educational electronic experiments

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Educational
Electronic Experiments

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INTRODUCTION

The twenty experiments described in this book were originally issued to teachers as a series of leaflets. The experiments are intended as constructional projects. In most cases the end product is a useful piece of apparatus.

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a double beam simulator

Introduction

In the past we have received many requests for details of a circuit which can produce two independent traces on the screen of a conventional cathode ray oscilloscope. The applications of such a circuit are many – the comparison of current and voltage waveforms, the phase relationship of an amplifier's input and output and the lead and lag of applied a.c. to capacitance and inductance being the most obvious.

The circuit described in this publication is a simplification of the well-known double beam switch but has been finalised only after a considerable amount of experimentation, since any circuit for educational construction must be simple and cheap and yet, at the same time, work efficiently. In practice, of course, these requirements are usually diametrically opposite and the final result is a compromise.

Basic Principles

Basically all double beam switches follow a conventional pattern in that two separate amplifiers to which the two signals to be compared are fed are switched on and off alternately at high speed. On the screen, therefore, as a result of persistence of the phosphor material and also of the human eye, two distinct traces are seen.

Fig. 1 shows the block diagram of this beam splitting principle. The output of a square wave generator is fed to two amplifiers in such a way that when amplifier Y1 is operating, the amplifier Y2 is not operating and vice versa. The output of the two amplifiers is fed to the Y plates of the cathode ray tube either direct or via the internal amplifiers in the oscilloscope. In order that the two traces can be separated it is necessary to introduce some means of altering the standing anode current of one amplifier with respect to the other and this can be achieved by varying the bias between the two valves.

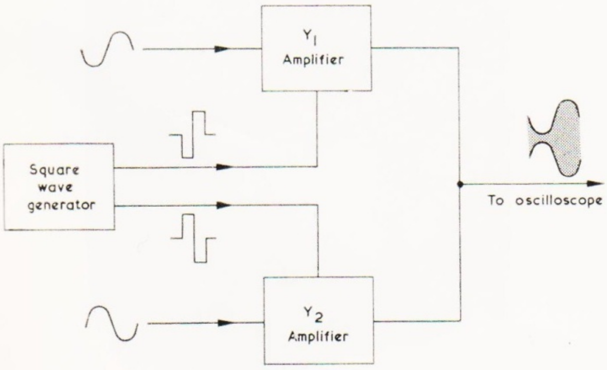


FIG. 1

Practical Circuit

Fig. 2 shows the practical circuit. V1 is the multivibrator valve producing two trains of antiphase square pulses which are fed to two identical Schmitt amplifiers V2 and V3.

Referring to the amplifier containing valve V2, when a negative square pulse arrives at the left-hand grid of V2, this half becomes non-conductive. The right-hand section of valve V2, however, is able to conduct and in the absence of any signal to its grid passes a standing anode current depending on the auto cathode bias resistors R8 and RV9.

When a positive pulse arrives at the left-hand grid of V2, however, this half passes a large current and a considerable voltage drop occurs across the common cathode resistors R8 and RV9. Thus the cathode becomes very positive with respect to the right-hand grid of V2 and this potential is sufficient to cut this half off. Valve V3 works in an identical way but in antiphase.

Adjustment of resistor RV9 varies the standing anode current of the right-hand sections of valves V2 and V3 during the conduction half cycles and thus acts as a trace separator. Potentiometers RV12 and RV13 act as grid leak resistors and can also be used to vary the magnitude of the input signals.

Referring to the square wave generator containing valve V1, RV3 is a preset potentiometer which is adjusted until the square wave output is symmetrical about its axis. The slider on the potentiometer should be approximately in the half-way position but for individual valves and components a little adjustment about this position may be found necessary.

The frequency of the generator can, of course, be varied by using different values of resistors and capacitor C1, but for the values of components given, the measured frequency of 2kHz was found suitable when examining waveforms in the frequency range 25–200Hz. For higher frequencies the square wave generator must be modified to supply a correspondingly higher square wave frequency.

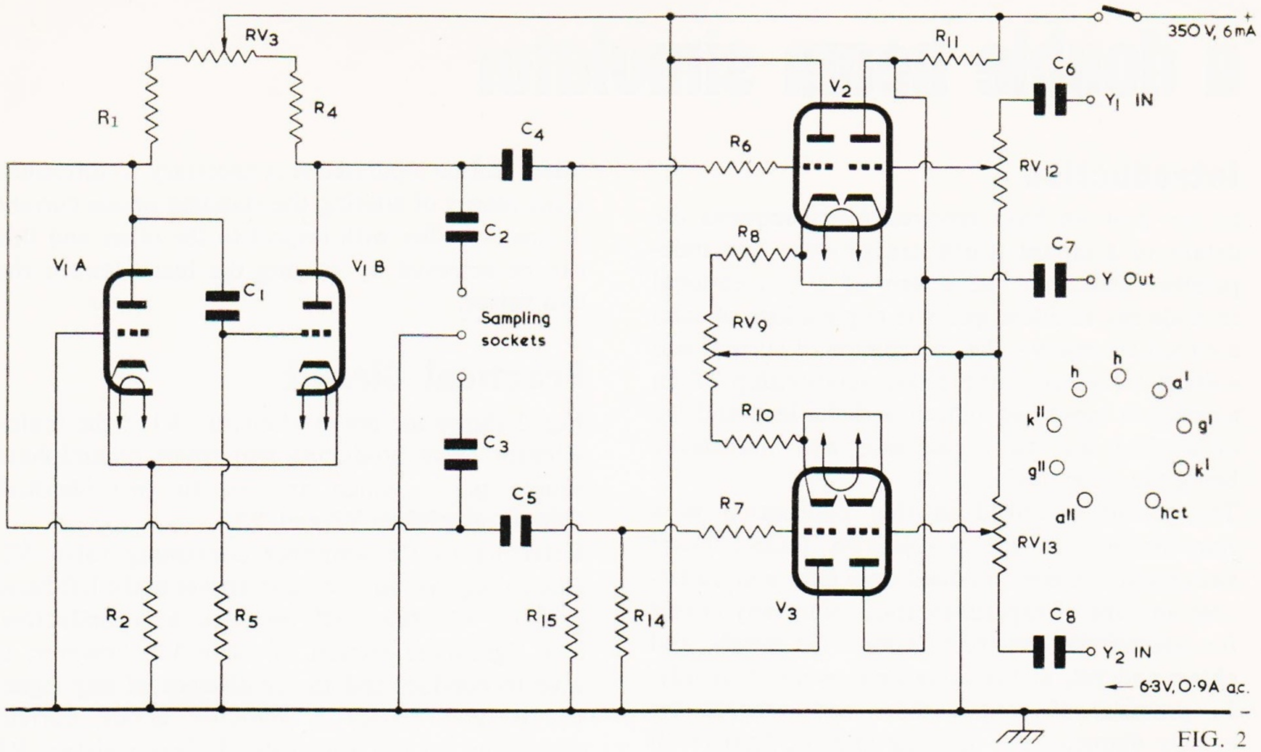


FIG. 2

Power Supplies

The double beam switch was tried out in conjunction with the Mullard Students' Oscilloscope and it was therefore decided to operate the unit from the oscilloscope power supplies, and with the given values of components, therefore, the following supplies are necessary:

h.t. 350V, 6mA d.c.
l.t. 6·3V, 0·9A a.c.

Construction

Figs. 3 and 4 show internal and external views of the prototype unit. No great difficulties were found in the final layout except that it is advisable to make the actual wiring as short as possible in order that the high frequency component of the square wave is not attenuated by stray capacitances in the layout. Since the unit may also be used as a source of square waves, sampling sockets can be fitted in the square wave generator circuit.

Component Values

R1	47kΩ ½W carbon resistor
R2	100kΩ ½W carbon resistor H.S.
RV3	100kΩ linear potentiometer W.W.
R4	47kΩ ½W carbon resistor
R5	470kΩ ½W carbon resistor
R6	470kΩ ¼W carbon resistor
R7	470kΩ ¼W carbon resistor

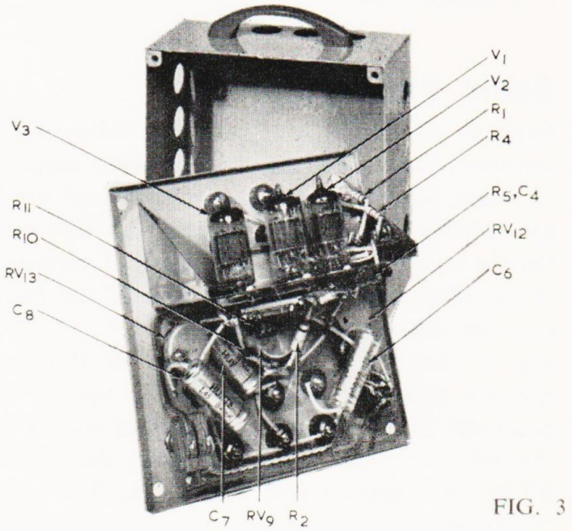


FIG. 3

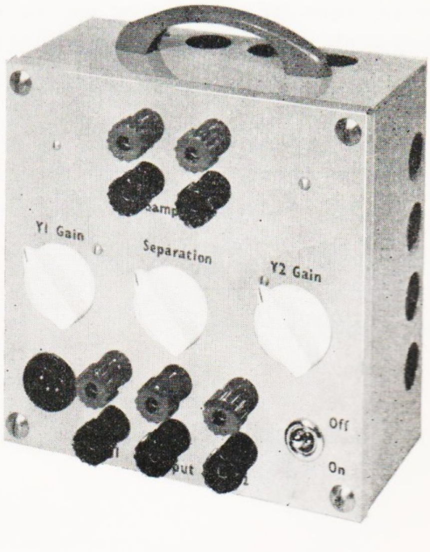


FIG. 4

R8	1·5kΩ $\frac{1}{2}$W carbon resistor H.S.
RV9	2kΩ linear potentiometer W.W.
R10	1·5kΩ $\frac{1}{2}$W carbon resistor H.S.
R11	220kΩ $\frac{1}{2}$W carbon resistor H.S.
RV12	500kΩ linear potentiometer
RV13	500kΩ linear potentiometer
R14	2MΩ $\frac{1}{4}$W carbon resistor
R15	2MΩ $\frac{1}{4}$W carbon resistor
C1	470pF silver mica H.S. 350V wkg.
C2	0·001μF 350V wkg.
C3	0·001μF 350V wkg.
C4	150pF silver mica H.S. 350V wkg.
C5	150pF silver mica H.S. 350V wkg.
C6	0·1μF 350V wkg.
C7	0·1μF 350V wkg.
C8	0·1μF 350V wkg.
V1	ECC82
V2	ECC83
V3	ECC83

H.S. denotes high stability
W.W. denotes wire wound

Applications

It is hoped that the double beam switch will be found useful in the examination of phase shift in inductors, capacitors and transformers. This technique can also be used to display simultaneously the voltage/time and current/time curves in capacitor charge and discharge.

Fig. 5 shows an experiment set up to show current lag in a capacitor fed from a 50Hz source.

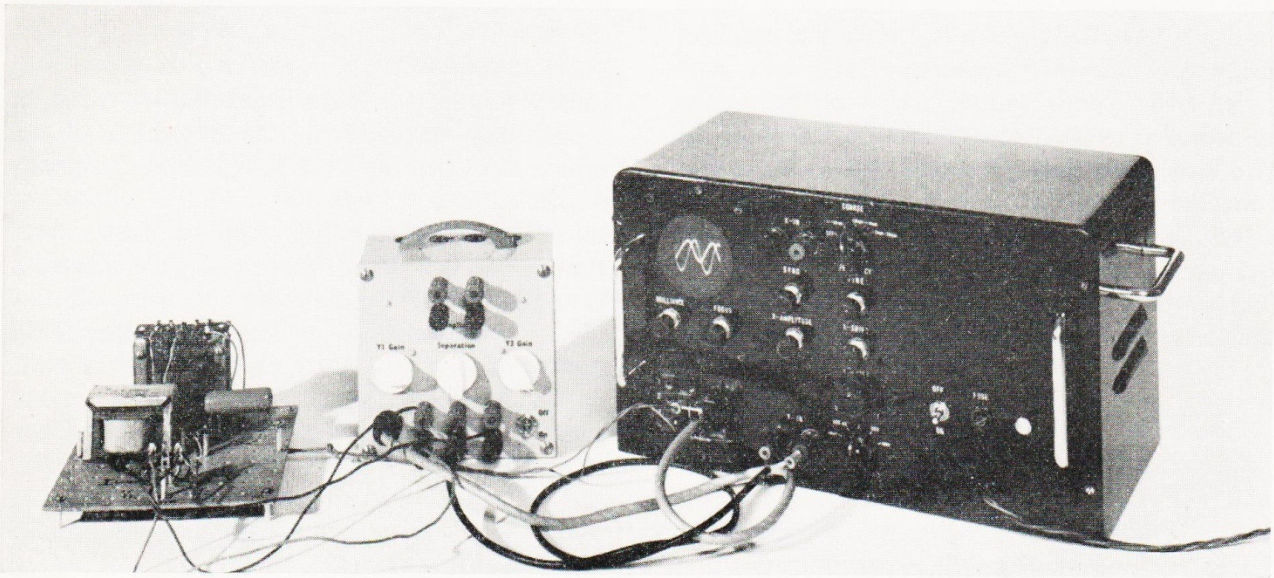


FIG. 5

1MΩ/volt d.c. voltmeter

Introduction

Apart from being an extremely useful instrument where there is a need to measure low voltages whilst drawing minimum current, this voltmeter provides a useful exercise in circuit assembly and also serves as an interesting example of an application of silicon transistors.

The voltmeter described in this leaflet is a multi-range instrument measuring potential differences from 200μV to 32 volts in eight ranges with an effective input resistance of 1MΩ/volt. The instrument is provided with a number of controls for initial calibration, zero error adjustment and for checking the internal battery e.m.f.

Practical Circuit

The complete circuit for the voltmeter is shown in fig. 1. Essentially it is a two stage d.c. amplifier using two pairs of transistors arranged in long-tailed pair configuration. The voltage to be measured is applied across the base wafers of the two input transistors TR1 and TR2 via a chain of series resistors R20 to R26. A switch S2 is used to select the correct value of resistance for any desired voltage range.

The outputs from transistors TR1 and TR2 are fed to the base wafers of a second long-tailed pair containing transistors TR3 and TR4, the outputs from which are connected via a complex switch S1 to a 100μA meter M.

Each long tailed pair can effectively be considered as a bridge circuit which is in balance until a difference in potential is applied between the input terminals. A number of components are therefore made variable in order that the circuit can be balanced even though the transistors themselves are not necessarily identical in characteristic. Variable resistor RV2, for example, adjusts the bias to the base of transistor TR1 so that in the open circuit condition the bases of transistors TR1 and TR2 are at the same potential. Potentiometer RV5 varies the collector load values of the input transistors so that when the input terminals are short circuited, the input to the second pair of transistors is equal, resulting in zero deflection on the meter.

Variable resistor RV11 which, in conjunction with resistor R10, acts as a shunt resistance to the input signal, may be adjusted for calibration of the instrument when the input terminals are internally connected to a 1·5 volt battery B2.

In series with the output from transistor TR4 another pre-set resistor is found. This acts as a multiplier resistor to the meter and once adjusted should not be touched again until such time as the

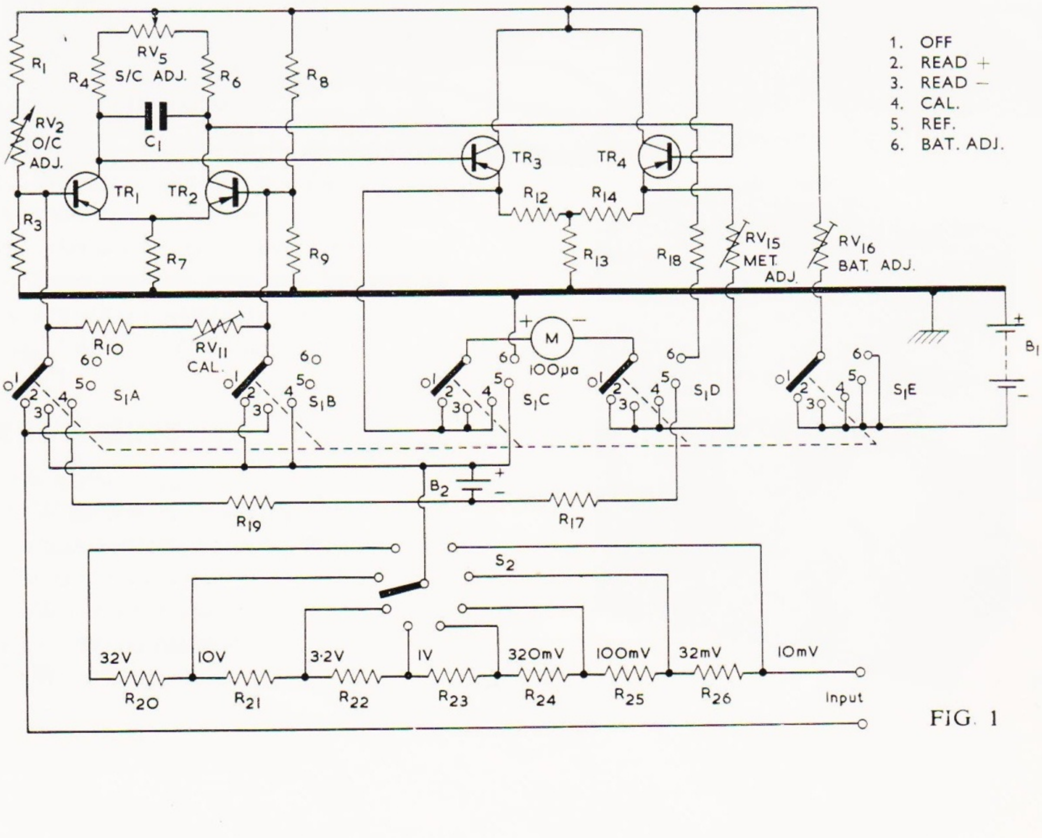


FIG. 1

meter or the output pair of transistors are replaced. Resistor RV16, which is a pre-set variable in series with the main supply battery B1, is adjusted to maintain a constant voltage (about −7 volts) to the instrument.

Switch S1 has five banks with six positions on each. Position 1 is the 'off' position. In position 2 the instrument indicates input voltages according to the setting of the range switch S2. In position 3 the input terminals are reversed so that the instrument can measure voltages of opposite polarity. In positions 4 and 5 the output from the reference battery B2 is applied to the input transistors and to the meter respectively. These positions are used for calibration of the instrument. Finally, in position 6 the meter measures the potential difference of the main supply originating from battery B1.

Construction

A prototype voltmeter was made up to test the circuit—and the external and internal views of this assembly are shown in figs. 2 and 3 respectively. Apart from the obvious care needed when wiring up the five bank switch no special attention need be paid to layout of the components and many different forms of construction will no doubt be suggested.

When the prototype unit was completed some initial difficulty was found in balancing the 'open' and 'short circuit' conditions (see section headed 'Calibration and Use') and this was found to be entirely due to the fact that the two transistors selected at random for the output long-tailed pair had markedly different characteristics. The amplification factor of one transistor was found to be 16 and of the other was 60. Although both these values fell within the published spread of characteristics for this particular transistor, it was found impossible to adjust the circuit. However, when these two transistors were placed in the input long-tailed pair, their characteristics were easily balanced by variable resistors RV2 and RV5.

It may be felt necessary to include some means of indicating that the instrument is switched on and it was for this reason that a pilot light operating from a second 1·5 volt battery was added to the prototype.

Component Values

R1	250kΩ	H.S. ±1%
RV2	100kΩ	linear carbon potentiometer
R3	100kΩ	H.S.
R4	33kΩ	H.S.
RV5	25kΩ	3W linear potentiometer, W.W.
R6	33kΩ	H.S.
R7	10kΩ	H.S.
R8	300kΩ	H.S.
R9	100kΩ	H.S.
R10	10kΩ	H.S.
RV11	50kΩ	2W linear potentiometer, W.W.
R12	3·3kΩ	H.S. ±1%
R13	4·7kΩ	H.S.
R14	3·3kΩ	H.S. ±1%
RV15	5kΩ	3W linear potentiometer, W.W.
RV16	5kΩ	3W linear potentiometer, W.W.
R17*	22kΩ	H.S.
R18*	72kΩ	H.S.
R19	2·2MΩ	H.S.
R20	22MΩ	H.S. ±1%
R21	6·8MΩ	H.S. ±1%
R22	2·2MΩ	H.S. ±1%
R23	680kΩ	H.S. ±1%
R24	220kΩ	H.S. ±1%
R25	68kΩ	H.S. ±1%
R26	22kΩ	H.S. ±1%
C1	0·25μF, paper, 100 volt working (or less)	

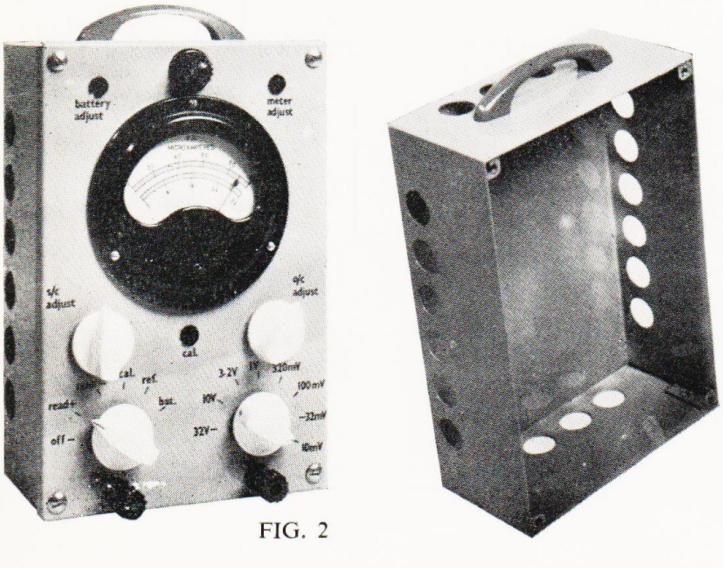


FIG. 2

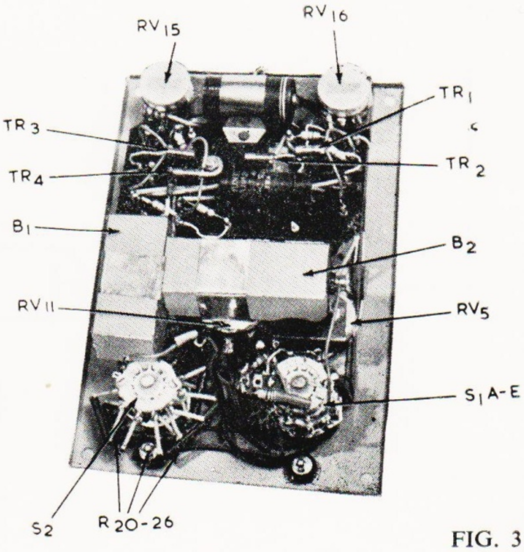


FIG. 3

TR1-4	Mullard BCZ11 transistors
S1	Five pole, six way rotary switch
S2	Single pole, eight way rotary switch
B1	9 volt layer battery. Ever Ready PP9 for example
B2	$1\frac{1}{2}$ volt cell battery. Ever Ready U10 for example
Meter	100μA f.s.d. moving coil type

All resistors $\frac{1}{4}$ watt unless otherwise stated.
H.S. denotes high stability types.
W.W. denotes wire wound.
*Includes meter resistance (see below).

Meter Resistance

As will be seen from the components list, resistors R17 and R18 have values which include the meter resistance. Since some schools might have meters of which the resistance is not known, a simple method of determining the resistance is given here. Set up the circuit as shown in fig. 4, adjusting RV1 for full scale deflection on the meter. Connect a resistance box across the meter and adjust until the meter reads exactly half scale. The resistance in the resistance box is then equal to the meter resistance.

Calibration and Use

Immediately the circuit has been wired up and even during use it is necessary to make certain adjustments to the various controls. These adjustments are given below.

1. Set switch S1 to 'bat. adj.' and adjust resistor RV16 for full scale deflection.
2. Set range switch to '10mV' and system switch S1 to 'Read +'. Adjust open circuit control (RV2) for zero reading.

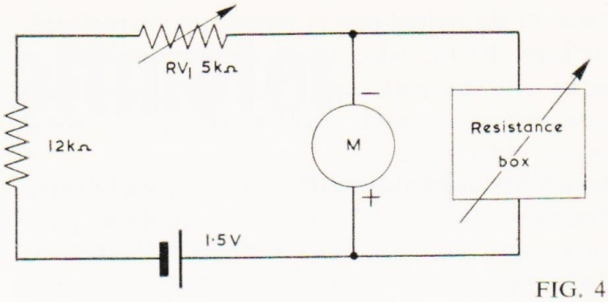


FIG. 4

3. Short circuit input terminals and adjust short circuit control (RV5) for zero reading.
4. Repeat (2) again if necessary.
5. Set system switch to 'ref' and note meter reading.
6. Turn system switch to 'cal' and adjust resistor RV11 until meter reads same value as in (5) above.
7. Connect instrument terminals to known e.m.f. and with range switch at correct setting and system switch at 'Read +', adjust RV15 for correct meter reading.

During normal use the only control needing constant adjustment is the open circuit control RV2. From time to time, however, it is recommended that the short circuit control and the battery adjust control are also reset.

Stability and Accuracy

Accuracy of the instrument is calculated at being better than 1% even at fractional scale readings. The circuit operates satisfactorily at temperatures up to 75°C and the typical maximum open circuit zero drift has been found to be better than 5%.

variable e.h.t. supply unit

Introduction

This article describes a variable e.h.t. supply unit which is simple, reliable and comparatively safe to use.

When designing the unit it was decided that it should provide an output which could easily be varied from zero to about 5kV with a maximum short circuit current of less than 2mA. It was also decided that for safety reasons the unit should contain a minimum of capacitance so that it would not store high voltages after it had been switched off. At the same time the design had to be such that the output should be virtually free from ripple.

In the first prototype, which operated from 50Hz mains, it was found impossible to obtain good smoothing without using large value capacitors and a high value of series resistance. Thus the time constant of the circuit was such that the unit took some time to lose its voltage after being switched off.

A second factor which discouraged the use of mains supply was the variation in terminal voltage. In most parts of the country variations of ±10% are fairly common and in some districts transient increases of 100% have been reported. Such increases in final output voltages from the simple e.h.t. unit could well damage connected apparatus. It was for these and other reasons that the e.h.t. unit described in this book was designed around a transistorised d.c. push-pull converter circuit operating from dry batteries.

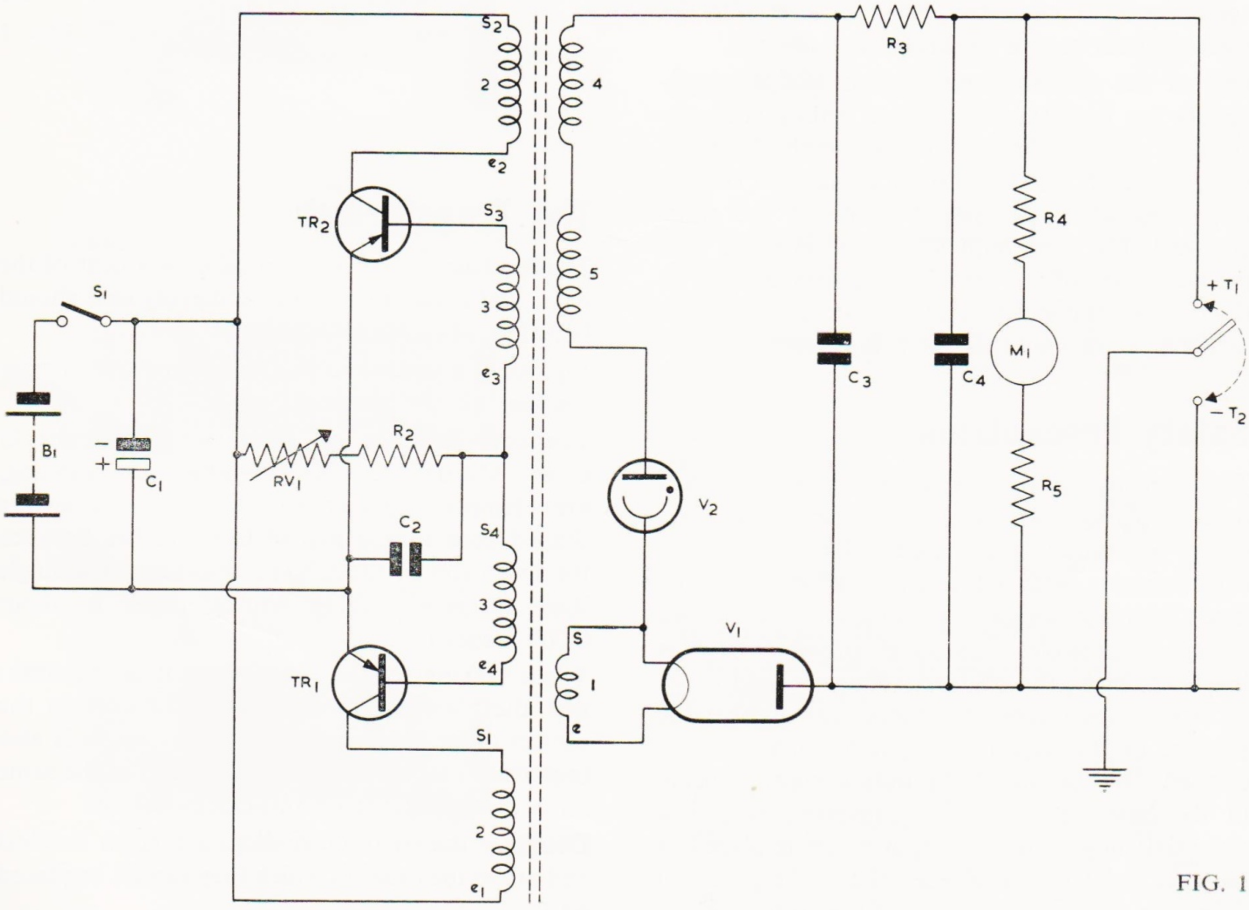


FIG. 1

The Circuit

Fig. 1 shows the circuit of the final prototype. Two power transistors TR1 and TR2 are connected in a push-pull converter arrangement operating from a 12 volt battery at an average current of 500mA. The base resistor RV1 is variable and allows the base current of the transistors to be adjusted, thus providing a means of varying the e.h.t. output. Using the transistors and transformers recommended, the converter oscillates at a frequency of about 2kHz.

The e.h.t. side of the transformer consists of two sets of windings connected in series. The alternating voltage produced in these windings is half wave rectified by the valve V1, the heater current of which is obtained from a few turns of wire wound on the transformer limb.

The d.c. output is smoothed by a conventional resistance/capacitance filter network C3, R3, C4. The capacitors are of low value since at a frequency of 2kHz only a very small time constant is required to give good smoothing.

Across the output terminals of the unit a bleeder resistance chain, represented by R4 and R5 in the diagram, is connected. This bleeder helps to improve the regulation of the unit and also provides an ideal means of monitoring the output voltage, since a 100μA meter placed in series with the bleeder chain can be calibrated in kilovolts.

One of the disadvantages of transistor d.c. converters has been the difficulty of getting such circuits to start oscillating. In the circuit described here, however, the transistors commence oscillation even when the output terminals are short circuited. The neon bulb V2, placed in series with the secondary of the transformer, fires as soon as the transistors commence to oscillate and therefore serves as a warning that e.h.t. is present.

Safety Precautions

There are very obvious and real dangers with any unit supplying outputs of the order of 5kV and every precaution must always be taken when experimenting with e.h.t. Every effort has been made with this design to provide as much built-in safety as possible. The short circuit current is less than 2mA; the off-load voltage is held down to 5kV by the bleeder resistance chain; either the positive or the negative output terminals can be earthed; the spindle of the output control, being in the base circuit of the converter, is at low potential; finally, if the output meter is placed at the mid point of the bleeder chain, the potential difference between any parts of the meter—which is on the front panel and therefore not inaccessible—and earth cannot exceed 2·5kV no matter which of the output terminals is at earth potential.

Regulation & Ripple Voltage

Fig. 2 illustrates the regulation characteristic of the prototype unit. The maximum output is just under 5kV and the maximum short circuit current is 1·6mA. As will be appreciated, the regulation curve is linear and indicates an output impedance of only 3MΩ.

The ripple voltage under normal operating conditions has been found to be better than 0·75%.

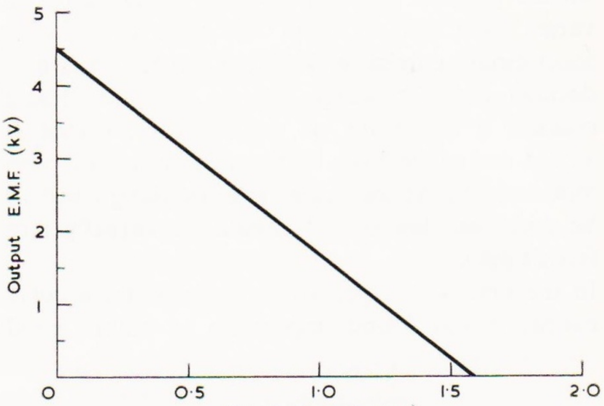


FIG. 2

The Transformer

The most important and critical component of the e.h.t. unit is the transformer and every care should be taken when constructing this item.

Fig. 3A is a schematic diagram of the transformer showing all the windings.

The core is made up from two ferroxcube U cores—Mullard type FX2380—which, after winding, are clamped together so as to form a square shaped core with a gap of 0·002 inches between the two pairs of faces. (The thickness of a single sheet of good quality writing paper is about 0·002 inches.)

When making up the transformer it is important that the windings are placed on the core in the correct order to obtain proper coupling. It is also important that all the coils are wound in the same sense (i.e. clockwise or anti-clockwise).

Details of the separate windings are given overleaf and are in the order in which they should be placed on the core.

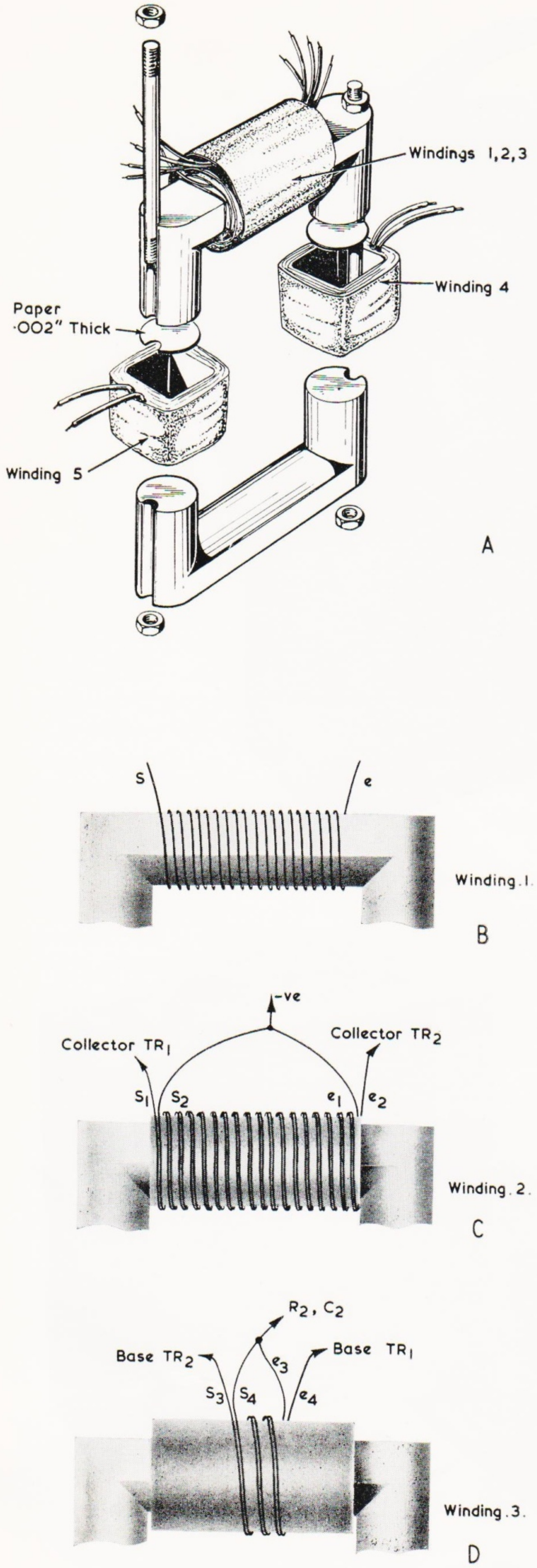


FIG. 3

1. **V1 HEATER WINDING** (see fig. 3B)
   20 turns of 22 s.w.g. p.v.c. covered single conductor copper wire wound in single layer over two layers of good quality p.v.c. tape. Finally, cover the winding with three layers of the same tape.

2. **COLLECTOR WINDINGS** (see fig. 3C)
   2×18 turns *bifilar* wound in single layer, 26 s.w.g. enamelled copper wire. Finally, cover with two layers of p.v.c. tape.

3. **BASE WINDINGS** (see fig. 3D)
   2×3 turns *bifilar* wound in single layer, 26 s.w.g. enamelled copper wire, Finally, cover with two layers of p.v.c. tape.

All the above windings are placed on the same limb of the transformer.

4 & 5. **SECONDARY WINDINGS**
3,300 turns 40 s.w.g. enamelled copper wire, paper interleaved between layers and finally wax dipped. Both windings are placed over a single layer of polythene sheeting wrapped around the transformer limb.

It is of interest to know that a coil similar to 4 or 5 forms the primary winding of some types of standard output transformer with a 9/16 in. square core.

Assembly

When assembling this unit, special care should be taken when mounting the components on the e.h.t. side of the circuit owing to insulation problems. In the prototype illustrated in figs. 4 and 5, all the components were mounted on the underside of a formica sheet. This was then covered by a second sheet of similar material to cover up the heads of the bolts. Certain components such as the on/off switch, meter, neon indicator, output control and the terminals are allowed to project through both layers of formica.

The transistors were mounted on heat sinks of dimensions 10×7cm and fashioned from 14 s.w.g. aluminium. These heat sinks are, of course, essential in this circuit.

As will be seen from the external view of the unit, a brass arm was placed centrally between the output terminals and grooved so that it could be put in contact with either terminal. In practice, this arm is connected to earth and thus provides a simple method of switching either the positive or the negative output terminals to earth potential.

In the prototype, the double sheet of formica formed the lid of a metal box measuring 9×9×3 in.

