# A COMPACT CURRENT PULSE SUPPLY FOR SMALL SCALE EXPERIMENTS

by

R.A. BURDEN
K.J. HOPKINS

## A B S T R A C T

A current pulse supply unit is described, suitable for small-scale laboratory experiments requiring currents up to 6 kA. The maximum working voltage is 10 kV and the total installed capacity (which is easily varied) is 10 × 0.5 μF. The required voltage is preset and the charging cycle automatically tripped at this voltage. The capacity in use, and the working voltage are both easily varied so that, with a given load, both risetime and current are flexible quantities. Three charging rates are available and are approximately linear throughout their range. There are three modes of operation for the charge-discharge-recharge cycle:

(a) manual;

(b) automatic - the discharge sequence commences as the preset voltage is reached and recharging starts as soon as the capacitor voltage drops below a pre-determined level.

(c) delayed automatic - an interval occurs between the end of the charging cycle and the fire sequence; this interval being preset and widely variable.

Performance tests show that risetimes are variable down to 2 μsec and the maximum current available is usually greater than 1 kA (depending on the load and capacity used), and can be as high as 6 kA. The cycle time is typically of the order of 1 - 10 seconds although it may reach 25 seconds with the maximum capacity operating at the peak voltage.

The circuit incorporates safety interlocks which operate a capacitor dump switch.

U.K.A.E.A. Research Group,
Culham Laboratory,
Nr. Abingdon,
Berks.

November, 1965

# CONTENTS


| | Page |
|---|---|
| INTRODUCTION | 1 |
| CIRCUIT DESCRIPTION AND DETAILS OF CONSTRUCTION | 1 |
| Construction and Layout | 1 |
| The Operating Cycle | 2 |
| The Charge and Discharge Circuits | 2 |
| Dump Circuit and Safety Interlocks | 3 |
| GENERAL OPERATION AND CYCLING MODES | 4 |
| CALIBRATION AND PERFORMANCE TESTS | 4 |
| SUMMARY | 7 |
| REFERENCES | 7 |

## INTRODUCTION

A common means of testing and setting up multiple magnetic search coil probes, is to use the field produced by a current pulse in a coil system, often of the Helmholtz type. While considering the design of such a pulsed current source it became apparent that there was a general need for a compact current pulse supply unit of this type. This prototype unit has been used in the calibration of magnetic and piezo-electric probes; to provide a voltage sweep for a double Langmuir probe; as a current pulse calibration unit and as a high voltage, high current trigger unit. Modifications have been incorporated so that the final unit is of flexible design and general application.

The control circuits are based on plug-in unitised equipment so that maintenance and servicing problems are kept to a minimum. For reliability of operation a vacuum switch, rather than a conventional relay, has been used for the charging switch; and the small size of the BK 396 ignitron has helped to keep the unit compact. The duty cycle is low enough to eliminate the need for cooling water supplies to the ignitron. The prototype was built into a standard 4'6" rack.

In this prototype an accurately calibrated, non-inductive resistor is included in the output circuit and the potential developed across this is used as a calibration source for the output current. For accurate work this potential must be monitored for each pulse, although in general the spread in output is less than 1%, which is adequate for most applications.

## CIRCUIT DESCRIPTION AND DETAILS OF CONSTRUCTION

### CONSTRUCTION AND LAYOUT

The complete unit is illustrated in Fig.1; the layout is as follows. The top panel contains the mains voltage supply switch and fuses and the start charge, stop charge, and dump controls. Switches on this panel select the trigger mode and the charge rate, and a meter indicates the capacitor voltage. Below this panel the two shelves for unitised equipment of the 2000 series hold the voltage sensing unit, timing and trigger units and a power pack. The rest of the space is taken up with the high voltage circuit and access is only through the interlocked side or rear doors. The prototype illustrated also contained a variable voltage mains supply which was specifically required for an experimental application which would not generally be included.

