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Aerodynamics Technical Memorandum 315

A PULSED POWER SUPPLY FOR HYDROGEN BUBBLE FLOW VISUALISATION

By

C.W. SUTTON and R.J. ANDERSON

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A PULSED POWER SUPPLY FOR HYDROGEN BUBBLE FLOW VISUALISATION

By

C.W. SUTTON [redacted] R.J. ANDERSON

SUMMARY

This paper describes a pulsed power supply with a continuously adjustable pulse amplitude range of 10 to 200 volts and a load current capability range 0.1 to 2 amperes. Both the pulse width and the pulse rate are independently adjustable over the ranges 1 to 150 milliseconds and 1 to 100 pulses per second respectively. A solid state D.C. relay, controlled by an integrated circuit timer, is used to switch the load current.

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16. ABSTRACT:

This paper describes a pulsed power supply with a continuously adjustable pulse amplitude range of 10 to 200 volts and a load current capability range 0.1 to 2 amperes. A solid state D.C. relay, controlled by an integrated circuit timer, is used to switch the load current.

CONTENTS

1. INTRODUCTION

This paper describes a pulsed power supply, which incorporates a solid state D.C. relay, to facilitate the generation of hydrogen bubbles for flow visualization in a water tunnel.

In practice, it is usual to apply a D.C. voltage with the positive connected to an earthed plate (anode) and the negative connected to a metal probe (cathode). For a given current this configuration produces a volume of gas bubbles (hydrogen) at the probe twice that generated at the anode (oxygen).

Ideally, the bubbles of hydrogen gas are released in a fine stream at the strategically placed cathodic probe and move through the water under the influence of encountered flow patterns. However, instead of a continuous stream of bubbles it is often desirable to control the rate of release of bubbles for comparison of flow path lengths or to obtain a clearer visualization of the flow pattern. Moreover, for a given rate of bubble generation, the risk of fusing a delicate probe is much less with pulse operation, than with continuous operation.

2. CIRCUIT DESCRIPTION

2.1 General

Various techniques for producing a pulsed power supply for hydrogen bubble flow visualization have appeared in the literature, for example Reference #1. Such techniques range from the use of magnetic or reed switch relays, which are unsuited for prolonged usage or fast switching of high voltages or large currents, through to solid state devices such as the transistor and thyristor.

Transistors are easily operated as switching devices but it becomes difficult to remain within the various ratings of the transistor as the operating voltages increase.

Thyristors are readily available with adequate voltage and current ratings for hydrogen bubble pulsed power supply applications. Unfortunately, the thyristor is difficult to turn off in a D.C. circuit, especially over a broad operating envelope of load voltages and currents.

However, a relatively new device referred to as a high voltage solid state D.C. relay has proven very convenient for medium speed, repetitive D.C. switching of resistive loads throughout the desired operating envelope of 10 to 200 volts, 0.1 to 2 amperes.

#1
BURLEY R. and GRIGG P.L. "A Solid State Pulser For Hydrogen Bubble (Flow Visualization) Technique." Scientific Instruments 1970, VOL 3.

2.2 Solid State D.C. Relay

There are a variety of solid state relays commercially available such as the gated-off SCR devices, but that actually used is a Teledyne High Voltage Solid State D.C. Relay Series 603-3. This is a four terminal device which is analogous to the conventional single-pole, single-throw, normally-off relay.

The Series 603-3 device is rated for 250 volt, 5 ampere resistive load switching with an input turn-on control voltage of between 4 and 10 volts D.C. and a turn-off control voltage less than 0.4 volts D.C.

An inbuilt pulse transformer provides isolation between the input control and the output load circuit. Rise, fall and turn-on times are typically less than 25 microseconds with the turn-off delay being typically 100 microseconds.

2.3 Pulse Generation

2.3.1 Controls

The pulse requirements initially specified were:

<u>Pulse duration</u>
Adjustable over the range 1 to 100 milliseconds.

<u>Pulse repetition frequency</u>
Adjustable over the range 1 to 50 Hertz.

However, these requirements can lead to erratic operation and user inconvenience if the pulse duration (width) becomes comparable or longer than the pulse period, which is the reciprocal of the pulse repetion frequency.

The potential inconvenience is avoided by providing two variable controls in the pulse generation circuit which individually adjust the pulse on-time (t1) and the pulse off-time (t2). This ensures that there is a practical combination for all settings of the pulse controls.

The pulse range is:

<u>Pulse on-time</u>
Adjustable over the range 1 to 150 milliseconds.

<u>Pulse off-time</u>
Adjustable over the range 10 to 1000 milliseconds.

2.4 Pulse Circuit

An integrated circuit precision timer was chosen for the pulse generator and although only a single timer of the Type 555 was required the actual pulse generator is half of a more readily available Type 556 dual timer. As the integrated circuit timer is capable of directly driving the control circuit of the solid state relay the pulse circuit is simpler than if a discrete component transistor multivibrator was used.

Voltage comparators, within the integrated circuit timer package sense the voltage across the timing capacitor C8 (Fig. 1) and produce an output level change whenever the charge-discharge cycle causes the voltage across C8 to reach predetermined limits.

Consider Vcc as the voltage applied across the integrated circuit timer; when the upper limit of approximately 0.6Vcc is reached, as C8 charges through D2, RV1,& R7 the internal voltage comparator causes C8 to discharge through R5 & RV2 and an internal discharge transistor until the lower limit of approximately 0.3Vcc is reached. When this occurs the voltage comparator disables the discharge transistor and the output voltage level (Pin 1) is immediately switched to almost Vcc. Diode D2 becomes forward biased and allows C8 to recharge.