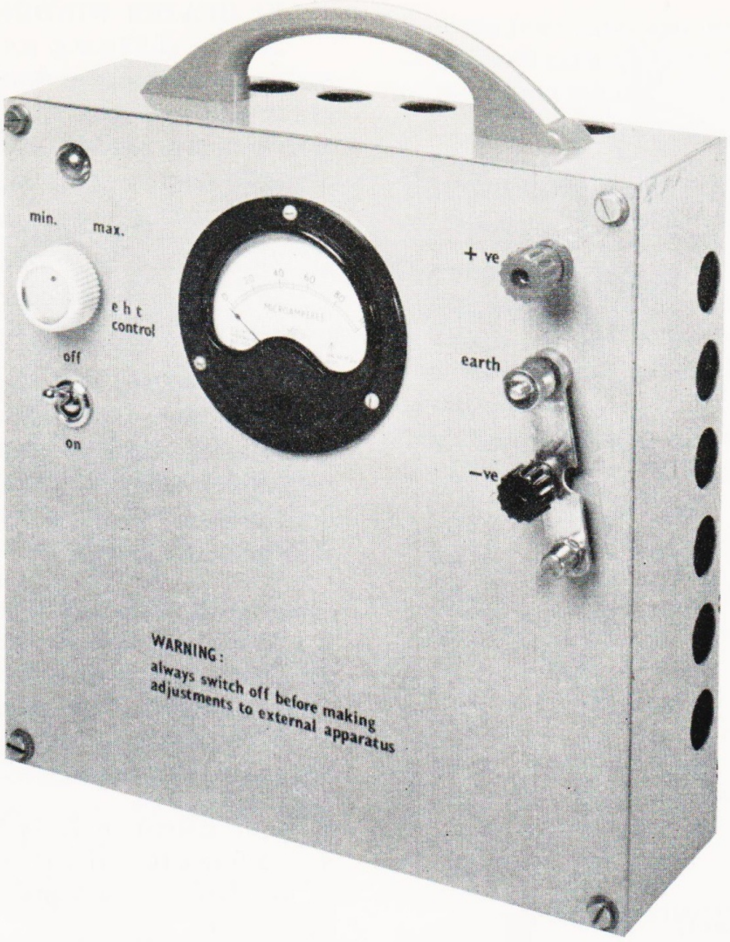

min.
max.
e h t
control
off
on
MICROAMPERES
+ ve
earth
—ve
WARNING:
always switch off before making
adjustments to external apparatus

FIG. 4

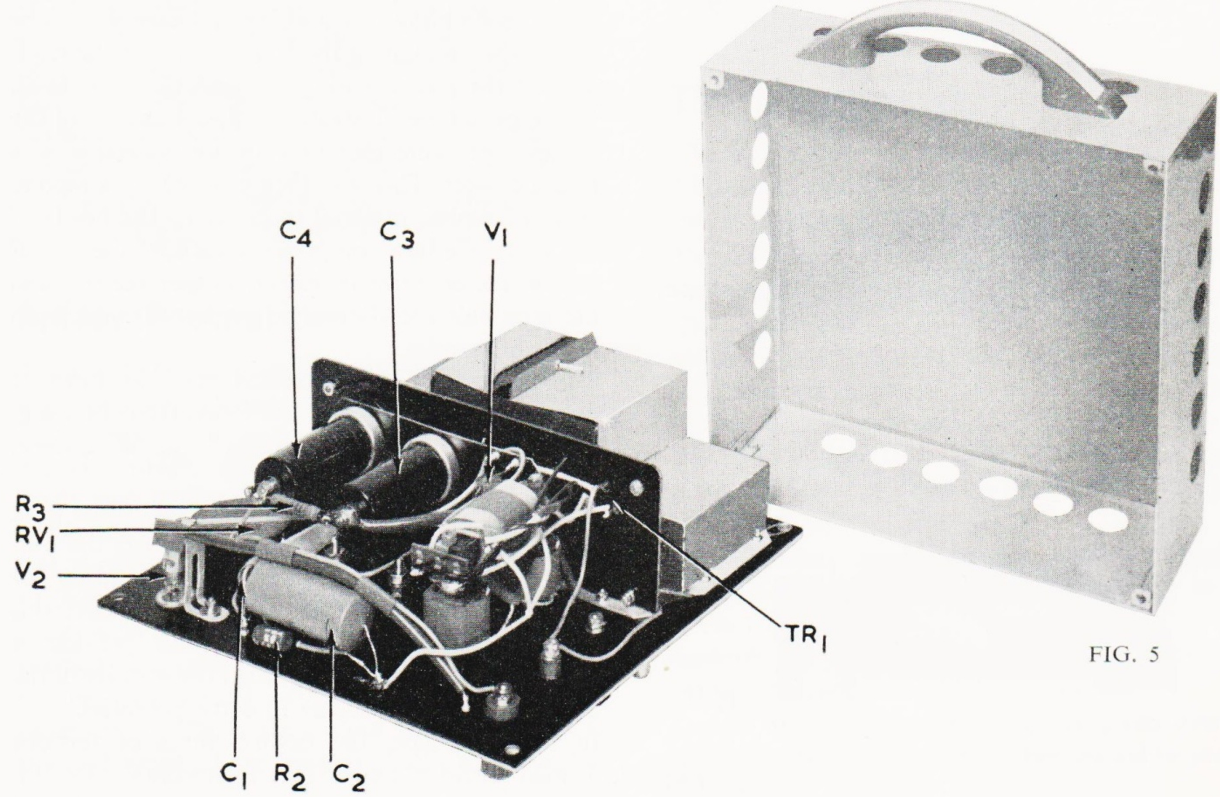

C4
C3
V1
R3
RV1
V2
TR1
C1
R2
C2

FIG. 5

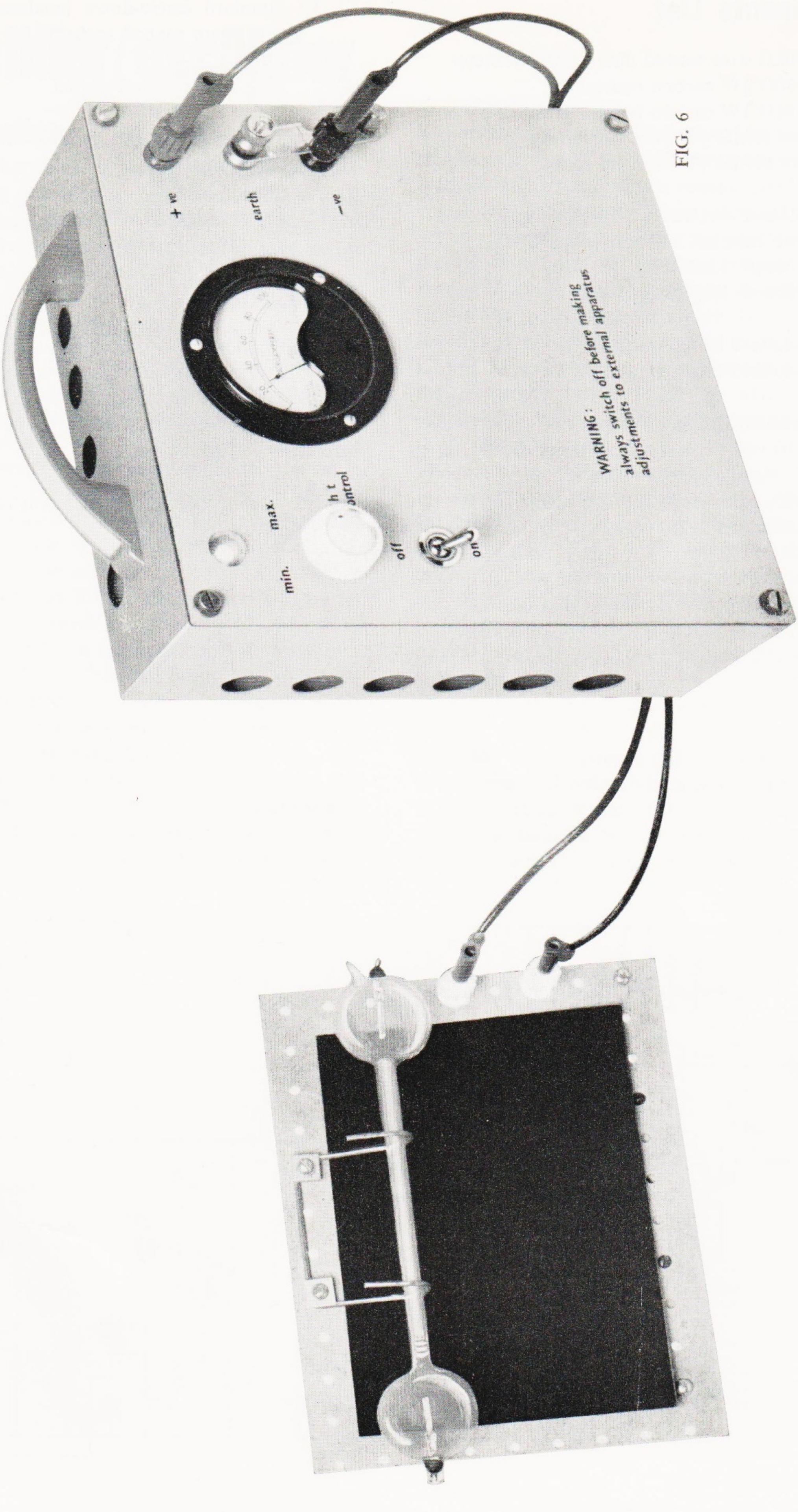

+ve
earth
–ve
WARNING:
always switch off before making
adjustments to external apparatus
min.
max.
h t
control
off
on

FIG. 6

Components List

RV1	50kΩ wire wound linear potentiometer
R2	330Ω ½W carbon resistor
R3	1MΩ 1W carbon resistor H.S.
R4	5×10MΩ ¼W H.S. (in series)
R5	5×10MΩ ¼W H.S. (in series)
C1	1000μF electrolytic, 15 volt wkg.
C2	1μF tubular, 250 volt wkg.
C3	1000pF 10kV wkg.
C4	1000pF 10kV wkg.
TR1	Mullard OC28 transistor
TR2	Mullard OC28 transistor
V1	Mullard EY51 e.h.t. rectifier
V2	110 volt neon, small bayonet cap fitting
M1	100μA moving coil instrument. Preferably calibrated 0–10.
T1, T2	Standard screw-down insulated terminals with 4mm central socket
S1	Single pole, on/off switch
B1	3x EverReady 126 bell batteries in series (or equivalent)

H.S. denotes high stability.

Applications

The applications of a unit such as this are many. It will operate standard discharge tubes, can be used as a source for electrostatic experiments or electrical machines and can also be applied to insulation testing.

Fig. 6 shows the prototype unit operating a discharge tube.

amplifier/oscillator

Introduction

Basically, the unit is a thermionic valve amplifier with built-in provision for variation of anode load, grid bias and positive or negative feedback. The pentode valve in the unit can also be used in the triode mode.

Circuit Description

Fig. 1 is a circuit diagram of the complete unit. Switch S1 in the grid circuit has three positions. At position 1 the grid is connected to a pair of input terminals T1 and T1′ so that signals derived from an external source can be applied to the valve. At position 2 the grid is connected to an internal transistor oscillator sub-circuit which is shown at the left hand side of the diagram. This oscillator, which operates at a frequency of 2·5Hz, has two controls RV5 and RV15. The former is a pre-set type and is adjusted for good wave shape. The latter control adjusts the amplitude of the output from the oscillator. The final position of switch S1 connects the grid to a parallel resonant circuit L1,C8 which can be inductively coupled to the anode resonant circuit L2,C9.

Switch S3A, S3B has two positions. In one, the valve is connected conventionally as a pentode and in the other it is connected in the triode mode with screen and suppressor grids strapped to the anode.

The anode and screen switch S2A, S2B has six positions and in five of these, different values of anode load (R25-R29) and screen resistor (R17-R21) are connected into circuit. These values of resistance are so arranged that in either the pentode or triode modes of connection optimum values of anode load and screen grid resistor can be selected.

In the final position of the switch the anode of the valve is connected to a parallel resonant circuit L2,C9. This circuit can be inductively tuned over the frequency range 2·5Hz to 4Hz and thus enables the characteristics of a tuned amplifier to be demonstrated.

The bias of the valve can also be adjusted by means of variable resistor RV24. At the same time, varying degrees of negative feedback can be introduced by way of switch S4 which has three positions. In one position the bias resistor is not by-passed and the feedback is thus at a maximum. In other switch positions different values of by-pass capacitance (C11,C12) are brought into circuit to reduce feedback.

Positive feedback can also be introduced into the unit by varying the coupling between the anode and grid resonant circuits (L1,L2). This is arranged by a mechanical system which enables a ferrite core to be moved in or out of the common former on which the inductances are wound. The coupling between the coils and hence the positive feedback

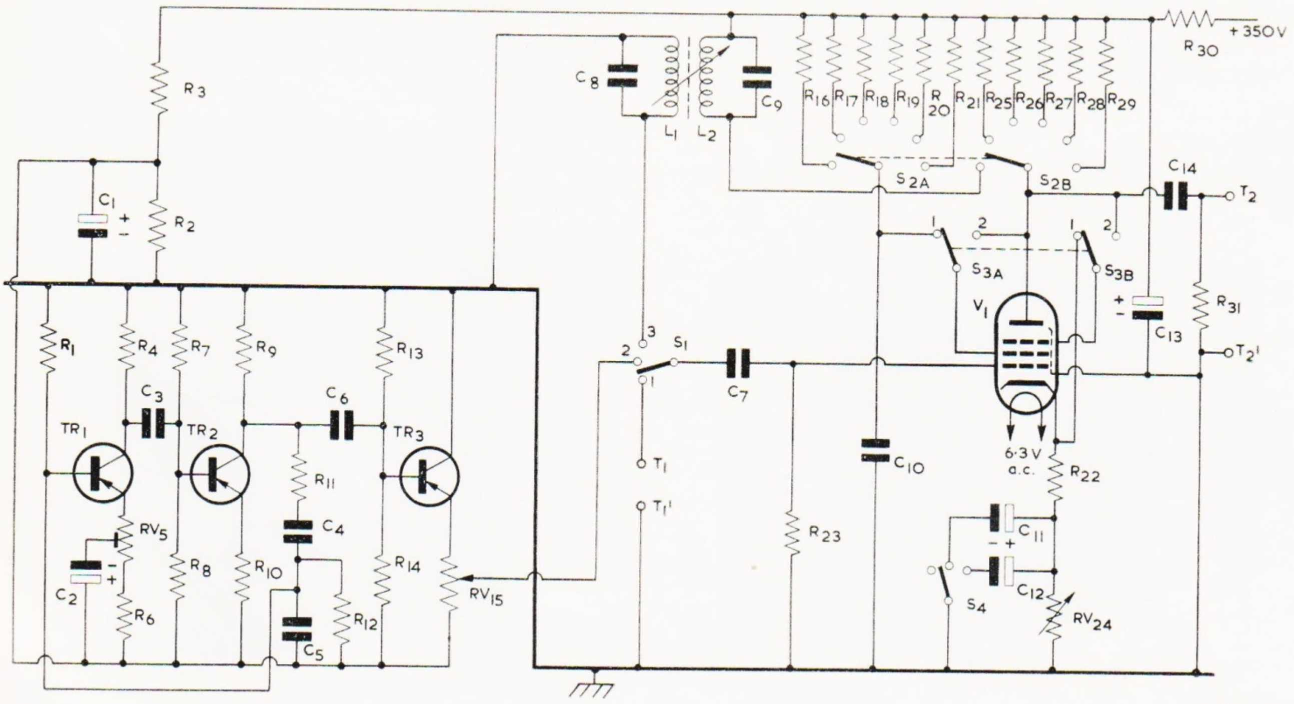


FIG. 1

is at a maximum when the ferrite core lies in the exact centre of the system. Fig. 2 is a sketch showing the main details of this system. This arrangement is also used to tune inductively the anode inductance L2 when demonstrating the action of a tuned amplifier.

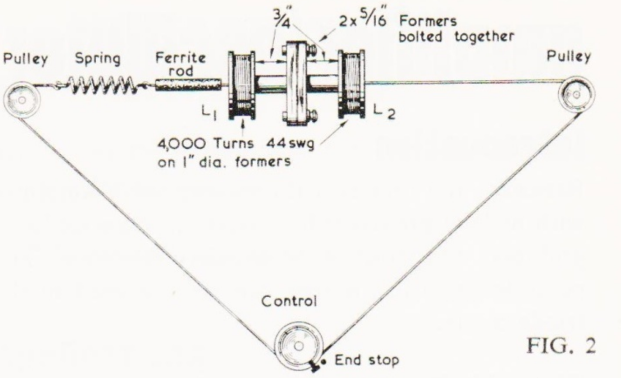


FIG. 2

Power Supplies

The power requirements of this unit are as follows:

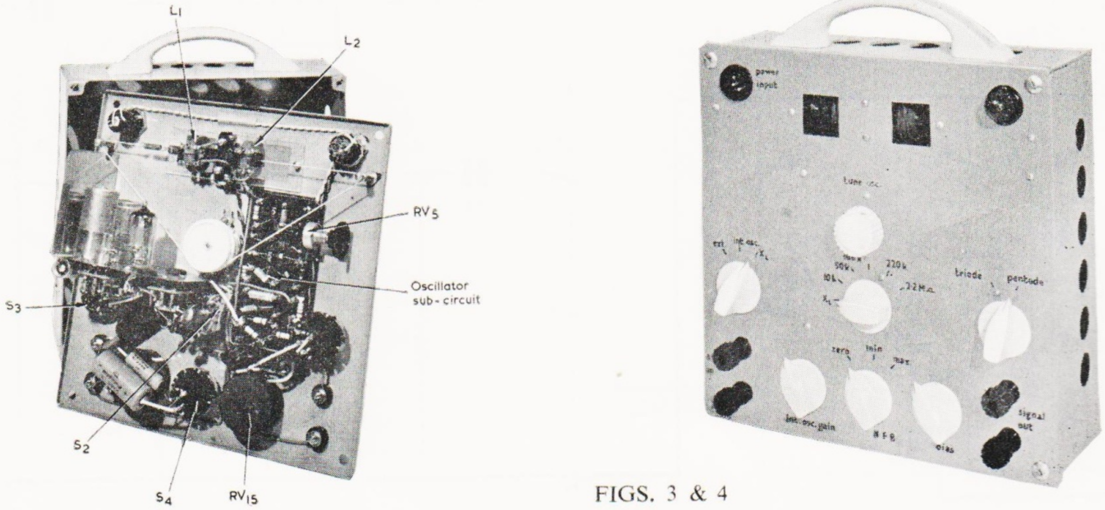
350 volts d.c., 3mA
6·3 volts a.c., 0·5A

Construction

Apart from the obvious care required when assembling the mechanical linkage system between the two coils and also when wiring up the switches, the unit needs no special care in construction. The prototype unit, which is illustrated in figs. 3 and 4, was made up on the underside of the lid of a metal box which measured 9" × 9" × 3". A small perspex window let into this lid enables the student to see for himself how the coupling between the two coils is varied.

Components List

R1	27kΩ
R2	47kΩ
R3	470kΩ
R4	4·7kΩ
RV5	1kΩ linear pre-set potentiometer W.W.
R6	1kΩ
R7	39kΩ
R8	10kΩ
R9	4·7kΩ
R10	3·3kΩ
R11	5·6kΩ
R12	4·7kΩ
R13	47kΩ
R14	8·2kΩ
RV15	5kΩ linear potentiometer W.W.
R16	47kΩ
R17	150kΩ
R18	220kΩ
R19	470kΩ
R20	1MΩ
R21	4·7MΩ
R22	100Ω
R23	470kΩ
RV24	5kΩ linear potentiometer W.W.
R25	10kΩ, $\frac{1}{2}$W
R26	50kΩ, $\frac{1}{2}$W
R27	100kΩ, $\frac{1}{2}$W
R28	220kΩ, $\frac{1}{2}$W
R29	2MΩ, $\frac{1}{2}$W



FIGS. 3 & 4

R30	47kΩ, 2W
R31	100kΩ, 1W

All resistors ¼ watt unless otherwise stated.

C1	400μF electrolytic, 12V wkg.
C2	8μF electrolytic, 6V wkg.
C3	0·1μF, 250V wkg.
C4	0·01μF, 250V wkg.
C5	0·01μF, 250V wkg.
C6	0·1μF, 250V wkg.
C7	0·1μF, 350V wkg.
C8	0·01μF, 250V wkg.
C9	0·01μF, 250V wkg.
C10	0·1μF, 350V wkg.
C11	100μF electrolytic, 12V wkg.
C12	1000μF electrolytic, 12V wkg.
C13	16μF electrolytic, 500V wkg.
C14	0·25μF electrolytic, 500V wkg.

TR1–3	Mullard ACY40 or OC71 transistors
V1	Mullard EF86
L1	See fig. 2
L2	See fig. 2
Ferrite Core	Mullard FX 2728

Terminals	Standard screw down types with 4mm central socket
S1	Single pole, three way rotary switch
S2	Two pole, three way rotary switch
S3	Two pole, two way rotary switch
S4	Single pole, three way rotary switch, break before make.

Operation of Unit

Used in conjunction with an oscilloscope connected to the output terminals T2 and T2′, the unit can demonstrate a number of interesting phenomena. These demonstrations are numerous and many are indeed obvious so it will suffice to list only the most important of them.

1. Effect of anode load on output signal amplitude.
2. Effect of anode load on output signal shape.
3. Effect of bias on output signal amplitude.
4. Effect of bias on output signal shape.
5. Effect of an input signal which is too large.
6. Effect of negative feedback on output signal amplitude.
7. Effect of negative feedback on output signal shape.
8. Effect of tuned load on output signal amplitude and shape.
9. Effect of anode-to-grid positive feedback.
10. Effect of over coupling between anode and grid (squegging).

stabilised transistor power supply unit

Introduction

With the ever increasing use of semiconductors—devices which may require currents as low as 1mA and as high as 3 ampères—the need for stabilised low voltage power supply units has now become more necessary and this leaflet describes such a unit. This unit was originally designed for use in the Educational Service but it has been agreed that some schools and probably most technical colleges will be interested in the circuit details.

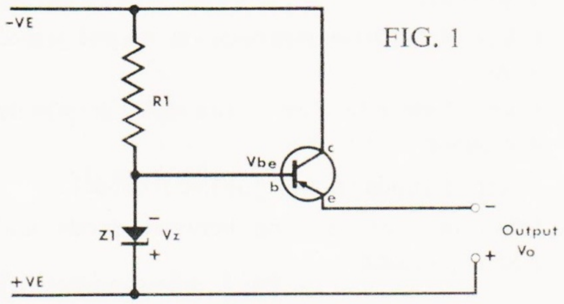


FIG. 1

General Specification

The unit operates from conventional mains supplies and can give a number of different stabilised output voltages over a current range from zero to 3 ampères. For an output current of 2 ampères, for example, the unit can supply +12·75 volts and −12·75 volts (with respect to a common terminal). Alternatively it can supply 25 volts. For zero output current these potentials rise to 13·5 volts and 27 volts respectively.

The maximum continuous current which can be drawn from either of the 13 volt terminals is 3 ampères and from the 25 volt supply is 4 ampères. If both 13 volt supplies are in continuous operation, the total current drawn must not exceed 4 ampères.

Stabilisation

A number of forms of stabiliser circuits were tried and rejected before the final prototype was accepted. Some of these circuits were too complex

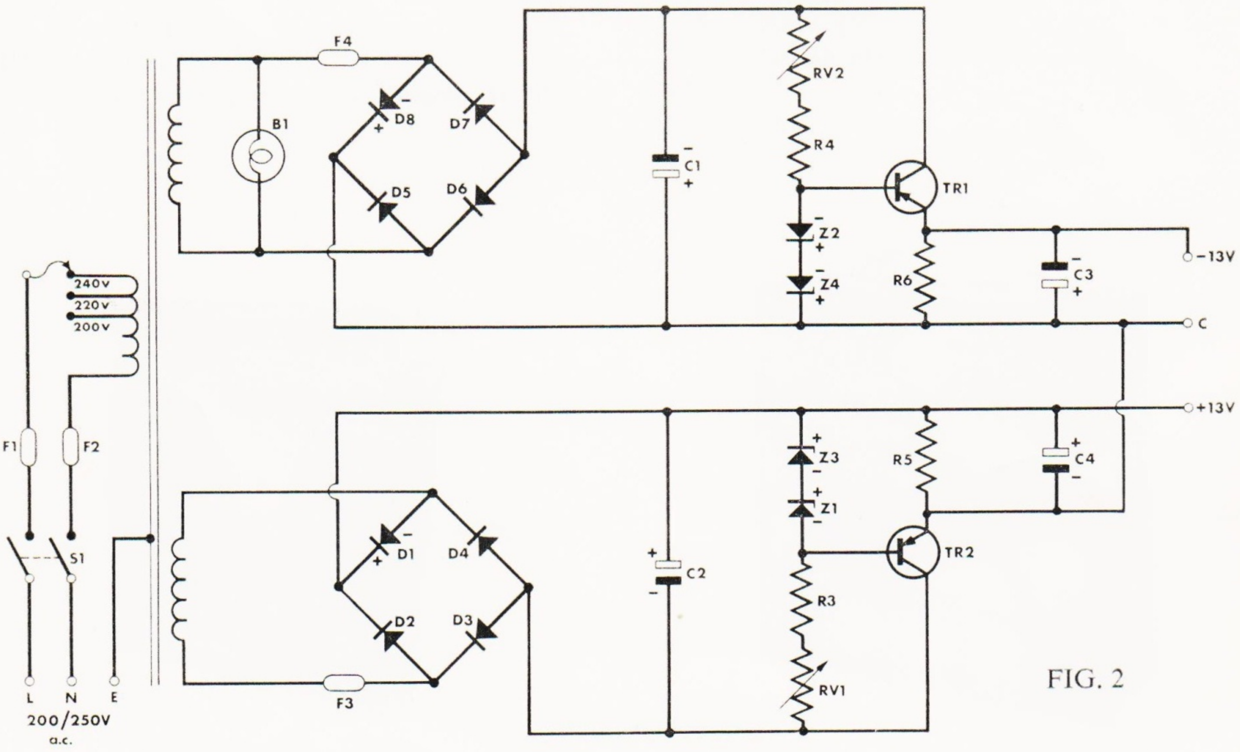


FIG. 2

and too expensive—others failed to operate successfully over the desired current range. It was decided finally that a transistor should be used in an emitter follower circuit with voltage stabilisation on the base. Such a circuit is shown in fig. 1. In broad terms, the circuit operates in the following manner. The output voltage between transistor emitter and positive rail is a function partly of the potential drop across the transistor and partly of the potential difference between base and emitter terminals (V_{be}).

However, the base-emitter voltage is the difference between the output voltage (V_o) and the zener voltage (V_z). If the zener diode Z1 maintains a constant voltage, therefore, the base-emitter voltage increases as the output voltage decreases ($V_{be} = V_z - V_o$). Consequently any tendency for the output voltage to drop causes an increase in V_{be} which increases the output voltage again. Under normal conditions, therefore, the output voltage remains substantially constant for large changes in output conditions.

Resistor R1 has a critical value which depends upon the parameters of the zener diode and of the transistor. In practice, therefore, it is usually semi-variable and is adjusted to suit any individual combination of semiconductors.

Circuit Description

Fig. 2 illustrates the complete circuit of the final prototype. It will be realised that the upper and lower halves of the circuit are identical and the unit is to all intents and purposes two separate power packs using a common transformer primary. Taking the top half of the diagram, rectifier diodes D5 to D8 form a full wave bridge circuit with reservoir capacitor C1. Z2 and Z4 are zener diodes which, in conjunction with resistors RV2 and R4 and transistor TR1, form a stabilisation circuit. Capacitor C3, in conjunction with the ohmic resistance of the transistor, gives additional smoothing of the d.c. output.

The outputs from both halves of the unit are cross connected so that voltages of either polarity with respect to a common point can be obtained. It should be noted that there is no common earth in the circuit and a real earth may be connected to any one of the three output terminals.

Finally, the need for the fuses F3 and F4 should be noted. These fuses protect the transistors from overload.

Construction

The prototype unit was constructed in a metal box $9'' \times 9'' \times 3''$ and illustrations of this are shown in figs. 3 and 4. No great difficulty in layout was experienced although it is, of course, essential that the rectifiers, zener diodes and transistors are mounted on separate heat sinks of adequate dimensions. In the prototype the heat sinks were themselves mounted on a large section of insulating material such as paxolin or formica. The sections were then bolted one either side of the mains transformer.

Heat Sinks

In the prototype all the heat sinks were fashioned from lengths of L-shaped aluminium angle $\frac{1}{8}''$ thick and $1\frac{1}{2}'' \times 1\frac{1}{2}''$ in cross section. When completed, the heat sinks were painted with blackboard paint to improve radiation efficiencies. Specific details are as follows:

Each rectifier, 3·75 square inches, $\frac{1}{8}''$ aluminium ($1\frac{1}{4}''$ of $1\frac{1}{2}'' \times 1\frac{1}{2}''$ angle).

Each zener diode, 3 square inches, $\frac{1}{8}''$ aluminium ($1''$ of $1\frac{1}{2}'' \times 1\frac{1}{2}''$ angle).

Each transistor, 22 square inches, $\frac{1}{8}''$ aluminium (3 sections of $5''$ of $1\frac{1}{2}'' \times 1\frac{1}{2}''$ angle, bolted together to form a step shaped assembly).

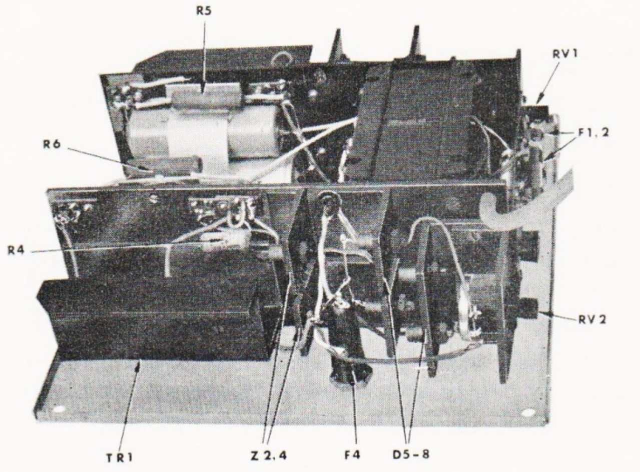


FIG. 3

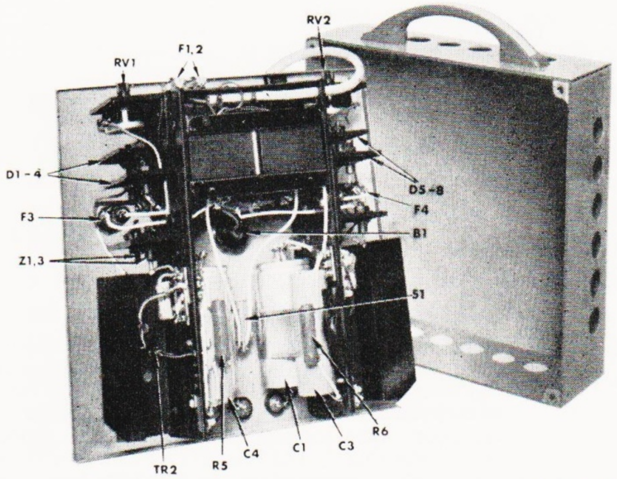


FIG 4.

Components List

RV1,2	50Ω, 3 watt pre-set wire wound variable resistor
R3, 4	20Ω, 3 watt wire wound resistor
R5, 6	100Ω, 5 watt wire wound resistor
C1, 2	6,400μF, 25V d.c. electrolytic capacitor
C3, 4	2,000μF, 25V d.c. electrolytic capacitor
D1–8	Mullard BYX38-300 silicon rectifiers
Z1–4	At the time of original publication no 13V voltage regulator diode was available and the circuit used two BZY93-6V8 diodes in each half of the circuit (as indicated in fig. 2). These may now be replaced by a single BZY93-C13 in each half of the circuit.
TR1,2	Mullard OC29 transistors
F1, 2	2 amp fuses
F3, 4	3 amp fuses
SW1	Double pole on/off switch
T1–3	Screw down terminals with 4mm sockets
B1	20V, 0·1A pilot lamp

Transformer

Primary	240V a.c. tapped for 200 and 220 volts
Secondary 1	15V at 4 amps
Secondary 2	15V at 4 amps

In the prototype unit a 30 volt, 4 amp centre tapped secondary transformer was used. The windings to the centre tap were unsoldered and brought out to spare tags. This transformer was purchased retail and is manufactured by Douglas Electronics Ltd., Louth, Lincs, under the type number MT21AT.

Connections to Semiconductors

Fig. 5 shows the terminal connections to the various semiconductors used in the circuit. Note that in all these devices the actual casing is connected internally to one of the electrodes and as a consequence all the heat sinks must be insulated electrically from the chassis and from each other.

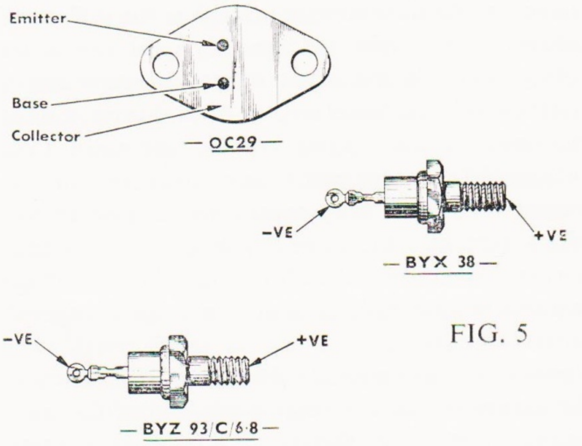


FIG. 5

Setting Up

When the unit is completed the simplest way to set it up is to load each half separately for an output current of 3 ampères and to adjust the base variable resistor for a terminal voltage of 12·5 volts. Certain measurements of zener current and base current at different output conditions may also be found useful at this time. Details are as follows:

OUTPUT CURRENT (Amps)	OUTPUT VOLTAGE (V)	ZENER CURRENT* (mA)	BASE CURRENT* (mA)
–	13·5	150	negligible
1	13·25	100	4
2	12·75	45	14
3	12·5	14	24

*Values may vary for individual zener diodes and transistors.

CIRCUIT MODIFICATION

Some users of this circuit have found that, owing to the inherent time delay in standard fuses, sudden short circuits across the output of this unit can cause the transistors to fail. A simple yet effective way of overcoming this is to connect a silicon rectifier diode immediately in series with the collector of each transistor. This diode limits the effect of reverse biasing which can occur under short circuit conditions. The forward impedance of the diode is such that it increases the output impedance of the unit slightly but this still remains less than 1 ohm. A suitable diode is the Mullard BYX38 which can be mounted on the transistor heat sink via an insulating washer (Mullard part number 56242).

critical potentials in gases

Introduction

The accurate determination of the critical potentials of gases involves the use of specially prepared tubes which as a consequence are extremely expensive. If, however, results with a fair margin of error are acceptable, the experiments described in this article will be found to be satisfactory and economic in comparison since a commercially available thyratron is used.

Theory of Critical Potentials

Briefly, the critical potentials of a gas—excitation and ionization—occur as follows. If a gas molecule is bombarded by electrons, a certain minimum energy is required before any electron is able to cause any significant change of state. When this minimum energy is attained, an electron in the valency shell of the gas atom is excited by the collision and jumps into an orbit of higher energy. Immediately afterwards a return to the equilibrium or ground state may occur, the excess energy being given off as a quantum of electromagnetic radiation. The frequency of this radiation is proportional to the energy given up in this transition and can be calculated from the expression $E = h\nu$ where h is Planck's constant. This minimum energy is the excitation energy which varies from gas to gas but which in the case of Xenon is of the order of 8·4 volts.

If now the speed and hence the energy of the bombarding electron is increased further, a second critical state is reached where a valency electron is given sufficient energy to leave the atom completely, causing ionization. This second critical potential is the ionization potential which also varies from gas to gas but for Xenon is of the order of 12 volts.

A second excitation can occur at a potential higher than that of the first critical potential. Here an orbital electron of higher energy is lifted from the ground state to a level of higher energy. Upon returning, the electron emits a quantum of radiation at a higher frequency than that emitted after the first excitation.

A further complication in some elements—notably mercury and the inert gases—is that there exist one or more energy levels in which electrons may remain excited for comparatively long periods. When an electron is raised to such a level, the atom is said to be metastable and, as a rule, does not have time to return directly to the ground state before further collisions occur. If a metastable atom is struck by an energetic electron it may be excited to an even higher state or may even be ionized. If a higher excitation state is reached by an atom which has previously been metastable, it may quickly return to the equilibrium condition by emitting a quantum of radiation at the appropriate frequency.

Fig. 1 indicates the various excitation and ionization potentials for Xenon which is the gas chosen for the experiments described in this book.

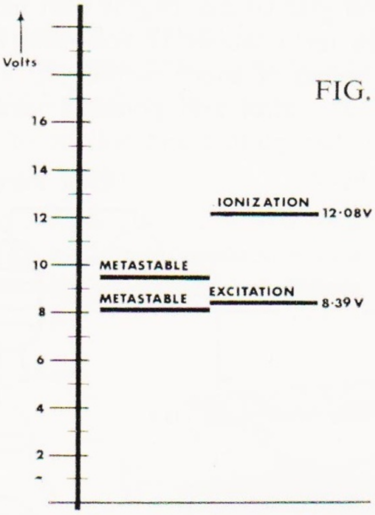


FIG. 1

Experiment 1: Determination of First Excitation Potential of Xenon

In this experiment a modified Hertz method is used. It is assumed that cathode-emitted electrons, with just sufficient energy to cause excitation, come to rest after an excitation collision and are then unable to overcome a retarding potential existing between two electrodes placed in the electron stream. The Mullard EN91 thyratron, which is Xenon filled, can be used to demonstrate this effect.

Apparatus:

The circuit diagram of the apparatus used is shown in fig. 2. Major components include the thyratron, a 6·3 volt a.c. supply for the heater, a variable power supply to accelerate the electrons in the gas, a limiting resistor, a voltmeter and a sensitive microammeter.

It will be seen from the circuit diagram that the anode is used as a target and is maintained at a small negative potential with respect to the control grid by virtue of electron flow through the valve. The control grid is connected to the positive side of the power supply and the grid g_2, which in the

EN91 surrounds all the other electrodes, is connected to the cathode so as to form a field free space. A limiting resistor, 10,000Ω in value, is placed in series with the power supply to prevent possible overload if the gas should ionize during the experiment.

Method:

The apparatus is switched on with the applied voltage to the control grid set to zero. When the heater has had sufficient time to reach a steady temperature the microammeter connected to the anode will indicate a steady current arising from thermionic emission at the cathode.

The control grid voltage (V_g) is then increased in small steps up to about 11 volts and the corresponding values of anode current (I_a) noted.

A graph of control grid potential versus anode current is then plotted and will be of the form shown in fig. 3.

FIG. 2

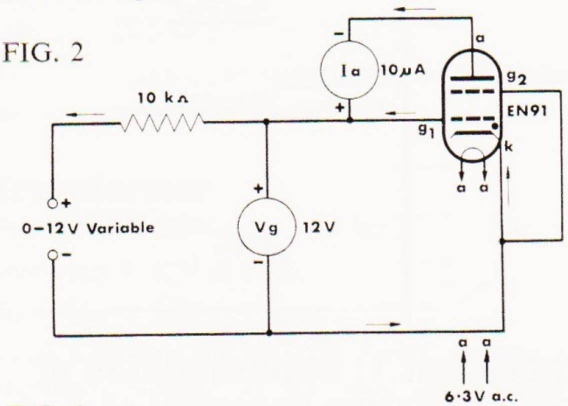
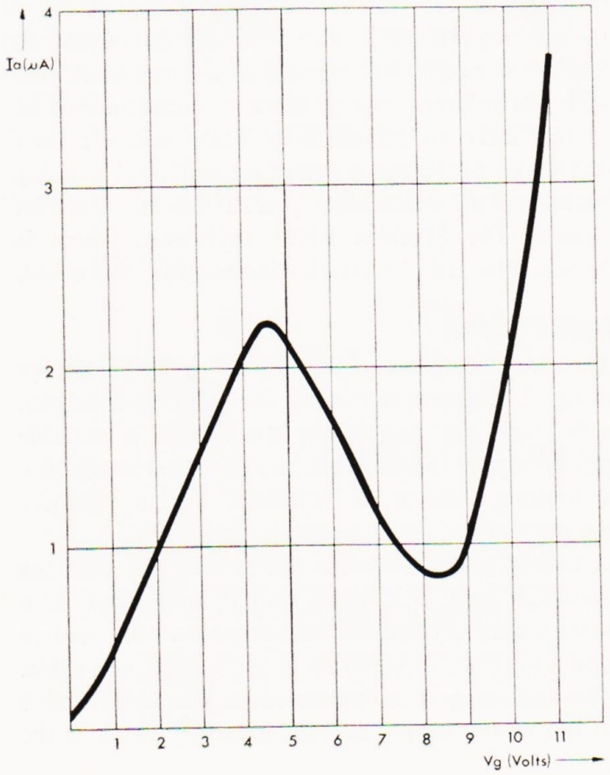


FIG. 3



The shape of this curve may be explained as follows. Even at grid potentials lower than expected for ionisation, a few electrons passing through the centre of the control grid cylinder have sufficient velocity to cause excitation and therefore lose their energy. They are thus unable to overcome the negative field surrounding the target. As the applied voltage is increased, more and more electrons lose their energy after excitation and the target current falls accordingly. A minimum value of target current is achieved when most of the electrons passing through the control grid are able to cause excitation. As the potential is increased beyond this critical value, electrons, after causing excitation, are able to accelerate sufficiently to overcome again the retarding potential and the target current commences to rise.

Observations:

A number of curves for different specimens of EN91 thyratron has been taken giving a value of first excitation potential at about 8·2 volts.

It might be of interest to note that if the readings are taken with extreme accuracy, there is an indication of sharper dips in the region of 8 to 9 volts. These may indicate metastable states.