The circuit diagram is given in Fig.2, and a block diagram of the trigger circuit in Fig.3. Figs.4 and 5 give detailed views of the components and layout of the high voltage parts of the circuit. On the upper (perspex) shelf the capacitor link board is at the front while behind it are arranged the vacuum relay and the high-voltage transformer. The trigger pulse isolation transformer is mounted in a hole cut in the shelf and the non-inductive current monitor resistor is mounted on an S.R.B.F. panel alongside the shelf, on the main framework of the rack. On the lower (S.R.B.F.) shelf are mounted the capacitor bank, ignitron, dump resistor and dump switch. One of the door interlock switches can be seen in Fig.5.

## THE OPERATING CYCLE

The circuit diagram given in Fig.2 is largely self explanatory; the mode of operation is briefly as follows. With manual traggering and the required charging rate, capacitance and voltage selected, the sequence commences with the START control S3 which (via RL2/1) energises RL1 and RL1H. The latter starts the charging cycle and this is indicated by the control panel lamp. The cycle is terminated by the voltage sensing unit when the capacitors reach the preset voltage. This unit causes RL2 to open thus opening RL1H and RL1. Manual operation of the trigger control triggers the thyratron which in turn triggers the ignitron via a pulse transformer. The capacitors then discharge through the ignitron into the external load.

With the switch S2 set to AUTO the circuit functions as for manual operation except the START Control S3 is shorted by RLA/1 after its initial operation at the beginning of the cycle. The operating cycle is then controlled by the voltage sensing unit which controls RL2/1.

The cycle is stopped by either the STOP or DUMP controls.

## THE CHARGE AND DISCHARGE CIRCUITS

Linear charging rates are to be preferred since the operation of the voltage sensing unit is more certain under these conditions and current surges, which occur with resistive charging, are eliminated. These conditions are obtained by using a higher voltage supply than actually required, in this case a 13 mA, 12 kV transformer. The three separate charging rates are provided by varying the tappings on the primary winding.

The circuit is designed to work with a predominantly inductive load so that

$$f \sim \frac{1}{2\pi\sqrt{LC}}$$

where f is the frequency of the damped oscillatory discharge waveform. The layout of the discharge circuit involves a degree of compromise since flexibility of capacitor value and low inductance are somewhat conflicting requirements. In the prototype unit the stray inductance was kept to ~1.5 μH.

The internal construction of the BK 396 ignitron is such that to ensure reliable triggering, a high voltage trigger pulse is required. This unit uses a 1.5 kV trigger pulse, applied via a 3:1 step-up transformer. This transformer also provides the necessary voltage isolation.

## DUMP CIRCUIT AND SAFETY INTERLOCKS

Since high voltages are in use in the circuit, the rack in which the prototype was built has interlocks on all doors which:

(a) operate a solenoid-type dump switch and

(b) interrupt all mains supplies to the H.T. circuits.

The dump circuit discharges the capacitors through a 20 kΩ, 100 W resistor (thus limiting the current to 500 mA), and will reduce the voltage on 5 μF from 10 kV initially, to 70 volts, in 0.5 seconds. The dump circuit can be operated by the dump control S5 or by any of the door interlocks, as well as any event such as mains failure or inadvertent interruption of the mains supply.

In the event of the dump resistor becoming open-circuit there are two indications that the capacitors are still charged. The meter will continue to show the capacitor voltage and the "sense volts" indicator lamp on the voltage sensing unit will stay alight. It is recommended that an earth rod of approved design be available for use in the event of such a fault occurring.

A neon discharge lamp is incorporated as a safety gap in the potential divider circuit which is monitored by the voltage sensing unit. In the event of an open circuit in the monitoring section of the divider, the maximum potential which will appear across the indicating meter or the voltage sensing unit is the striking potential of the lamp i.e. ~180 volts.

The capacitor link board (L - Fig.2) is designed so that the terminals of capacitors not in use can be shorted together as a further safeguard.

## GENERAL OPERATION AND CYCLING MODES

With the switch S2 set to MANUAL, the charging cycle is initiated using the START control. A manual trigger pulse is required to discharge the capacitors, and the START control must be used to recommence operation.

If switch S2 is set to AUTO, the automatic cycling modes are obtained. Depending on the trigger system, the mode may be either "automatic" or "delayed-automatic". The automatic system takes a trigger from the charging switch as it opens when the preset voltage is reached and uses this to trigger the discharge cycle. When the capacitor voltage, as seen by the voltage sensing unit, drops below a predetermined level (usually 200 volts), this unit recommences the charging cycle. This mode of operation gives the highest repetition rate.