In conventional timer circuits the timing capacitor usually charges through a timing resistor connected directly to the Vcc. Such an arrangement would, in this application, produce an interaction between the two pulse controls. This interaction is avoided by including diode D2 in the charging circuit which connects to the output of the timer instead of directly to Vcc.

During discharge of C8 the output voltage of the timer is approximately at ground potential which results in D2 being reverse biased, since the sawtooth voltage waveform across C8 is maintained between the limits of +0.3Vcc and +0.6Vcc, thus creating independent charge and discharge paths. Interaction between the two pulse controls RV1 and RV2 is therefore negligible.

Timing accuracy, compared with the conventional timer circuit,is degraded during the charging period because of small variations in amplitude of the output voltage and the nonlinearity with current of the diode (D2) forward resistance. The effect on repeatability of pulse timing and linear calibration of the pulse controls is negligible for the component values used. Calibration curves for both controls are shown in Fig. 2.

2.4.1 Turn-on control

The turn-on control RV1 is in the charging circuit and controls the time t1 for the voltage level across C8 to increase from 0.3Vcc to 0.6Vcc. This corresponds to the time that the output voltage of the timer is near Vcc. From Reference #2.

#2
SIGNETICS Digital,Linear, MOS, Applications Book.

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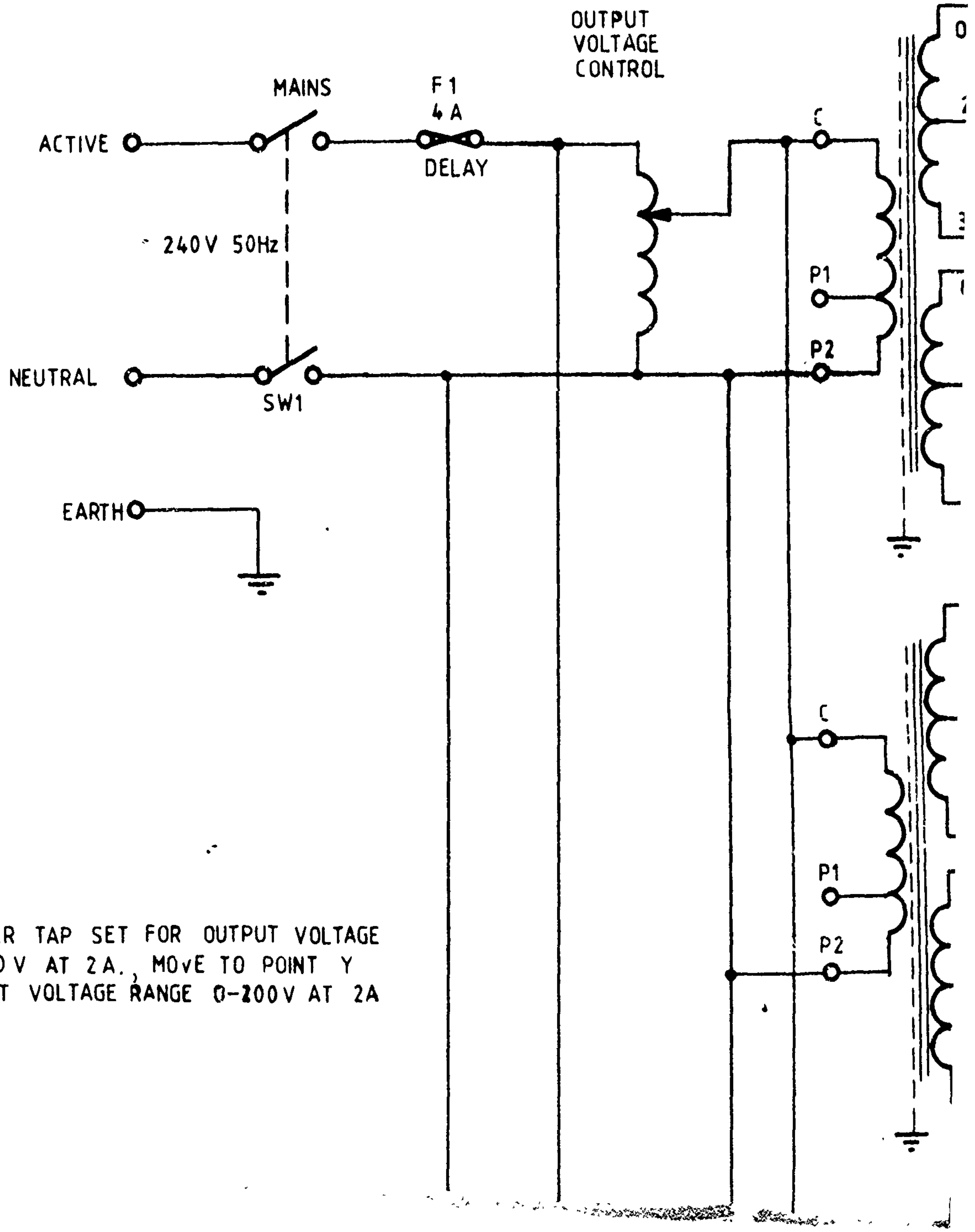
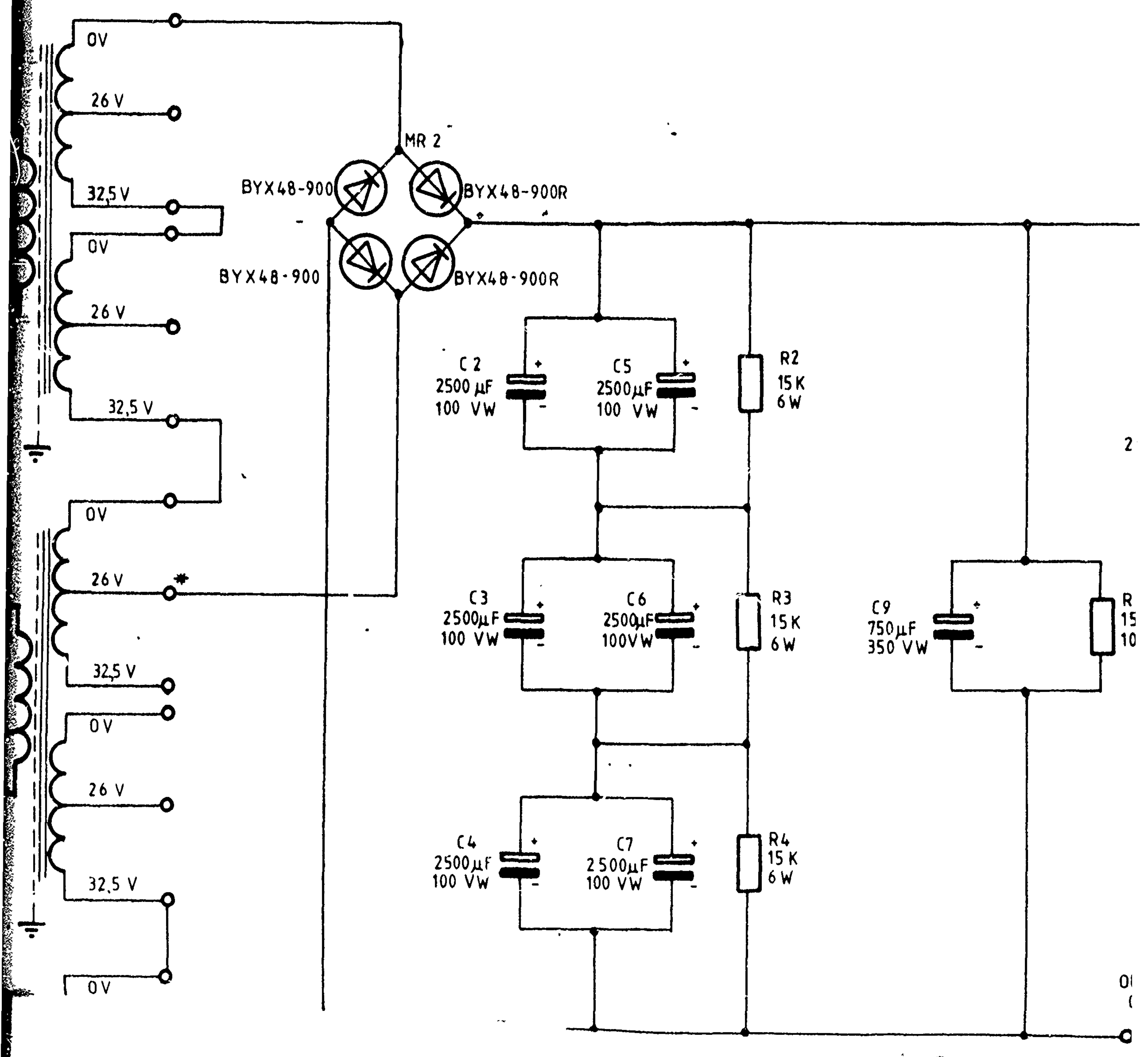