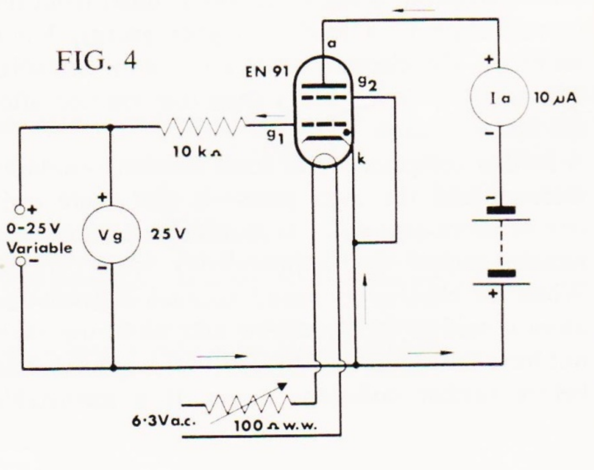
Experiment 2: Determination of Ionization Potential of Xenon

The Mullard EN91 Xenon filled thyratron has again proved successful in this experiment. The energy of cathode emitted electrons is increased to a sufficient level to allow ionization and a small current flows to the target electrode which is maintained at a large negative potential of about 50 volts.

Apparatus:

The circuit diagram of the apparatus used is shown in fig. 4. Major components include the thyratron,

FIG. 4



power supplies (one variable), a voltmeter and a sensitive microammeter.

It will be realised that electrons emitted from the cathode are accelerated towards the positive control grid. The anode of the thyratron is again used as a target and is maintained at a large negative potential with respect to the cathode. The grid g_2 is connected to the cathode and a 10,000Ω resistor is connected in series with the control grid supply voltage to limit the cathode-grid current after ionization. Without this resistor, the current may exceed the maximum permissible value of 10mA resulting in destruction of the thyratron.

It has been found desirable to operate the heater of the thyratron at a greatly reduced voltage to reduce the space charge to a minimum and thus to increase the sensitivity of the experiment.

Method:

With an anode potential of about −50 volts the potential applied to the control grid is set to 15 volts. The heater voltage is then *slowly* adjusted for maximum reading of anode current (I_a) which should be of the order of 1μA. The applied potential (V_g) is reduced to zero and then increased in small steps up to about 20 volts, the corresponding anode current being noted. A graph of applied voltage versus anode current is plotted and should be of the form shown in fig. 5. The exact potential at which ionization takes place is found by extending the curve back to cut the V_g axis.

Observations:

This experiment has been carried out with a number of different EN91 thyratrons and results have varied between 12 and 12·5 volts.

If the experiment is conducted carefully, a slight discontinuity in the curve will be seen in the region of $V_g = 14$ volts. The reason for this is obscure but is possibly due to excitation.

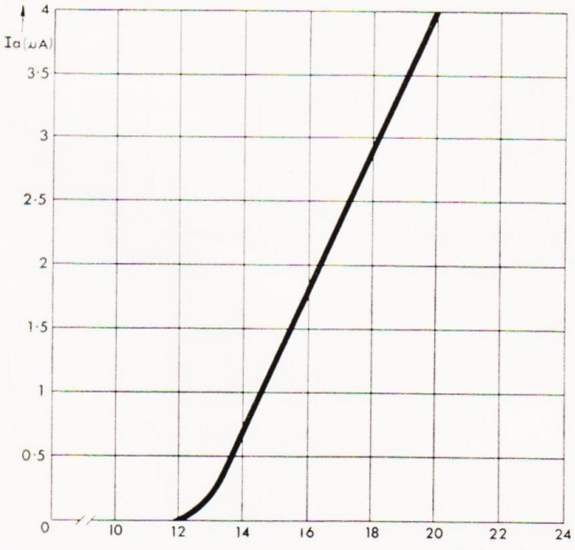


FIG. 5

Meters:

In both experiments the applied potential was measured on a 20,000Ω per volt instrument. For current measurements a 10μA meter is called for but if unobtainable, a transistor d.c. current amplifier can be used.

Power Supplies:

In both experiments, the potentials can be derived from Educational Service power packs, details of which are contained on pages 14 and 58 of "Demonstrations & Experiments in Electronics & Magnetism". Briefly, the unit has a variable output up to 150 volts. The current drawn in both experiments is negligible since it is limited by the 10,000Ω series resistor. The same power supply unit can also provide the 6·3 volt heater supplies.

Thyratron EN91:

This tube is readily available and costs very little. It should be used in conjunction with a B7G base, the connections to which are shown in fig. 6.

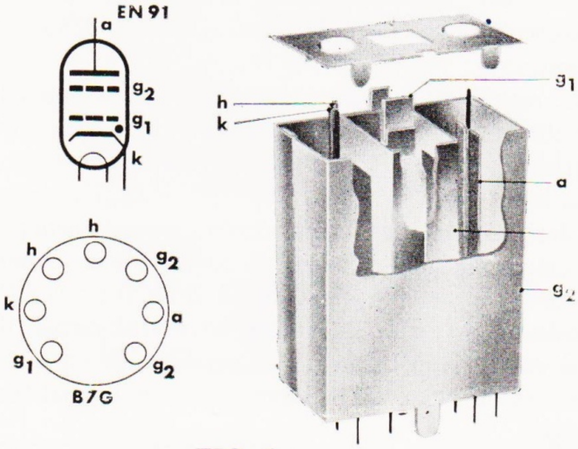


FIG. 6

It should be remembered that for any conventional application, operation of the thyratron at any heater voltage other than that recommended by the manufacturer may seriously damage the cathode and greatly shorten the life expectancy of the device.

References

Although these particular experiments represent a new approach to the determination of critical potentials, details of other methods and further explanations of the theory might also be of interest. Some references are given below.

PHYSICS OF THE ATOM by Wehr-Richards. Addison-Wesley Co. Inc.

ELECTRONICS by Parker. Arnold.

Note:—Mullard Ltd do not manufacture suitable thyratrons containing gases other than xenon.

a low voltage electrometer

Introduction

When designing this instrument, applications in mind included ρ_H (pH) measurement, determination of low magnitude electrostatic potentials and the detection and examination of sub-atomic particles by various means. The specification required, therefore, an instrument with a very high input resistance and one which would draw a negligible current from the source of potential.

After completion the instrument was found to have an input resistance of 10^{10} ohms which made it suitable theoretically for such applications. At the same time additional applications were discovered and these were the measurement of transient voltages and also small currents.

Circuit Description

The circuit diagram is shown in fig. 1. Essentially the unit consists of an electrometer valve V1 followed by a bridge circuit containing n-p-n transistors TR1 and TR2. The bridge can be balanced by means of set-zero control RV9 in conjunction with the meter M.

The maximum voltage range which can be applied to the grid of the electrometer valve is 4 volts. By arranging for a standing bias of —2 volts, however, the input range is modified to ±2 volts. This bias is derived from the filament current passing through resistor R1 and is applied to the grid either directly, if the input switch S1 is in the 'REST' position, or via an externally connected circuit if the switch is in the 'READ' position.

The on/off switch S3 has three positions so that the filament voltage is switched on just before the anode voltage, thus satisfying a general recommendation for electrometer valves.

The transient voltage probe uses diode D1 and capacitor C1. A transient voltage applied to the probe charges C1 which then discharges slowly through the high resistance of the electrometer unit and the high back resistance of the diode. In practice the discharge takes several seconds and allows sufficient time for the meter to indicate the value of the original voltage.

The output voltage of the unit appears between the points marked XX′ on the circuit diagram and it is here that the meter is connected. Alternatively, further stages of voltage amplification could be connected.

The overall input-to-output voltage gain of the unit is a little less than unity so that the output does not exceed 4 volts. In the prototype instrument a 25–0–25μA meter was used in conjunction with three multiplier resistors R5, R6, R7 and range switch S2. The values of these resistors were calculated to give meter ranges of ±25mV, ±250mV and ±2·5V for full scale deflection. The total resistance between points XX1 should not be less than 1000Ω to protect the bridge from overload.

Constructional Details

Figs. 2 and 3 show external and internal views of the prototype unit which was constructed to test the circuit design. It was found essential to take precautions in the construction to avoid introducing leakage paths in the input stages.

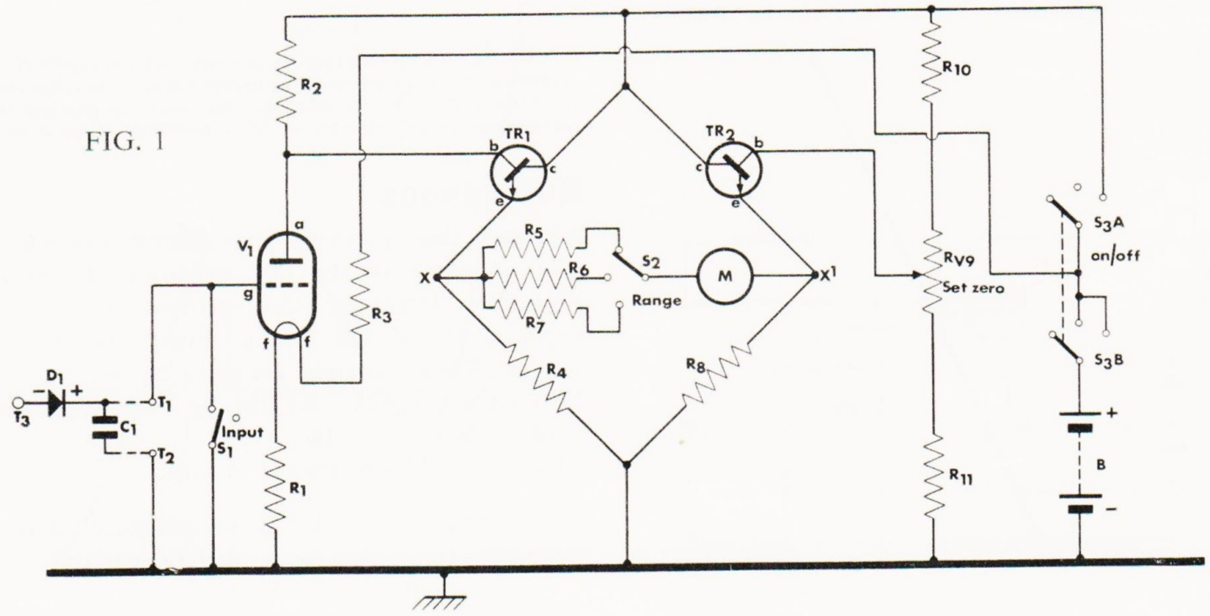


FIG. 1

The input terminal T1 was mounted on a disc of *clean* perspex about 2″ in diameter and the whole assembly was fitted under a hole of 1″ diameter cut in the lid of an iron conduit box of dimensions $6\frac{1}{4}'' \times 9\frac{1}{4}'' \times 3''$.

The grid lead of the valve should be as short as possible and in the prototype was connected *directly* to terminal T1 via the switch S1, which must be a top quality nylon loaded type. Small components, including the electrometer valve, were mounted on a piece of good quality paxolin sheet which was then attached to the meter terminals. All inter-connections were made on small turret lugs mounted on the paxolin sheet as standard tag strips may not have sufficiently good insulation properties.

It is essential to avoid contamination of input components. These should therefore be handled with sterile tweezers when being fitted. To reduce the effects of electromagnetic radiations the valve was mounted inside a copper cylinder. This cylinder, the iron conduit box and the common earth line of the circuit were then electrically inter-connected so as to form a field-free space. The probe unit was fashioned from perspex in such a manner as to make the attachment to the main terminals of the electrometer as simple as possible and Fig. 4 is a photograph of the probe attached to the unit. The two batteries which are specified in the Components List below were mounted in the bottom of the box.

Components List

R1	220Ω 5% $\frac{1}{8}$W
R2	100kΩ 5% $\frac{1}{8}$W
R3	1kΩ 5% $\frac{1}{8}$W
R4	10kΩ 5% $\frac{1}{8}$W
R5 R6 R7	see text
R8	10kΩ 5% $\frac{1}{8}$W
RV9	50kΩ carbon potentiometer
R10	47kΩ 10% $\frac{1}{8}$W
R11	100kΩ 10% $\frac{1}{8}$W
C1	300pF polystyrene capacitor
S1	single-pole, two-way NYLON rotary switch
S2	single-pole, three-way rotary switch
S3	Two-pole, three-way rotary switch
V1	Mullard ME1404 electrometer valve
TR1	Mullard OC140 transistor
TR2	Mullard OC140 transistor
D1	Mullard OA202 diode
M	see text
B	18 volt battery (2×PP9 or equivalent)
T1-3	Screw down terminals with 4mm socket

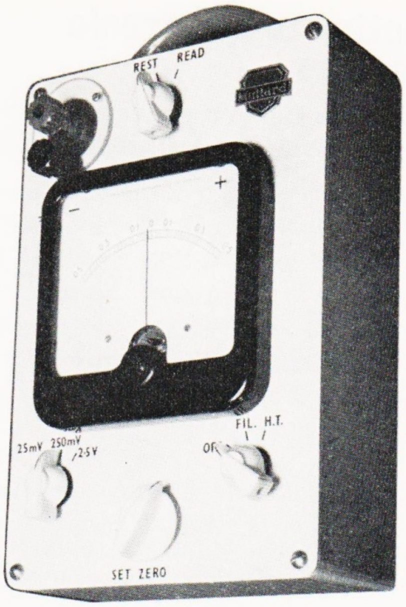


FIG. 2

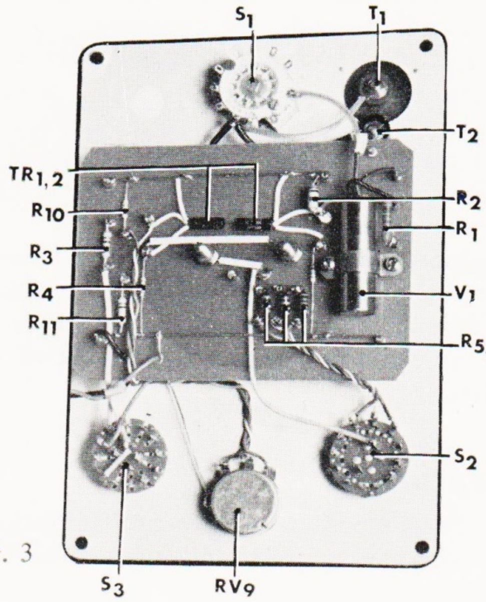


FIG. 3

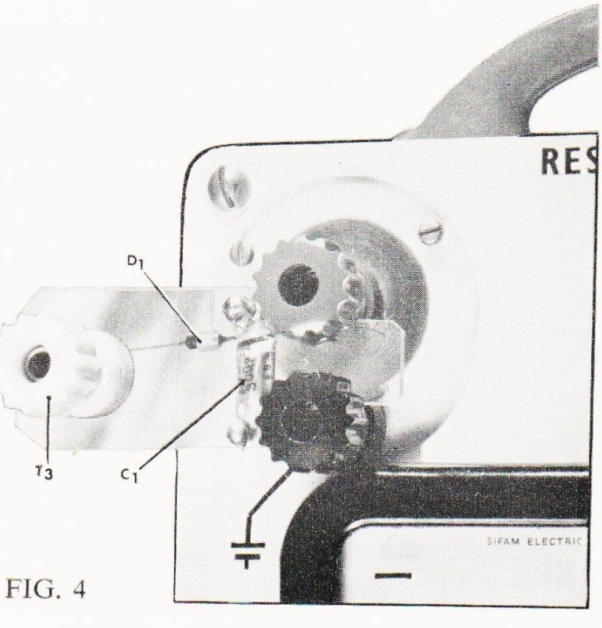


FIG. 4

Connection to Electronic Components

Fig. 5 shows the lead-in connections to the electrometer valve, the transistors and the diode.

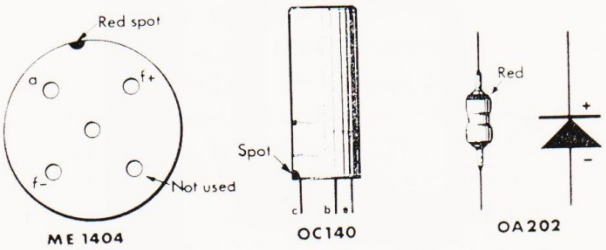


FIG. 5

Calibration

It is not possible to publish a calibration curve since this may vary from instrument to instrument. When the circuit has been built up, therefore, such a curve must be plotted by applying known potentials. Fortunately the calibration curve is linear to a first approximation and only a few plots need be taken. It should be noted, however, that, as a result of the non-linear input characteristic of the electrometer valve, the slopes of the calibration curves for positive or negative inputs will not be the same.

For indirect current measurements, the potential drop across a circuit series resistance is measured. If for example a 1MΩ resistor is used, the electrometer can measure currents of the order of 10^{-9} Ampères.

Operation

There is a set procedure for taking voltage measurements with the completed instrument. This is set out below:

1. Set input switch to 'REST' position.
2. Turn range switch to minimum sensitivity (2·5V).
3. Switch S3 to 'H.T.' position and adjust set zero as necessary.
4. Connect external source and turn input switch to 'READ'.
5. If a greater sensitivity is required, operate range switch and re-adjust set zero with input switch at 'REST' position.
6. Return input switch to 'REST' position before disconnecting external circuit.

NOTE: It is recommended that the battery voltage is checked from time to time.

Drift and Stability

Some drift of the bridge balance point occurs on the most sensitive range of the instrument and it is advisable to re-adjust the set zero control between readings. The minimum drift occurs after the instrument has 'warmed up'. At this time the average rate of drift is of the order of 0·5mV per minute.

The sensitivity of the instrument is so high that under certain conditions it is liable to indicate electrostatic charges even on clothing some distance away. This, however, only occurs if the input terminals are left open circuit with the input switch in the 'REST' position.

Characteristics

Some measurements of the characteristics of the prototype instrument have been taken and are given here.

Input resistance	$> 10^{10}\Omega$/volt
Input current	$\simeq 10^{-10}$A
Minimum readable input	$\pm 0{\cdot}5$mV
Maximum input	$+2$V, $-2{\cdot}3$V
Output resistance	$\simeq 10^{3}\Omega$
Output current	$\simeq 10^{-3}$A
Current gain	$= 10^{7}$
Voltage gain	$\leqslant 1$

a decade scaler

Introduction

For some time there has been an obvious requirement for a scaler which is comparatively inexpensive and yet reliable and versatile. The unit described here uses the latest techniques and falls broadly within this specification.

The scaler has a maximum count rate of 400Hz and will accept and count most standard waveforms. Power supplies are derived from a 12 volt d.c. source which gives the added advantage of portability.

The unit described here has four stages of electronic counting with the final output modified to operate a standard electro-mechanical register so that a total count of 10^7 can be accommodated. It is not necessary to make up all the stages of counting at one time and it might be considered advantageous to make up the power supplies and first stage initially, adding additional counting stages at later dates.

Counting Circuit

Fig. 1 illustrates one of the stages of electronic counting. The complete circuit is shown on Page 31. It is usual practice in this series of experiments to give some technical explanation of the principles of operation of the various items of apparatus if space allows. In this book, however, explanations are limited to a description of the operation of the counting tube, the input and output circuits and the power supplies.

The counter tube used in this circuit has thirty identical rod-shaped cathodes arranged in a circle concentric with the common circular plate anode. The cathodes are divided into three groups of ten and arranged so that every third electrode going around the ring belongs to the same group. These groups are named main cathodes (marked k_0 ; $k_1 \ldots k_9$ on the circuit), the guide A cathodes (A on circuit) and the guide B cathodes. All the guide A cathodes are connected internally and brought out to a single connection as are the guide B cathodes.

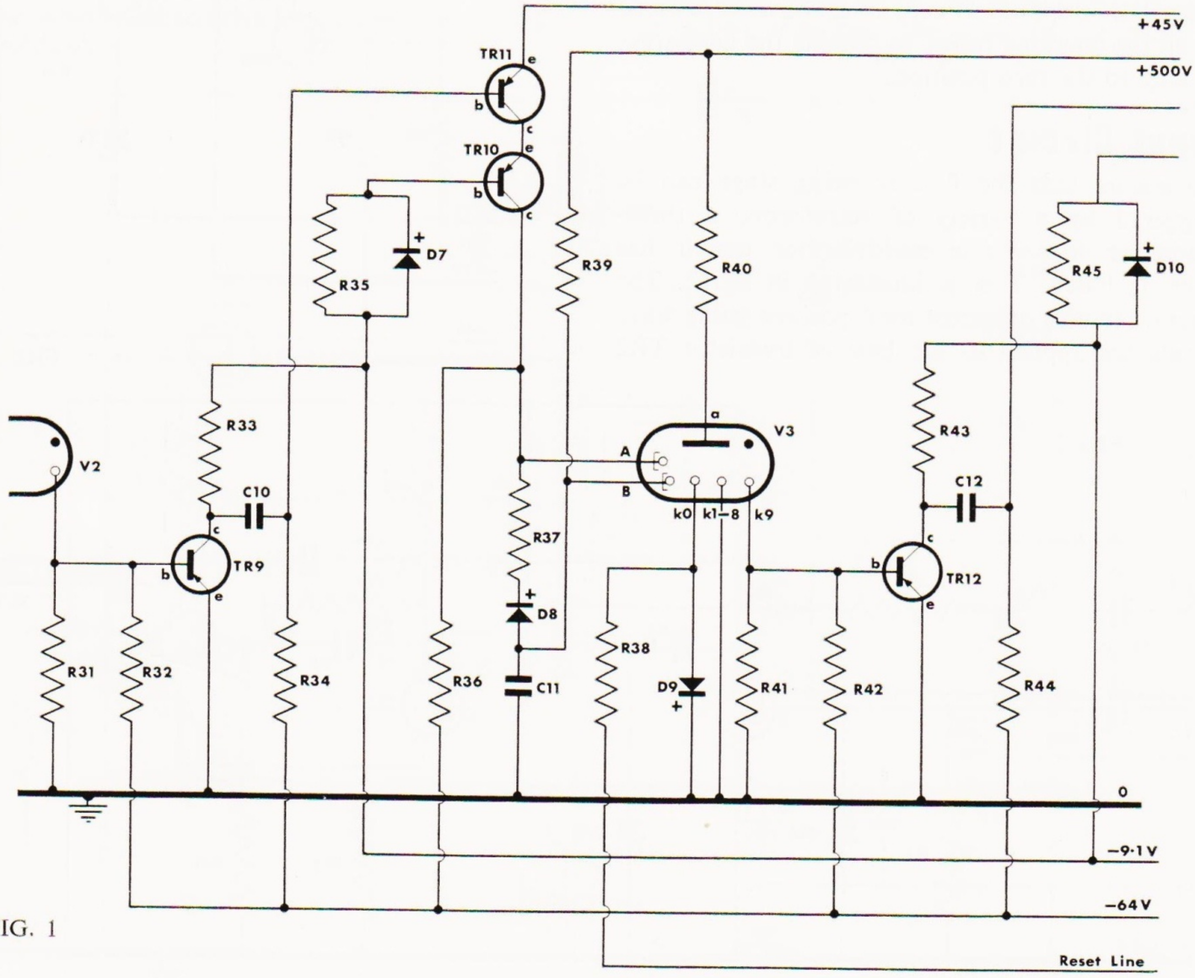


FIG. 1

The glow discharge normally rests on a main cathode, thus providing indication, and may be seen through the dome of the tube as an orange glow. The position of the discharge can be related to the number of input pulses by the use of an external and numbered escutcheon.

The function of the guide cathodes is to transfer the discharge from one main cathode to the next on the receipt of an input signal and the method employed in this circuit is as follows. An input signal arriving at the base of transistor TR9 is amplified, suitably shaped and converted into two negative pulses. The first pulse is applied to the guide A cathodes followed immediately by the second pulse applied to the guide B cathodes. This causes the discharge to move to the next main cathode in sequence.

In this unit, the main cathode circuitry is arranged so that, as the discharge on k_9 is extinguished, a negative pulse is fed from this electrode to the first transistor TR12 of the next stage. Cathode k_0 is connected to the other main cathodes via diode D9 so that it not only takes part in the normal counting cycle but can also be used for re-setting the discharge to the zero position. The reset circuit will be found on the left hand side of the main circuit diagram and is arranged so that a negative pulse can be applied directly to the k_0 main cathode of all the counting tubes, so causing the discharges to step to the zero position.

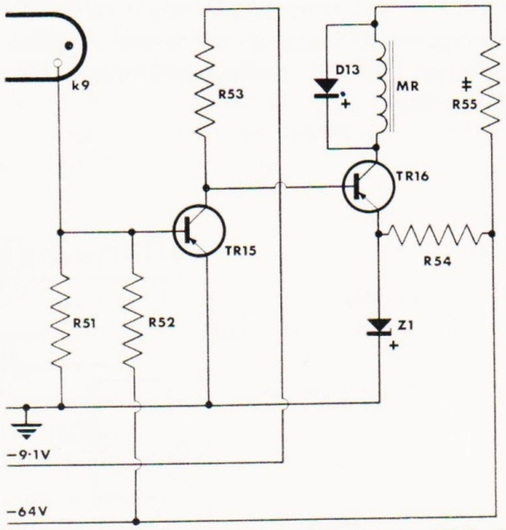
Input Circuit

To ensure that the first counting stage can be triggered by a variety of waveforms, a three-transistor monostable multivibrator circuit has been included. This is illustrated in fig. 2. The circuit remains quiescent until positive going wave fronts are applied to the base of transistor TR2 or until negative going wave fronts are applied to the base of TR1. In either case the monostable circuit produces one pulse and then returns to the quiescent state.

Input waveforms of most shapes and of amplitude 0·5V → 10V are suitable for triggering the input circuit but, where the input is applied direct to transistor TR2, the total impedance of the signal source and resistor R6 must be greater than 5kΩ.

Output Circuit

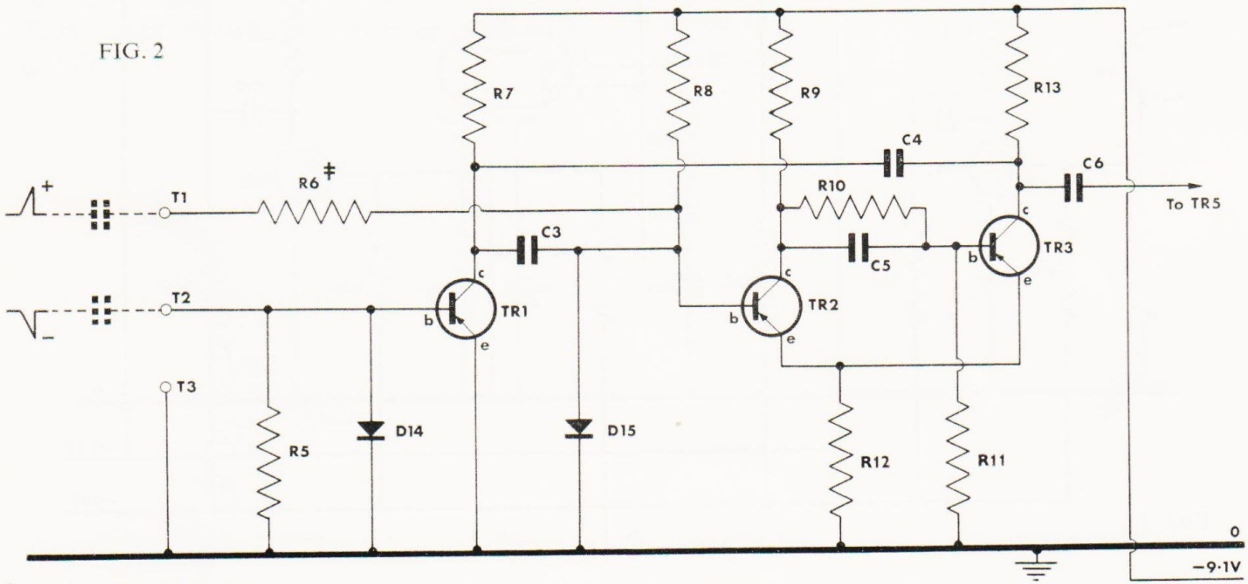
If required, a final stage of electro-mechanical counting can be used and a typical output circuit is shown in fig. 3. Positive pulses from the cathode k_9 of the counting tube are applied to the base of transistor TR15 which then cuts off. Thus a negative pulse is applied to transistor TR16 which conducts a large current, energising the electromagnetic register MR connected in series with the transistor collector and the −64V supply. Zener diode Z1 provides additional bias to transistor TR16.



‡ Total Resistance of R55 and MR Should be 3kΩ

FIG. 3

FIG. 2



‡ R6 + Source Impedance > 5kΩ

Power Supplies

The scaler requires four different voltages and these can be supplied from a single power supply unit. The supply details are as follows:

+500V	+10%, −15%	at 0·5mA per stage
+45V	±5%	at 12mA per stage
−9·1V	±5%	at 5mA per stage
−64V	±5%	at 12mA per stage

To this should be added the requirements of the input and output circuits:

INPUT CIRCUIT	−9·1V	±5% at 3mA
OUTPUT CIRCUIT	−9·1V	±5% at 1·5mA
	−64V	±5% at 10mA using a 2·5KΩ mechanical register

To obtain such supplies, a specially designed transformer is required as it is not practical to design a potential divider circuit with sufficient stability to maintain the output voltages within the 5% tolerance limits. It was decided, therefore, to take advantage of this and to base the power supply unit on a transistor d.c. converter operating from a 12 volt source.

Fig. 4 shows the circuit diagram of the d.c. converter which was used in the prototype scaler. The output is sufficient to drive four stages of electronic counting and an additional stage of electromechanical counting. Sufficient additional power is available to operate a standard geiger-müller tube via a suitable voltage divider circuit. The converter has three secondary windings. Winding 2 in conjunction with rectifier diode D16 and capacitor C15 gives +500V d.c. Winding 4, which is centre tapped, in conjunction with diodes D17 and D18 and capacitor C16 supplies +45V d.c. Winding 3 is also centre tapped and provides −64V d.c. direct and −9·1V d.c. via the zener diode Z2.

The Transformer

At first sight the transformer seems complicated. If, however, the detailed instructions for winding which are given below are followed closely, even the most inexperienced person should be able to make up a transformer that operates successfully.

Instructions for Winding

BOBBIN: Make or obtain a mandrel ½″ square and about 6″ long and place over this three layers of writing paper. Construct a bobbin 1½″ long on the mandrel from thin cardboard (a cigarette packet for example), winding three layers with all overlapping faces glued. When dry, ensure that the bobbin slips over the paper on the mandrel.

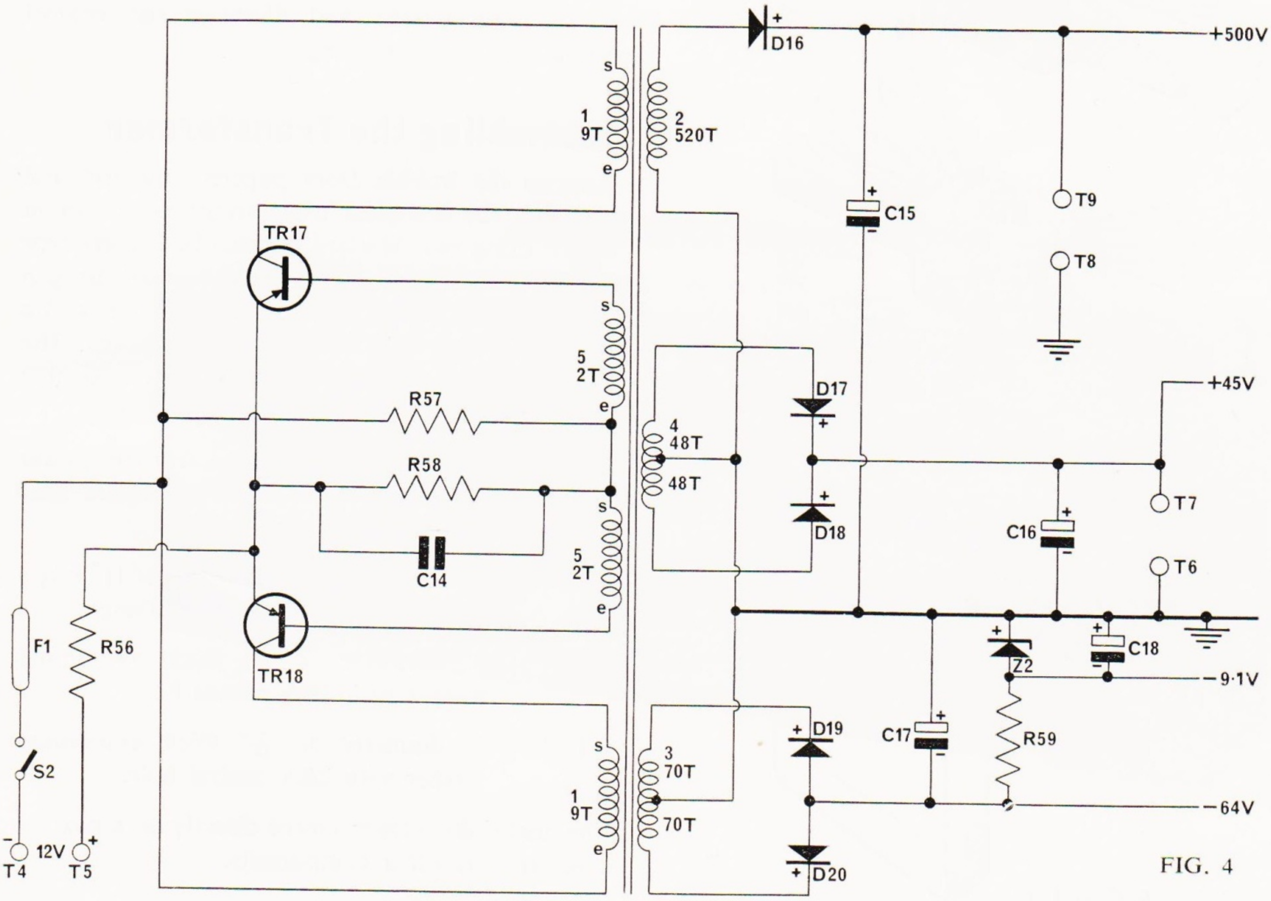
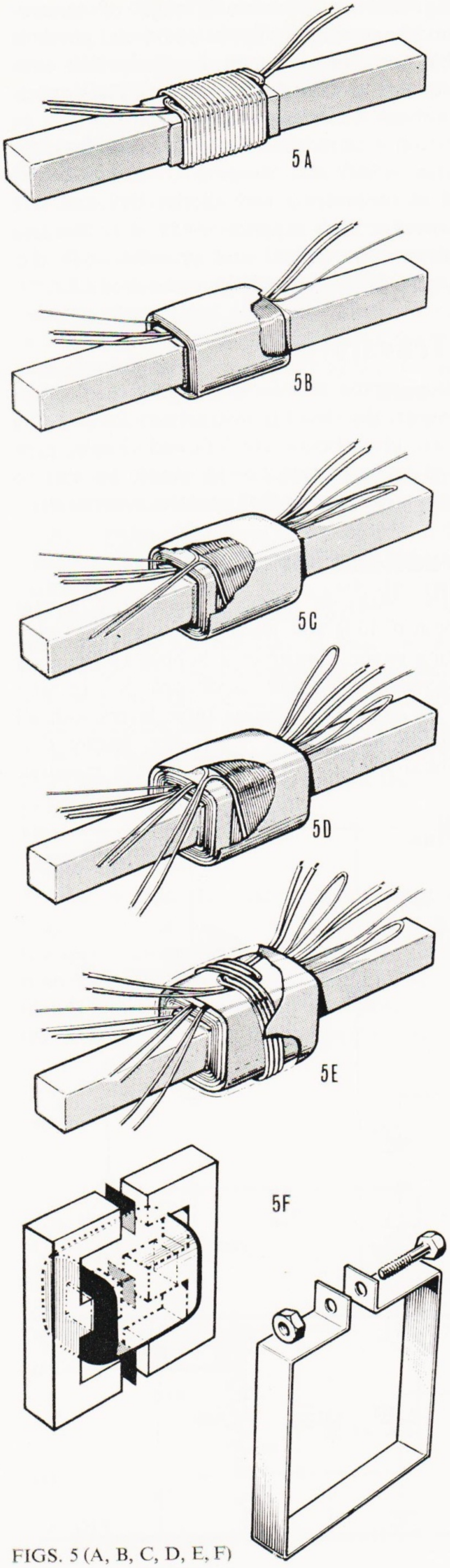


FIG. 4



FIGS. 5 (A, B, C, D, E, F)

COLLECTOR WINDING (1): 2×9 turns bifilar wound in single layer using 24swg plastic covered single strand wire. To ensure that the finished winding is fixed securely to the bobbin, it is suggested that the pairs of windings are placed as shown in fig. 5A. Finally, cover with a single layer of thin cardboard.

SECONDARY WINDING (2): 520 turns of 36swg enamelled copper wire in three layers, each separated by one layer of writing paper as shown in fig. 5B. Cover with a single layer of thin cardboard.

SECONDARY WINDING (3): 140 turns of 24swg enamelled copper wire in two layers. Bring out centre tap at 70 turns as shown in fig. 5C. Cover with one layer of thin cardboard.

SECONDARY WINDING (4): 96 turns of 24swg enamelled copper wire in two layers. Bring out centre tap at 48 turns as shown in fig. 5D. Cover with one layer of thin cardboard.

BASE WINDING (5): 2×2 turns bifilar wound in single layer using 24swg plastic covered single strand wire. To ensure winding is secure, interlock wire ends as shown in fig. 5E and cover with one layer of thin cardboard.

NOTE: Ensure that all windings are commenced in the same direction and that cellulose compound backed tape is not used anywhere in the transformer as cellulose attacks and dissolves the enamel insulation on the windings.

Assembling the Transformer

Remove the bobbin from papered mandrel and assemble the complete transformer as shown in fig. 5F using two Mullard ferroxcube E cores type FX1819. It is advisable to have a small air gap between the touching faces of the two cores and a single thickness of writing paper is suggested. The metal clamp used to hold the final assembly together can be made from tin plate.

HEAT SINKS: All the semiconductors in the power supply unit except the zener diode require heat sinks. Details are as follows:

TR17, 18	For each transistor 4″ length of $1\frac{1}{2}''\times1\frac{1}{2}''$, $\frac{1}{8}''$ thick L-shaped aluminium angle.
D16	$\frac{3}{4}''$ diameter × $\frac{1}{8}''$ thick aluminium washer with 2BA central hole.
D17-20	$\frac{5}{8}''$ diameter × $\frac{1}{16}''$ thick aluminium washer with 2BA central hole.

The heat sinks were mounted directly on a paxolin sheet as were other components.