If recording apparatus is in use, and separate trigger pulses are needed to prime it before the current pulse, then the "delayed automatic" mode is the more useful. In this mode the START control S3 initiates the charging cycle, and at the same time the trigger unit starts cycling. By adjusting the interval between trigger pulses to be greater than the time required to charge the capacitors to the preset voltage, there will be an interval between the end of the charging cycle and the discharge trigger pulse. The pulse from the charging switch can then be used to open shutters etc.

The three charging rates available have a large overlap. The charging rate is approximately linear from 0 - 5 kV, with switch S1 set to LOW; 0 - 7 kV, MED. and 0 - 10 kv, HIGH. For voltages less than 2 kV the LOW charging rate must be used as the other rates are too fast to allow the voltage sensing unit to operate correctly.

All sequences are interrupted by the STOP control S4, and the dump control, S5, allows the capacitors to be earthed if required.

The capacity in use is simply varied by means of the link-board L and can be altered to suit the load and obtain the desired risetime. The voltage is preset using a potentiometer on the voltage sensing unit.

## CALIBRATION AND PERFORMANCE TESTS

The simplest way to calibrate and monitor the current output, is to use a resistor in series with the load, and measure the potential developed across it. This method, although the most direct, has several disadvantages. The resistance will increase as the risetime of the current pulse decreases, due to the skin effect, and for risetime less than a microsecond this method is subject to large corrections. As the original aim was to use this unit to provide current pulses with risetimes greater than 10 μsec, this was not a serious limitation. For faster pulses an alternative would be to use a high frequency Rogowski coil with a suitable integrator. The more serious limitation of inductive effects however, does mean that the resistor must be carefully designed. Following a suggestion of Mr B.A. Ward of this laboratory a co-axial low-inductance design has been used in which the current flows down a copper conductor and returns along a co-axial outer conductor of stainless steel. This design was also developed independently by Milne, Srivastava and Wilson[(1)]. The potential developed across the outer stainless steel conductor is measured, thus eliminating any inductive effects in the leads. The value of this resistor was adjusted by the A.E.R.E. electrical standards laboratory, to be 0.010 (± 0.25%) ohms. This serves as a primary calibration for the unit as well as a useful means of calibrating Rogowski coils.

The unit was originally required for working into three coil systems which were effectively inductive loads of 16 μH, 250 μH and 33 mH respectively. The performance tests and calibration have been made with these loads. As they cover a considerable range, however, this was felt to be adequate, and representative of probable conditions of use.

The performance tests are summarised in Tables 1 and 2 which show the variation of

(a) output current against capacitor voltage (Table 1) and

(b) pulse risetime and current against capacity used (Table 2)

TABLE 1

VARIATION OF OUTPUT CURRENT WITH CAPACITOR VOLTAGE FOR THREE LOADS

| Capacitor volts (kV) | External load | Current pulse (amps) |
|---|---|---|
| 1 | 16 μH | 315 |
| 5 | | 1350 |
| 10 | | 2740 |
| 1 | 250 μH | 75 |
| 5 | | 350 |
| 10 | | 690 |
| 1 | 33 mH | 7 |
| 5 | | 31 |
| 10 | | 64 |

Capacity used 1 μF.

TABLE 2

VARIATION OF OUTPUT PULSE RISETIME AND CURRENT WITH CAPACITY USED, FOR THREE LOADS

| Capacity ($\mu$F) | External load | Current pulse amplitude (amperes) | Current pulse risetime ($\mu$sec) |
|---|---|---|---|
| 0.5 | 16 $\mu$H | 2100 | 4.3 |
| 1 | | 3020 | 5.8 |
| 2 | | 4050 | 9 |
| 3 | | 4980 | 11 |
| 4 | | 5700 | 12 |
| 5 | | 6200 | 13 |
| 0.5 | 250 $\mu$H | 520 | 19 |
| 1 | | 720 | 26 |
| 2 | | 950 | 34 |
| 3 | | 1170 | 43 |
| 4 | | 1260 | 47 |
| 5 | | 1380 | 52 |
| 0.5 | 33 mH | 44 | 190 |
| 1 | | 70 | 270 |
| 2 | | 90 | 390 |
| 3 | | 105 | 470 |
| 4 | | 120 | 520 |
| 5 | | 135 | 580 |