✱ TRANSFORMER TAP SET FOR OUTPUT VOLTAGE RANGE 0-110 V AT 2 A., MOVE TO POINT Y FOR OUTPUT VOLTAGE RANGE 0-200 V AT 2A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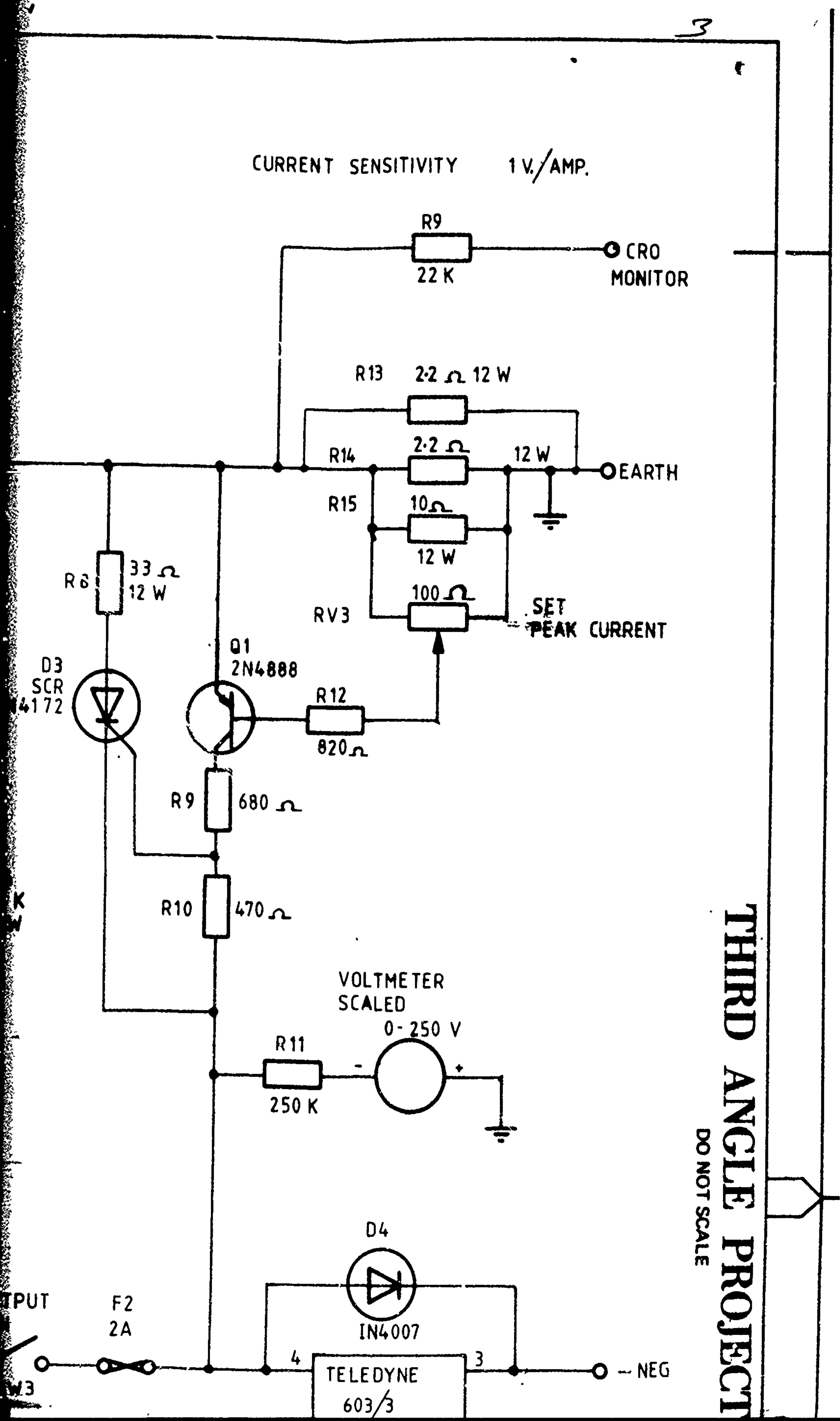
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EARTH
R15 10 Ω 12 W
RV3 100 Ω
SET
PEAK CURRENT
R8 33 Ω 12 W
D3
SCR
Q1
2N4888
R12
820 Ω
R9 680 Ω
R10 470 Ω
VOLTMETER
SCALED
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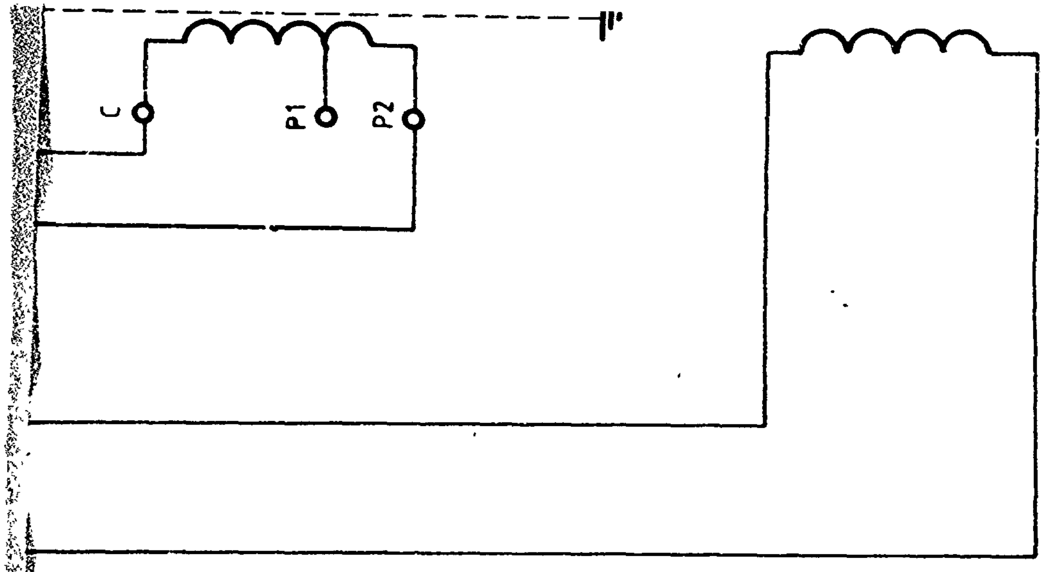