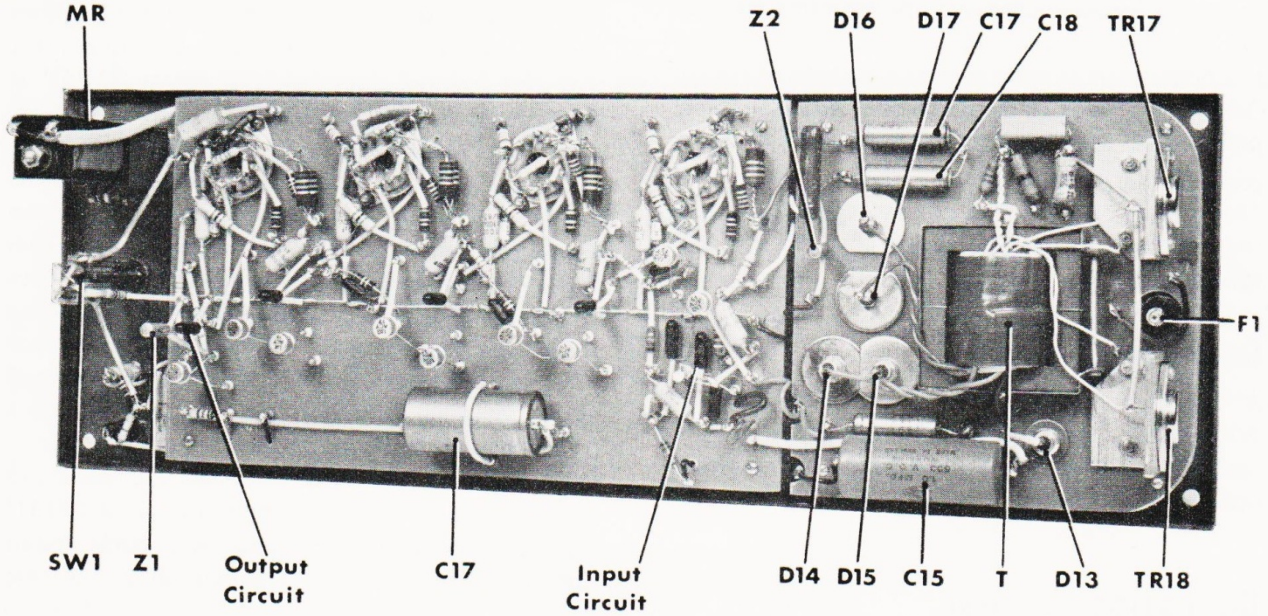

MR
Z2
D16
D17
C17
C18
TR17
F1
SW1
Z1
Output Circuit
C17
Input Circuit
D14
D15
C15
T
D13
TR18

FIG. 6

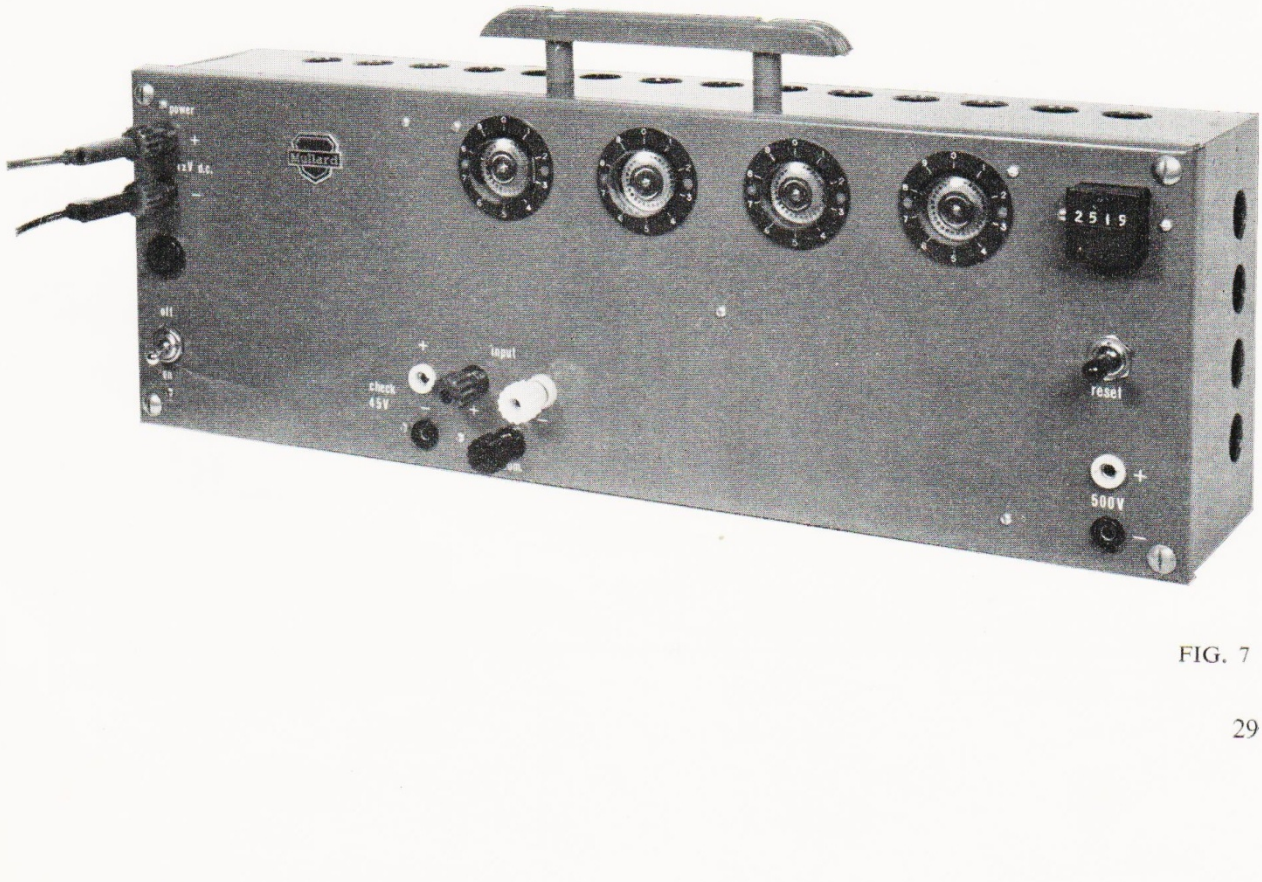

power
+
12V d.c.
−
Mullard
2515
off
on
check 45V
+
−
input
+
−
reset
+
500V
−

FIG. 7

Construction

Figs. 6 and 7 show internal and external views of the prototype unit which has four stages and an electromagnetic register. Layout should present little difficulty and if the power supply section is placed at one end of the box, there should be no danger of induced signals in the counting circuits. For convenience, apart from input terminals, two additional pairs of 4mm sockets have been provided. One pair is used to monitor and check the 45V supply and the other pair provides 500V for a geiger-müller tube circuit.

The box used for the prototype was not a standard conduit box but was of dimensions 18″×6″×4″ with knock-outs.

Components List

A full list of components is given on page 31. Where value tolerances are stated, these are the maximum tolerances allowable for correct circuit operation. Working voltages, where shown, are minimum preferred values.

Operation and Use

When the unit is completed, the off-load outputs from the power supply should be checked. If these are approximately correct, they should be checked again with the scaler operating. Final adjustments of output can, if necessary, be made by altering the nominal value of resistor R56 in the power supply unit. The total current drawn by the power unit is of the order of 1·5A and it is therefore possible to operate from dry batteries for a short time. Periodic measurements of the output voltage should be made, however, by checking the +45V rail which, as stated, can be brought out to 4mm sockets on the panel of the scaler. It is important that this voltage does not fall below 42·75V if the scaler is to operate correctly.

This scaler can count most standard waveforms up to a maximum frequency of 400Hz and these include sine waves, square waves and pulses from a geiger-müller tube. The only precautions which should be taken are that the amplitude of the waves should not exceed 10V r.m.s. and that when feeding signals direct to transistor TR2, the total impedance of the signal source and resistor R6 should exceed 5kΩ. Coupling capacitors can be used to block direct current to the input circuit if necessary.

It might be of interest to note that the scaler can be used as a time standard by feeding in a 100 Hz signal derived from the ripple in a 50Hz mains operated full wave rectifier circuit. In such a case the scaler can indicate time measurements down to 10 milliseconds. It is suggested that a 12 volt secondary on a standard mains transformer is connected to a four diode bridge circuit to provide the necessary 100 cycle signal.

COMPONENTS LIST

Resistors

No.	Value	Tol.	Watts
R1 R20 R30 R40 R50	820kΩ	7%	¼
R2	470kΩ	7%	¼
R3	100Ω	7%	¼
R4 R17 R27 R37 R47	47kΩ	7%	¼
R5 R7	12kΩ	7%	¼
R6	see text		¼
R8	10kΩ	7%	¼
R9 R13	1·5kΩ	7%	¼
R10	4·7kΩ	7%	¼
R11	6·8kΩ	7%	¼
R12	270Ω	7%	¼
R14 R24 R34 R44	270kΩ	7%	¼
R15 R25 R35 R45	120kΩ	10%	¼
R16 R26 R36 R46	9·1kΩ	7%	1
R18 R28 R38 R48	150kΩ	10%	¼
R19 R29 R39 R49	10MΩ	10%	½
R21 R31 R41 R51	33kΩ	7%	¼
R22 R32 R42 R52	330kΩ	5%	¼
R23	2·2kΩ	7%	¼

No.	Value	Tol.	Watts
R33 R43 R53	5·6kΩ	7%	¼
R54	47kΩ	7%	½
R55	see text		¼
R56	2×5·6Ω in parallel	5%	6 w.w.
R57	1·5kΩ	5%	½
R58	20Ω	5%	2 w.w.
R59	2·2kΩ	5%	2 w.w.

w.w. indicates wire wound.

Capacitors

No.	Value	Voltage	Type
C1	1μF	250V	paper
C2	0·22μF	125V	paper
C3	0·047μF	125V	moulded 10%
C4	0·01μF	125V	moulded 10%
C5	470pF	125V	mica 5%
C6	0·022μF	125V	moulded 10%
C8 C10 C12	0·018μF	125V	moulded 10%
C7 C9 C11 C13	1200pF	125V	moulded 10%
C14	1μF	125V	moulded 10%
C15	1μF	500V	paper
C16 C17	64μF	64V	electrolytic
C18	32μF	64V	electrolytic

Transistors

TR1, 2, 3, 6, 9, 12, 15	Mullard ACY20 or OC75
TR4, 5, 7, 8, 10, 11, 13, 14, 16	Mullard ACY17
TR17, 18	Mullard OC35

Diodes

D1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 15	Mullard OA91 or OA81
D3, 6, 9, 12	Mullard OA202
D16	Mullard BY127* or OA211 or BY100
D17, 18, 19, 20	Mullard BY126* or OA210

Zener Diodes

Z1	Mullard BZY88C5V1 or OAZ200
Z2	Mullard BZY88C9V1 or OAZ207

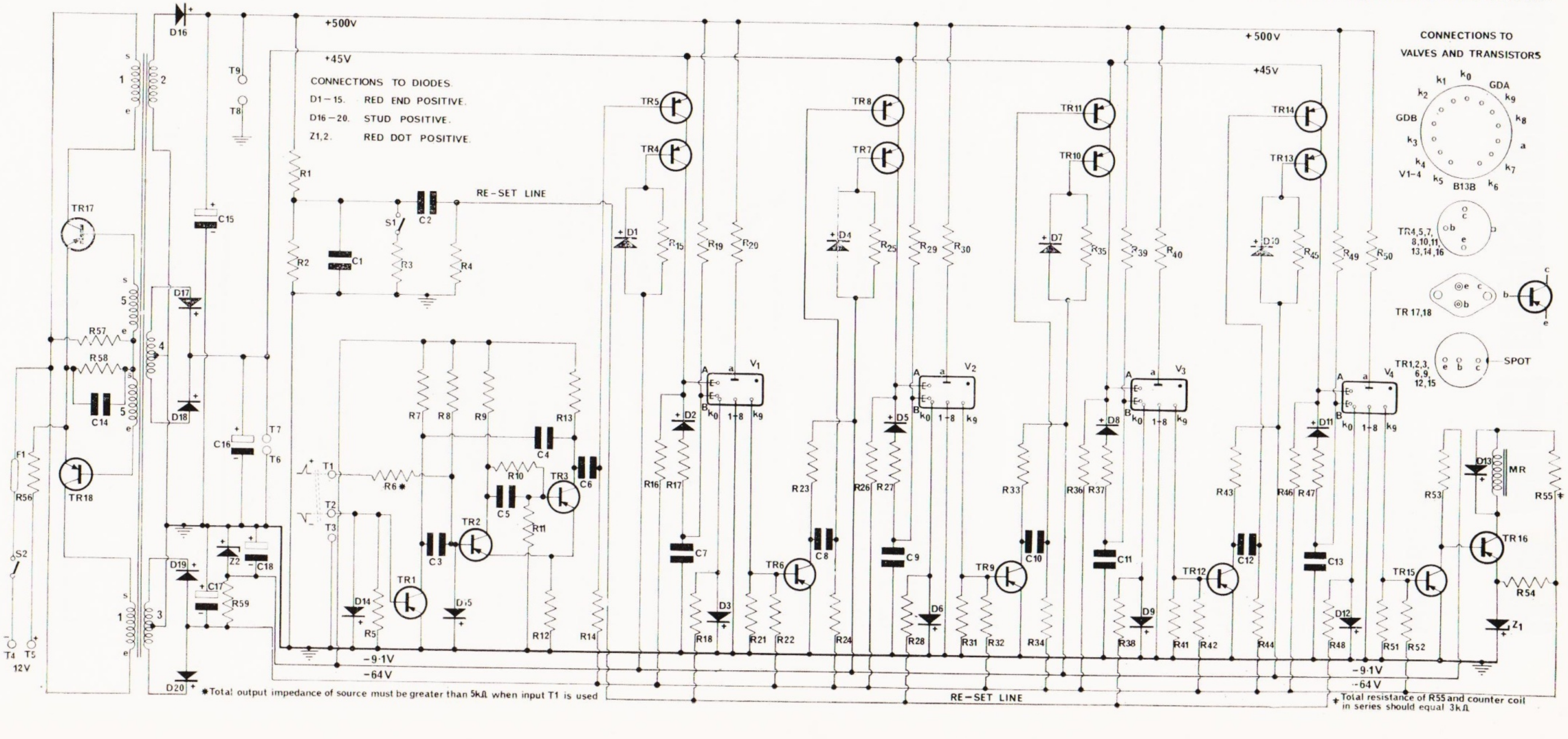
Counting Tubes

V1-4	Mullard Z504S
Valve bases	4×B13B
S1	Single-pole, spring-loaded, press to make toggle switch
S2	Single-pole, on/off switch
MR	High resistance electromagnetic register—resistance 2–3kΩ

Transformer Core - 2 Mullard Ferroxcube E cores type FX1819

T1–5	Screw down terminals with 4mm sockets
T6–9	4mm shrouded sockets
F1	2·5A fuse and holder

*No heat sinks required with BY127 or BY126.


CONNECTIONS TO DIODES.
D1–15. RED END POSITIVE.
D16–20. STUD POSITIVE.
Z1,2. RED DOT POSITIVE.

CONNECTIONS TO VALVES AND TRANSISTORS

*Total output impedance of source must be greater than 5kΩ when input T1 is used

†Total resistance of R55 and counter coil in series should equal 3kΩ

Hall effect measurements

Introduction

The Hall Effect is named after E. H. Hall who discovered it in 1879 in the Rowland Laboratory of the Johns Hopkins University. He was experimenting with a strip of gold leaf and found that a magnetic field perpendicular to the strip caused a deviation of the charge carriers in the material. The effect is of great importance in the semiconductor field since it allows a measurement to be made of the charge carrier density and also allows determination of the polarity of the carriers i.e. electrons or holes.

Theory

If a suitable specimen of metal or n-type (excess negative charge carriers) semiconductor material has its end faces connected to a battery, electrons will flow from left to right (FIG. 1). A magnetic field (B) applied perpendicularly to the paper exerts a force on the electrons, causing a few of them initially to drift towards side Q of the material. This initial drift of electrons sets up a transverse electric field between faces R and Q opposing the drift of further electrons and the transverse current rapidly falls to zero.

The potential difference between faces Q and R can be measured with a high impedance voltmeter and is called the *Hall Voltage* (V_H). The polarity of V_H is in most cases governed by the predominant carriers in the material i.e. electrons in n-type and holes in p-type. If holes are the predominant carriers they drift from right to left in FIG. 1 and on applying the magnetic field a few are caused initially to drift towards the side Q. The polarity of the voltage between Q and R is therefore different from the case of an n-type sample.

Measurement of the Hall voltage, field strength, current and material thickness enables the calculation of a quantity known as the *Hall Coefficient* (R_H).

$$R_H = \frac{V_H \times t \times 10^8}{I \times B} \text{ cm}^3/\text{Coulomb} \qquad (1)$$

where V_H = Hall voltage in volts
t = material thickness in centimetres
I = current through material in amperes
B = flux density in gauss

The electron concentration *n* (or in the case of a p-type semiconductor, the hole concentration *p*) is given by the formula:

$$n \text{ (or } p) = \frac{1}{R_H \times e} \text{ cm}^{-3} \qquad (2)$$

where $e = 1{\cdot}6 \times 10^{-19}$ Coulombs.

One of the most commonly measured electrical properties of a semiconductor is its resistivity (ρ). This can easily be obtained by measuring the voltage V_ρ between two points, using a high impedance voltmeter, as shown in FIG. 2. The value of ρ can be calculated using the equation:

$$\rho = \frac{V_\rho \times w \times t}{I \times \ell} \ \Omega\text{cm} \qquad (3)$$

where V_ρ = voltage between the two points in volts
w = material width in centimetres
t = material thickness in centimetres
I = current through material in amperes
ℓ = distance between the two points in centimetres.

The results obtained in equations (1) and (2) can be used to calculate the carrier mobility (μ). This is the drift velocity of the charge carrier acquired per unit electric field and is given by:

$$\mu = \frac{R_H}{\rho} \text{ cm}^2/\text{volt sec.} \qquad (4)$$

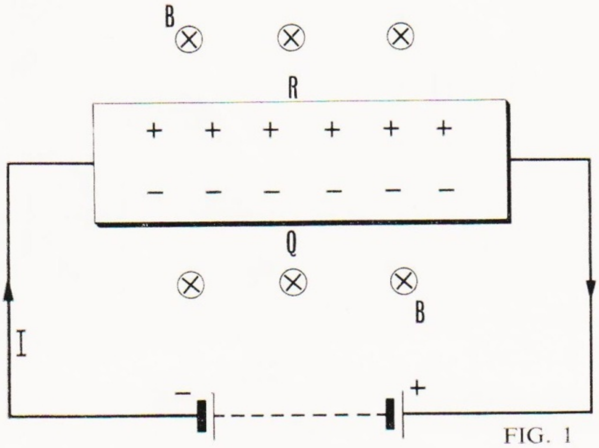


FIG. 1

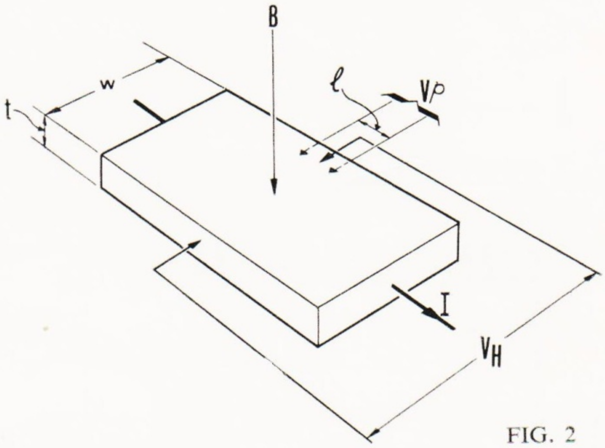


FIG. 2

Materials

Hall effect is present in all metals but is more easily measured in the semiconductor materials. With most metals, the Hall voltage is very small and large fields must be applied before any indication is possible, even on the most sensitive instruments.

Experiments were successfully carried out using normal-production transistor base wafers which measure approximately 5 × 5 × 0·4mm. These wafers were of n-type germanium and can be purchased from the Mullard Educational Service. In practice, it was found convenient to make contacts to the corners of the wafer as shown in Figures 3 and 4.

FIG. 4 shows the completed prototype viewed from both sides. The sketch is drawn to scale and can be used as a template when constructing the holder.

Practical Measurements

The circuit of FIG. 3 is set up and RV2 is varied to set the current at a convenient value. This value will depend upon the size of the material, the size of the field and the sensitivity of the instrument measuring V_H. R3 is a fixed limiting resistor necessary to prevent excessive current and subsequent damage to the sample. For the wafer quoted, the current should not exceed 12mA.

If two contacts are used for the voltage measurement and they are not exactly opposite each other, a residual voltage will be indicated on the voltmeter*, even before a field is applied. To eliminate this voltage, three contacts (a, a′, a″) are used with a potentiometer RV1 and the null point is obtained before applying the field. The field is then applied and the voltage measured.

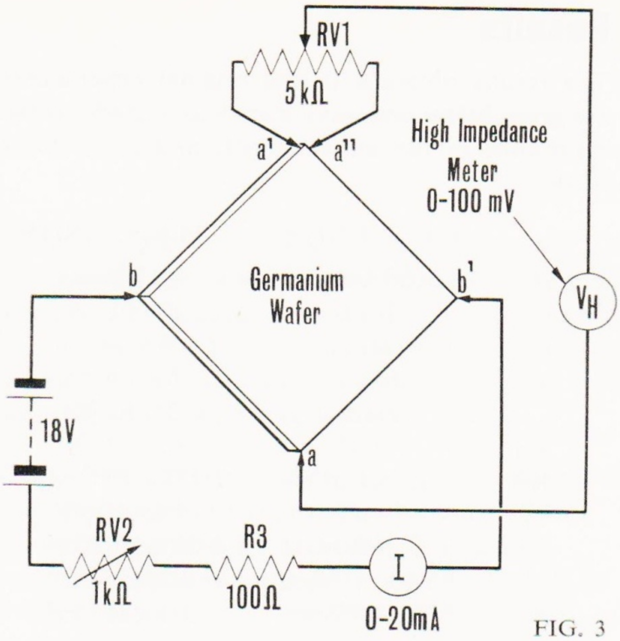


FIG. 3

The field direction and current direction can be reversed in turn, four values of V_H obtained and a mean value calculated. The various measurements taken can then be substituted in equation (1) to obtain R_H and, in turn, R_H used to calculate n.

The resistivity of the sample can also be measured (with the field removed) by passing a known current through the sample and measuring the potential drop (V_ρ) across the contacts a′ and a″. RV1 must be disconnected when this measurement is taken. Use formula (3) to calculate ρ and substitute this value for ρ in equation (4) to obtain the carrier mobility (μ).

When making the above calculations some difficulty can arise unless care is taken with the units mentioned earlier. Many authors quote widely differing quantities and systems and in the section marked Theory all calculations are made in terms of volts, amperes, centimetres and gauss.

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* A suitable instrument is described in this book. The 1MΩ/VOLT D.C. VOLTMETER.

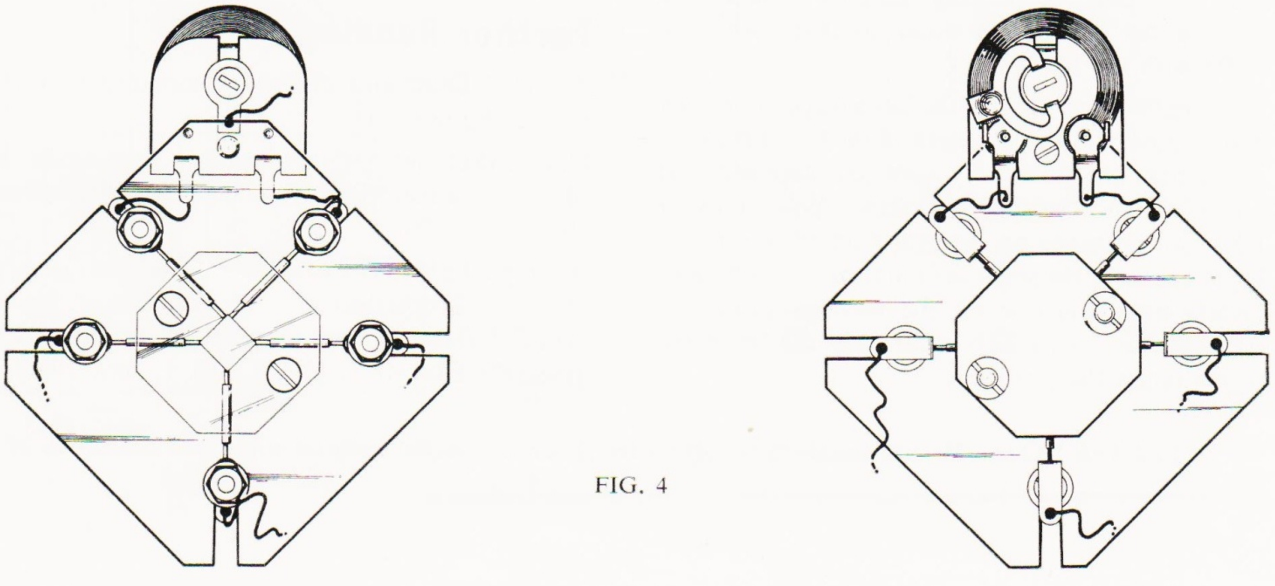


FIG. 4

Results

The results obtained in the original experiments are given below and serve merely as a guide to the magnitude of the measurements and calculations made.

	C.G.S. UNITS	M.K.S. UNITS
B	1000 Gauss	$0{\cdot}1\,\mathrm{Wb/m^2}$
I	3mA	$3\times10^{-3}\mathrm{A}$
t	0·38mm	$3{\cdot}8\times10^{-4}\mathrm{m}$
ω	6mm	$6\times10^{-3}\mathrm{m}$
l	2mm	$2\times10^{-3}\mathrm{m}$
V_H	9·3mV	$9{\cdot}3\times10^{-3}\mathrm{V}$
R_H	$11{,}780\,\mathrm{cm^3/C}$	$1{\cdot}178\times10^{-2}\mathrm{m^2/C}$
V_ρ	94mV	$9{\cdot}4\times10^{-2}\mathrm{V}$
ρ	3·56Ωcm	$3{\cdot}56\times10^{-2}\Omega\mathrm{m}$
μ	$3{,}300\,\mathrm{cm^2/Vsec}$	$0{\cdot}33\,\mathrm{m^2/Vsec}$
n	$5{\cdot}3\times10^{14}/\mathrm{cm^3}$	$5{\cdot}3\times10^{8}/\mathrm{m^3}$

Apparatus

The specimens which we can supply for testing are usually fairly small and fragile and for this reason it is recommended that some form of holder be made. It is difficult to connect wires to the surfaces of the material and thus it is suggested that spring-loaded point contacts are employed.

In the prototype holder, 8mm watch-strap bars were used and held in position by solder tags which also served as terminals. An exploded view of the holder is shown in FIG. 5 and the only component requiring any degree of accuracy of manufacture is the Perspex piece containing the bars and wafer. The centre hole can be drilled and then filed out with a $\frac{1}{8}$ inch square file until it is 5mm square. The holes for the watch-strap bars are drilled into the sides of the Perspex using a size 52 drill. The piece of packing material is necessary to raise the germanium wafer so that contact is made with the bars.

The length of the slots on the large piece of Perspex will be governed by the length of the bars obtained. These bars are stocked by most jewellers and cost a few shillings each. The balance potentiometer RV1 can be made an integral part of the holder by using one of the small carbon trimming potentiometers now available on the market. These are typically less than 1 inch square and can be bolted to the larger Perspex piece.

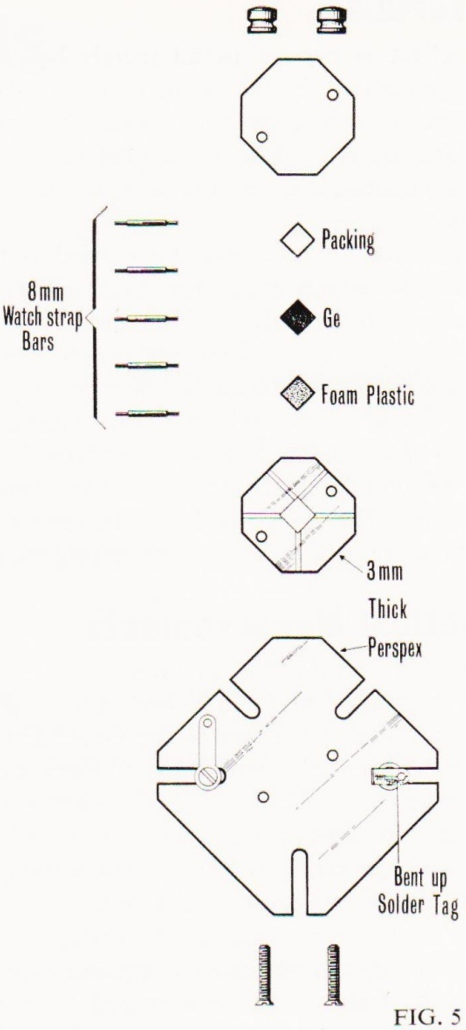


FIG. 5

This leaflet is intended only as a guide and other experiments possible, though not attempted, include variation of resistivity, and hence carrier mobility, with temperature, the effect on Hall voltage of various temperatures, and the measurement of magnetic fields once the initial results are obtained for a given sample.

Further Reading

The Hall Effect and Related Phenomena by E. H. Putley (Butterworth).

Hall Effect in Semiconductor Compounds by M. J. O. Strutt (Electronic and Radio Engineer 1959, pp. 2–10).

A Simple Laboratory Method for the Measurement of Some Properties of a Semiconductor, by B. Stuttard (International Journal of Electrical Engineering Education, Vol. 1, No. 1, June 1963).

PLEASE NOTE: We are unable to supply pieces of semiconductor material with leads connected.

a.f./r.f. oscillator

Introduction

The unit described here comprises two oscillators in one box. The audio oscillator section provides an extremely stable 1V output over the theoretical frequency range 15Hz to 20kHz and the radio frequency section provides an output over the frequency range 260kHz to 11·5MHz. Provision is made for the radio frequency to be modulated by the audio frequency.

The circuit is a 'hybrid' using three transistors and a low voltage pentode and it operates from a 12 volt d.c. supply.

Circuit Description

The complete circuit is illustrated in Fig. 1. The audio oscillator section is a Wien bridge circuit incorporating transistors TR1, TR2 and TR3, the frequency of the output being determined by the values of resistors RV11, R12, capacitors C6, C7 or C8 and resistors RV10, R9, capacitors C3, C4 or C5. Switch S_1A, B therefore acts as the coarse frequency control and ganged variable resistors RV10 and RV11 as the fine frequency control.

Thermistor R4 in conjunction with capacitor C1 maintains the output at a relatively constant amplitude irrespective of frequency, the measured stability being better than 2%. To avoid distortion, the external loading of the oscillator via socket SK1 and gain control RV7 should not be less than 1kΩ.

With the component values shown, the measured frequency ranges of the prototype were as follows:

With capacitors C5 and C8	15 to 200Hz
With capacitors C4 and C7	150Hz to 1·9kHz
With capacitors C3 and C6	1·4 to 19kHz

The radio frequency oscillator section uses the low voltage pentode V1 in a conventional transitron circuit, the output frequency being determined by variable capacitor CV15 and inductance L1, L2, L3 or L4.

The three pole switch S_4A, B and C is the coarse frequency control, any given position of which brings into circuit the appropriate inductance and series resistance (R22, R22+R21 or R22+R21+R20).

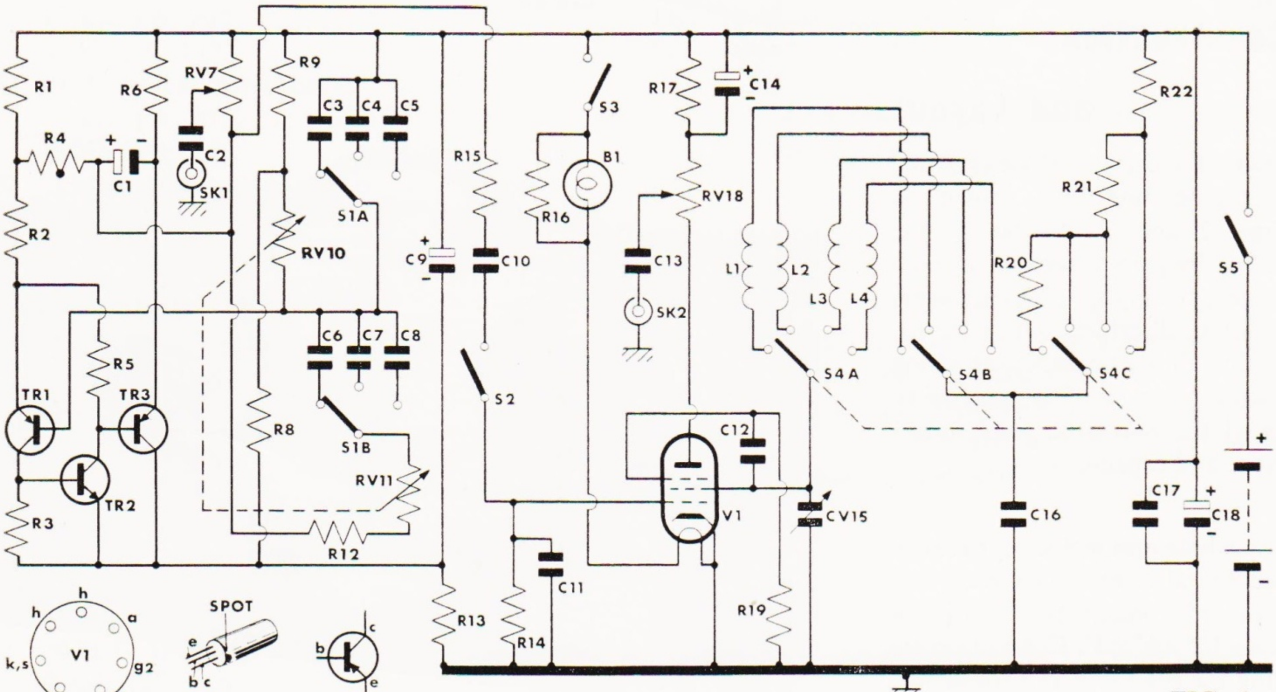


FIG. 1

Switch S2 is the modulation on/off switch and S3 is the on/off switch for the r.f. section. It will be seen that the heaters of the valve operate from the 12 volt supply via bulb B1 which not only reduces the voltage at the heater to the required 6 volt but also acts as a visual indication when the r.f. section is on.

The output from the r.f. section is taken from co-axial socket SK2 via gain control RV18 and capacitor C13. Switch S5 is the main on/off switch and is arranged so that, for the r.f. section to be on, both switches S5 and S3 have to be operated.

The current drawn by the audio frequency section is 12mA and by the r.f. section is 325mA, nearly all of which is needed for the valve heater.

The unit as a whole operates successfully over the input voltage range 9·5 to 13 volts, the variation in output frequency being only about 1·5% over this large input voltage range. In comparison, however, the amplitudes of both the r.f. and the a.f. outputs vary considerably as the supply voltage falls.

Construction and Layout

Internal and external views of the prototype unit are shown in Figs. 2 and 3. As far as the audio frequency section is concerned, the layout of components is not at all critical but in the r.f. section all inter-component wiring should be as short as possible to avoid the effects of stray inductance and capacitance.

The whole unit including batteries was found to fit conveniently in a standard conduit box of dimensions 12″ × 6″ × 3″. Connection coding for the valve and transistors is shown in the circuit diagram.

Construction of Inductances

Four frequency ranges were incorporated in the radio frequency section. Not all these ranges overlap as this is not strictly necessary if only the normal broadcast bands and intermediate frequencies need be covered. The four coils which were constructed for the prototype covered the following frequency ranges:

L1	260 to 400kHz	(long wave)
L2	450 to 950kHz	(lower medium wave and 465kc/s i.f.)
L3	900kHz to 2·1MHz	(upper medium wave)
L4	4·5 to 11·5MHz	(short wave and 10MHz i.f.)

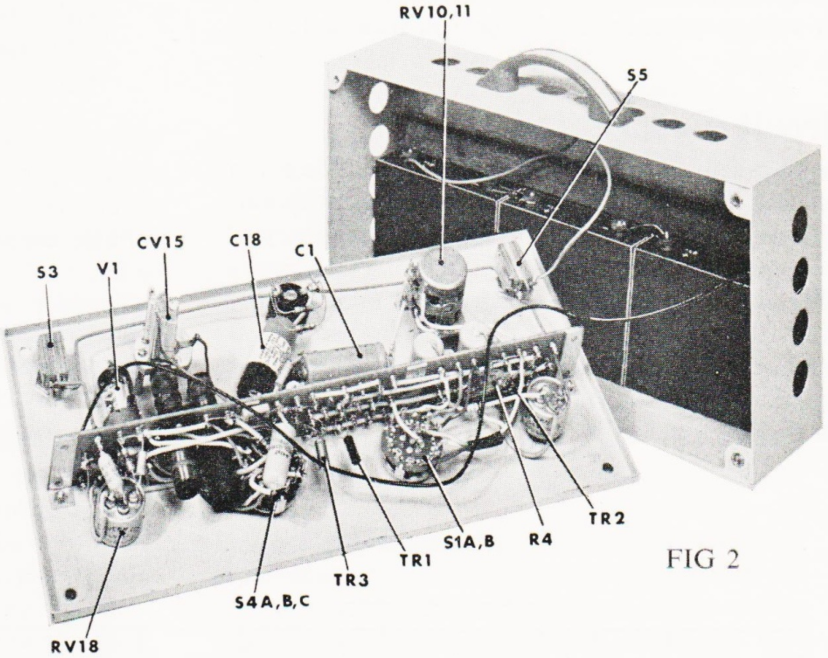


FIG 2

FIG 3

All the coils were wound on similar formers which were 3cm long and 1·2cm external diameter. Winding details are as follows:

L1 440 turns 42s.w.g. (0·0040″) enamelled copper wire wound in four groups of 110 turns (see Fig. 4).
L2 300 turns 40s.w.g. (0·0048″) enamelled copper wire wound in four groups of 75 turns (see Fig. 4).
L3 120 turns 36s.w.g. (0·0076″) enamelled copper wire, close wound in a single layer.
L4 35 turns 24s.w.g. (0·022″) enamelled copper wire, close wound in a single layer.

For the frequency ranges shown, no composition cores are required in these coils. These ranges could, however, be extended if such cores were used.

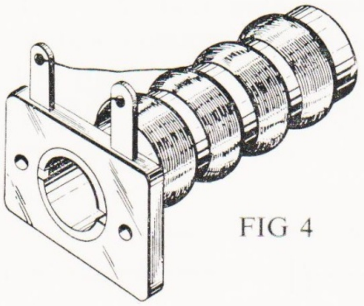


FIG 4

Components List

R1	100Ω, ¼W, 10%	
R2	1·2kΩ, ¼W, 10%	
R3	1·5kΩ, ¼W, 10%	
R4	STC thermistor type R53	
R5	6·8kΩ, ¼W, 10%	
R6	470Ω, ¼W, 10%	
RV7	1kΩ, potentiometer, linear	
R8	6·8kΩ, ¼W, 10%	
R9	820Ω, ¼W, 10%	
RV10	10kΩ, carbon potentiometer	log. ganged, ±5%
RV11	10kΩ, carbon potentiometer	
R12	820Ω, ¼W, 10%	
R13	100Ω, ¼W, 20%	
R14	220Ω, ¼W, 20%	
R15	47kΩ, ¼W, 20%	
R16	47Ω, ½W, 5%	
R17	100Ω, ¼W, 5%	
RV18	500Ω, carbon potentiometer, linear w.w. 5%	
R19	1MΩ, ¼W, 5%	
R20	470Ω, ¼W, 2%	
R21	1kΩ, ¼W, 2%	
R22	2·2kΩ, ¼W, 2%	
C1	1000μF, 15V wkg.	
C2	0·1μF, 12V wkg.	
C3	0·01μF, 12V wkg., HS close tolerance	
C4	0·1μF, 12V wkg., HS close tolerance	
C5	1μF, 12V wkg., HS close tolerance	
C6	0·01μF, 12V wkg., HS close tolerance	
C7	0·1μF, 12V wkg., HS close tolerance	
C8	1μF, 12V wkg., HS close tolerance	
C9	64μF, 16V wkg.	
C10	0·01μF, 12V wkg., 20%	
C11	0·02μF, 12V wkg., 20%	
C12	0·01μF, 12V wkg., 5% non-inductive mica	
C13	0·01μF, 12V wkg., 20%	
C14	6·4μF, 6V wkg.	
CV15	150pF, tuning capacitor, log. law	
C16	0·47μF, 12V wkg., 20%	
C17	1000pF, 25V wkg., 20%	
C18	500μF, 25V wkg.	
S1	two-pole, three-way rotary switch	
S2	single-pole, two-way rotary switch	
S3	single-pole, two-way toggle switch	
S4	three-pole, four-way rotary switch	
S5	single-pole, two-way toggle switch	
L1	Long wave coil	see separate details
L2	Medium wave (1) coil	
L3	Medium wave (2) coil	
L4	Short wave coil	
SK1	Co-axial socket	
SK2	Co-axial socket	
B1	6·5V, 0·3A, MES pilot lamp and holder	
V1	Mullard EF98 and B7G holder	
TR1	Mullard OC45	
TR2	Mullard OC140	
TR3	Mullard OC72	
BAT	3×4·5V bell batteries (Ever Ready Type 126, for example)	

Calibration

The audio frequency section of the unit can be calibrated against a known source by the Lissajous figure or by the beat frequency method.

Calibration of the radio frequency section can also be carried out by comparison with another r.f. generator or directly against a wavemeter.

a binary adder/subtractor

Introduction

This unit has been designed primarily as an aid to the teaching of binary arithmetic. It is essentially a binary counter chain, each stage having its own independent set switch, enabling the student to set up a number and subsequently add to it or subtract from it. The results are indicated by 6 volt lamps. The unit can also accept and count pulses from an external source – a telephone dial for example.

The circuit given will accept square positive-going pulses. However, methods by which it can be modified for negative-going pulses are described. The unit is designed to count at a maximum rate of 500 pulses per second.

Circuit Description

The unit consists of a chain of 'bistable' circuits. Fig. 1 illustrates one such stage. The parts of the circuit drawn in broken line are practical additions to the basic circuit.

Transistors T11 and T12 are interconnected so that when T11 is fully conducting it holds T12 off and when T12 is fully conducting it holds T11 off. Two static states are therefore possible – hence the name 'bistable'.