Capacitor voltage 10 kV

The output waveform is a damped sine-wave. At high capacitor voltages the current pulse will consist of several half-cycles but at the lower voltages may be limited to the first half-cycle only. The conditioning of the ignitron will have some effect but generally the voltage at which ringing commences is 2 - 3 kV. Fig.6 is an oscillogram of the current monitor resistor output for a typical pulse. The main factor restricting the risetime will be the stray inductance in the unit itself which will limit the risetime to ~1 $\mu$sec with 0.5 $\mu$F capacitor. However if the stray inductance or the capacitance is much reduced the risetime will be correspondingly smaller. With slight modifications, the prototype unit has been operated with an output pulse risetime of ~0.4 $\mu$sec. At this level however the formative time of the ignitron (~0.1 - 0.3 $\mu$sec) becomes comparable with the output pulse risetime and the jitter in triggering becomes a serious problem.

## SUMMARY

A general purpose current pulse supply unit is described suitable for small-scale experiments. The performance of the unit is summarised and the limitations discussed.


## REFERENCES


1. MILNE, J.D., SRIVASTAVA, K.D. and WILSON, M.N. A low inductance shunt for measuring heavy current pulses. Nucl. Instrum. Meth., vol.29, no.2, October, 1964, pp.356.

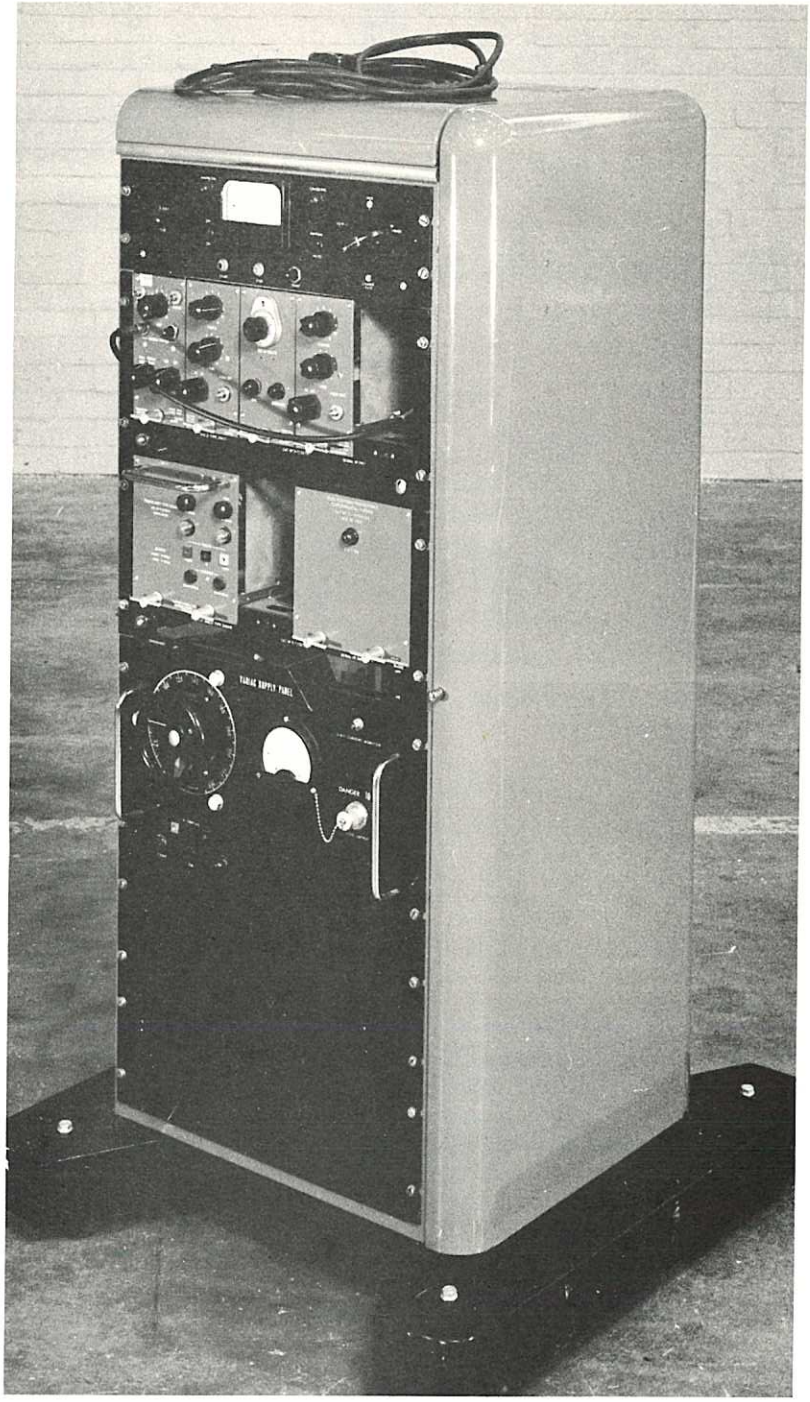
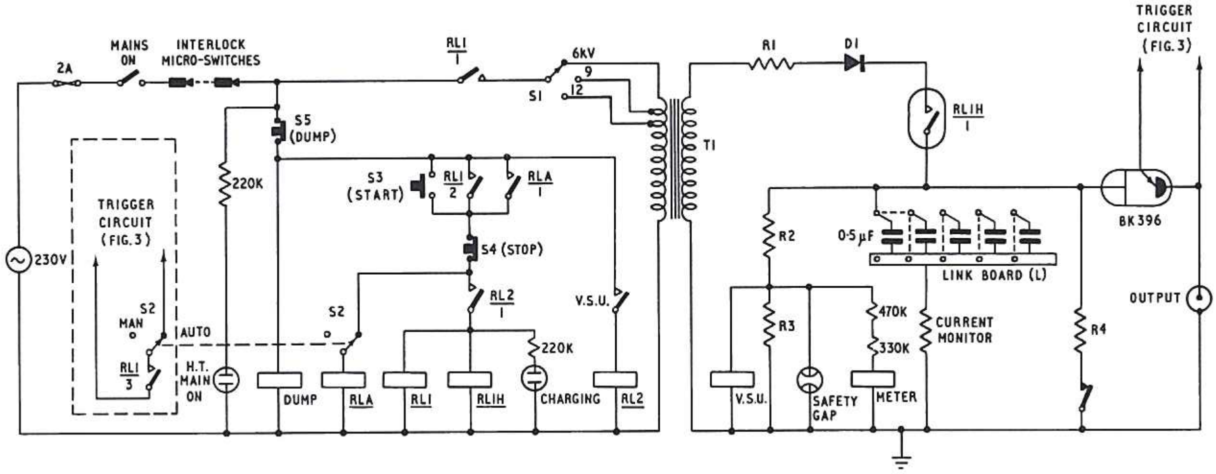


Fig.1 General view of the prototype unit. (CLM-M58)




COMPONENTS

| | | AERE Catalogue number |
|---|---|---|
| D1 | 5 x T36EHT80 rectifiers in series | 3-7/6761 |
| R1 | 10 x 10MΩ Dubilier (MVP) in parallel | 3-7/20330 |
| R2 | 1 x 100MΩ Welwyn type F44F | 36/60017 |
| R3 | 1 x 5MΩ Welwyn type F44F | 36/60013 |
| R4 | 1 x 24kΩ , 100W, W/W, type RWV1-P | 3-7/19728 |
| Capacitors----all 0.5μF, 10kV | | 3-7/31261 |
| RL1, RL2, RLA-----Thorn plug-in relay | | 3-3/0577 |
| RL1H------Ferranti vacuum relay, type 30U5CM | | |

| | | AERE Catalogue number |
|---|---|---|
| Meter | 0-50μA, DC moving coil | 3-6/0482 |
| Safety gap-----neon lamp (180V striking) | | 3-2/0892 |
| Dump solenoid-------Westool 400/3/2/230/250 | | 6-4/1165 |
| V.S.U. | | Type 1737A |
| T1-----------AERE type RC 142 | | |