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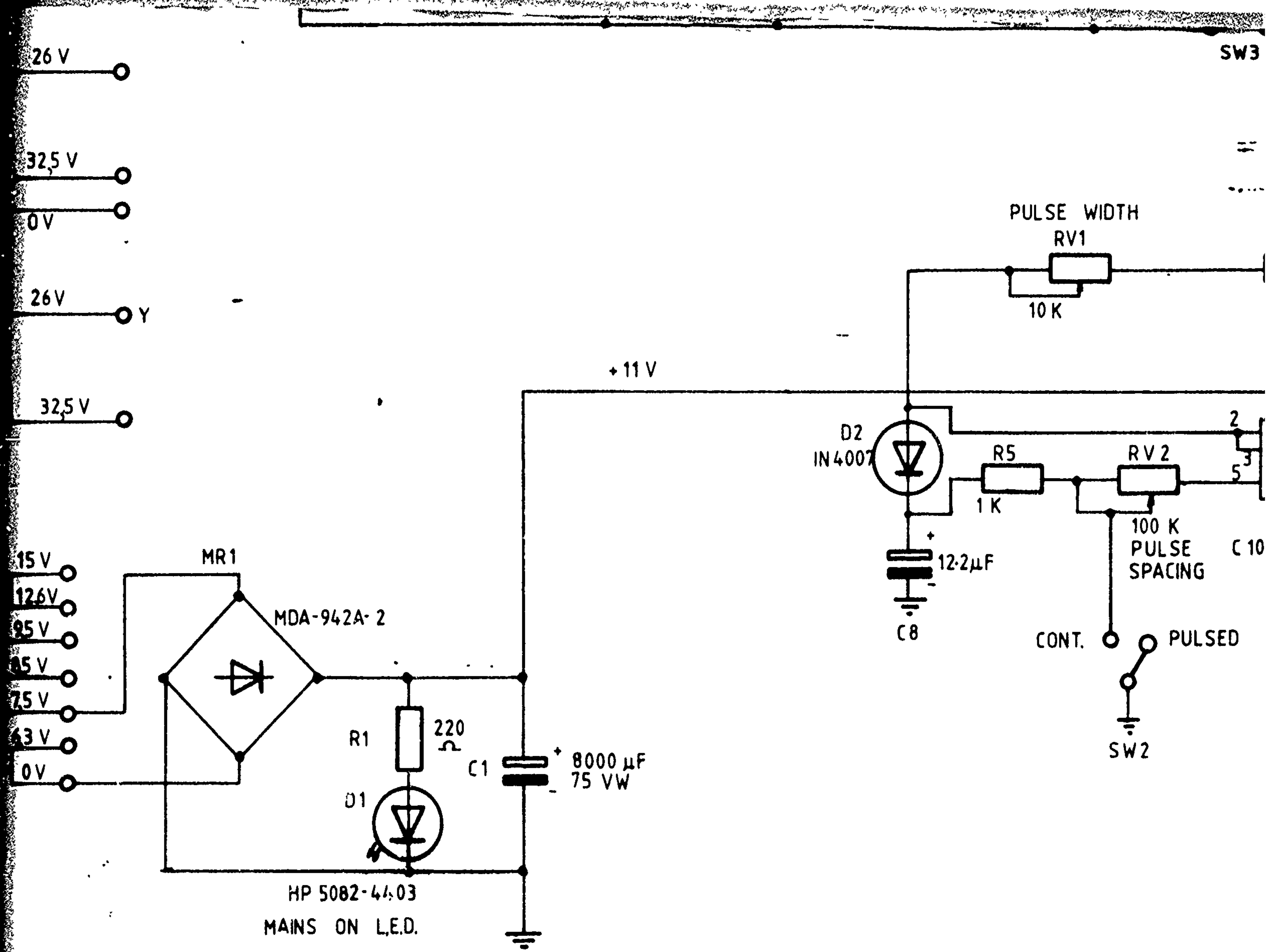
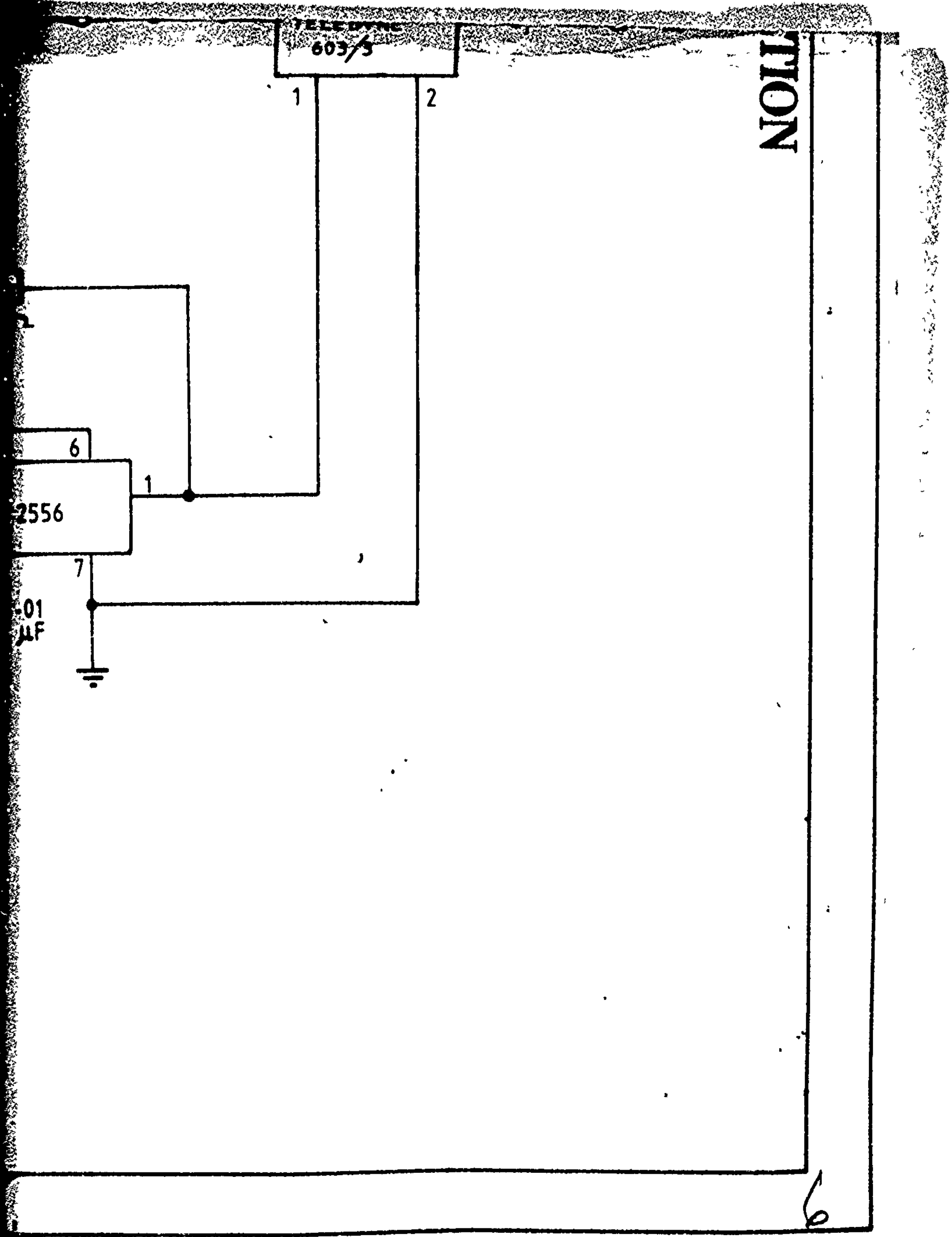


