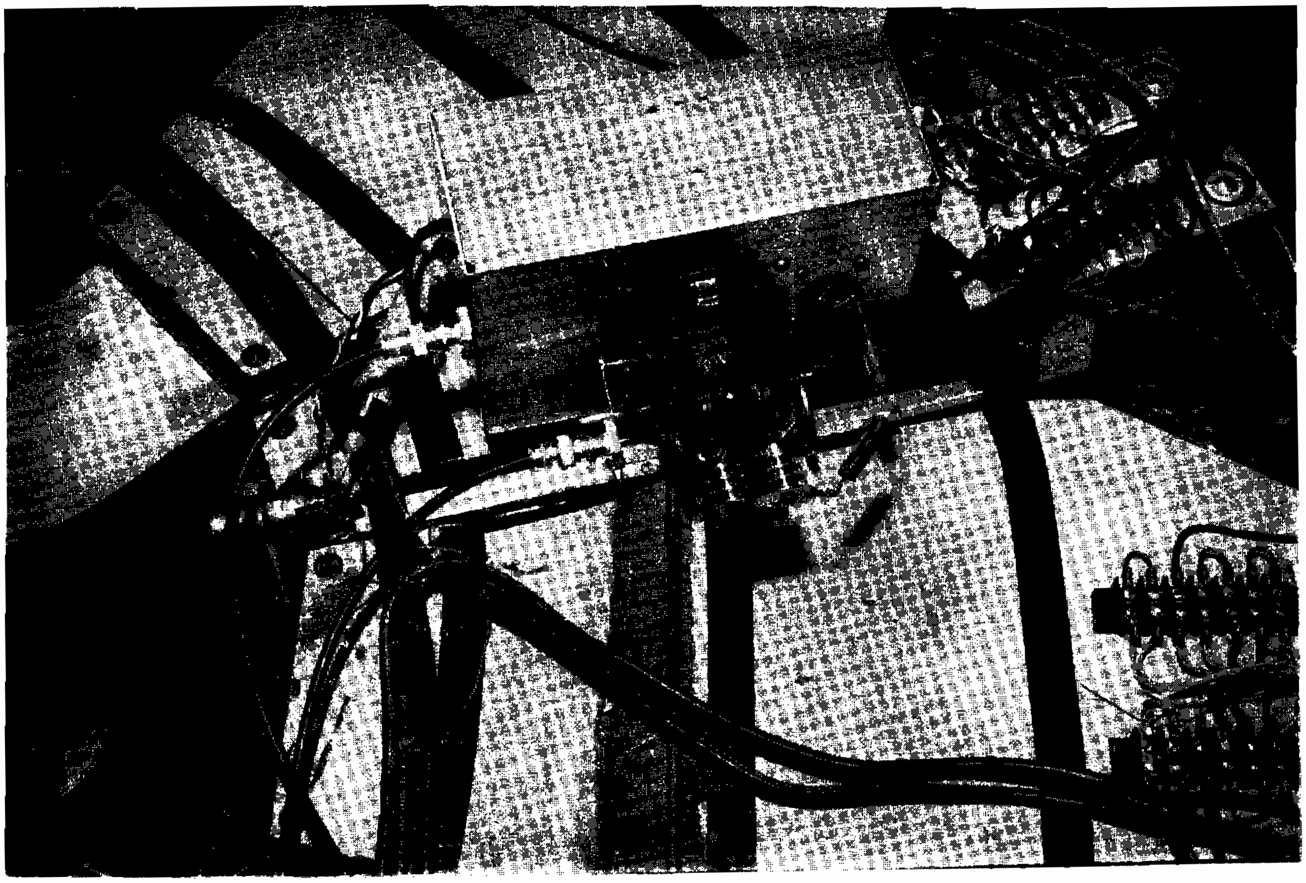

ALUMINUM
VACUUM
TANK
55cm
31cm
RF
OSCILLATOR
829B
CONTROL
CIRCUITS
INSULATED
GAP
RF SHORT
FLANGES
VOLTAGE
DIVIDING
CAPACITOR
FERROELECTRIC
CAPACITOR