Fig.2 Circuit diagram. (CLM-M58)

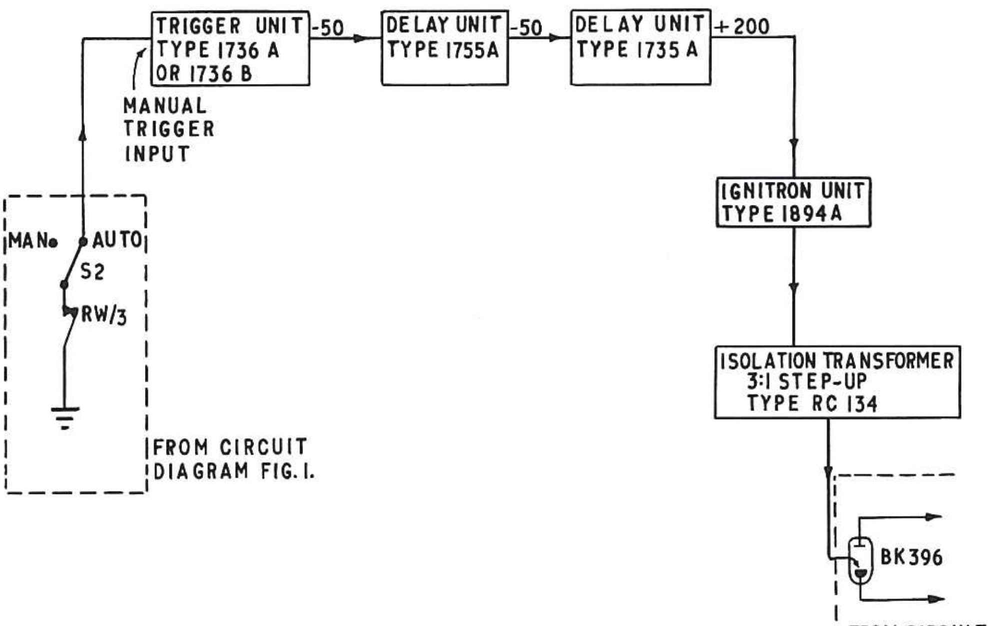



Fig.3 Trigger circuit block diagram. (CLM-M58)