FIG. 1 PULSED POWER SUPPLY



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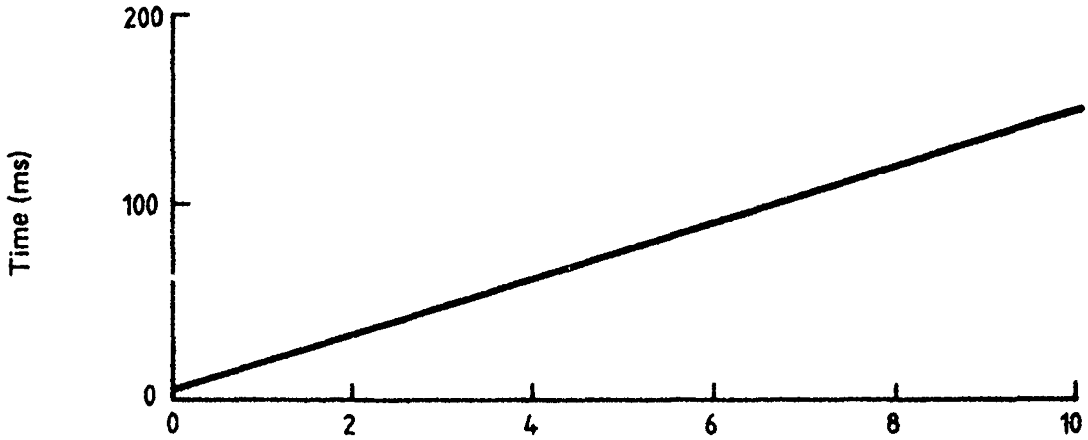

FIG. 2a PULSE WIDTH CONTROL RV1 –(TURNS CLOCKWISE)