Fig. 2



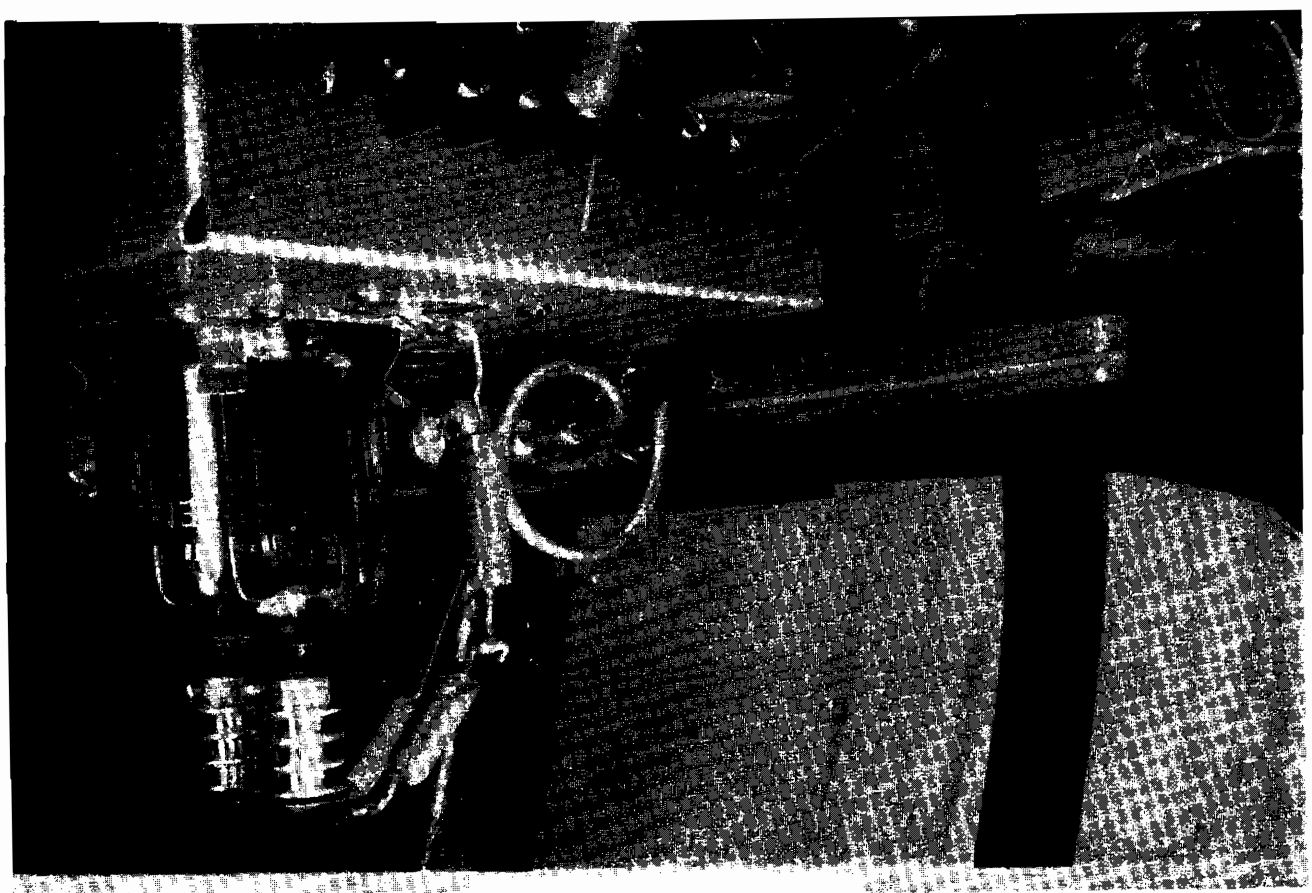


Fig. 3

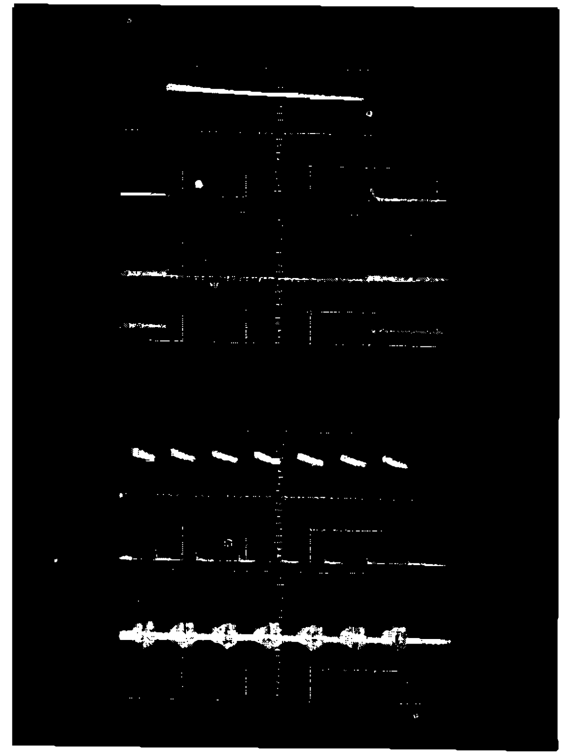


Fig. 4

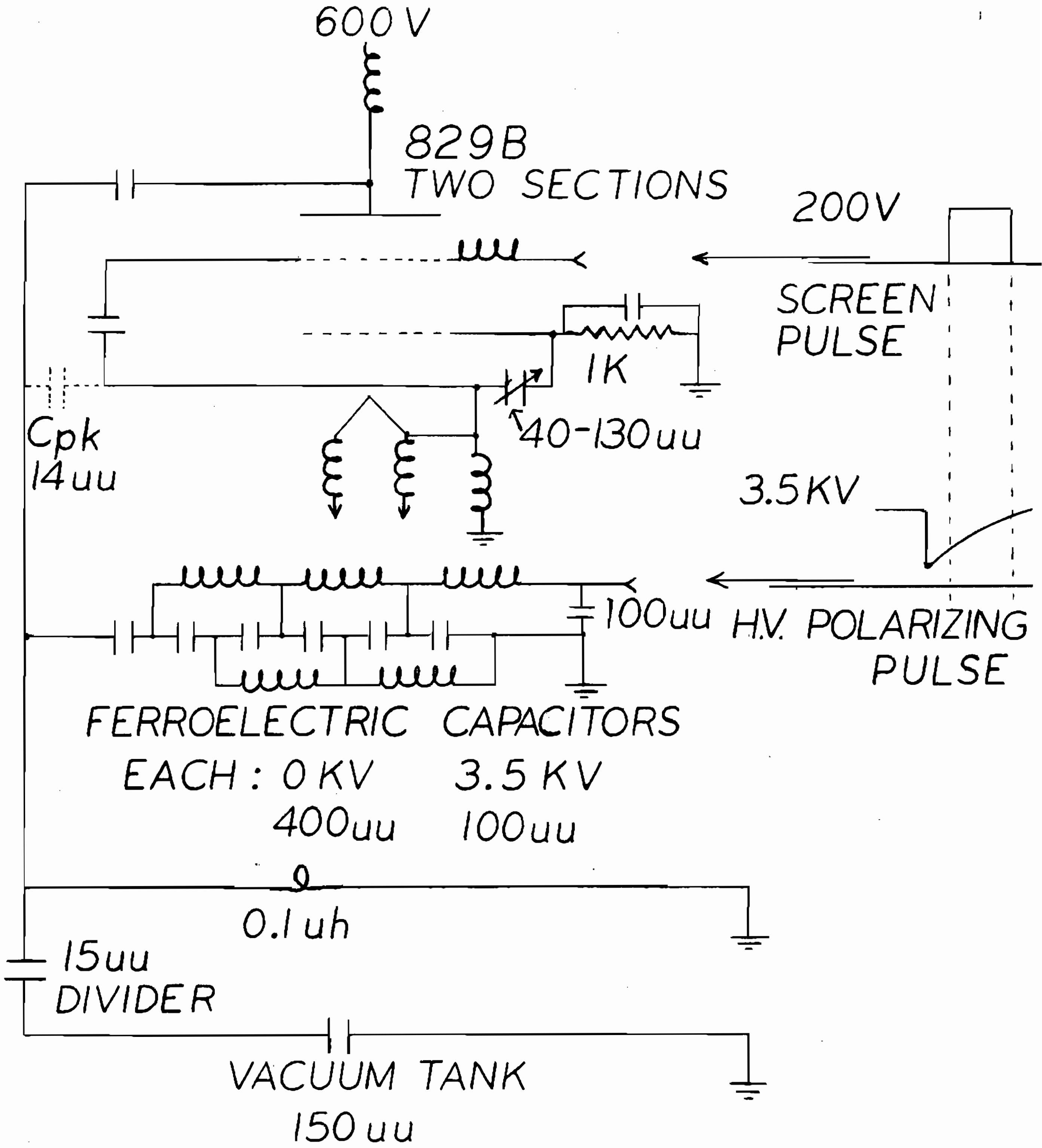

600 V
829B
TWO SECTIONS
200V
SCREEN
PULSE
1K
Cpk
14uu
40-130uu
3.5KV
100uu
H.V. POLARIZING
PULSE
FERROELECTRIC CAPACITORS
EACH : 0 KV 3.5 KV
400uu 100uu
0.1 uh
15uu
DIVIDER
VACUUM TANK
150 uu