Consider the condition where T11 is conducting. Its collector is then at about 0 volts and, due to the potential divider chain R35 and R38, the base potential of T12 is positive and T12 is held off. The collector of T12 is thus at about –6 volts

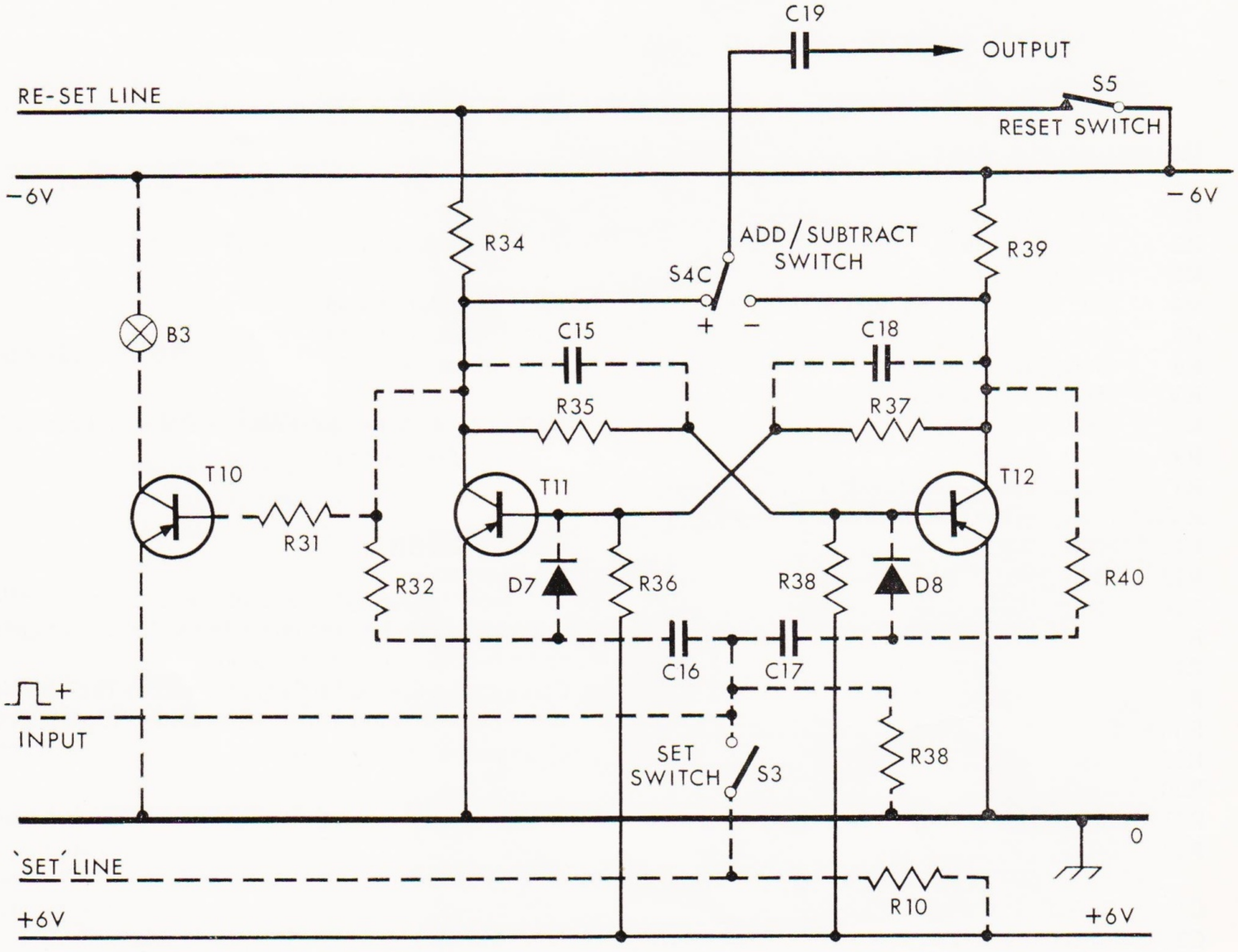


FIG 1

which holds T11 on via R37. The 'state' of the circuit may be changed over by applying a short positive-going pulse to the base of T11. As T11 commences to cut off its collector voltage falls, causing T12 to commence conducting. Once the change-over has been initiated cumulative action ensues, T12 'bottoming' rapidly and T11 cutting off. Components C15 and C18 are 'speed-up' capacitors added to increase the switch-over rate. To get the circuit to change its state again, the next incoming pulse must be applied to the base of T12. The incoming pulses are directed to the appropriate base by diodes D7 and D8. When T11 is off, the negative potential on its collector reverse biases D7 (via R32). The next incoming positive pulse will therefore get through to the base of T12 but not to the base of T11.

The state of the circuit is indicated by lamp B3, driven by transistor T10. The lamp lights indicating a '1' when T11 is non-conducting, its collector then being at about −6 volts, giving sufficient base current in T10 to cause it to saturate.

Switch S3 is a biased-to-break switch which enables a '1' to be put into the stage manually. When the switch is operated a positive pulse from the +6 volt line is applied to the gating diodes D7 and D8 (via capacitors C16 and C17). Switch S5 enables the entire unit to be re-set to the '0' condition. The switch is normally closed (biased-to-make). Momentary operation of S5 removes the negative bias from the base of T12 causing it to cut off. Thus the collector potential of T12 and therefore the base potential of T11 become negative. So, as the switch returns to its closed position, T11 conducts and the lamp is extinguished.

The output from the circuit is taken via the add/subtract switch S4 and C19 to the input of the next stage. An output pulse occurs as the collector potential of T11 rises from −6V to 0V due to T11 changing over from the cut-off to the conducting condition. Clearly an output pulse is obtained for every two input pulses i.e. each stage divides by 2. Thus every other pulse is 'carried' to the next stage.

Addition & Subtraction

Here the well-known 'addition of complement' method is used for subtraction. When the add/subtract switch is switched to 'subtract' the output pulses are inverted or 'complemented'. Hence it is the complements of numbers and not the numbers themselves which are added to the subsequent stages.

Inputs

The circuit is designed to receive square positive-going pulses of amplitude 3 to 12 volts. The constructor may wish to actuate the circuit from negative-going pulses. Possibly the easiest way of doing this is to use n-p-n transistors throughout (Mullard BFY52 is suitable), being careful of course to reverse the +6 and −6 volt supply lines and gating diodes.
Alternatively the squarer/inverter circuit illustrated in fig. 3 may be used. This has alternative inputs for negative and positive pulses. The circuit can be used to square the outputs from such sources as sinusoidal signal generators, sawtooth generators etc. The amplitude of the input should be restricted to the range 0·5 to 10 volts.

Power Supply

The requirement for a −6V 0 +6V power supply may be met by using large dry batteries or a mains powered supply unit. If dry batteries are used it is advisable to place large electrolytic capacitors (1000μF or more) across the supply lines. The current requirements are as follows:

at +6V	40μA per stage
at −6V	65mA per stage.

Most of the 65mA required from the negative supply is for the lamps. A suitable circuit for a mains powered supply unit is the 6 0 6V unit also described in this book.

Construction

The layout of components is not critical. Any number of stages may be employed according to individual requirements. The Educational Service prototype, illustrated in fig 4, contains seven stages, giving a most significant digit of 2^6. The circuit diagram, fig. 2, and list of components are arranged so that further stages may be conveniently added.

Components List

RESISTORS: (all ±10%, ⅛ watt)

R1, 3	12kΩ	(B803104NB/12k)
R2	see fig. 3	
R4	10kΩ	(B803104NB/10k)
R5, 9	2·2kΩ	(B803104NB/2k2)
R6	4·7kΩ	(B803104NB/4k7)
R7	270Ω	(B803104NB/270E)
R8	6·8kΩ	(B803104NB/6k8)
R10	1kΩ	(B803104NB/1k)
R11, 21, 31 etc.	4·7kΩ	(B803104NB/4k7)
R12, 22, 32 etc.	15kΩ	(B803104NB/15k)
R13, 23, 33 etc.	4·7kΩ	(B803104NB/4k7)
R14, 24, 34 etc.	1kΩ	(B803104NB/1k)
R15, 25, 35 etc.	4·7kΩ	(B803104NB/4k7)
R16, 26, 36 etc.	220kΩ	(B803104NB/220k)
R17, 27, 37 etc.	4·7kΩ	(B803104NB/4k7)
R18, 28, 38 etc.	220kΩ	(B803104NB/220k)
R19, 29, 39 etc.	1kΩ	(B803104NB/1k)
R20, 30, 40 etc.	15kΩ	(B803104NB/15k)

CAPACITORS:

C1	0·047μF	(C280AE/P47k)
C2	680pF	(C295AC/D680E)
C3	0·01μF	(C280AE/P10k)
C4	0·022μF	(C280AE/P22k)
C5, 10, 15 etc.	0·001μF	(C295AC/D1k)
C6, 11, 16 etc.	0·22μF	(C280AE/A220k)
C7, 12, 17 etc.	0·22μF	(C280AE/A220k)
C8, 13, 18 etc.	0·001μF	(C295AC/D1k)
C9, 14, 19 etc.	0·1μF	(C280AE/P100k)

SEMICONDUCTORS:

T1, 2, 3, 4, 7, 10 etc.	Mullard ACY20 or OC83 transistors
T5, 6, 8, 9, 11, 12 etc.	Mullard ACY20 or OC71 transistors
D1, 2, 3, 4, 5, 6, 7, 8 etc.	Mullard OA91 or OA95 germanium diodes.

SWITCHES:

S1, 2, 3 etc.	Single-pole toggle switch *biased to break position*
S4, A, B, C etc.	Two-way, multi-pole rotary switch
S5	Single-pole toggle switch *biased to make position*
S6 A, B	Two-way, two-pole on/off switch

MISCELLANEOUS:

4mm terminals, M.E.S. bulb holders

B1, 2, 3 etc.	6V, 0·05A bulb M.E.S. fitting.

NOTE: This components list is complete for three binary stages and is arranged so that the values of additional components required for additional stages are easily extracted.

Mullard part numbers given in brackets.

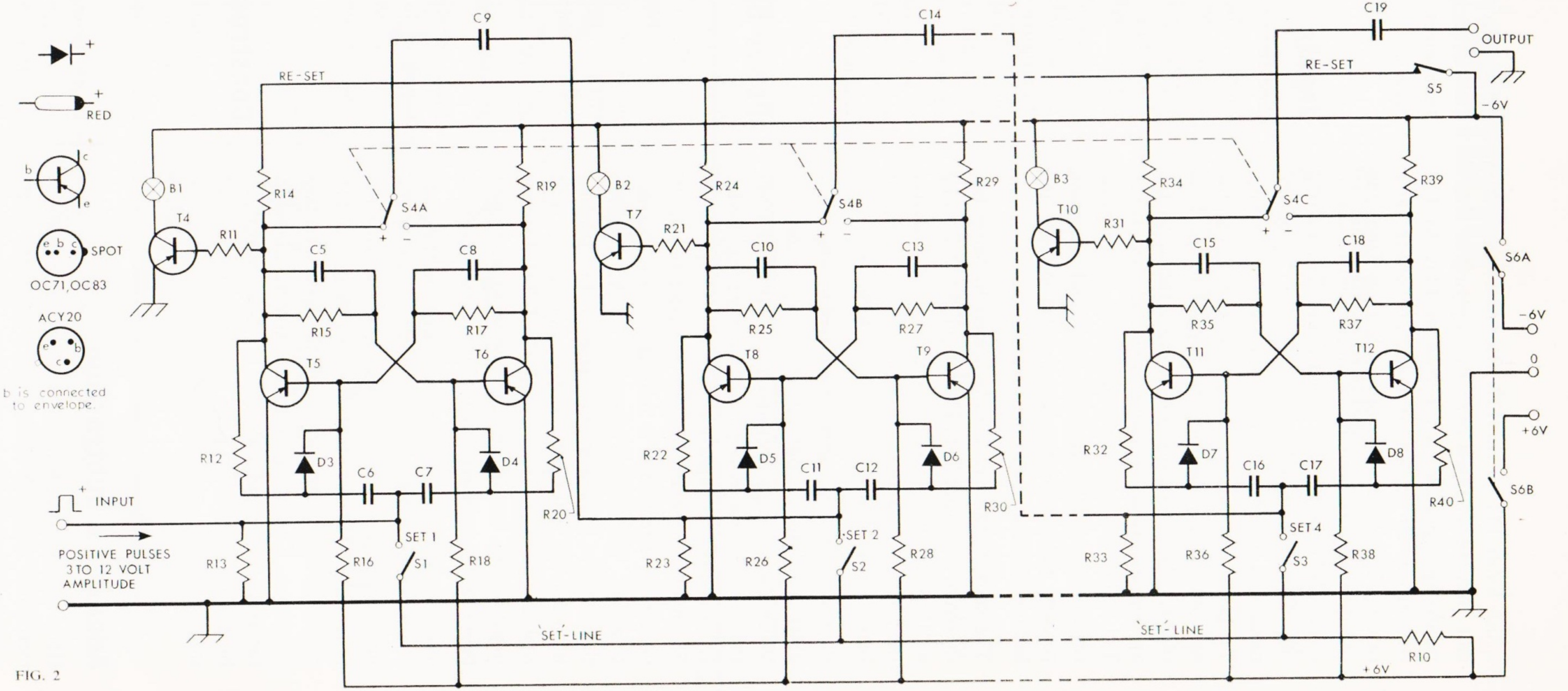
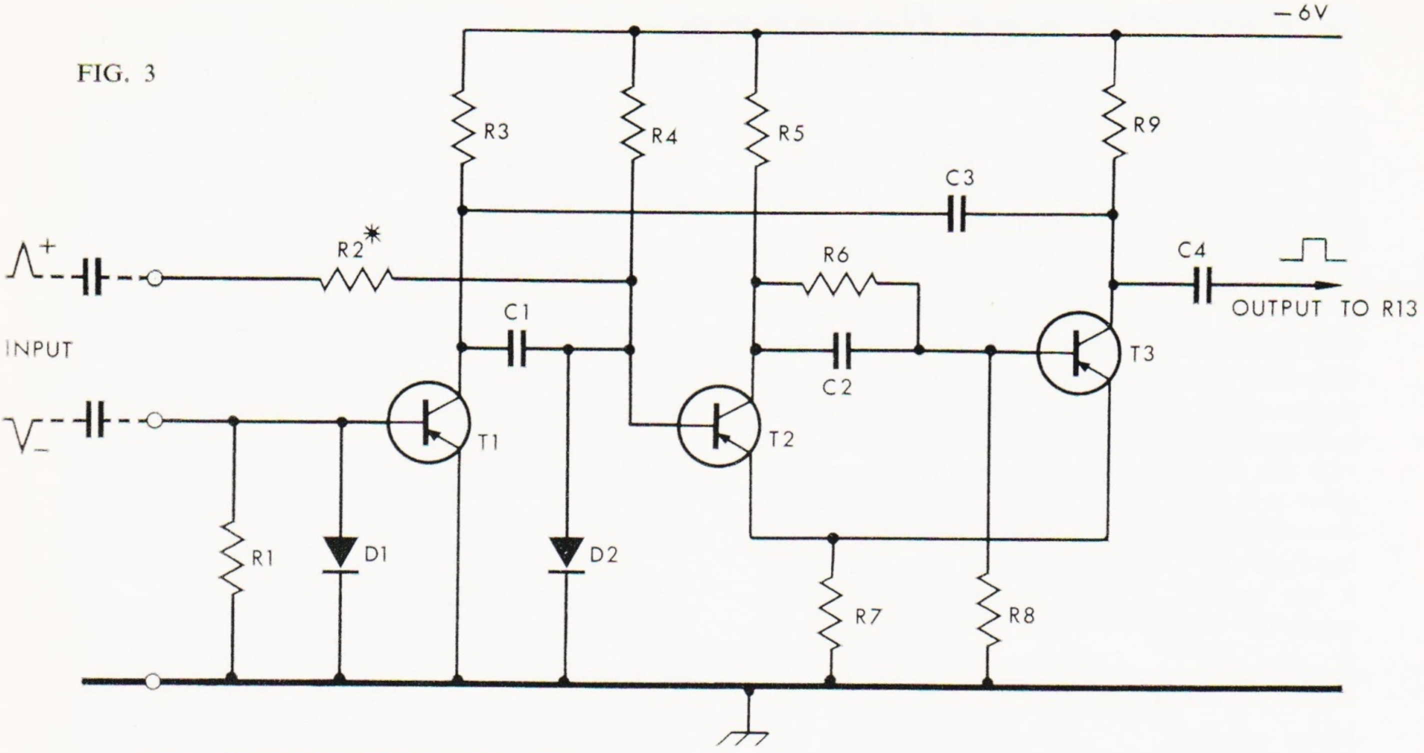


FIG. 2

FIG. 3



* R2 + SOURCE IMPEDANCE > 5kΩ

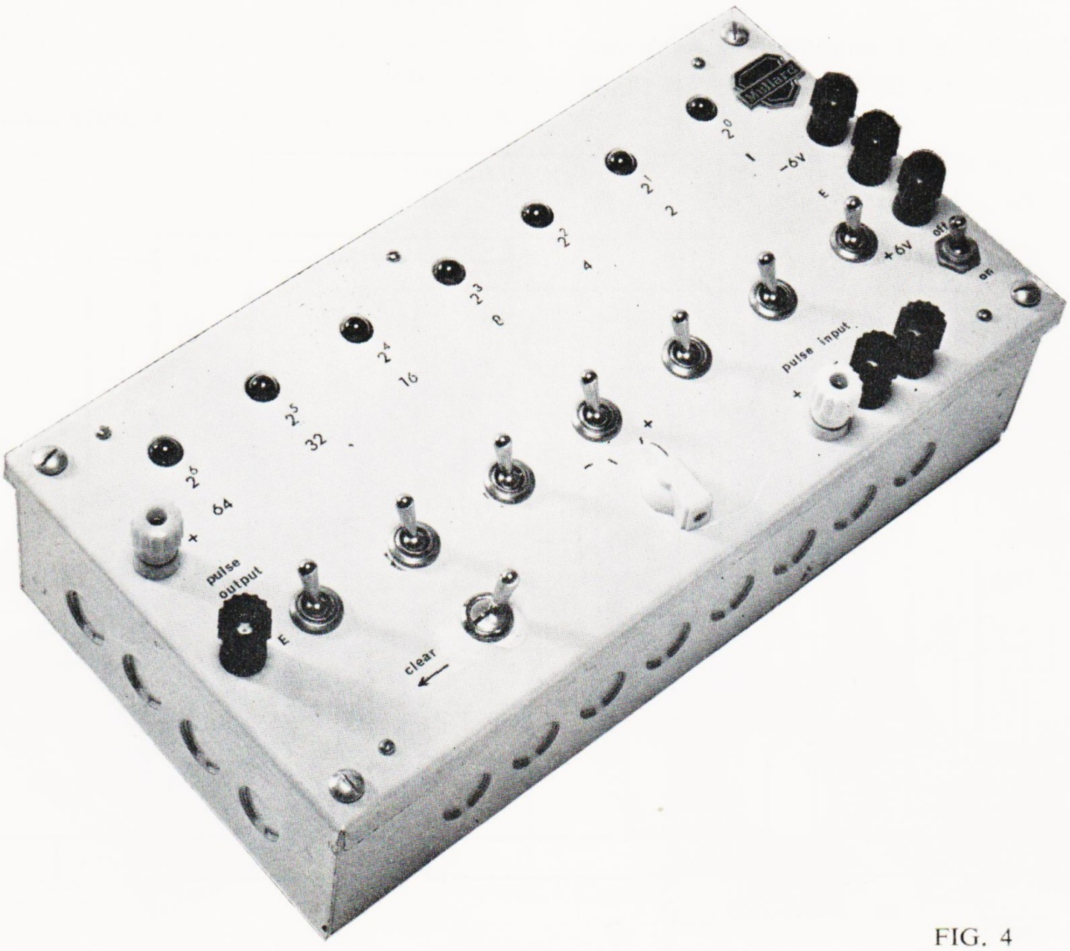


FIG. 4

a pupil's oscilloscope

Introduction

Most educational and training establishments now have a demonstration oscilloscope and this, being a relatively costly and complex piece of apparatus, is often not made accessible to the students themselves.

It was with this thought in mind that the pupil's oscilloscope described in this book was designed. This oscilloscope represents possibly the simplest design ever produced since it incorporates no shift, brilliance or focus controls. It operates from a 12 volt d.c. supply and even from dry batteries for short periods. This instrument is not intended for demonstration purposes since it is too small nor is it suitable for quantitative measurements. However it can be used by small groups of students for qualitative measurements.

Brief Specification

Power supplies	12V d.c., 550mA
Tube diameter	1 inch
Vertical amplifier	1·6V r.m.s. for full scale deflection with max. gain
Timebase oscillator frequency	15Hz–10kHz in two ranges
Controls:	
Vertical amplitude control	Continuously variable and incorporating power on/off switch
Timebase range switch	Position 1 Off Position 2 15Hz–400Hz Position 3 350Hz–10kHz
Timebase fine control	
Horizontal attenuator (see text)	

Terminals:

Power supply terminals

Earth

Vertical (Y) amplifier input

Access to X plates (see text)

Circuit Details

Fig. 1 illustrates the complete circuit diagram. Transistors TR1 and TR2 in conjunction with the transformer make up a d.c. converter circuit operating from 12 volts d.c. The output from the secondary winding on the transformer is half wave rectified by diode D1, capacitor C1 acting as a reservoir capacitor. The 400V potential obtained in this manner is connected to the final anode of the cathode ray tube.

R3 is a surge limiting resistor to protect the diode from 'spikes'.

A lower voltage (300V) is also obtained from the

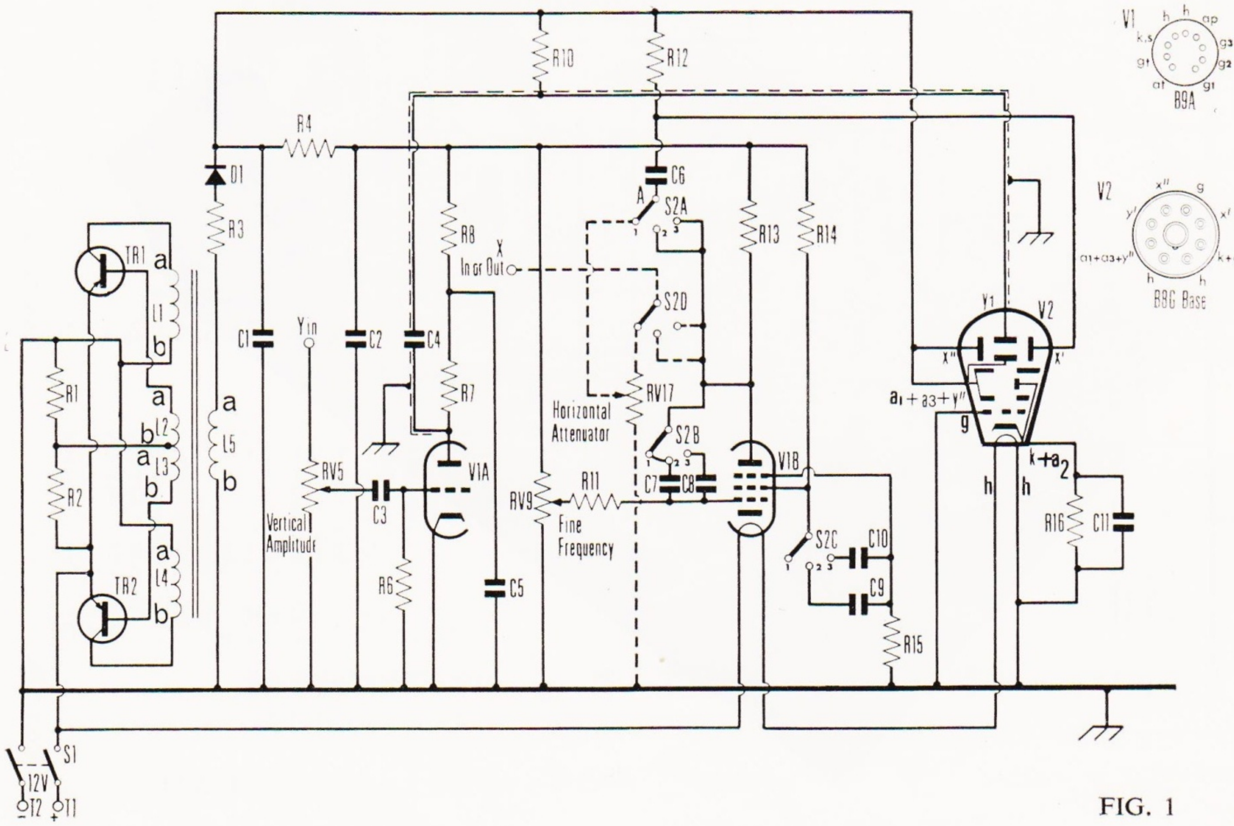


FIG. 1

same secondary winding by further filter components R4 and C2, and is used to operate the single triode-pentode valve V1. The triode section of this valve is used as a vertical amplifier, the signal being applied to the grid of the valve via gain control RV5 and coupling capacitor C3. Potentiometer RV5 incorporates the main on/off switch S1.

The pentode section of the valve is used as a timebase oscillator connected in the familiar transitron arrangement, the frequency of the sawtooth waveform being determined by capacitors C8, C10 or C7, C9 in conjunction with the fine frequency control RV9.

The 'X in' terminal in this circuit is connected via attenuator RV17 to the X′ plate of the cathode ray tube. This connection, in conjunction with the switch S2, ensures that when the timebase is operating, a sawtooth waveform is available at the terminal. When the timebase is switched off this terminal can be used as a means of deflecting the spot on the screen by an externally produced signal. Thus, for example, Lissajous figures can be displayed. It is also possible to dispense with this attenuation arrangement by ignoring all this part of the circuit drawn in broken line and connecting the 'X in' terminal direct to point A in the diagram.

Both the valve and the cathode ray tube have 6·3V, 300mA heaters and these can therefore be operated in series across the 12 volt supply.

Construction

Figs. 2 and 3 illustrate the internal and external appearance of a prototype constructed to test this circuit. It will be realised that essentially the unit comprises a box (dimensions 4×4×3 inches) from which the cathode ray tube is allowed to project to a distance of 2¼ inches. To protect the tube from damage in this exposed position a piece of copper tubing, 1¼ inches outside diameter, was affixed to the lid of the box. Finally, a slot was cut axially in the underside of the copper tube so that eddy current losses cannot occur if magnetic deflection assemblies are being used.

In the layout of components and wiring it is recommended that the transformer is placed as shown since there is some risk of induction from the transformer entering the cathode ray tube and modulating the trace.

Components List

R1	1·5kΩ		
R2	390Ω ½ watt		
R3	10kΩ		
R4	33kΩ		
RV5	500kΩ linear potentiometer		
R6	8·2MΩ		
R7	220kΩ cracked carbon		
R8	47kΩ cracked carbon		
RV9	2MΩ logarithmic potentiometer		
R10	2·2MΩ	R14	100kΩ
R11	220kΩ	R15	1MΩ
R12	2·2MΩ	R16	1MΩ
R13	47kΩ		
RV17	(if required – see text) 500kΩ linear potentiometer		

All resistors are ¼W, 10% unless otherwise stated.

C1	0·47μF	400V min. wkg.

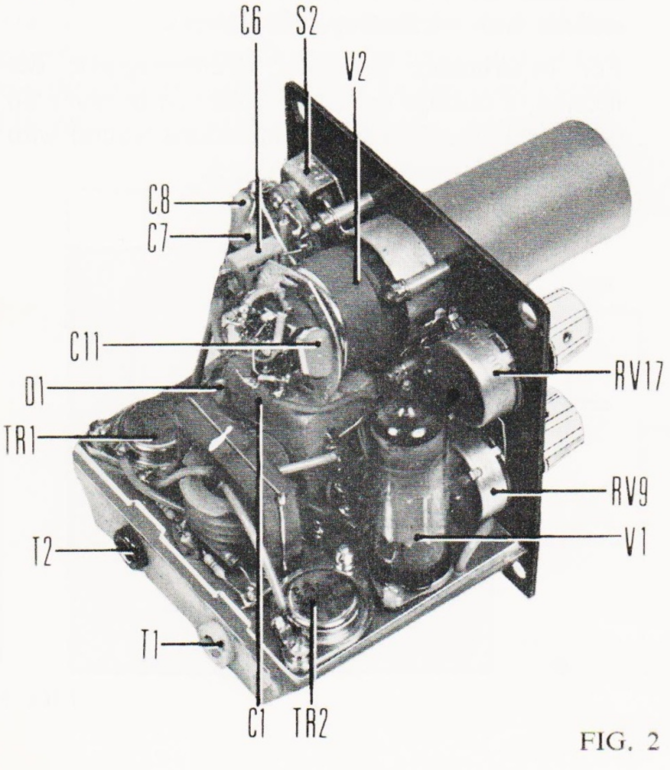


FIG. 2

FIG. 3

C2	1μF	400V min. wkg.
C3	0·22μF	150V ,, ,,
C4	0·1μF	500V ,, ,,
C5	0·1μF	150V ,, ,,
C6	0·1μF	400V non-inductive
C7	0·015μF	150V ,, ,,
C8	1000pF	150V ,, ,,
C9	0·015μF	150V ,, ,,
C10	1000pF	150V ,, ,,
C11	0·22μF	miniature
TR1, 2	Mullard OC29 power transistors	
D1	Mullard OA211 or BYX10 rectifier diode	
V1	Mullard ECL80 triode pentode	
V2	Mullard DH3-91 cathode ray tube (300mA heater version)*	
S2	Three-way, four-pole rotary switch (if attenuator required) Three-way, three-pole rotary switch (if attenuator not required)	

B9A base (for valve)
B8G base (for cathode ray tube)
5×4mm terminals
Transformer core Mullard ferroxcube E core type FX1007 and I core type FX1107.

*If desired a 3″ tube such as the Mullard DG7-31 may be used, in which case it is necessary to change the tube base and to make provision for focus and brilliance controls.

Constructing the Transformer

This is probably the simplest of all the d.c. converter transformers designed in this series of publications and, providing the following instructions are followed carefully, there will be no difficulty in its manufacture.

1. On the ferroxcube E core wind one layer of high grade $\frac{3}{4}$ inch p.v.c. tape directly on the centre limb. Place a pair of parallel 26 swg (0·018) enamelled copper wires at one end of the limb and bifilar wind 12 turns in one layer, keeping wires free from crossover as shown in fig. 4a. Identify the start and end of the windings and cover with one layer of p.v.c.

2. Next, bifilar wind 3 turns of the same gauge wire, again identifying the start and end of the windings as shown in fig. 4b. Cover with one layer of tape.

3. Wind 450 turns of 36 swg (0·0076) enamelled copper wire on a suitable bobbin ($\frac{23}{32}$ inch inside diameter) and place this over the existing windings on the centre limb.

4. Finally, fix the I core and the E core together with adhesive as shown in fig. 4c.

NOTE: All windings should be in the same sense and the completed transformer cemented to the chassis with a suitable adhesive.

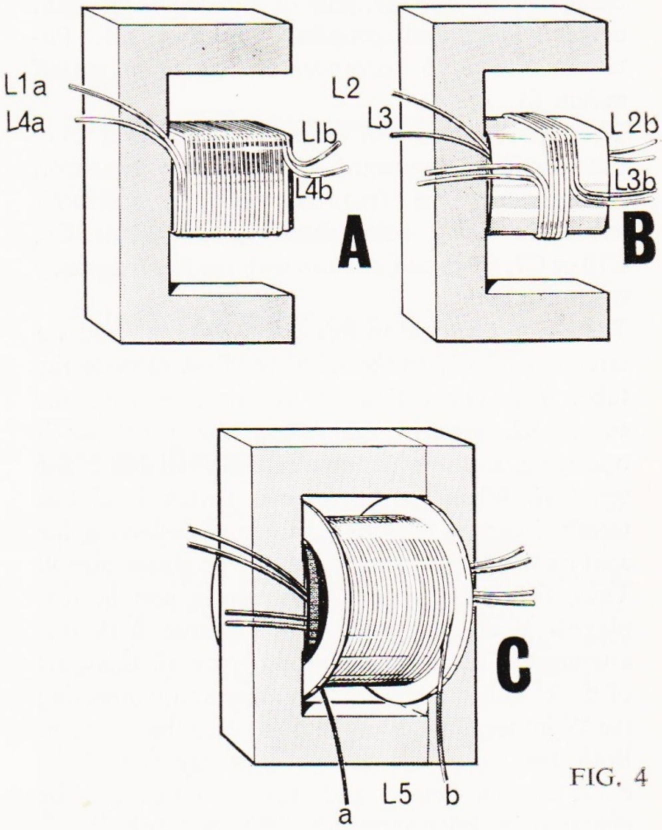


FIG. 4

Applications

As stated in the introduction, this oscilloscope has been designed for qualitative use by the student. It can also serve as a means of familiarising the student with oscilloscopes in general.

For experiments involving electromagnetic deflection, a suitable deflection yoke can be made up using two transformer U laminations wound with 300 turns of wire as shown in fig 5.

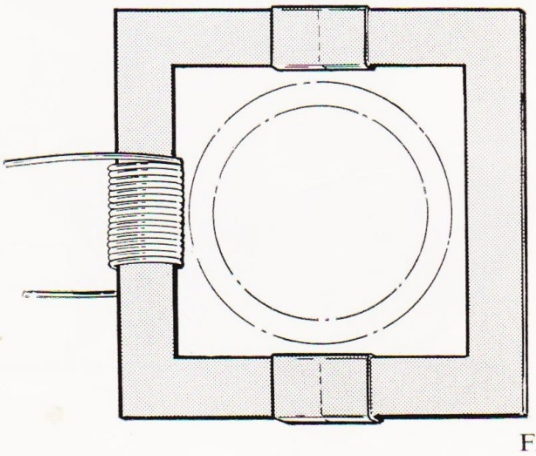


FIG. 5

resistance and capacitance subsuttition boxes

Introduction

When engaged in the design of prototype circuits the Educational Service has often found the need for a quick method of both capacitance substitution and continuously variable resistance. In both cases, only a limited degree of accuracy has been required and to overcome this problem, therefore, two units have been designed using standard components.

Resistance Box

The schematic circuit diagram of this unit is shown in fig. 1. It comprises six potentiometers ranging in value from 10Ω to 1MΩ and interconnected so that any single one can be used independently either as a variable resistor or as a potentiometer. Alternatively, by using the terminals T1 and T2, the unit can be used as a conventional resistance decade box. By using good quality potentiometers with as large a diameter track as is economically suitable, fairly accurate calibration (within 10%) can be obtained by dividing the total arc of the slider rotation into ten equal divisions, each division thus representing one-tenth of the total track resistance. A more precise calibration can, of course, be obtained by direct resistance measurement techniques. The maximum permissible current for each of the potentiometers depends upon the power dissipation specified by the manufacturer. In the components list, details of maximum permissible currents are given for each potentiometer recommended.

Figs. 2 and 3 show interior and exterior views of the prototype unit constructed to test the circuit design. All the components specified can easily be accommodated in a steel conduit box of dimensions 12×6×3 inches.

Components List

RV1	10Ω, 12W wire wound potentiometer (Colvern Ltd.)
RV2	100Ω, 5W wire wound potentiometer (Colvern Ltd.)
RV3	1kΩ, 3W
RV4	10kΩ, 3W
RV5	100kΩ, 3W
RV6	1MΩ, carbon potentiometer

Screw down terminals with 4mm central socket.

Maximum permissible currents for these potentiometers are as follows:

RV1	1·1A	i.e. 11 volts maximum between ends of track
RV2	224mA	i.e. 22 volts maximum between ends of track
RV3	55mA	i.e. 54 volts maximum between ends of track
RV4	17·3mA	i.e. 160 volts maximum between ends of track
RV5	5·5mA	i.e. 550 volts maximum between ends of track
RV6	1mA	i.e. 1000 volts maximum between ends of track.