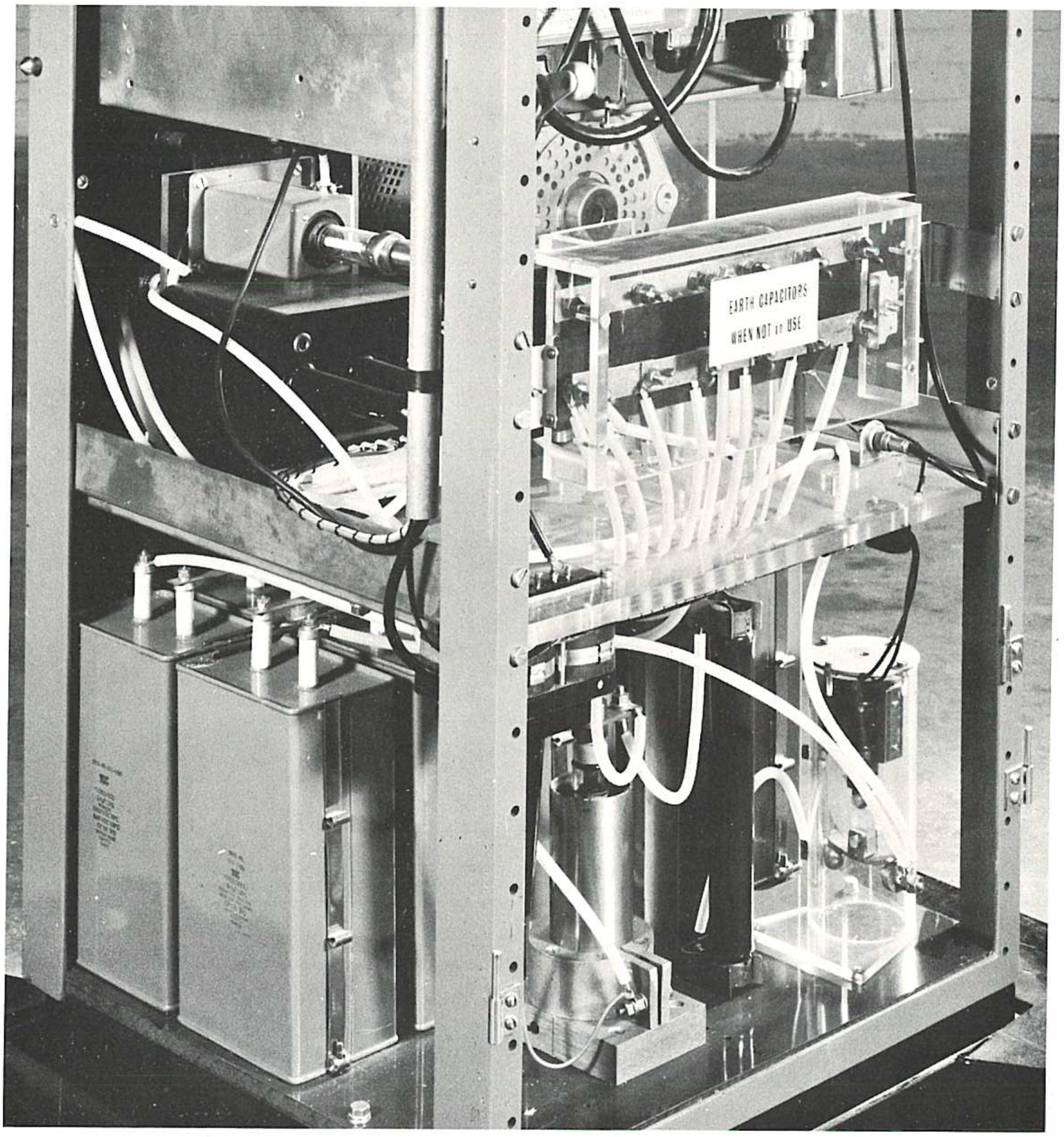



Fig.4 Detailed view of high voltage circuits. (CLM-M58)