Fig. 5

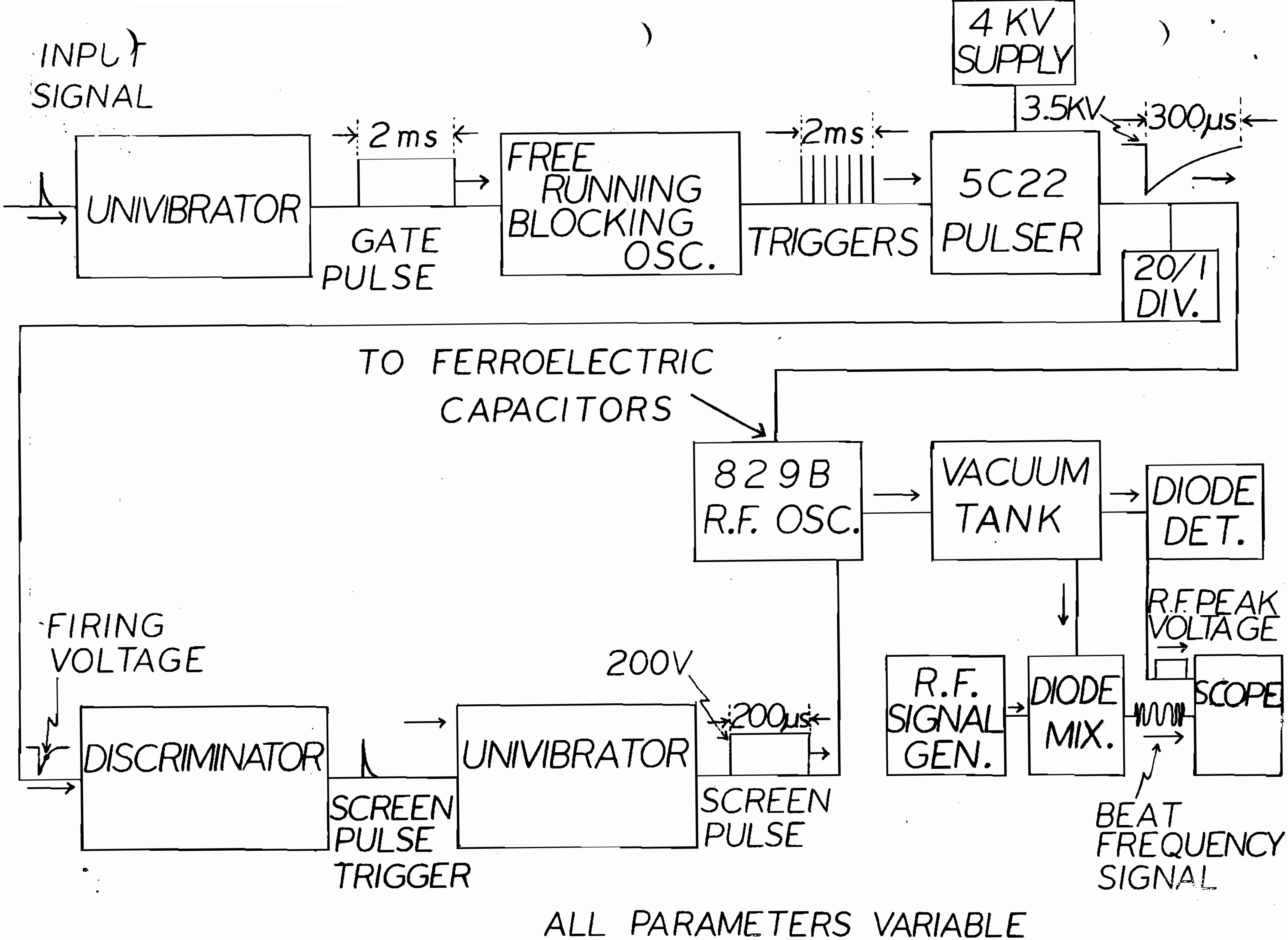

INPUT SIGNAL
UNIVIBRATOR
2 ms
GATE PULSE
FREE RUNNING BLOCKING OSC.
2ms
TRIGGERS
4 KV SUPPLY
3.5KV
300μs
5C22 PULSER
20/1 DIV.
TO FERROELECTRIC CAPACITORS
829B R.F. OSC.
VACUUM TANK
DIODE DET.
R.F. PEAK VOLTAGE
R.F. SIGNAL GEN.
DIODE MIX.
SCOPE
BEAT FREQUENCY SIGNAL
FIRING VOLTAGE
DISCRIMINATOR
SCREEN PULSE TRIGGER
UNIVIBRATOR
200V
200μs
SCREEN PULSE
ALL PARAMETERS VARIABLE