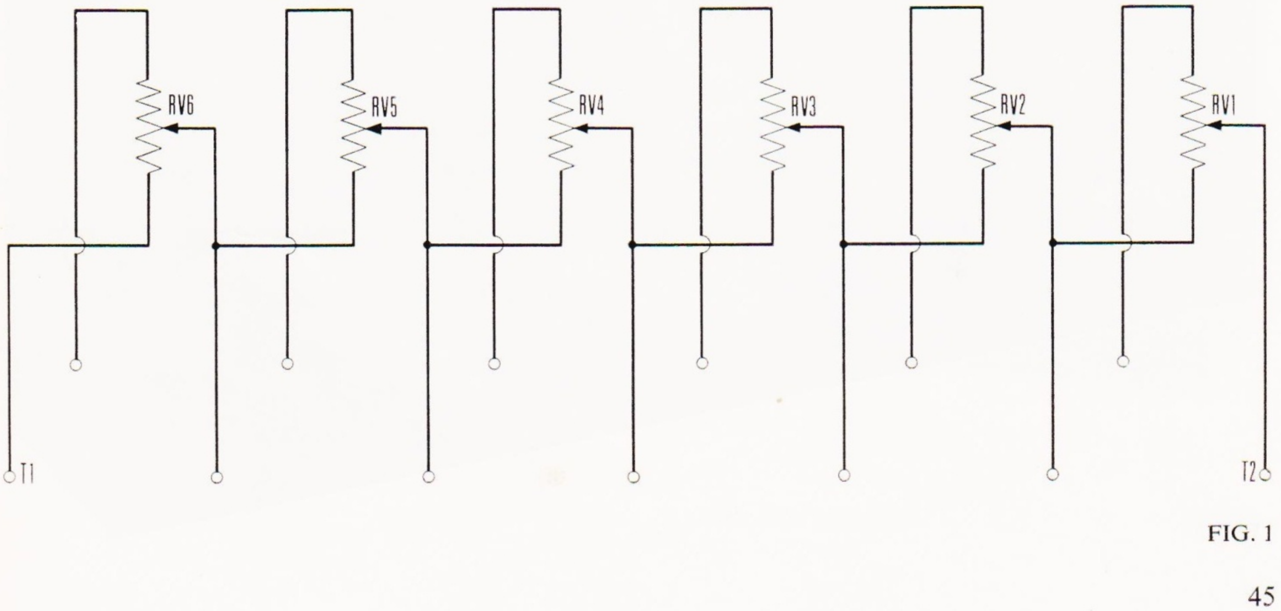


FIG. 1

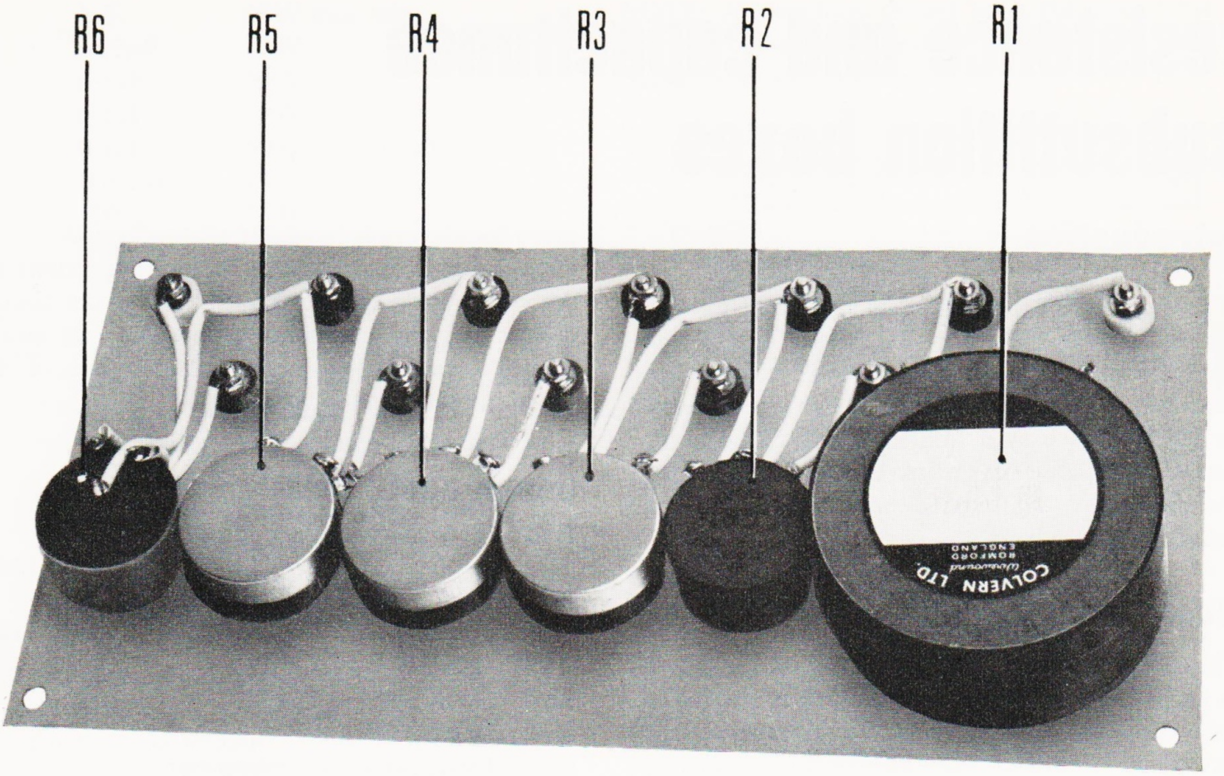

R6
R5
R4
R3
R2
R1
COLVERN LTD.
Wirewound
ROMFORD
ENGLAND

FIG. 2

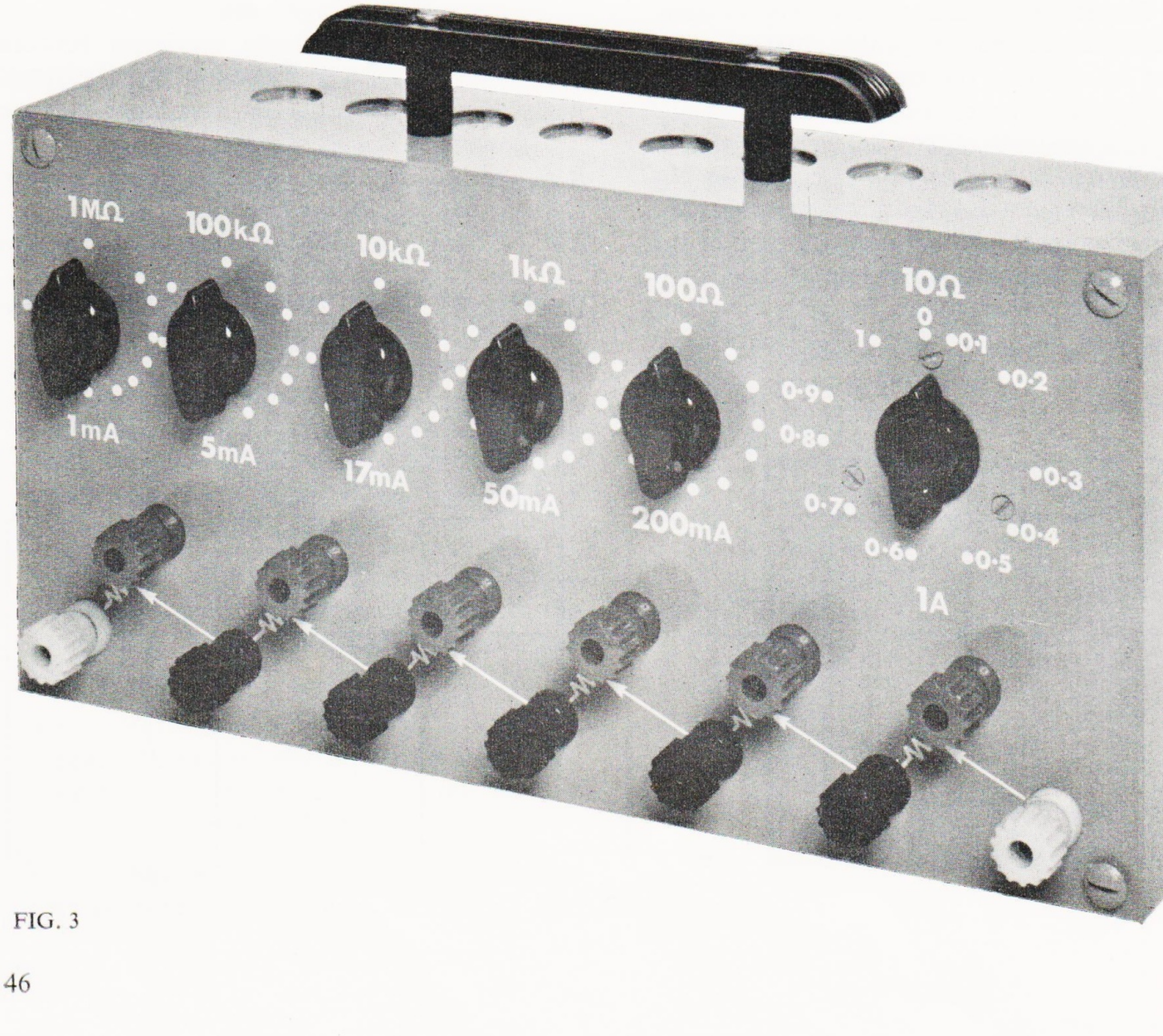

1MΩ
100kΩ
10kΩ
1kΩ
100Ω
10Ω
0
1
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1mA
5mA
17mA
50mA
200mA
1A

FIG. 3

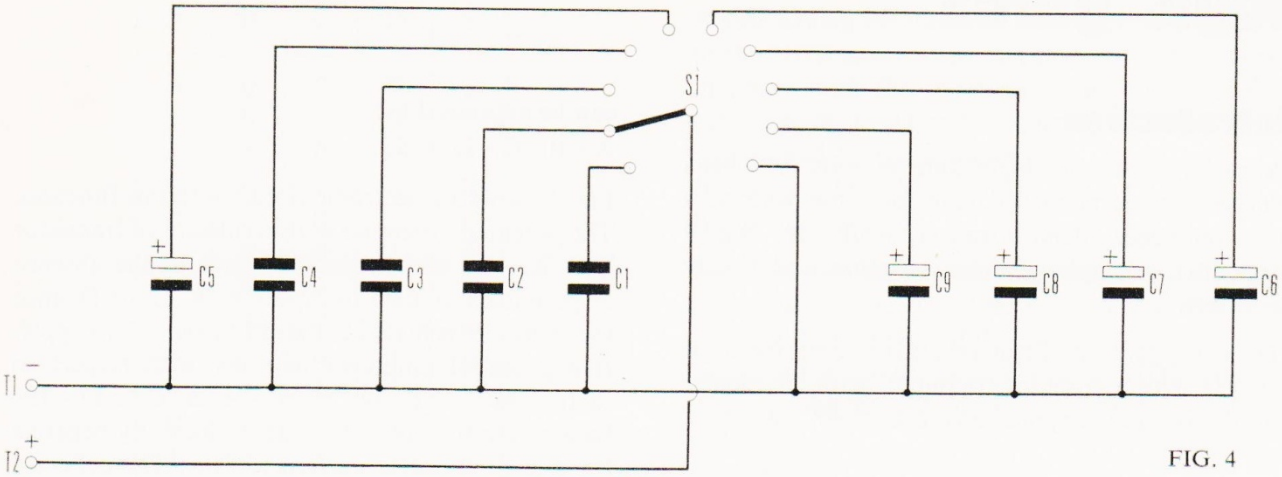


FIG. 4

Capacitance Box

The circuit diagram of this unit is shown in fig 4 and comprises nine capacitors connected to the ten-way switch S1. The first nine switch positions are used to select fixed capacitance values ranging logarithmically from 100pF to 10,000μF. The final switch position is a short circuit representing infinite capacitance.

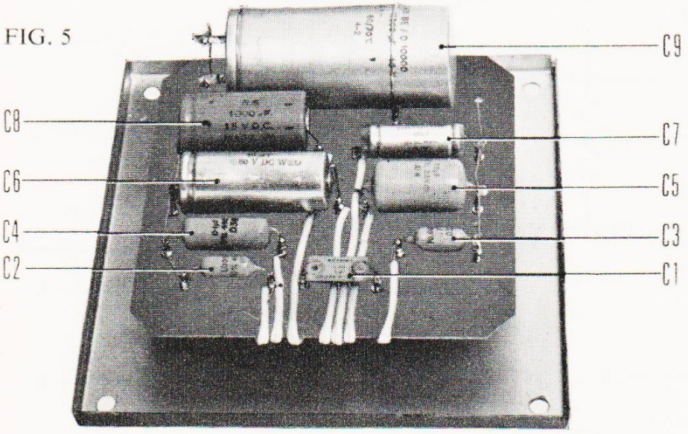
Figs. 5 and 6 show internal and external views of the prototype unit which was encased in a conduit box of dimensions 6 × 6 × 3 inches.

The accuracy of the capacitance values depends here entirely upon the tolerance of capacitors chosen. It is therefore recommended that close tolerance components are used where obtainable.

Components List

C1	100pF 500 volts wkg.
C2	0·001μF 500 volts wkg.
C3	0·01μF 500 volts wkg.
C4	0·1μF 400 volts wkg.
C5	1μF 400 volts wkg.
C6	10μF electrolytic 50 volts wkg.
C7	100μF electrolytic 50 volts wkg.
C8	1000μF electrolytic 50 volts wkg.
C9	10,000μF electrolytic 25 volts wkg., Mullard Type C432 series.
S1	10 way, single pole rotary switch.
T1, T2	screw-down terminals with central 4mm socket.

FIG. 5



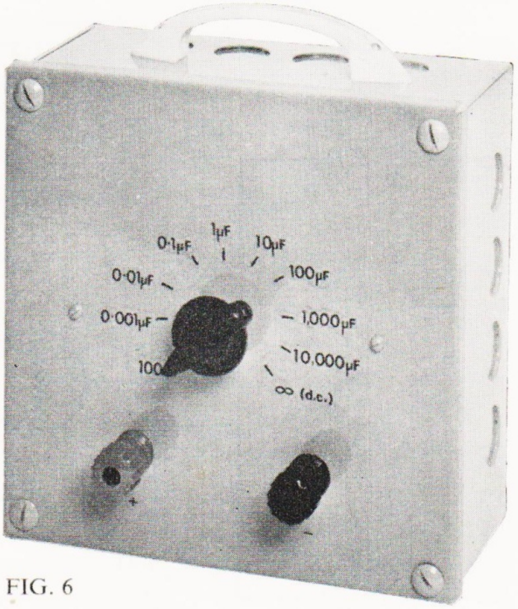


FIG. 6

logic gates

Introduction

A series of simple logic gate circuits has been devised and is published here for those who wish to commence demonstration work on digital computer principles, Boolean algebra and binary arithmetic.

The main purpose of this article is to describe some of the basic circuitry required with particular emphasis on the applications to Boolean algebra.

The Inclusive NOR Gate

The inclusive NOR gate is a device having one output and two or more inputs. The output condition of the gate changes if – and only if – any one or more of the input conditions change. Also, the change in output is always anti-phase to changes in input.

In Boolean algebra terms the function of, say, a four input NOR gate can be expressed as follows: $A \cup B \cup C \cup D = S'$ where A, B, C, D are inputs and S is the output.

Alternatively, in the generalised form of Boolean algebra attributed to Newman, the same equation can be expressed as:

$$A+B+C+D=\overline{S}$$

Fig. 1 shows an electronic circuit with this function. The potential difference at the collector of transistor TR1 is —6V with respect to earth in the absence of potentials applied to inputs A, B, C, or D since the transistor is biased to cut-off by the +6V supply. If a potential difference of —6V with respect to earth is applied to any point – A, B, C or D – the base of the transistor becomes sufficiently negative for a large collector current to flow. The collector potential thus falls to zero if the correct values of circuit components are chosen.

Allocating the symbol '0' to represent zero voltage and the symbol '1' to represent —6V, it is possible to draw up a table showing all possible combinations of input and output conditions. Such a table, called a 'Truth Table', is shown in table 1.

The symbol for a four input NOR gate is also illustrated in fig. 1. The numeral '1' written in the gate indicates that only one of the inputs needs to be energised to cause the gate to operate. The heavy black bar on the output side of the gate is the negater sign which indicates that the output is anti-phase or complementary to the input.

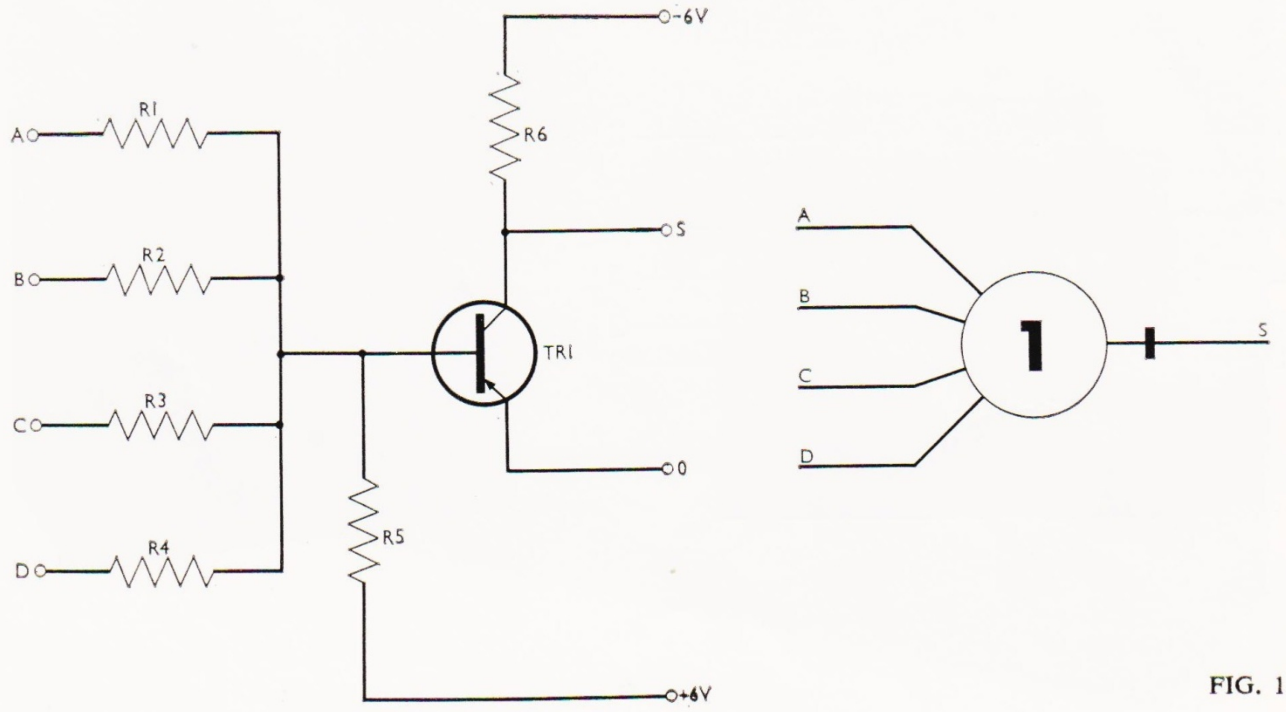


FIG. 1

TABLE 1

A	B	C	D	S
0	0	0	0	1
1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
1	0	0	1	0
1	0	1	0	0
1	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	0	1	1	0
1	0	1	1	0
1	1	0	1	0
1	1	1	0	0
0	1	1	1	0
1	1	1	1	0

The Inclusive OR Gate

A gate having the inclusive OR function is identical to the NOR gate except that now the output varies in phase with the input. An OR gate with four inputs A, B, C, D and output S can therefore be represented by the equations:

$A \cup B \cup C \cup D = S$ or

$A + B + C + D = S$

Fig. 2 shows the circuit diagram of an OR gate with four inputs. It will be realised that this comprises a four input NOR circuit in series with a single input NOR circuit (i.e. a NOT circuit). This can be proved in Boolean algebra terms as follows:

First gate: $A \cup B \cup C \cup D = S_1'$

Second gate: $S_1 = S'$

therefore by substitution

$$A \cup B \cup C \cup D = S_1' = S$$

The symbol for the OR circuit is shown in the diagram as is also an alternative comprising two NOR circuits in series.

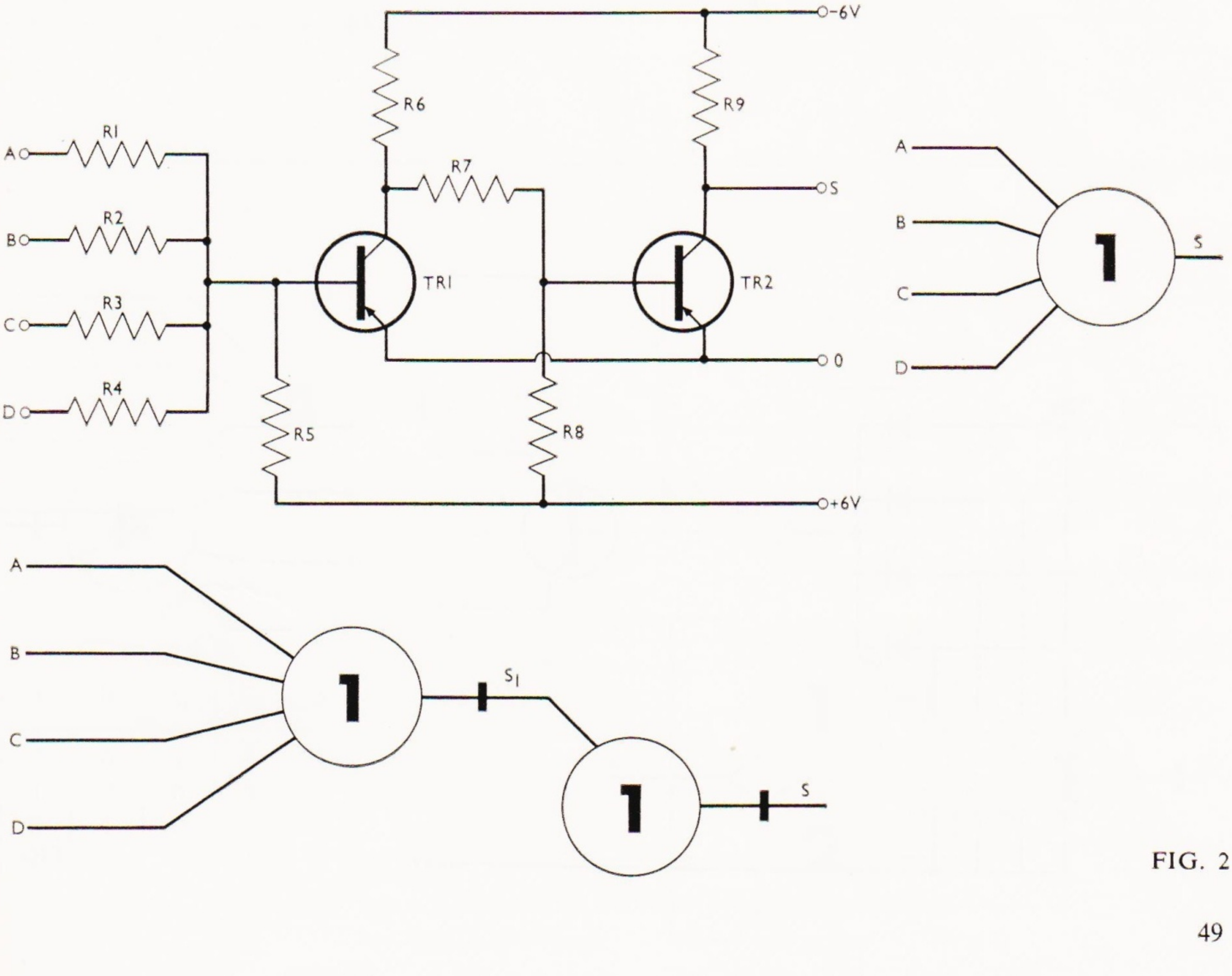


FIG. 2

The NAND Gate

The NOT-AND or NAND gate is a device having one output and two or more inputs. The output changes if – and only if – *all* the inputs change. Also, the output is anti-phase to the input.

For a four input NAND gate, for example, this can be represented by:

$A \cap B \cap C \cap D = S'$ or

$A . B . C . D = \overline{S}$

Fig. 3 shows the circuit diagram of a four input NAND gate. Here, once again, in the absence of any inputs at A, B, C, D, the transistor TR2 is biased to cut-off and the collector (output) is −6V with respect to earth. This bias can only be removed if all the inputs are connected to a potential of −6V with respect to earth.

Also shown in fig. 3 is the symbol for the four input NAND gate. Notice how the numeral '4' is used to indicate that all four inputs must be energised before the gate operates. Again the negater bar indicates that the output is anti-phase or complementary to the input.

The truth table for this gate is shown in table 2.

TABLE 2

A	B	C	D	S
0	0	0	0	1
1	0	0	0	1
0	1	0	0	1
0	0	1	0	1
0	0	0	1	1
1	1	0	0	1
1	0	1	0	1
1	0	0	1	1
0	1	1	0	1
0	1	0	1	1
0	0	1	1	1
1	1	1	0	1
1	0	1	1	1
1	1	0	1	1
0	1	1	1	1
1	1	1	1	0

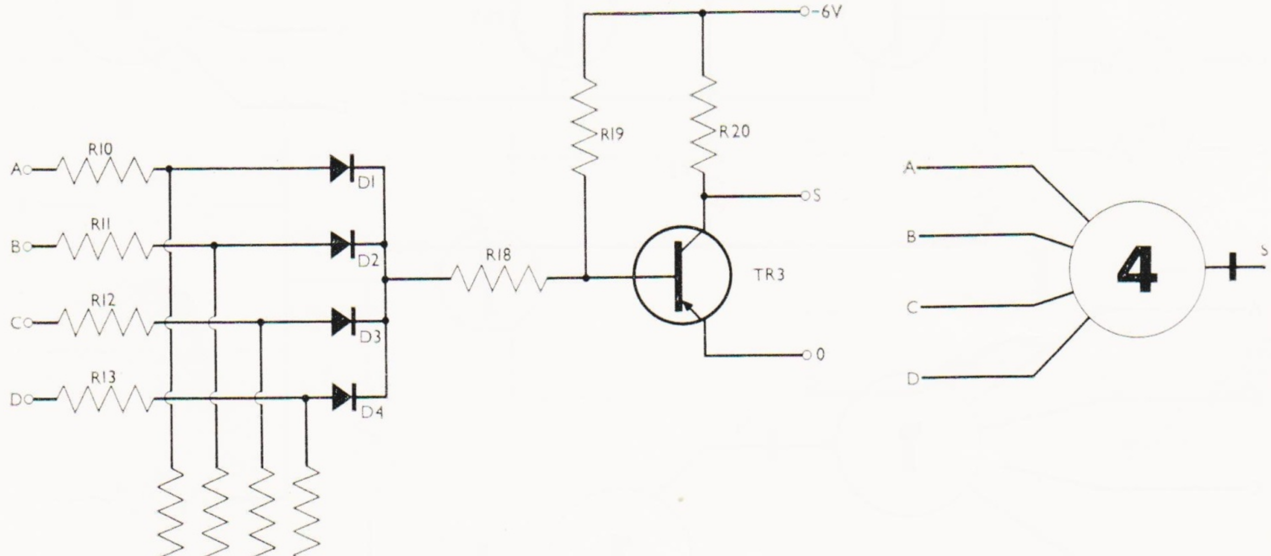


FIG. 3

The AND Gate

The AND gate is identical to the NAND gate except that the output and inputs vary in phase. Thus:

$A \cap B \cap C \cap D = S$ or

$A \,.\, B \,.\, C \,.\, D = S$

As will be seen from the circuit shown in fig. 4, the AND gate can be considered as a NAND gate in series with a single input NOR (i.e. NOT) gate. Thus:

First gate: $A \,.\, B \,.\, C \,.\, D = \overline{S_1}$

Second gate: $S_1 = \overline{S}$

Therefore by substitution

$$A \,.\, B \,.\, C \,.\, D = \overline{\overline{S}} = S$$

The symbol for the four input AND gate is shown at B together with the equivalent circuit of a NAND and a NOT gate in series.

Exclusive OR Gate

The *exclusive* OR gate is similar to the inclusive OR in that the output changes when one of the inputs is changed. However, in the exclusive gate, the output returns to zero if all the inputs are identical (0 or 1). Thus:

$(A \cap B') \cup (A' \cap B) = S$ or

$A \,.\, \overline{B} + \overline{A} \,.\, B = S$

A symbolic representation of a two input exclusive OR circuit is shown in fig. 5 and comprises an AND gate and two NOR gates. If inputs A and B are both energised, the AND gate is also energised and prevents (or INHIBITS) the final NOR gate from changing its output from the '0' to the '1' condition.

The truth table for this gate which is also called a non-equivalence element is shown in table 3.

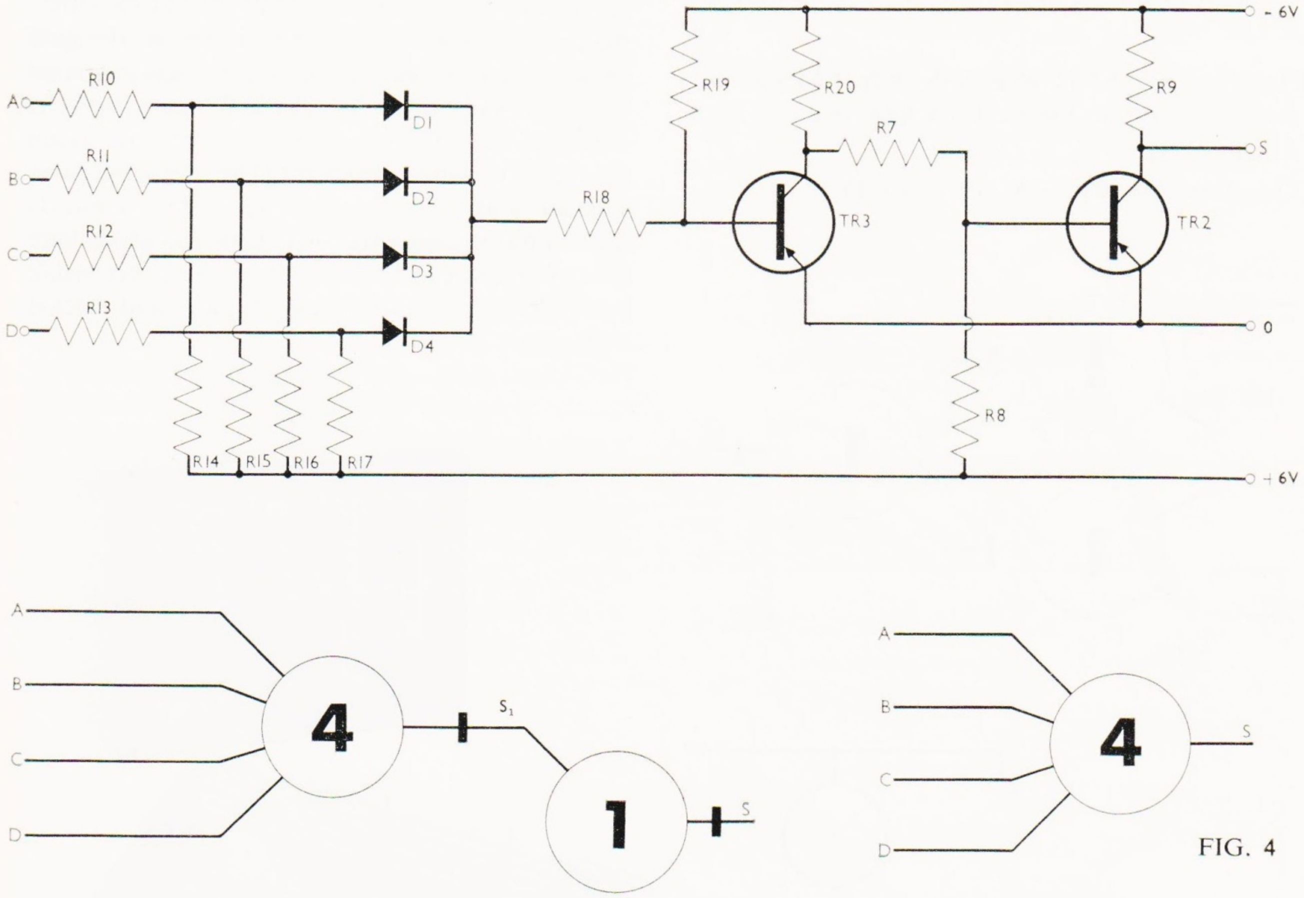


FIG. 4

TABLE 3

A	B	S_1	S_2	S
0	0	1	0	0
1	0	0	0	1
0	1	0	0	1
1	1	0	1	0

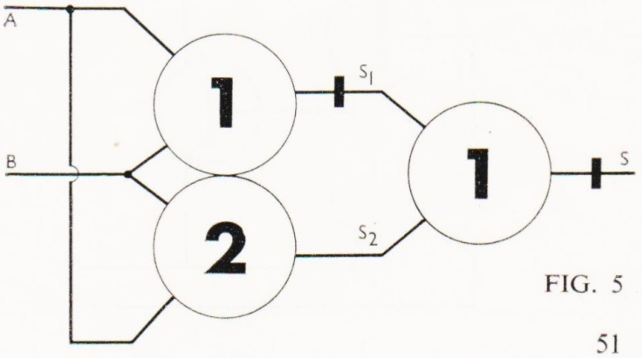


FIG. 5

Mixed Gates

Although it is not intended in this publication to deal with more than the principles of logic gates, it may be of interest to those teaching Boolean algebra to understand how the de Morgan theorem may be validated by demonstration.

The de Morgan theorem in one form may be stated as

$(A \cap B)' = A' \cup B'$ or $\overline{A \, . \, B} = \overline{A} + \overline{B}$

This may be validated by demonstrating that the function of a two input AND gate is identical to that of the arrangement of three NOR gates shown in fig. 6.

Gate X $A = S_1'$ (1)

Gate Y $B = S_2'$ (2)

Gate Z $S_1 \cup S_2 = S_3'$ (3)

Substituting for S_1 and S_2 in (3) from (1) and (2):

$A' \cup B' = S_3'$ (4)

However, the AND gate with output S_4 can be shown to have an identical function, thus:

$A' \cup B' = S_3' = S_4' = (A \cap B)'$

Therefore: $(A \cap B)' = A' \cup B'$ Q.E.D.

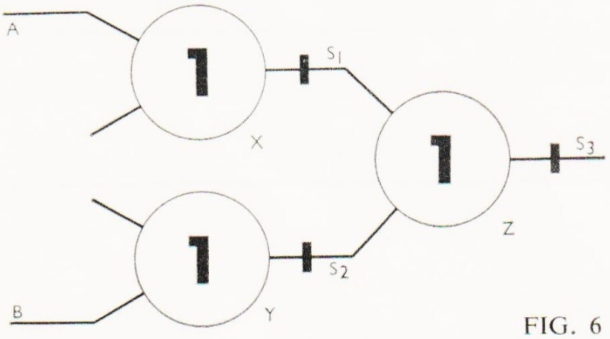


FIG. 6

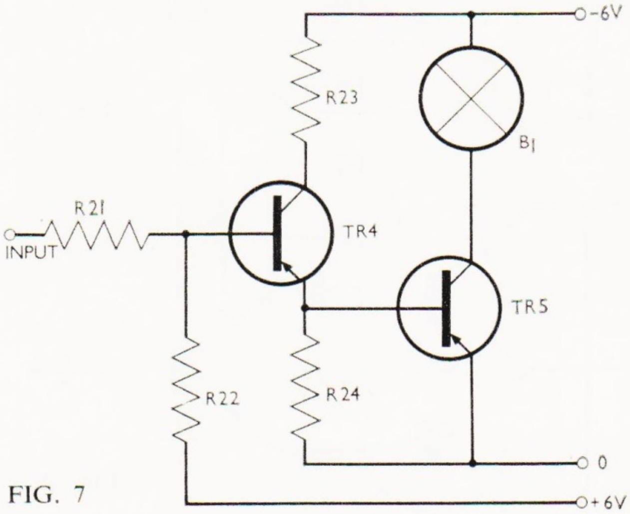


FIG. 7

Indicator Circuits

Although output and input conditions can be indicated on meters, a more economic and visually attractive method uses lamps. Fig. 7 shows the circuit required to operate a small torch bulb without drawing significant current from any gate to which the circuit is attached.

If the input of this indicator circuit is connected to the input or output of any of the gate circuits described, it will indicate a '0' or a '1' condition.

Visual Presentation

There are a number of ways in which these gates can be displayed and many teachers will no doubt have their own ideas on this. They may, however, be interested in one method which was used when designing these circuits.

A number of indicator circuits including lamps were placed in a box as shown in fig. 8. The gate circuits were wired up behind a paxolin panel which showed on the front only the gate symbols, input and output terminals and switches with which the inputs to various gates could be energised. Such a panel is also illustrated in fig. 8. The terminals used in this system were turret tags into which bare wire of 18 swg can be pushed to make a reasonable yet extremely cheap form of plug and socket connection.

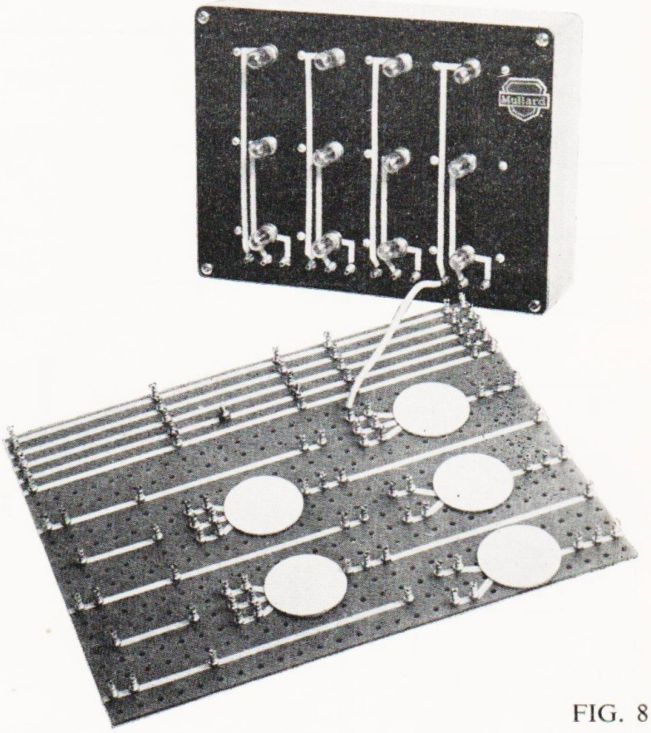


FIG. 8

Power Supplies

All the circuits described in this publication have been designed around a +6V, 0, −6V power supply. Current requirements are most reasonable and, unless a large number of gate circuits is required, it is possible to operate from dry batteries. Full power requirement details are listed below:

For each NAND gate
1mA at +6V, 4mA at −6V
For each NOR gate
40μA at +6V, 4mA at −6V
For each lamp circuit
40μA at +6V, 65mA at −6V

The circuits have been designed to accommodate up to a ±10% variation in power supplies which are therefore not very critical.

Components List

There should be no difficulty in obtaining any of the components required for these gate circuits as all of them are standard.

R1	15kΩ	R13	15kΩ
R2	15kΩ	R14	47kΩ
R3	15kΩ	R15	47kΩ
R4	15kΩ	R16	47kΩ
R5	220kΩ	R17	47kΩ
R6	2·2kΩ	R18	1·5kΩ
R7	15kΩ	R19	100kΩ
R8	220kΩ	R20	2·2kΩ
R9	2·2kΩ	R21	100kΩ
R10	15kΩ	R22	220kΩ
R11	15kΩ	R23	4·7kΩ
R12	15kΩ	R24	1kΩ

All resistors 10%, $\frac{1}{4}$ watt

TR1, 2, 3, 4	Mullard ACY20 or OC71 transistors
TR5	Mullard ACY20, OC72, OC78 or OC83 transistors
D1, 2, 3, 4	Mullard OA91, OA85 or OA81 diodes
B1	6·3V, 0·05A bulbs, M.E.S.
Terminals (see text)	turret tags.
Bulb holders	M.E.S.

an electronic organ

Introduction

An electronic organ circuit was published in the Mullard OUTLOOK in 1962 and since then there have been many requests for copies of the article. The interest shown in this device, which is both a toy and an educational circuit, has led to the production of a prototype which is described in this article. The approach used is similar to the original article but a tremolo circuit has been added. The prototype is virtually two complete organs, thus enabling a base accompaniment to be played, this system having been adopted in preference to the use of a common amplifier and the buffer amplifiers necessary to isolate the note generators. A block schematic diagram of half of the organ (treble or base) is given in fig. 1 and each section will be considered individually.

Generation of Notes

A single note generally consists of the fundamental and a number of harmonics, these harmonics determining the final sound of the note e.g. piano, trumpet, violin etc. and some commercially produced organs use a number of generators or oscillators to produce a single note, with the added necessity of providing many contacts on the keyboard note. Two types of generator were considered when designing this instrument – a transformer-coupled transistor sine-wave oscillator and a simple square-wave multivibrator. Knowing the difficulty most schools experience when attempting to obtain supplies of laminations and wire, it was decided to use the multivibrator. Also the circuit is far simpler and the components are less expensive and can be mounted on a small panel.

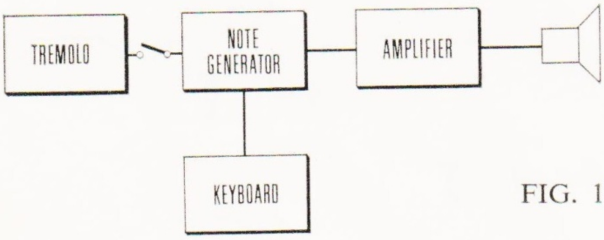


FIG. 1

Tremolo

A tremolo circuit has been added since it greatly enriches the sound of the organ but it can be switched out of circuit if required. The tremolo circuit is a simple transistor phase shift oscillator which adds very little to the cost of the whole project.

Amplifier

The amplifier used in the prototype has an output of approximately 50mW and has been selected for its simplicity, small size and low cost. The output from the organ can be fed to almost any amplifier (valve or transistor) though it may be necessary to insert an intermediate pre-amplifier. The one-transistor amplifier used here feeds a 2in. speaker and is suitable for insertion into a small box or a child's toy piano.

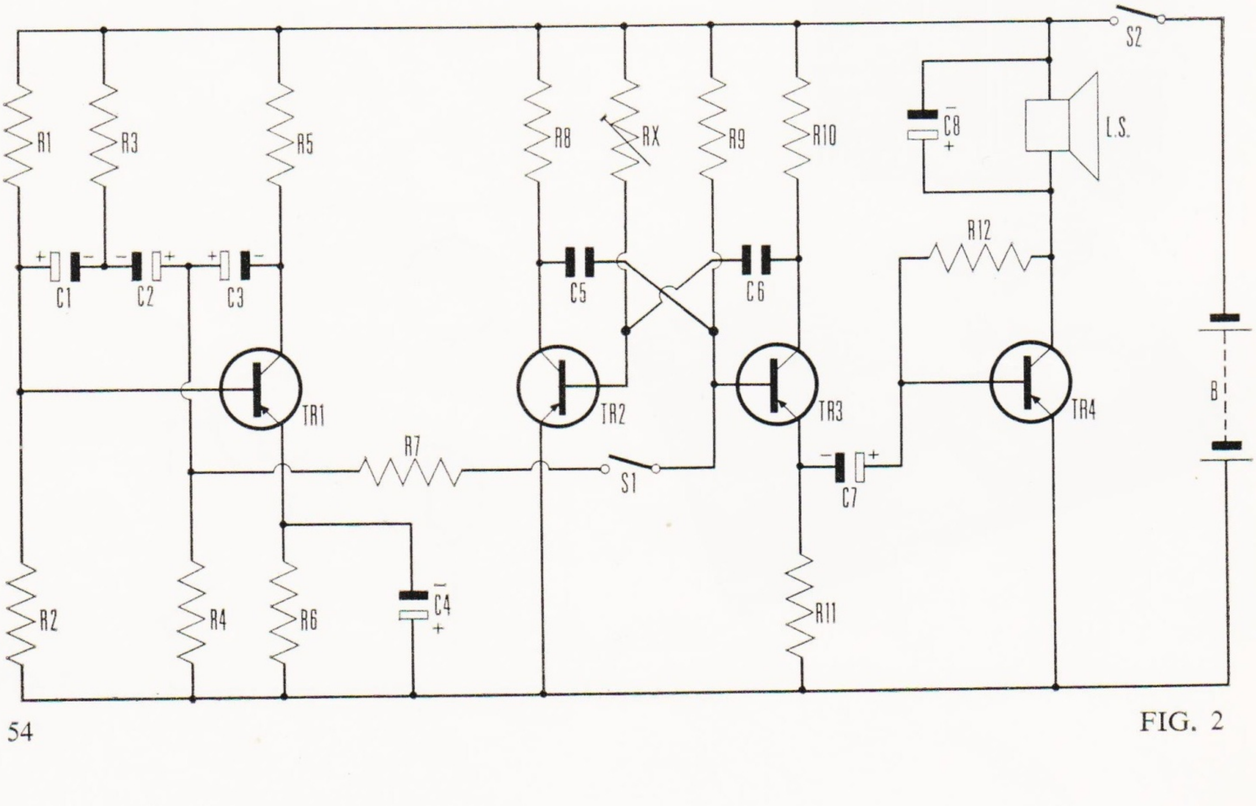


FIG. 2

Circuit Description

The complete circuit diagram is shown in fig. 2. TR1 is the tremolo oscillator transistor, its frequency being governed by the values of R3, R4, R5, C1, C2 and C3. This frequency can be calculated using the formula:

$$f = \frac{1}{2\pi CR\sqrt{6}}$$

and for the values quoted is 6·8Hz. The formula does not take into account the transistor input and output impedances and these have been disregarded since their effect is quite small. A certain amount of attenuation occurs in the feedback network and a transistor with a fairly high gain is necessary. The OC75 has been used successfully though a selected high gain OC71 would be equally suitable.