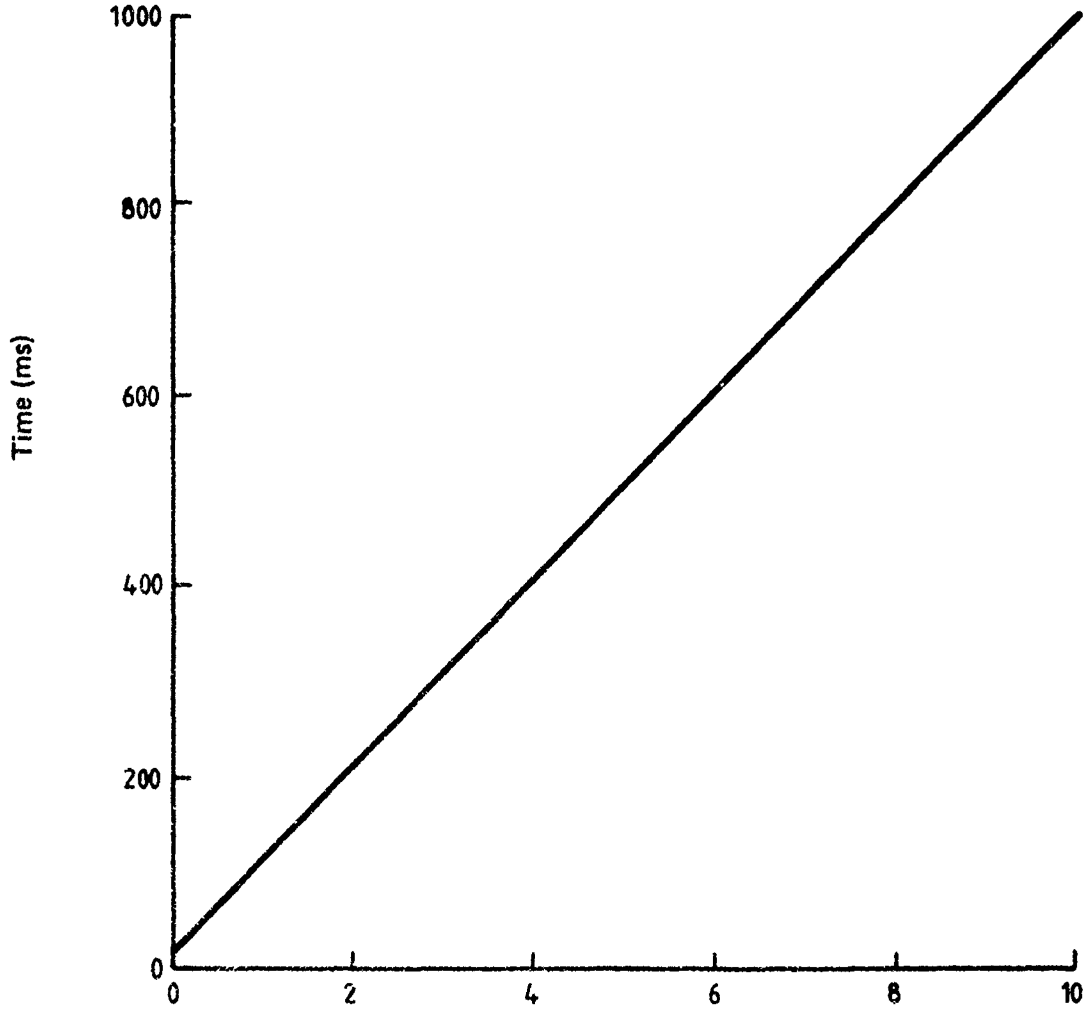

FIG. 2b PULSE SPACING CONTROL RV2 –(TURNS CLOCKWISE)

$$t1 \approx 0.7C8(RV1 + R7 + r)$$

Where r represents the effective diode forward resistance.

The near linear relationship between t1 and RV1 is shown in Fig. 2a.

2.4.2 Turn-off control

The turn-off control RV2 is in the discharge circuit and controls the time t2 for the voltage level across C8 to decrease from 0.6Vcc to 0.3Vcc. This corresponds to the time that the output voltage of the timer is less than + 0.4 volts. Again from Reference 2.

$$t2 \approx 0.7C8.RV2$$

The relationship of t2 to RV2 is graphed in Fig. 2b.

2.5 Continuous operation

A switch SW2 (Fig. 1) is provided to inhibit the pulse generator such that the solid state relay is in the turned on condition. This is achieved by preventing the timing capacitor C8 from charging to the upper limit of 0.6Vcc.

2.6 Voltage Supply

A conventional bridge rectifier and filter capacitor power supply circuit, connected to the secondary winding of a mains power transformer, provides a D.C. voltage to the solid state relay. The D.C. voltage is continuously adjustable, for control of the output pulse amplitude between -10 and -200 volts, with a variable autotransformer connected to the primary of the power transformer.

Unfortunately the requirement for 200 volts with load currents to 2 amperes created difficulties with filtering of the 100 Hertz mains ripple. Generally, capacitors with large capacitance have a low voltage rating. Hence the compromise between using single capacitors, with adequate voltage rating but low capacitance, and series connection of several capacitors of large capacitance but with inadequate voltage rating. The inherent ripple is apparent in Table 1.

OUTPUT Volts	OUTPUT Current(A)	RIPPLE (mV P-P)
20	1.0	90
20	1.7	230
50	3.0	230
100	1.0	30
100	1.9	80
200	0.9	20
190	2.0	60

TABLE 1. MEASURED RIPPLE AT CRO MONITOR POINT.

The filter capacitors charge above the average supply voltage during the pulse-off time. This unfortunately results in an initial peak current discharge at the start of each pulse. However, in practice the repeatability of bubble generation has been acceptable. An active filter is an alternative approach to reducing the ripple but is unattractive because of the rating needs of the associated power transistor.

The +11 volt supply for the pulse generator circuit is derived from the secondary of a separate transformer which is energised from the mains supply without being connected through the variable autotransformer.

2.7 Short Circuit Protection

A "crowbar switch" circuit (Fig.1) consisting of a silicon controlled rectifier (D3) and transistor (Q1) protects the solid state D.C. relay from peak current overload, particularly when pulse operation is in use and fuse protection alone is unsatisfactory. Typically fuses wont blow even when carrying currents in excess of 10 times the rated value, provided the overload is less than a few milliseconds duration, although fatigue from repeated surges may eventually cause the fuse to blow. Hence under short circuit conditions, combined with a short on-time, the solid state D.C. relay could be subjected to excessive peak currents.

To protect against this condition the voltage drop across RV3 (Fig.1), produced by the load current, is continually monitored by Q1. Should this voltage exceed a pre-determined value set by RV3, the SCR conducts to produce a momentary short circuit across the power supply to blow fuse F2.

The circuit was set to trip at a peak load current of 3.5 amperes. The completed unit is shown in Fig.3.

3. OPERATING INSTRUCTIONS

CAUTION

THE LOW OUTPUT IMPEDANCE AND VOLTAGE RANGE OF THE PULSE POWER SUPPLY RENDERS IT CAPABLE OF DELIVERING A LETHAL SHOCK.

(1) Securely mount the pulsed power supply where it is unable to come in contact with water even under accidental circumstances.

(2) Ensure that the mains lead from the unit properly mates with a correctly wired and earthed mains power outlet which preferably is on a core balanced relay protection circuit.