Fig. 6

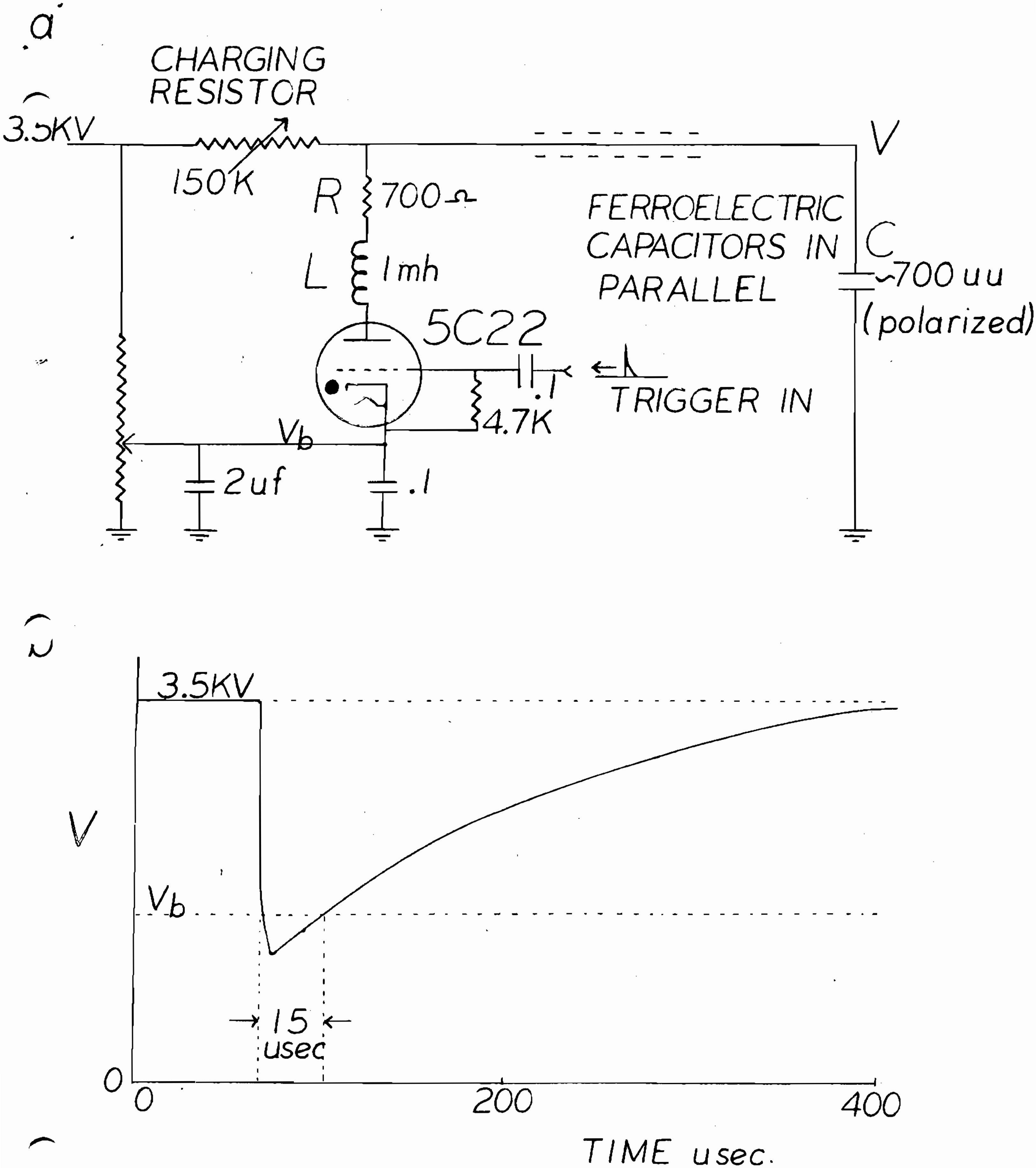

a
CHARGING RESISTOR
3.5KV
150K
R
700Ω
L
1mh
5C22
FERROELECTRIC CAPACITORS IN PARALLEL
V
C
~700 uu
(polarized)
.1
TRIGGER IN
4.7K
Vb
2uf
.1
b
3.5KV
V
Vb
15 usec
0
0
200
400
TIME usec.

Fig. 7