The note generator is a conventional multivibrator using transistors TR2 and TR3, the frequency at which the circuit oscillates being governed mainly by the value of capacitors C5, C6 and resistors Rx, R9. The value of C5 and C6 will need to be increased for the lower frequency (base) notes and these capacitors are given as C5A and C6A in the component list. Resistor Rx is shown for simplicity as a variable resistor but is in practice a number of preset potentiometers which are shorted out by contacts on the keys. The tremolo output is fed via R7 and switch S1 to the base of either TR2 or TR3.

The multivibrator output is taken from the emitter of TR3 via a coupling capacitor C7 to the base of transistor TR4. The collector load of this transistor is a high impedance speaker across which half the supply voltage is developed. This arrangement is known as the 'half supply voltage principle' and it has several advantages. The circuit is inherently thermally stable, uses only one transistor and requires no output transformer. As stated above, the output is approximately 50mW which is sufficient volume for an average sized room.

The supply voltage is not over-critical, the current consumption of the complete prototype (two tremolos, two multivibrators and two amplifiers) being only 30mA, supplied by a single 9 volt battery. An external view of the complete prototype is shown in fig. 3. A single on/off switch can be used if the treble and base sections are connected in parallel.

Components List

The following components are for one half of the organ less the preset potentiometers attached to the keyboard.

R1 82kΩ	R5 4·7kΩ	R9 12kΩ
R2 10kΩ	R6 1kΩ	R10 2·2kΩ
R3 4·7kΩ	R7 100kΩ	R11 100Ω
R4 4·7kΩ	R8 2·2kΩ	R12 39kΩ

Rx see text below

All resistors ¼W, 10%

C1 2μF electrolytic	C5A 0·25μF (base circuit)
C2 2μF electrolytic	C6 0·1μF (treble circuit)
C3 2μF electrolytic	C6A 0·25μF (base circuit)
C4 250μF electrolytic	C7 2μF electrolytic
C5 0·1μF (treble circuit)	C8 2μF electrolytic

All capacitors 12V wkg. minimum

TR1 Mullard OC75	S1, 2 single-pole, two-way toggle switches
TR2 Mullard OC71	
TR3 Mullard OC71	
TR4 Mullard OC72	B 9V battery (EverReady type PP9 or similar)

L.S. 80Ω permanent magnet loudspeaker

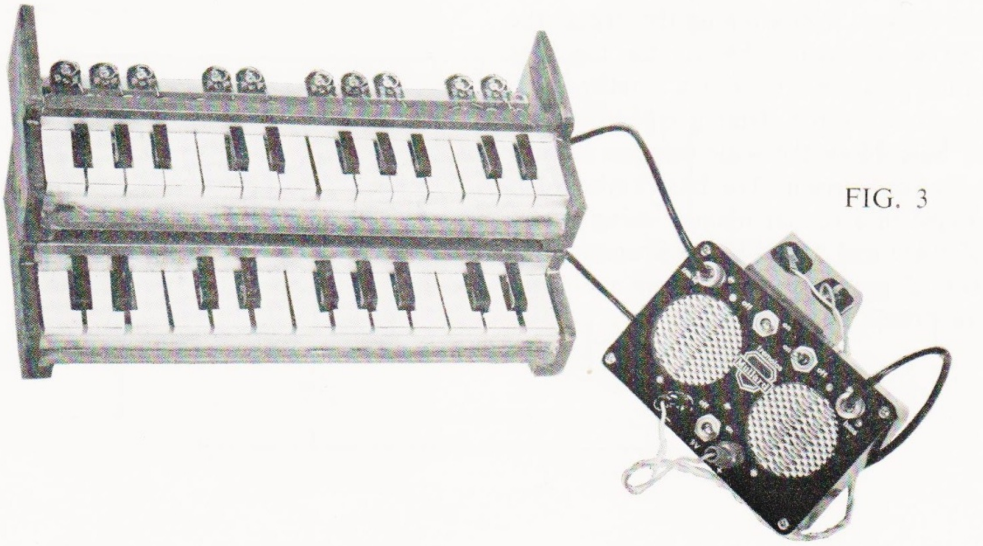


FIG. 3

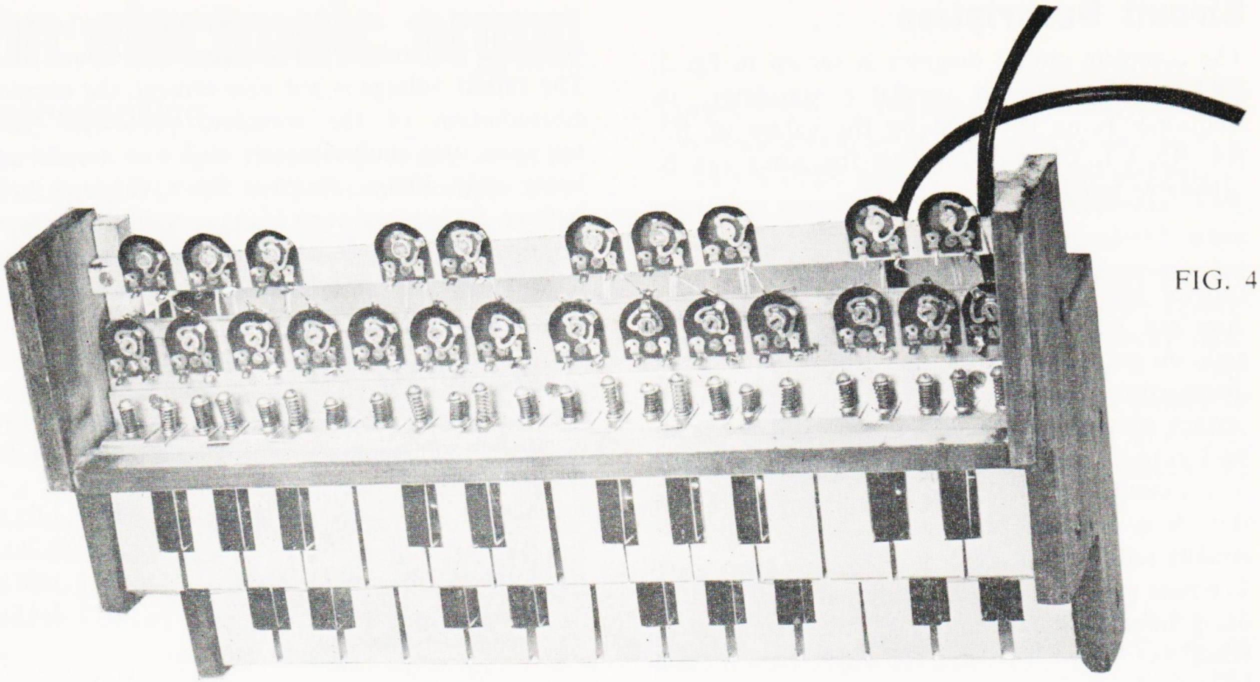


FIG. 4

Keyboard

The choice of keyboard is left to the individual and in this publication two of many possible types will be mentioned. The prototype keyboard (figs. 3 and 4) was made with the minimum of tools, the keys being cut from sheet aluminium. Small springs, which are seen in fig. 4, return the keys to their rest position and the front of each key rests on a strip of foam rubber which provides a degree of resilience.

The small preset potentiometers, one per note, are connected in series as in fig. 5 and thus tuning is incremental. The number of potentiometers will obviously be governed by the number of notes and for the treble keyboard the values used were 5kΩ and 10kΩ. The point is reached where the 5kΩ potentiometer is set at one end of the track and the higher value must therefore be used. This point is not fixed and depends upon the number of notes and the scale chosen. When tuning the organ, the first preset to be adjusted is that for the top note and this should be a 10kΩ type or a smaller value with a series fixed resistor. Tuning is then carried out note by note down the scale using a musical instrument for comparison. The base keyboard is made and tuned in a similar manner using potentiometers of 10kΩ and 20kΩ. In the prototype the total number of preset potentiometers used was 14×5kΩ, 16×10kΩ and 16×20kΩ.

Beneath each key is a piece of pliant brass strip which makes contact with the key when it is pressed and which shorts out certain of the preset potentiometers. The total resistance now in circuit determines the frequency of the multivibrator and hence that of the note. With this system, of course, only one note can be played at a time since the notes below it are out of circuit and this is indicated in fig. 5.

An alternative method of construction has been successfully carried out using a child's toy piano. When the internal mechanism is removed there is ample space remaining for the circuit components. Brass strip is used as before to make a switch and is attached to the existing keys. The base of the piano is usually plywood or hardboard and holes can be drilled in this for the speaker. This system could be extended as required to use the keyboard of an ordinary piano.

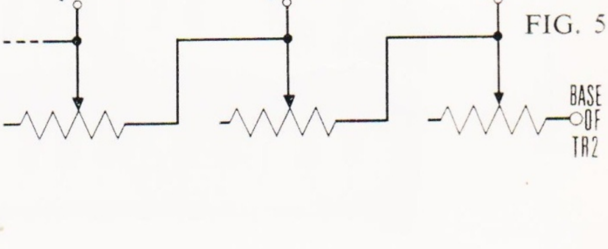


FIG. 5

an electronic timer

Introduction

The timer will accept most waveforms in the frequency range 50Hz to 10kHz and of amplitude 1 to 7Vr.m.s. The output from the timer is a nominal square wave of 3 volts amplitude which should be sufficient to operate any scaler and even some types of mechanical counter.

Circuit Diagram

The main circuit diagram is reproduced in fig. 1. Transistors TR1 and TR2 together make up a conventional d.c. bistable squaring circuit, the output to the scaler being taken from the collector of TR2.

The base of TR2 is connected via resistor R9 to a second bistable containing transistors TR4, TR5. This bistable or 'hold' circuit is required to ensure that the start sequence is commenced when a *pulse* arrives at the base of TR5. To stop the squaring circuit from passing a signal to the scaler, it is necessary to provide a second or 'stop' pulse to the base of transistor TR4.

Start and stop pulses may be fed directly to the bases of transistors TR4 and TR5 by way of press-to-make micro switches. It is, however, more convenient in most circumstances to arrange that these pulses are derived from the interruption of a light beam and, in this case, two further transistors TR3 and TR6 are required to act as inverter amplifiers.

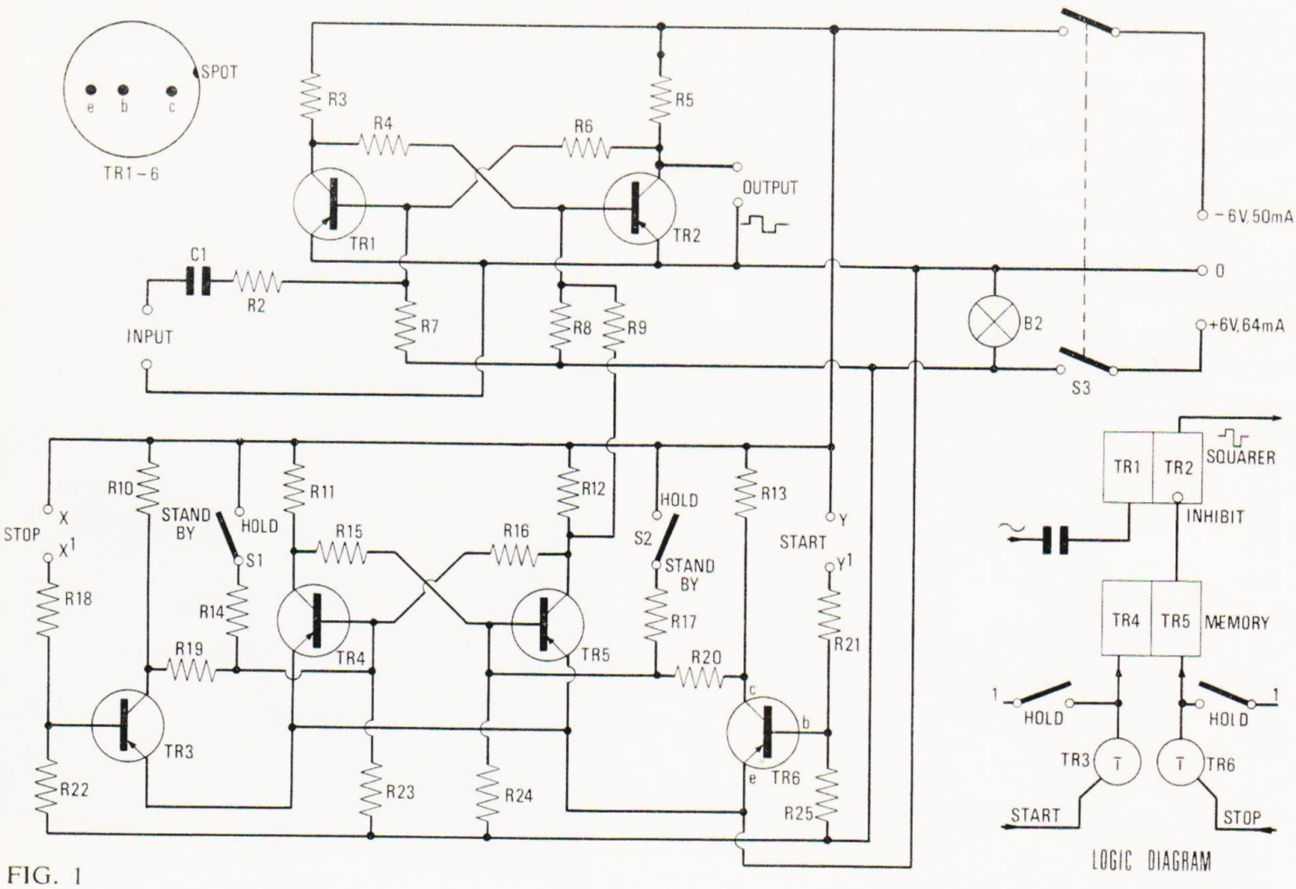


FIG. 1

Photo sensing devices such as photo diodes may then be connected across terminals XX′ and YY′ and illuminated. When the light beam to either photo diode is interrupted, the squaring circuit is then gated to start or stop running. It is essential that the light intensity falling on the photo devices is adequate to ensure that the change in resistance is large.

Mechanical 'hold' and 'standby' switches S1 and S2 may also be found convenient as they can be used to override pulses arriving from the photo sensing devices.

Also shown in fig. 1 is the logic equivalent circuit of the timer.

Time Scale

The successful use of this timer unit depends upon a readily available signal source of constant frequency. In many cases a standard signal generator will be suitable but for those schools which would prefer other means, fig. 2 shows the circuit diagram of a simple mains operated full wave rectifier unit giving 100Hz pulses. Time measurements down to 0·01 seconds can be taken with this unit.

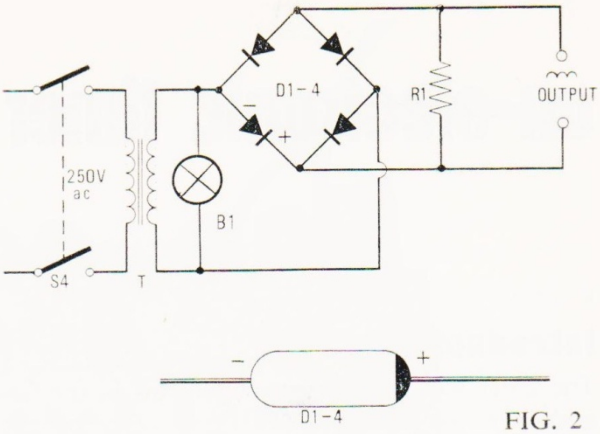


FIG. 2

Constructional Details

Figs. 3 and 4 show internal and external views of the prototype timer unit incorporated in a standard conduit box of dimensions 6″×6″×3″. As will be seen, the unit has been designed for an external power supply (–6V–0–+6V) and terminations XX′ and YY′ are standard co-axial sockets.

The time scale unit, shown in fig. 5, was assembled in a smaller conduit box of dimensions 4″×4″×3″.

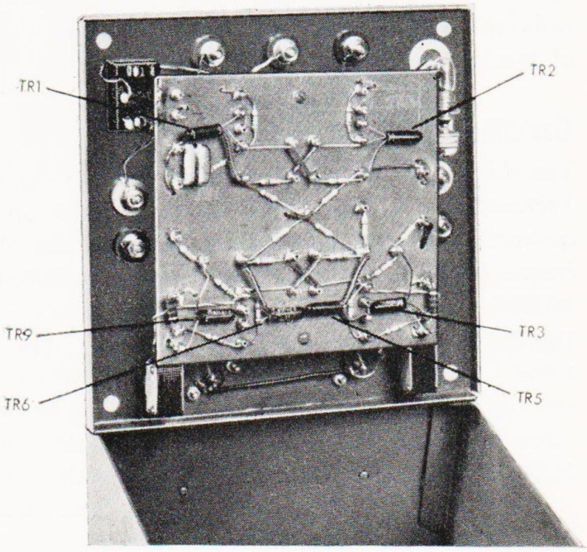


FIG. 3

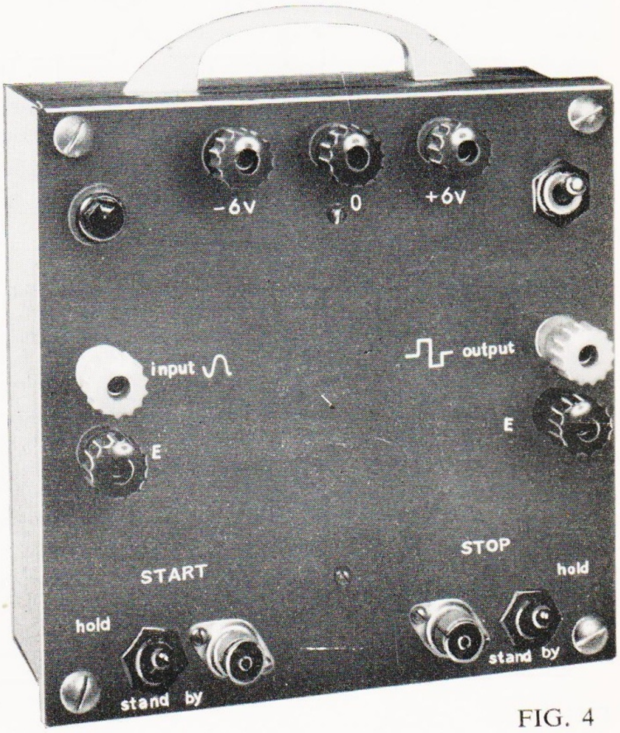


FIG. 4

Components List

All the electrical components used in the timer and time scale unit were standard items and should easily be obtainable. Details are as follows:

R1	10kΩ	R13	2·2kΩ
R2	1·5kΩ	R14	15kΩ
R3	2·2kΩ	R15	15kΩ
R4	15kΩ	R16	15kΩ
R5	2·2kΩ	R17	15kΩ
R6	15kΩ	R18	1kΩ
R7	220kΩ	R19	15kΩ
R8	220kΩ	R20	15kΩ
R9	15kΩ	R21	1kΩ
R10	2·2kΩ	R22	220kΩ
R11	2·2kΩ	R23	220kΩ
R12	2·2kΩ	R24	220kΩ
		R25	220kΩ

All resistors $\frac{1}{4}$W, 10%, carbon

C1	0·22μF
D1–4	Mullard OA91 or OA81 diodes
TR1–6	Mullard ACY22 or OC71 transistors
T	small filament transformer 6·3V a.c., low current
B1, B2	6V, 50mA bulbs
S1, S2	two-way, single pole toggle switches
S3, S4	two-way, two pole on/off switches

Terminals XX′, YY′ – Mullard ORP60 photodiodes or press-to-break micro switches.

A pack containing the essential electronic components for this timer is available from the Manor Electronic Supply Co., 29 Manor Road, Sherborne St. John, Basingstoke, Hants. from whom further details are available.

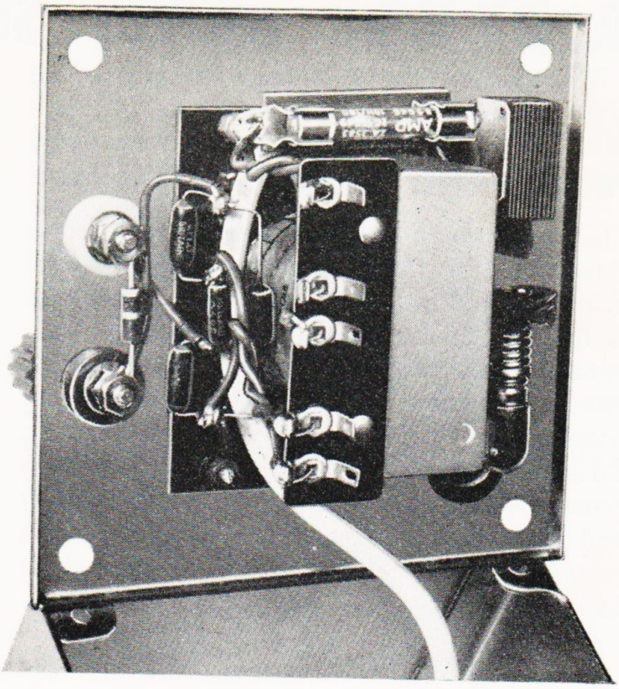


FIG. 5

A 6V 0 6V power supply

Introduction

This unit has been designed mainly for use with the Educational Service logic gates, binary adder/subtractor and computer circuits but it may also be found useful as a general power supply for transistor circuits. The unit provides two outputs relative to a common earth and these outputs are nominally −6V, 2A* and +6V, 250mA. In Educational Service logic applications, the main power requirements are from the negative supply and little current is required at +6V. It is for this reason that the positive supply of this unit is limited to 250mA.

Circuit Diagram

The circuit diagram of the power supply unit is illustrated in FIG. 1. The transformer T has two separate 6·3V secondary windings. These secondaries are each connected to full wave bridge rectifiers BR1 and BR2, reservoir capacitors C1, C2 and transistors TR1, TR2. These transistors are connected in the emitter-follower mode so as to reduce considerably the output resistance of the power supply unit. Thus for small changes in current drawn, the output voltage remains constant. This property is extremely important. The measured output impedance of the negative supply is less than 3Ω.

Potentiometers RV1 and RV2 can be used to set any required output voltage from zero up to a maximum of 9V off load.

In order that the positive and negative supplies have a common centre rail, transistor TR2 is an n-p-n device. In series with each transistor there is a diode (D1, D2). Although the inclusion of these diodes slightly increases the input resistance of the unit, they protect the transistors from the back emf due to a sudden overload. Continuous over-

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*See note on page 62.

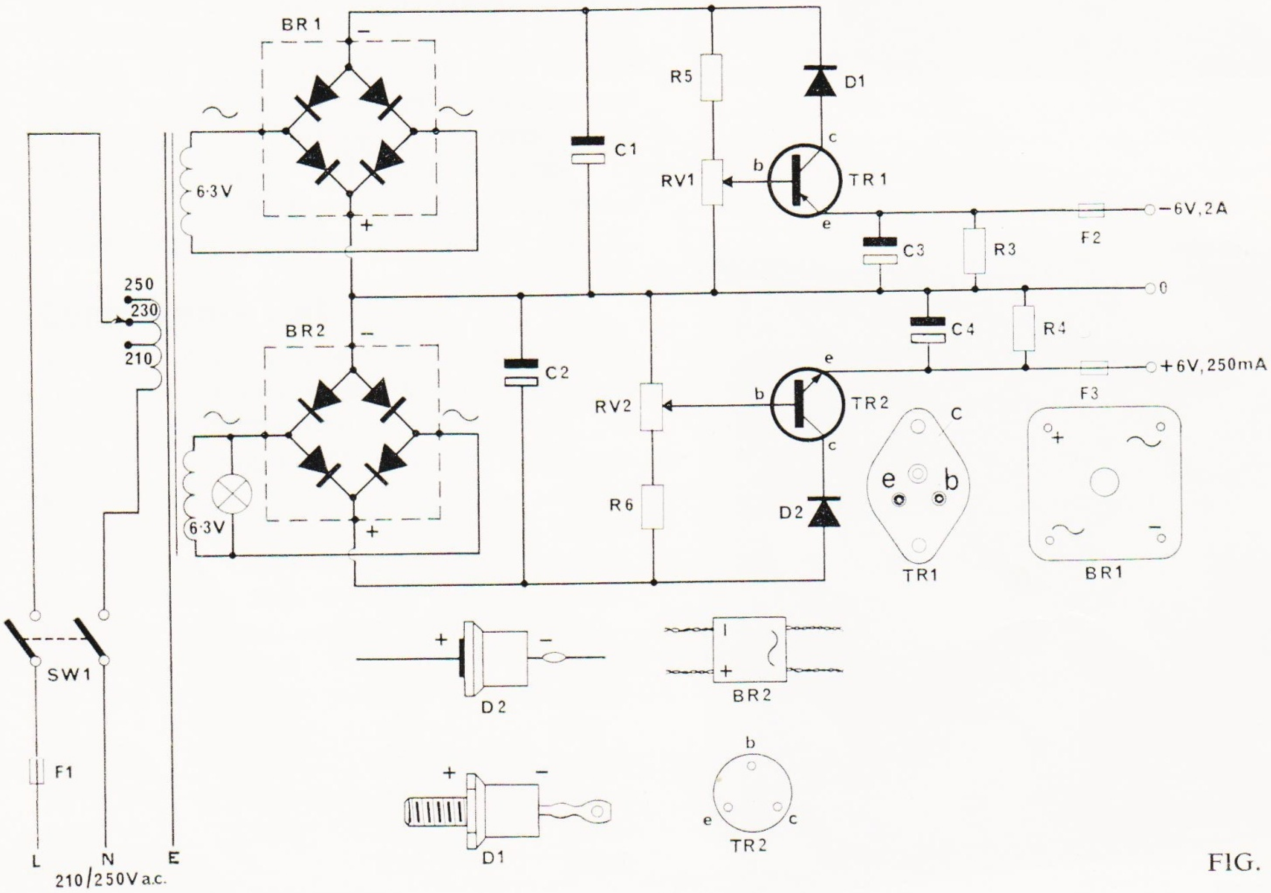


FIG. 1

load will, of course, cause one of the fuses F2 or F3 to blow.

The full wave rectifiers used in the prototype built to test the circuit design are now available in a pre-assembled and encapsulated circuit module. Although these modules are a little more expensive than four equivalent single rectifiers, they offer advantages from the practical assembly point of view as there is less wiring involved and no heat sinks need be made up. Alternatively, separate suitable rectifiers to hand may be used, in which case appropriate heat sinks will need to be incorporated and the size of the box increased.

Outlines of the various semiconductor devices are also shown in FIG. 1 so that there need be no confusion when wiring up the unit.

Assembly

The various components were found to fit easily into a standard conduit box of dimensions 9″ × 9″ × 3″ (23cm × 23cm × 7·6cm) and in the prototype were mounted on the underside of the lid as shown in FIG. 2. Heatsinks are required for the two transistors as follows:

TR1 3½″ × 3¼″ (90mm × 80mm)

TR2 2¾″ × 1¾″ (69mm × 46mm)

Both heat sinks were fashioned from ⅛″ thick aluminium sheet alloy.

An external view of the completed unit is shown in FIG. 3.

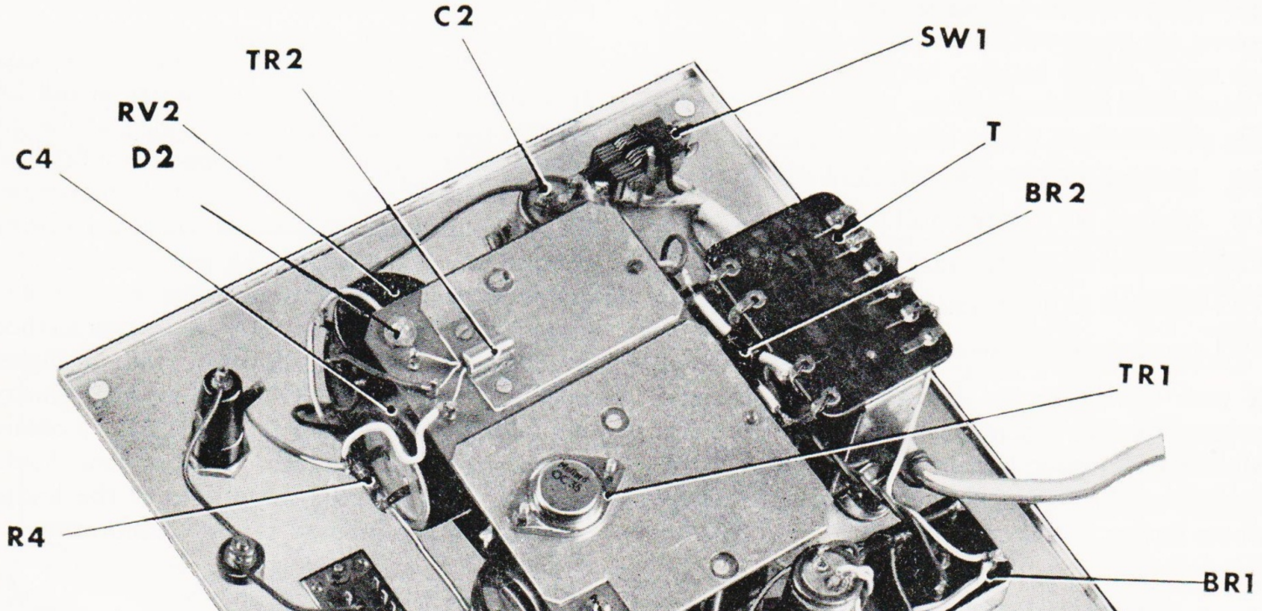


FIG. 2

List of Components

T	transformer: primary 210, 230, 240V, 50Hz secondary 2 × 6·3V, 2A minimum
B1	6·3V, 60mA bulb MES fitting
BR1	Mullard rectifier stack OSH02A–200 (or 4 × Mullard BYX13 rectifier diodes)
BR2	Mullard rectifier stack BY122 (or 4 × BYX38–300 or BYX22/200 rectifier diodes)
C1	2000μF electrolytic capacitor, 10V wkg
C2	800μF electrolytic capacitor, 10V wkg
C3	10,000μF electrolytic capacitor, 10V wkg
C4	10,000μF electrolytic capacitor, 10V wkg
RV1	500Ω, 3W wire wound potentiometer
RV2	500Ω, 3W wire wound potentiometer
R3	4·7kΩ, ½W resistor 10%
R4	4·7kΩ, ½W resistor 10%
R5	10Ω, 3W wire wound resistor
R6	10Ω, 3W wire wound resistor
F1	1 Amp fuse
F2	2 Amp fuse
F3	250mA fuse
D1	Mullard BYX38–300 or BYZ13 diode
D2	Mullard BYX10 or BYZ13 diode
TR1	Mullard OC35 transistor
TR2	Mullard AC127 transistor
SW1	two-pole, on/off switch

A pack containing the essential electronic components for this experiment is available from the MANOR ELECTRONIC SUPPLY CO., 29 Manor Road Sherborne St. John, Basingstoke, Hants. from whom further details are available.

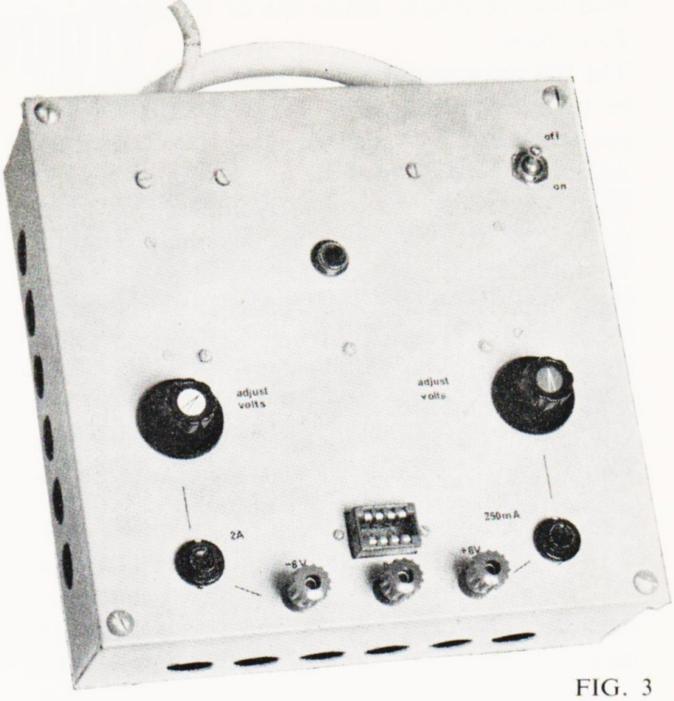


FIG. 3

*The 6V 2A specification assumes negligible voltage drop across the transformer secondary at full 2A output. For a small transformer rated at the 2A minimum the output from the apparatus at full load will be nearer 4V even with RV1 set to its maximum, the maximum output current obtainable at 6V being about 0·5A. If the full 6V 2A performance is required a heavier duty transformer may be employed (e.g. one rated at say 8A). A cheaper method is to employ a 2A transformer with a higher secondary voltage (e.g. 9V) or to tap the primary of a 6·3V 2A transformer at 205 or 200V to obtain a higher secondary voltage. However care should be taken not to exceed the ratings of the bridge transistor or the primary of the transformer.

solid state u.h.f./microwave oscillator (1GHz)

Introduction

It is hoped that this circuit will help satisfy the growing demand from educational establishments for an inexpensive microwave source. The circuit is based on a technical note from the Mullard Central Applications Laboratory.

The output may be fed into a transmission line, waveguide or antenna. Thus the relationship between wavelength and frequency may be verified and investigations on standing waves performed. In addition the oscillator may be used as a short range transmitter enabling the principles of aerials, propagation, reflection and reception to be demonstrated. The prototype gave an output of about 80mW at 1GHz (wavelength 30cm). Frequency adjustment is provided, the range being approximately 800MHz to 1.2GHz. The actual results obtained will depend upon the characteristics of the particular transistor used and upon the physical construction.

In addition to the oscillator, a simple modulating circuit is given. This circuit interrupts the power supply at 400Hz. Thus radiated signals, when detected and amplified, can be heard on a loudspeaker. The unit may be powered from a 12 volt battery and is, therefore, easily transported.

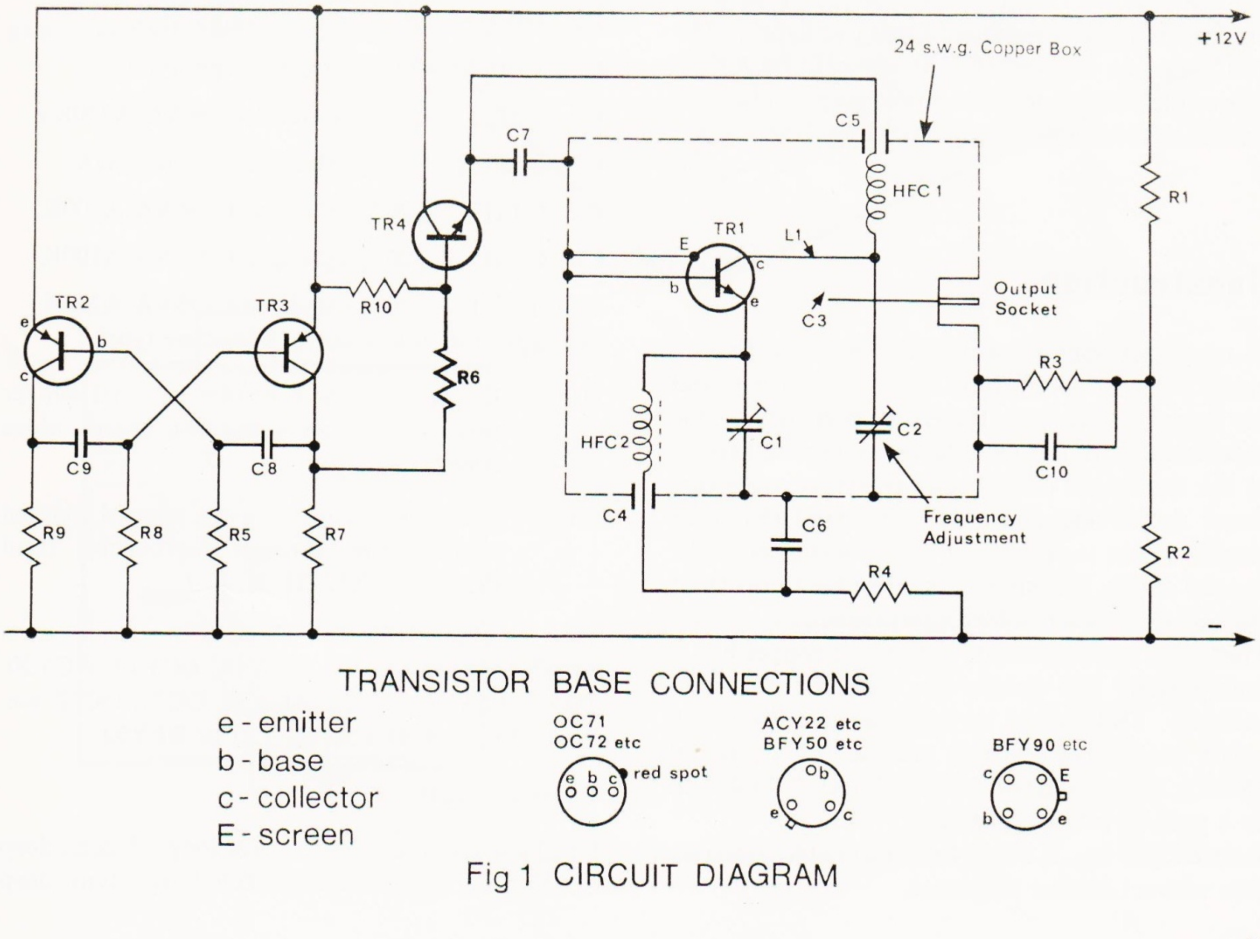


Fig 1 CIRCUIT DIAGRAM

Circuit Description (fig. 1)

The circuit utilises a BFY90 silicon planar transistor in the grounded base configuration. L1 and C2 constitute a series tuned circuit, C2 being the frequency adjustment. The tuned circuit is the collector load for TR1. At 1GHz a very small value of inductance is required and this is achieved by a piece of 22 s.w.g. copper sheet of dimensions 2·5×1·2cm. The positive feedback necessary for continuous oscillation is obtained through the inherent capacitance between collector and emitter. Some feedback also takes place through connecting leads. Capacitor C1 by-passes some of the feedback signal and is necessary since, if this signal becomes too large, spurious oscillations at many ill-defined frequencies result. The oscillator is completely enclosed by a copper box to reduce stray capacitance effects.

In order to provide an audio frequency content in the oscillator output, the d.c. supply to TR1 collector is interrupted at 400Hz. This switching is performed by TR4 which is driven by a multivibrator (TR2 and TR3).

Power Supply

The unit requires a smooth 12 volt d.c. supply. The prototype was also successfully operated on 6 volts with a considerably reduced power output. The total current consumption is approximately 70mA.

Construction

In many previous Educational Electronic Experiments physical details have been unimportant and the layout design has, therefore, been left to the experimenter. In this case, however, certain aspects of the layout are critical and, therefore, constructional details are given. It is essential that lead lengths within the oscillator be as short as possible. In view of this, care should be taken not to overheat the transistor when soldering its leads.

The layout of components outside the copper box is unimportant but details are included for convenience. TR4 should be mounted in a heat sink which may be conveniently provided by a piece of 16 s.w.g. aluminium sheet doubled over. TR4 should be a push fit into the heat sink.

Reference to figs. 2, 3 and 4 should enable construction without further comment.