A core balanced relay will trip the mains supply off whenever a mismatch of typically 20 milliamperes or greater is detected between the active and neutral currents thus providing protection against prolonged mains current flow to ground. However, faults and unintentional current flows at the output of the pulsed power supply will not normally trip a

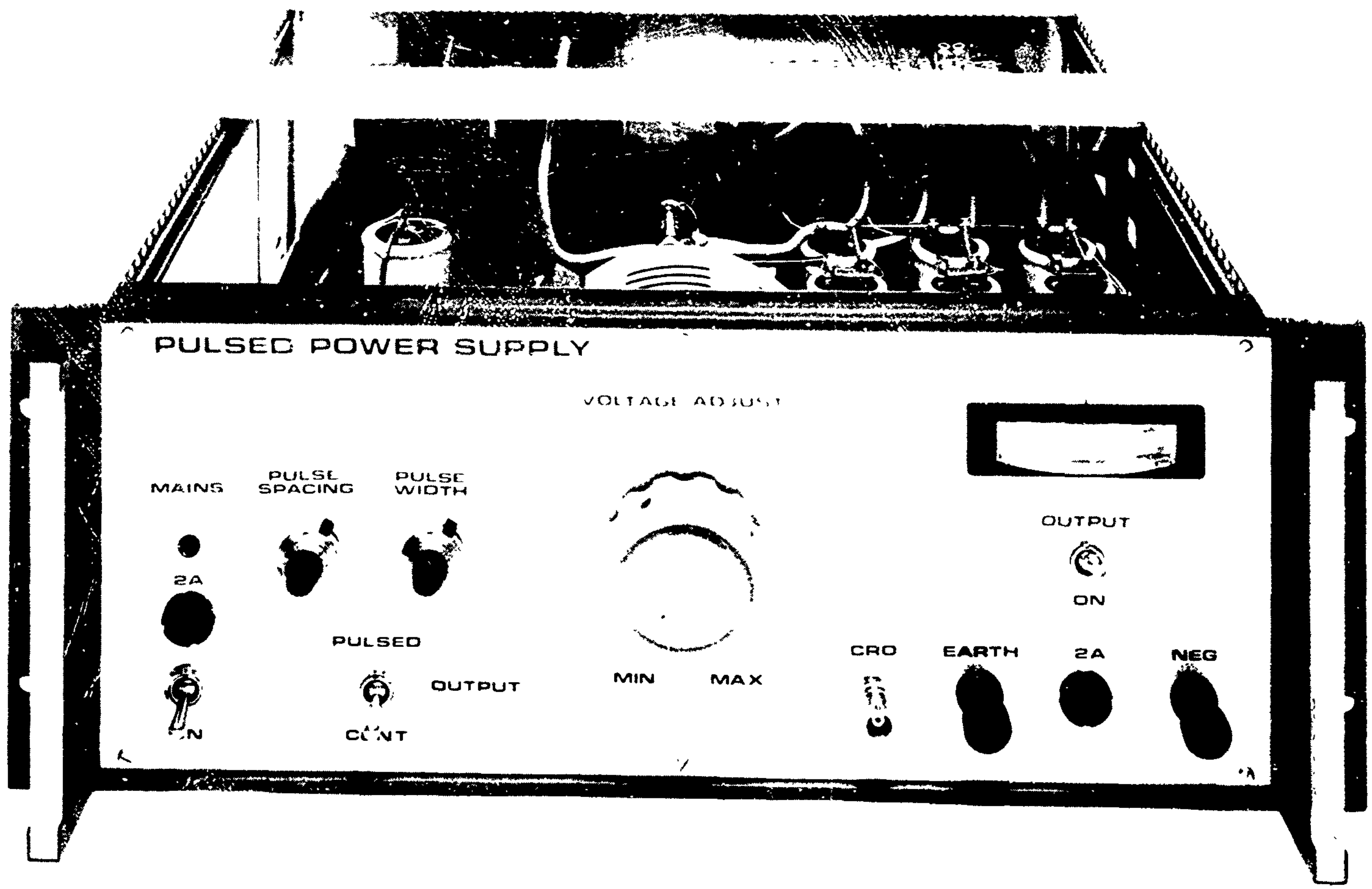

FIG. 3 COMPLETED UNIT

core balanced relay protection circuit.

(3) With the mains lead unplugged, securely connect the earthed positive output terminal of the pulsed power supply to the desired anode electrode and the negative output terminal through proper insulated fittings to the cathode probe.

(4) Ensure that:

(a) The output voltage control is fully anticlockwise.
(b) The mains switch is off.
(c) The output switch is off.

(5) Position the probe BEFORE connecting the mains cable to the power outlet and powering the pulsed power supply unit.

(6) Select pulsed operation for initial switch-on.

If continuous operation is desired, wait a few seconds before selecting "CONT". If pulsed operation is required then set the desired pulse width (pulse-on) and pulse spacing (pulse-off) times using the multiturn potentiometers in conjunction with the chart in Fig. 2. If necessary connect a monitoring oscilloscope to the CRO monitor connector.

CRO MONITOR POINT; current sensitivity approximately 1 volt/ampere

PULSE WIDTH CONTROL; sensitivity approximately 15 milliseconds/turn.

PULSE SPACING CONTROL; sensitivity approximately 100 milliseconds/turn.

(7) Switch mains on, then switch output on.

(8) Advance the output voltage control clockwise and monitor the pulse amplitude with the inbuilt voltmeter and/or an oscilloscope.

(9) Readjust pulse width, pulse spacing, output voltage control and use the output switch as appropriate.

<u>IMPORTANT</u>

(1) Avoid contact with the output of the pulsed power supply while the supply is switched on and for at least 1 minute after switching off.

(2) Ensure that replacement fuses for F2 (Fig.1) are Belling Lee type L1055 rated at 2 amperes.

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