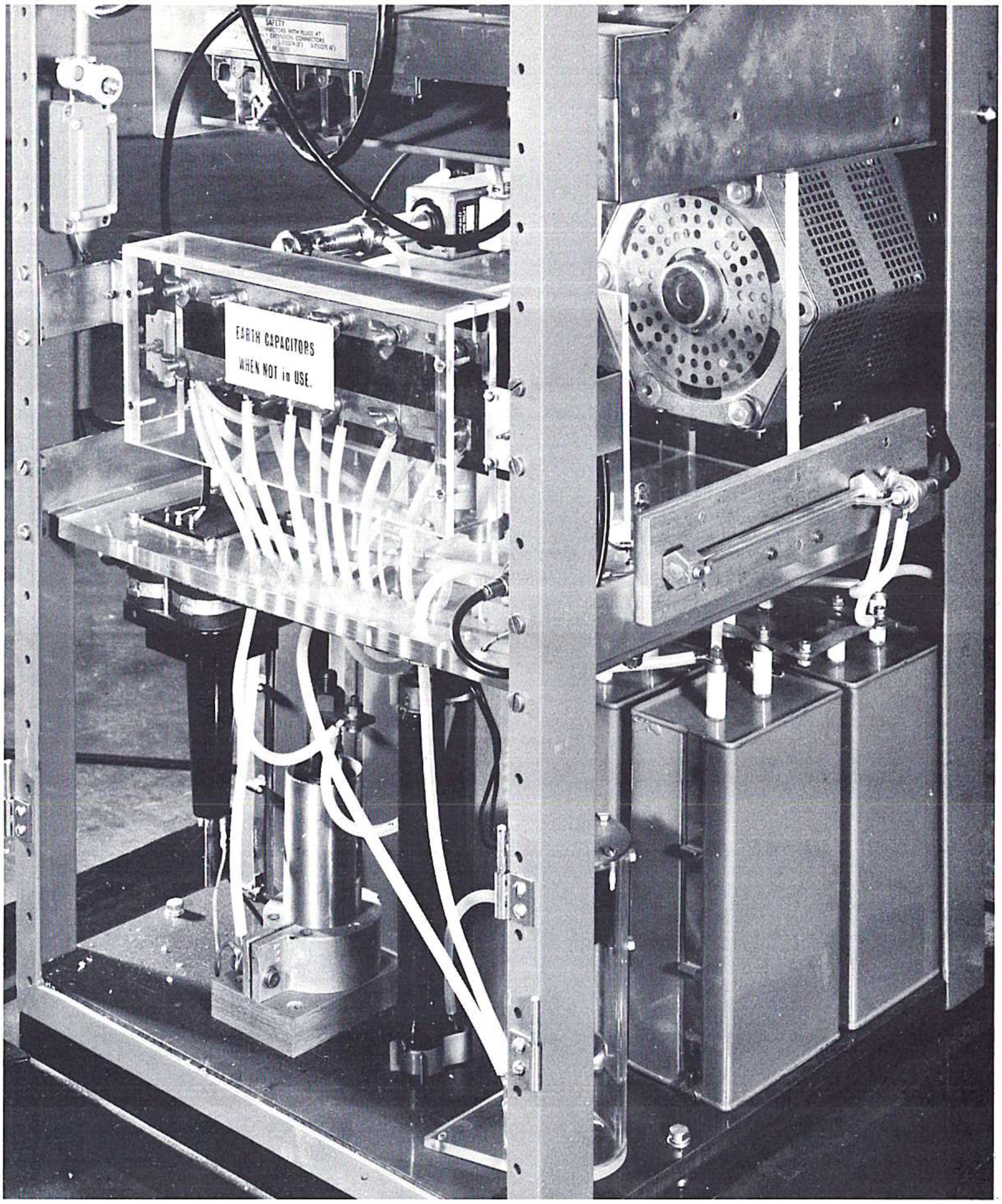



Fig.5 Detailed view of high voltage circuits. (CLM-M58)

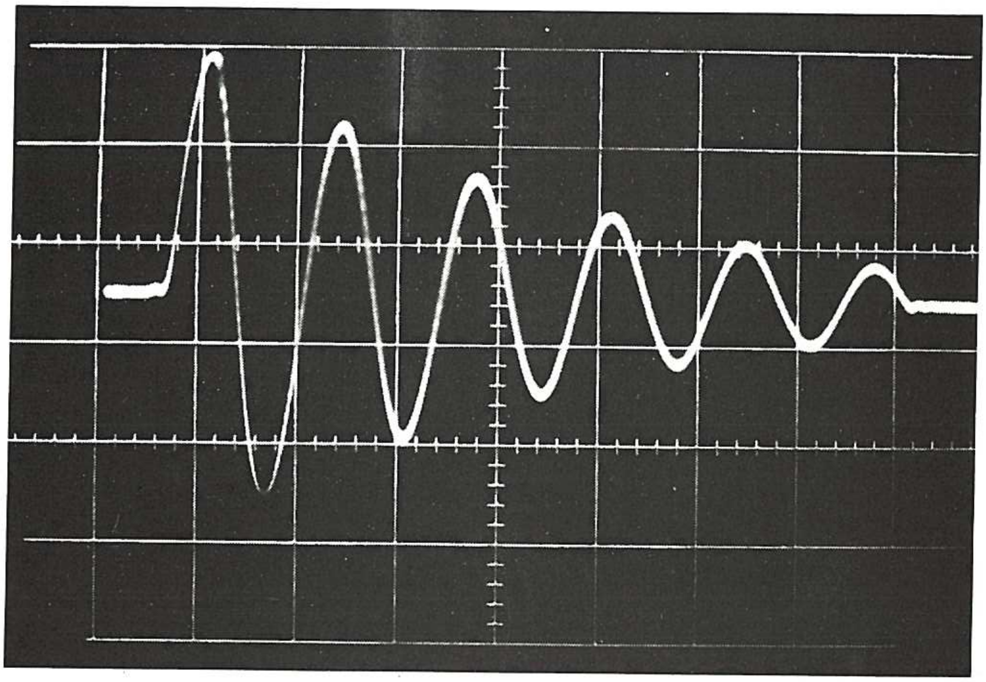


Fig.6　Oscillogram of output waveform.　(CLM-M58)