Component Lists

R1 200Ω ±20%, 1W, wire wound or carbon
R2 47Ω ±20%, 1W, wire wound or carbon
R3 560Ω ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/560E)
R4 100Ω ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/100E)
R5 47kΩ ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/47K)
R6 1kΩ ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/1K)
R7 1kΩ ±20%, $\frac{1}{8}$W, carbon (Mullard (B803104NB/1K)
R8 47kΩ ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/47K)
R9 1kΩ ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/1K)
R10 470Ω ±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/470E)

C1 1–3pF tubular ceramic trimmer (Mullard C004EA/3E)
C2 1–3pF tubular ceramic trimmer (Mullard C004EA/3E)
C4 1000pF ±20%, 'feed through' type
C5 1000pF ±20%, 'feed through' type
C6 0·22μF ±20% (Mullard C296AA/A220K)
C7 0·001μF ±20% (Mullard C296AC/A1K)
C8 0·1μF ±20% (Mullard C296AA/A100K)
C9 0·1μF ±20% (Mullard C296AA/A100K)
C10 0·22μF ±20% (Mullard C296AA/A220K)
(all capacitors low voltage, miniature type)

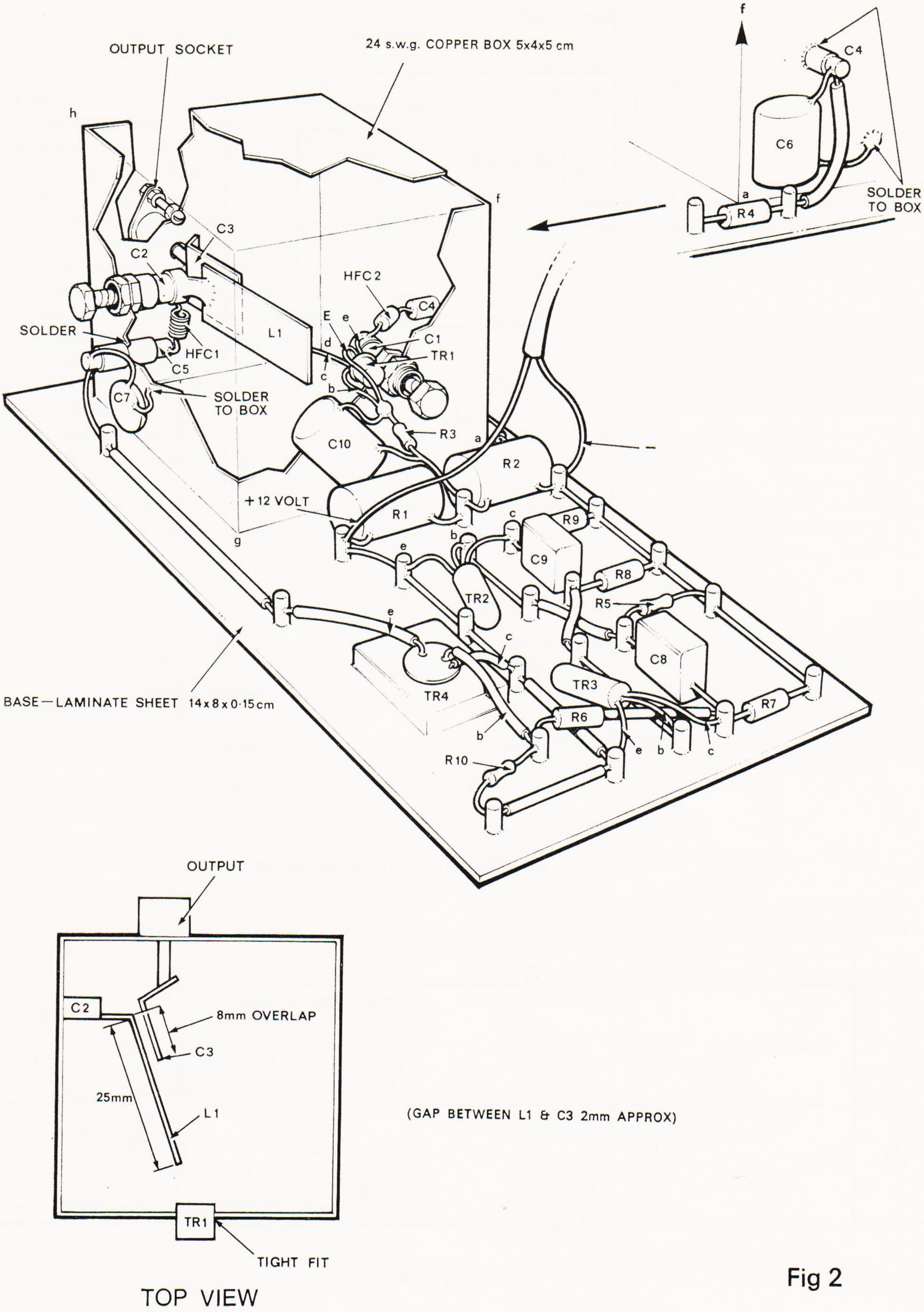
HFC1 12 turns 28 s.w.g. enamel covered copper wire, formed on $\frac{1}{8}$ in. drill shank, close coiled.

HFC2 1 lengthwise tuen 28 s.w.g. enamel covered copper wire through ferroxcube bead (Mullard FX1242)

TR1 Mullard BFX89, BFY90
TR2 Mullard ACY17, ACY18, ACY19, ACY20,
TR3 ACY21, ACY22, ACY39, OC71, OC72, etc.
TR4 Mullard BFY50, BFY51 or BFY52

Co-axial socket

L1 22 s.w.g. copper sheet, 2·5cm long×1·2cm. deep
C3 22 s.w.g. copper sheet, 1·2cm long×1cm. deep



(GAP BETWEEN L1 & C3 2mm APPROX)

TOP VIEW

Fig 2

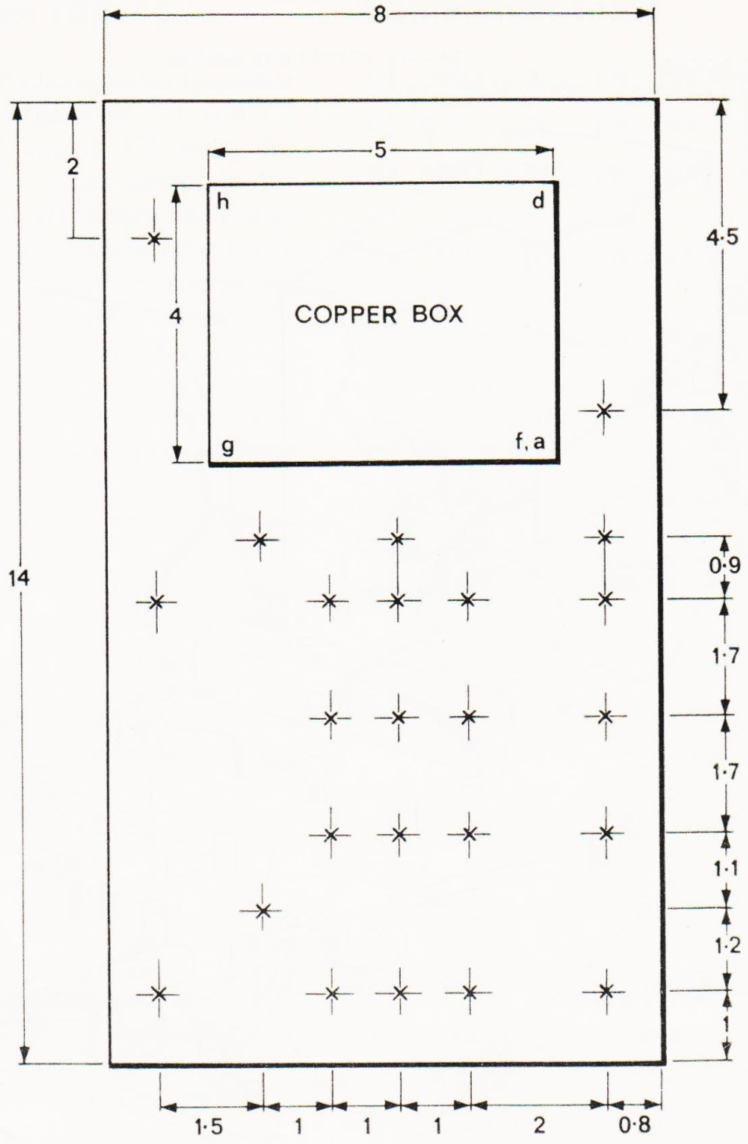


Fig 3

All dimensions in centimetres

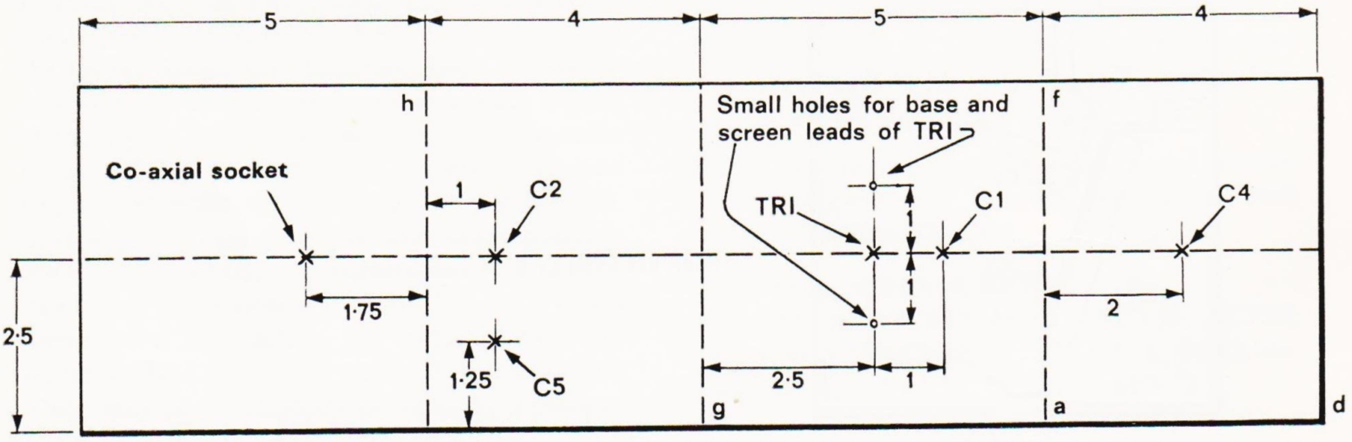


Fig 4

Tuning the Output

Fig. 5 shows a convenient termination which enables the output frequency to be set to the desired value. The short circuited transmission line causes a standing wave whose node and antinode positions may be detected; from these positions the frequency may be determined. Fig. 6 shows a suitable pick-up device. The pick-up coil should be moved along and in proximity to the lines. Antinode positions are indicated by maximum milliammeter readings and node positions by minimum readings. (The ratio of the maximum to the minimum reading is the 'standing wave ratio' which is theoretically infinite in this situation.) The distance between an adjacent node and antinode is a quarter wavelength and from this the frequency may be determined. ($v = f\lambda$, where v is taken as 3×10^8m/s, f is the frequency in Hz and λ is the wavelength in m.)

It may happen that no well-defined maxima and minima positions occur owing to spurious oscillation. This can be corrected by adjusting C1.

Fig. 7 shows a receiving device which may be used as an alternative to that of fig. 6. It is more dramatic since it gives a maximum sound output (400Hz) when the pick-up coil is adjacent to an antinode.

The receivers of figs. 6 and 7 may also be used to detect waves radiated from aerials and for other similar experiments.

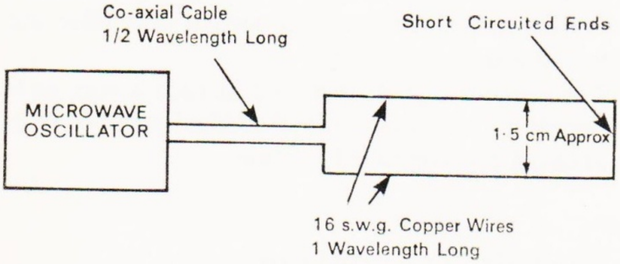


Fig 5

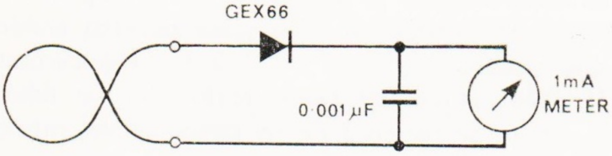


Fig 6

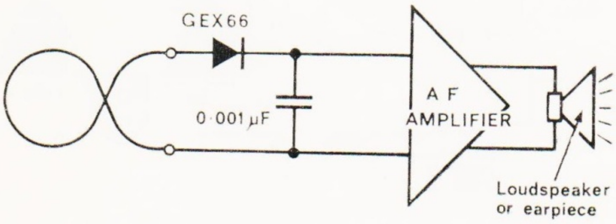


Fig 7

Aerials

The oscillator output may be fed into a conventional or experimental aerial array or waveguide. The short circuited line shown in fig. 5 will radiate over short distances especially if the short circuit is removed and the line spacing is increased.

Persons wishing to use the oscillator as a transmitter are reminded of the current Post Office regulations. Under certain conditions educational establishments may be granted a special licence. Interested persons should contact:

Radio Services Department/Radio Branch
GPO Headquarters
Armour House
St. Martin's le Grand
LONDON EC1

Note

The following companies are willing to supply a kit containing the essential electronic components for this experiment:

Manor Electronic Supply Co.
29 Manor Road, Sherborne St. John, Basingstoke, Hants.

Hawnt & Co. Ltd.
112–114 Pritchett Street, Birmingham 6

These companies are in some cases also able to supply components for purposes other than this experiment.

Interested persons should contact the above-mentioned companies.

a thyristor circuit for lighting control

Introduction

The purpose of this experiment is to provide a practical introduction to thyristors (silicon controlled rectifiers) and a useful apparatus.

The circuit employs the 'phase control' method of thyristor triggering and is especially suitable for the control of stage, theatre and room lighting. Persons wishing to use the circuit for motor speed control and other purposes should note that, whilst it can be used for a.c. and universal motors of the shunt, series or compound types, it is not suitable for equipments with transformer inputs or other devices presenting a similar input characteristic (e.g. induction motors). It is not suitable for synchronous machines, capacitive loads or fluorescent lighting. Another article in this book deals specifically with the control of fractional horse power motors. The circuit has been designed for powers up to 2kW but of course it is possible to control far higher powers using larger Mullard thyristors. (A heavier duty switch and filter etc. would also be necessary.)

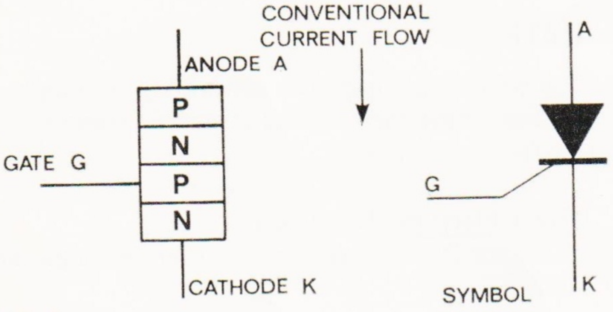


Fig1

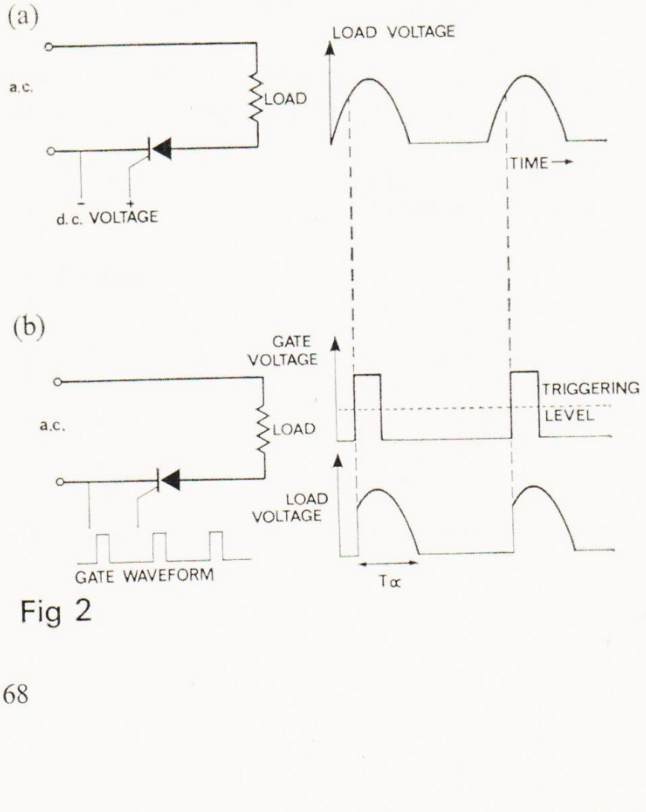


Fig 2

The circuit diagram is drawn in such a way as to permit construction from individual parts or from Mullard pre-assembled modules.

Circuit Description

The thyristor or silicon controlled rectifier (S.C.R.) is a four-layer semiconductor device having three electrodes as shown in fig. 1. The device is similar in many respects to an ordinary rectifying diode. However, conduction takes place between anode and cathode only when a sufficiently large current is applied at the gate. Once the thyristor has 'fired' it cannot be switched off by removing the gating signal; to switch the device off it is necessary to

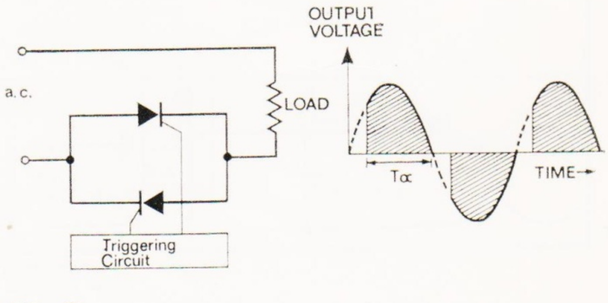


Fig 3

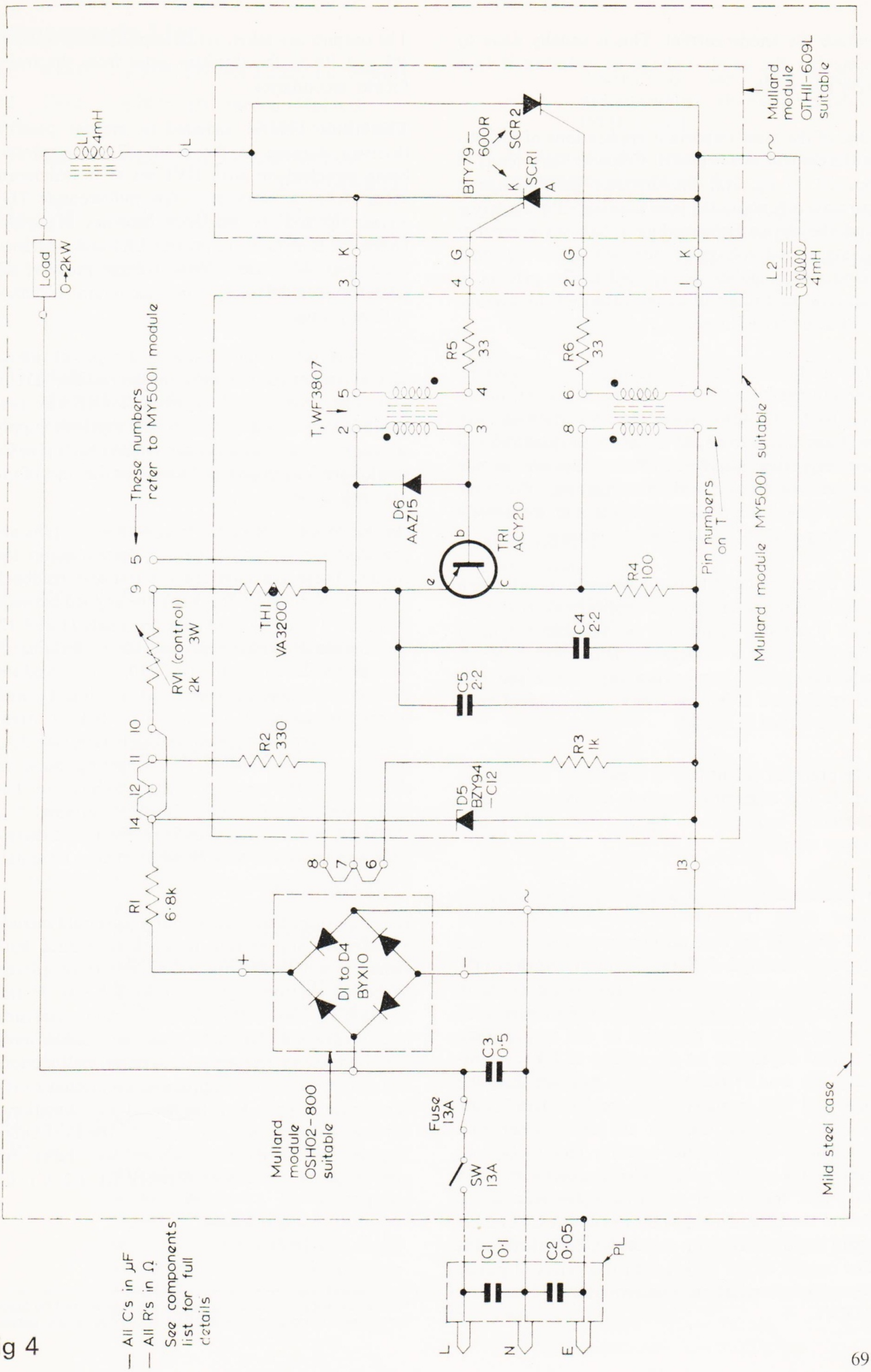


Fig 4

— All C's in μF
— All R's in Ω
See components list for full details

reduce the anode current. This is usually done by removing the anode voltage or reducing it to a very low value.

One of the most important applications of S.C.R.s is the control of a.c. power. Consider the circuits of fig. 2.* In fig. 2(a) the thyristor gate voltage is permanently above the level necessary for triggering and the device behaves like a half wave rectifier giving a load voltage as indicated. If on the other hand square pulses are applied to the gate as in fig. 2(b) the firing will be retarded and the average output power reduced.

The average output voltage may be adjusted by varying the time position of the triggering pulses relative to the supply waveform. A convenient way of doing this is to adjust the mark to space ratio of the triggering waveform. This is known as the 'phase control' method of triggering. The time 't_α' is called the conduction time and the corresponding angle 'α' is the *conduction angle*.

The circuit of fig. 2(b) is a half-wave circuit which is suitable for certain simple applications. However, such a circuit would not be suitable for lamp dimming since a noticeable flicker would occur, especially at low conduction angles. For this sort of application a full-wave circuit is required such as that shown in fig. 3.*

The practical circuit (fig. 4) is basically the same as fig. 3. The triggering circuit is a type of blocking oscillator synchronised by its unsmoothed d.c. power supply.

When the unsmoothed d.c. voltage appears across zener diode D5 and the base potential divider (R2 and R3), the base acquires a positive potential through winding 2–3 of transformer T and thus TR1 remains in the cut-off state. However, a charging current flows into C4 and C5 via RV1 and TH1 causing the emitter potential to rise with a time constant dependent on the setting of RV1. Eventually the emitter becomes more positive than the base and TR1 commences to conduct. Due to the positive feedback through the transformer (T), cumulative action ensues causing TR1 to bottom rapidly. C4 and C5 now discharge quickly through TR1 and the emitter potential again falls below that of the base, causing TR1 to cut off. C4 and C5 again begin to charge up and the whole cycle repeats. The output of the circuit then is a series of pulses whose time separation is determined by the setting of RV1.

The outputs are taken via current limiting resistors R5 and R6 to the thyristor gates from the transformer secondaries.

Thermistor TH1 is included to prevent possible thyristor damage in the event of the apparatus being switched on with RV1 set at its minimum value. After a delay of a few milliseconds TH1 warms up and its resistance becomes negligible. Diode D6 is included to protect TR1 under no load conditions when the reverse voltage pulse at the collector could exceed the maximum collector voltage rating.

The triggering circuit obtains its d.c. power (about 12 volts) from the full wave bridge rectifier (D1 to D4). The unsmoothed supply automatically synchronises the trigger circuit to the thyristor supply ensuring that at the end of each mains half cycle C4 and C5 are fully discharged ready for the start of the next half cycle.

On the Mullard MY5001 trigger module, pins are provided for access to various points within the circuit. These are intended for test and feedback purposes. Voltage feedback may be applied between terminals 9 and 10 or between terminals 11 and 12. The maximum voltage permissible at terminal 9 with respect to terminal 10 is +10, −10V, and the maximum voltage permissible at terminal 11 with respect to terminal 12 is +3, −10V. Current feedback may be applied through terminal 5, a positive current causing the triggering pulse to advance and the conduction angle to increase. The maximum current to be applied to terminal 5 is +100mA peak. A light-sensitive resistor, a thermistor or a transistor may be used between terminals 9 and 10.

It is important that thyristor circuits should include an effective suppression network to reduce both radiated and mains conducted interference levels to below the limits specified by B.S.800. If this measure is not adopted, radio and television interference will probably result and furthermore the conducted interference can cause malfunctioning of other electronic apparatus connected to the same mains supply. For this reason the Educational Service prototype was submitted to the Post Office Engineering Department whom we thank for approving the suppressor network L1, L2, C1, C2 and C3.

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*These are not practical circuits. No attempt should be made for example to connect one side of a battery to the a.c. mains.

Components List

R1	6.8kΩ	±20%, 8W (for a 240V a.c. supply)
R2	330Ω	±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/330E)
R3	1kΩ	±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/1k)
R4	100Ω	±20%, $\frac{1}{8}$W carbon (Mullard B803104NB/100E)
R5	33Ω	±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/33E)
R6	33Ω	±20%, $\frac{1}{8}$W, carbon (Mullard B803104NB/33E)
TH1		Mullard VA3200 N.T.C. thermistor (if the MY5001 module is used TH1 should be added in series with RV1 and terminal 9)
RV1	2kΩ	3W (or more) variable, wire wound or carbon (the greater the physical size, the smoother the control)
C1	0.1μF	300V a.c. Tested to BS613 or use plug suppressor unit P1.
C2	0.05μF	300V a.c.
P1		†Dubilier plug suppressor no. 2 (includes C1 and C2)
C3	0.5μF	300V a.c. To BS613 (†Dubilier 660M—20362)
C4	2.2μF	±20%, 250V (Mullard C280AE/A2M2)
C5	2.2μF	±20%, 250V (Mullard C280AE/A2M2) A single 4μF capacitor may be used for C4 and C5 but this should not be an electrolytic type
D1, D2, D3, D4		four Mullard BYX10 or BYX22–800 or BY127 or BYX36–400 silicon diodes Alternatively Mullard pre-assembled bridge module OSH02–800 or OSH01–400 may be employed
D5		Mullard BZY94–C12 or BZY88–C12 voltage regulator diode
D6		Mullard AAZ15 diode
TR1		Mullard ACY20 transistor
SCR1, SCR2		Two Mullard BTY79–600R or BTY87–600R thyristors on 4″×4″ *separate* heatsinks. The gate leads should be twisted together (but not short-circuited together) and made as short as possible to avoid possible misfiring due to pick-up from the power circuit Alternatively use the Mullard pre-assembled thyristor module OTH11–609L
T		Mullard WF3807 transformer. Observe pin connections given in fig. 4.
*L1 and L2		40 turns 14swg enamelled copper on pair of Mullard 'E' cores FX3328 or FX2527 (winding on insulating former on centre limb). Test to BS613. (Total number of core pieces required is four.)
SW		single pole, 13 amp on-off switch, domestic type is suitable
F		13 amp fuse (may be included in switch)

The Mullard components for this circuit may be ordered by educational establishments through Mullard industrial distributors. A list of distributors is available on request.

*Suitable ready wound and tested chokes may be purchased from:

GB Electrical Services Ltd.
1 Goodmayes Road
ILFORD Essex

†Distributed by Lugton & Co. Ltd., 210 Tottenham Court Road, London W1.

The following companies are willing to supply a kit of essential electronic components for this experiment:

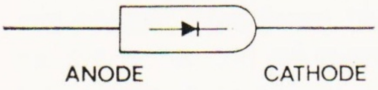
Hawnt & Co. Ltd.
112-114 Pritchett Street
BIRMINGHAM 6

Manor Electronic Supply Co.
29 Manor Road
Sherborne St. John
BASINGSTOKE Hants.

Interested persons should contact the above-mentioned companies direct.

Component connection key

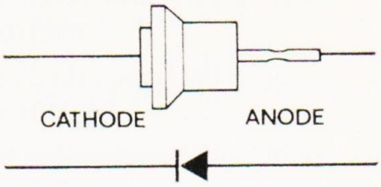
BYX10, BY127



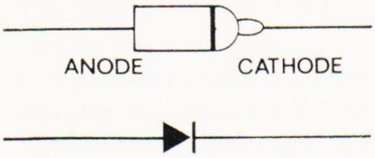
(DIODE SYMBOL ON BYX10 ONLY)

BYX22–800

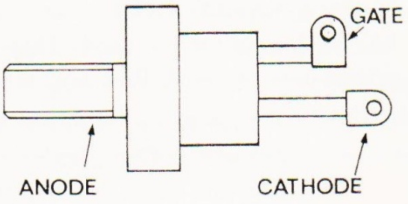
METAL ENVELOPE IS CONNECTED TO CATHODE



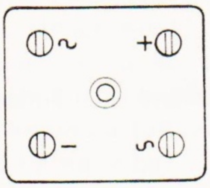
BYX36–400, BZY94–C12
AAZ 15

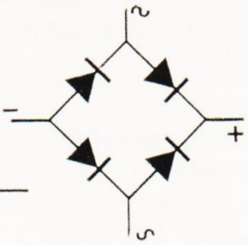


BTY79–600R, BTY87–600R

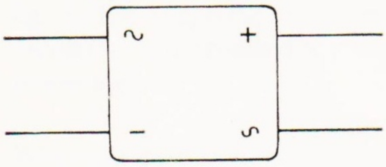


OSH02–800

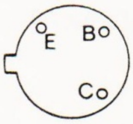




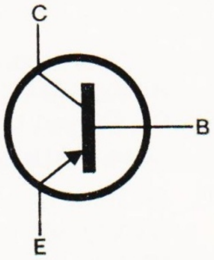
OSH01–400

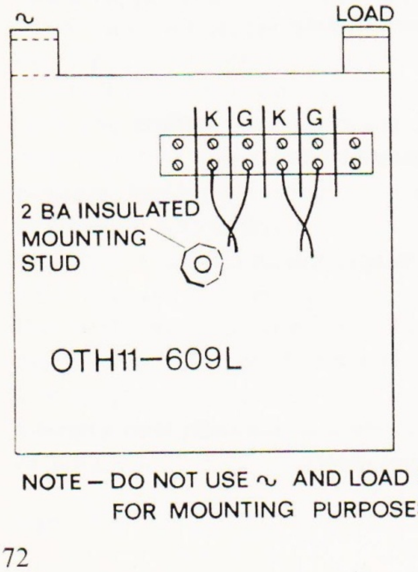


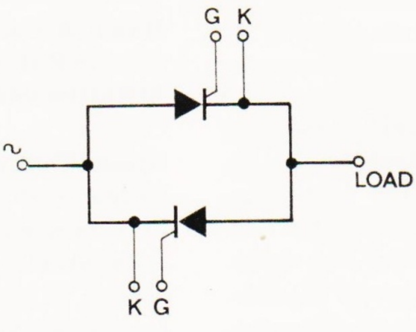
ACY 20



B CONNECTED TO ENVELOPE



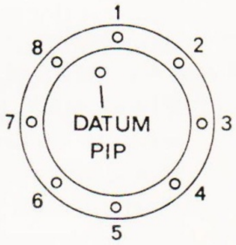




NOTE – DO NOT USE ~ AND LOAD LUGS FOR MOUNTING PURPOSES, MOUNT VERTICALLY.

WF 3807

NOTE–TERMINALS NOT MARKED. FOR CONNECTIONS SEE FIG 4



a motor speed controller

Introduction

Thyristors are used for many industrial control applications, particularly for motor speed control. The apparatus described here is one of the simplest electronic forms of motor speed controller. It is intended for the speed control of fractional horse power a.c. series motors of the type normally used in electric hand drills and food mixers ($\frac{1}{2}$ h.p. maximum). It is not suitable for induction motors which are often used on electric bench drills, lathes and washing machines. Lighting control is covered by another publication in this series.*

A typical electric drill has an unloaded speed of 2500 to 3500 rpm which is too fast for many applications—for drilling concrete for example a speed of 500 rpm is suitable. The controller not only enables the speed to be varied but also gives a reasonably constant speed under varying load conditions. This is achieved by using the motor back e.m.f. as a feedback signal.

Circuit Description

To maintain motor speed under changing conditions of motor load or mains supply, the motor back e.m.f. is used to change the thyristor conduction angle.

The motor is connected in series with the thyristor (SCR) and the a.c. supply (fig. 1). The network R1, C4, RV1, R2 and D2 establishes a positive going waveform at point E on the half cycles during which D2 is conducting. When the thyristor is not conducting the motor produces a back e.m.f. across the armature which is proportional to the residual flux and motor speed. This back e.m.f. appears as a positive feedback potential at the thyristor cathode (K).

The waveform of the gate voltage is indicated in fig. 2. On half cycles during which D2 is conducting, C4 charges up via R1 and D2. On half cycles when D2 is not conducting, C4 discharges through RV1 by an amount dependent on its setting. The state of charge of C4 at the start of the next half cycle therefore depends on the setting of RV1. In fig. 2 the waveform at the thyristor gate during conducting half cycles of D2 is shown for various settings of RV1. The thyristor fires as the gate waveform crosses the triggering level and by adjusting RV1 the conduction angle α can be varied between about 0 and 160°.

A change in motor speed, due for example to a load variation, results in a shifting of the level of the gate waveform and a consequent correction in conduction angle.

Resistor RV2 adjusts the minimum motor speed which can be obtained.

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*See 'A Thyristor Circuit for Lighting Control', in this book

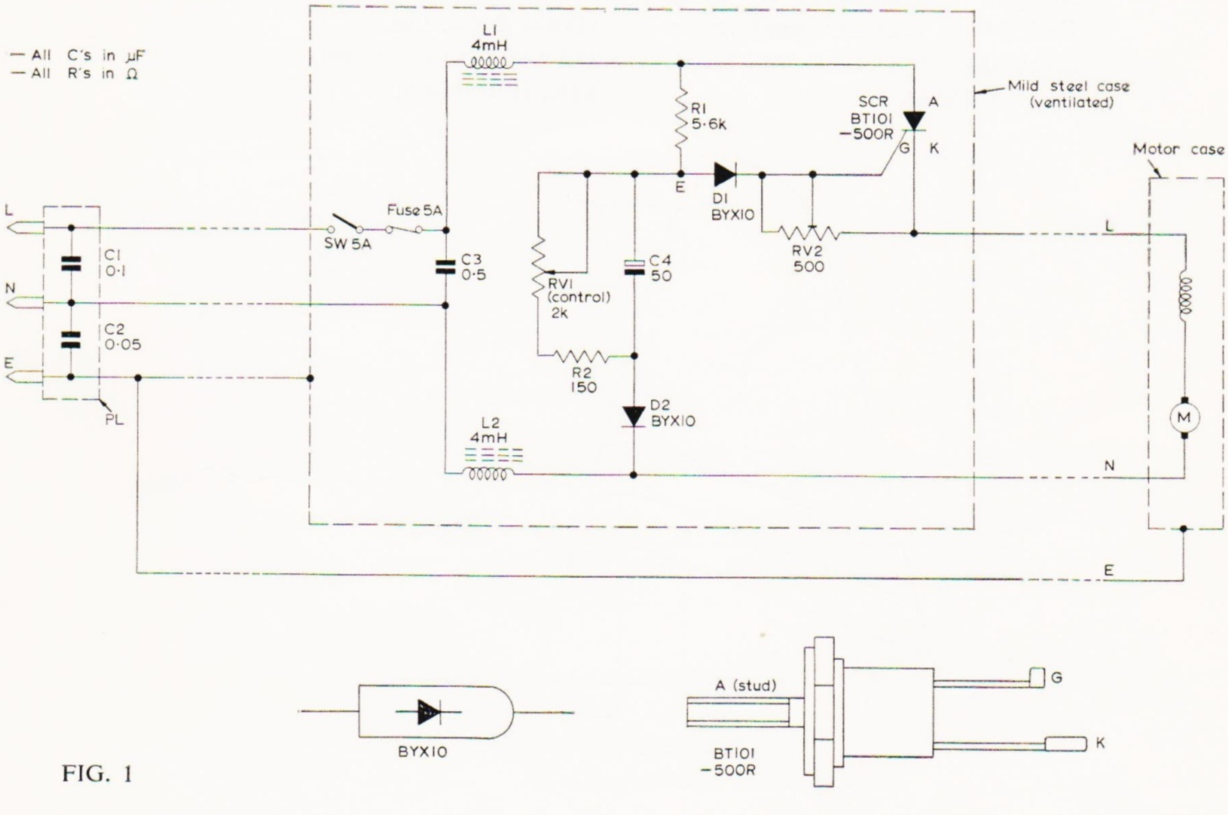

FIG. 1

Diode D1 isolates the trigger circuit when the thyristor is in the on state.

It is important that thyristor circuits should include an effective suppression network to reduce both radiated and mains conducted interference levels to below the limits specified by BS800. If this measure is not adopted, radio and television interference will probably result and furthermore the conducted interference can cause malfunctioning of other electronic apparatus connected to the same mains supply. For convenience the suppression network L1, L2, C1, C2 and C3 is the same as that used in 'A Thyristor Circuit for Lighting Control'.

Components List

R1	5·6kΩ	±20%, 6W
R2	150Ω	±20%, 3W
RV1	2kΩ	3W, wire wound, variable
RV2	500Ω	carbon pre-set (Mullard E097AC/470E)
C1	0·1μF	300V a.c. } Tested to BS613 or use plug suppressor unit PL
C2	0·05μF	300V a.c. } Tested to BS613 or use plug suppressor unit PL
C3	0·5μF	300V a.c. To BS613 († Dubilier 660M—20362)
C4	50μF	40V, d.c. electrolytic (Mullard C426AR/G50
PL		† Dubilier plug suppressor no. 1 (includes C1 and C2)
*L1 and L2		40 turns 14swg enamelled copper on pair of Mullard 'E' cores FX2527 or FX3328 (winding on insulating former on centre limb). Test to BS613.
SCR		Mullard BT101-500R thyristor (mount on 9 sq. in. heat sink)
D1,D2		Mullard BYX10 diodes
SW		Single pole, 5 amp (or more) on-off switch
F		5A fuse (may be included in switch)

*Suitable ready wound and tested chokes may be purchased from:

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ILFORD Essex

† Distributed by Lugton & Co. Ltd., 210 Tottenham Court Road, London W1

The Mullard components for this circuit may be ordered by educational establishments through Mullard industrial distributors. A list of distributors is available on request.

Note

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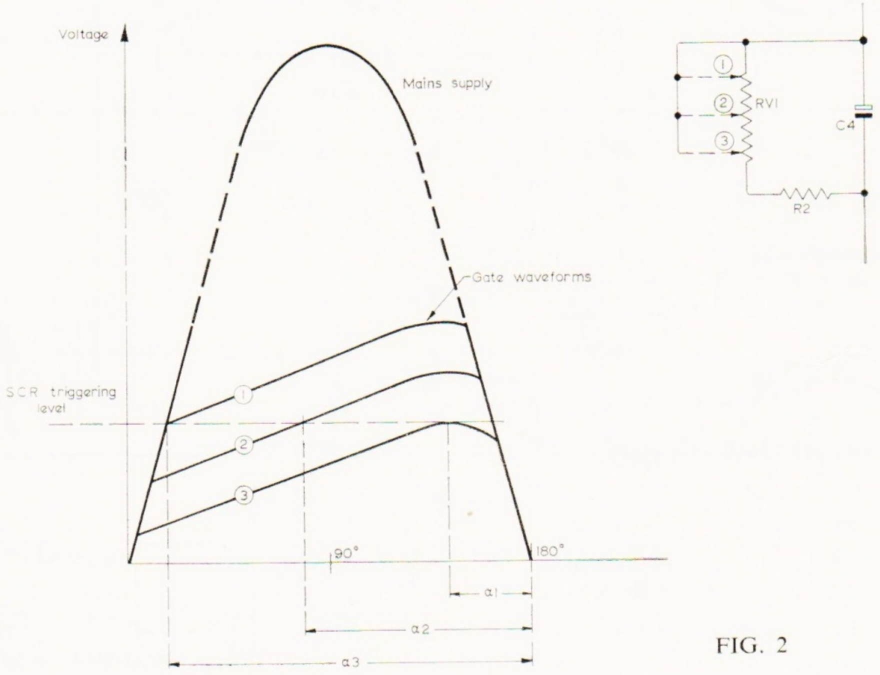

FIG. 2

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