THE instrument to be described embodies a number of circuits used collectively for the purpose of operating a range of Geiger-Müller (G.M.) counters and silicon surface barrier (s.s.b.) detectors.

The ratemeter in its complete form could represent to the science teacher an ideal means of demonstrating the relative characteristics of the two types of detector with various kinds of radiation. To the amateur it might be a useful and interesting instrument for radioactivity investigation at home or in the field where its self-contained power supplies and low weight allow complete freedom of movement.

GENERAL ARRANGEMENT

The electronics of the ratemeter are divided into five sub-units: G.M. Amplifier; S.S.B. Amplifier; Expander Stage; Ratemeter; and E.H.T. Generator and Power Supplies.

The physical arrangement of the instrument closely follows the same general pattern.

The majority of components comprising each sub-unit are mounted on a separate printed wiring board; four of these boards are installed in the underside portion of the main chassis and the fifth, the power supply board, is mounted on the top decks. The two transformers, and certain other components, as well as the dry batteries, are mounted directly onto the chassis. All operating controls and the meter are on the front panel. The loudspeaker unit is fitted inside the metal case.

Fig. 1 provides the key to the whole assembly. All sub-units are shown in block diagrammatic form with key references to inter-unit wiring and also references to appropriate circuit diagrams. All those components not included on the separate boards, but mounted on the chassis, front panel, and case, are shown in detail with all appropriate wiring.

Although the instrument is described in its complete form, capable of operating both types of detector, there is no reason of course, why only one type of detector should not be catered for with obvious economies where limited resources or interest so dictate. An example of this might, for instance, be where only alpha particles were to be detected. In this case only the S.S.B. detector amplifier, the ratemeter and two 9 volt batteries would be required to use S.S.B. detectors such as the 20th Century types SSNO3K and SSNO5K.

CHASSIS CIRCUIT

With reference to the inter-unit diagram Fig. 1, it can be seen that the instrument permits a solid state radiation detector and a G.M. counter to be connected simultaneously, the switch S1 ("S.S.B./G.M.") selecting the required device. An e.h.t. supply is internally generated and is available for direct application to the G.M. circuit or, suitably reduced, to the s.s.b. detector circuit. The amount of reduction needed will depend upon the maximum permissible voltage for the particular detector used.

With S1 in the "G.M." position the e.h.t. voltage is variable from zero to maximum by the front panel control VR1 ("G.M. E.H.T.").

In the "S.S.B." position S1 makes operative an internal preset e.h.t. control VR2 which sets the voltage across a variable attenuator chain R1, R2 and VR3 before being applied to the s.s.b. detector. VR3 is a front panel control ("S.S.B. VOLTS).

S2 ("ABG/A") is associated with the s.s.b. detector amplifiers. The purpose of this switch is to select the output either of the s.s.b. amplifier, whose output for alpha pulses is large in relation to others, or that of the expander stage whose added gain enables beta and gamma radiations to be detected in addition to alpha. In this way discrimination against beta and gamma pulses can be obtained by virtue of their small size. In the "ABG" (alpha + beta + gamma) position of S2 the noise discriminator control VR5 ("DISC") is operative. S4 ("M/B") selects internal battery or mains power and S5 ("E.H.T. OFF") enables the e.h.t. generator to be shut off completely.

The count rate, in three switched ranges (0–5, 0–50, and 0–500 counts per second) selected by S3 ("COUNTS/SEC and OFF") is displayed on a moving coil meter M1.

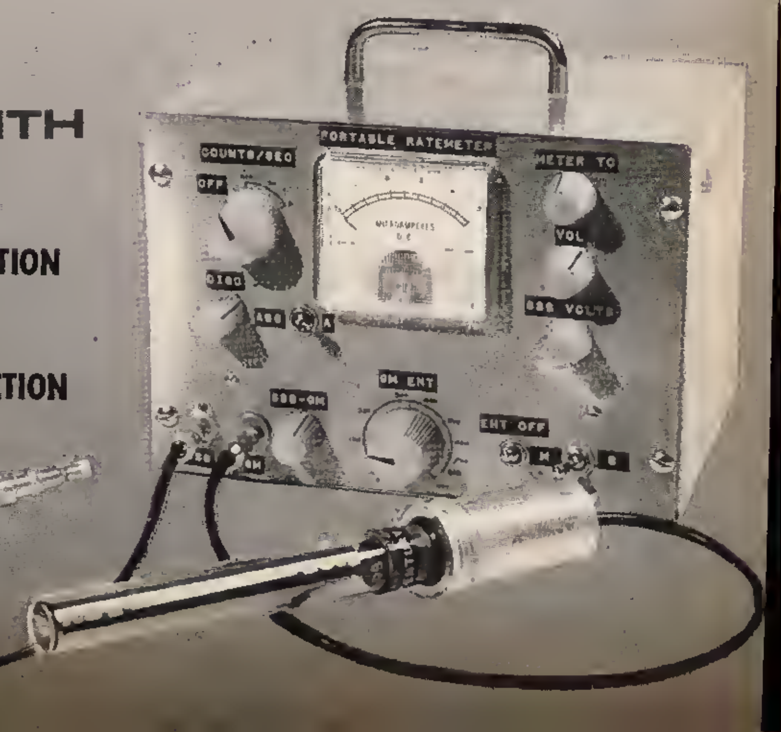
by D.V. SMITH

COMPLETELY PORTABLE

MAINS OR BATTERY OPERATION

ALL SOLID STATE CIRCUITRY

SEMI-MODULAR CONSTRUCTION



The "OFF" position of this control disconnects all power supplies. Audible indication of counts is provided via a loudspeaker LS1, the volume of which is controllable by VR4 ("VOL"). Control is given also of the meter time constant by VR6 ("METER T.C.").

The individual circuits of the sub-units will now be described.

G.M. AMPLIFIER

The simplest of these circuits is the G.M. amplifier (Fig. 2) in which TR1 and TR2 are connected as a cascaded emitter follower amplifier.

No voltage amplification is required with the large pulses usually obtained from a G.M. counter, but since the source impedance is rather high, some impedance transformation is necessary to drive the ratemeter circuit without undue attenuation. The cascaded emitter-follower circuit adequately fulfills this requirement.

The diodes D1 and D2 protect TR1 from the danger of large voltage transients.

The output is taken from point *H4* to the ratemeter, via S1.

S.S.B. DETECTOR ELECTRONICS

NOTE: A full description of the electronic circuitry required for solid state detectors appeared in an introductory article entitled *A Solid State Radiation Detector*—see PRACTICAL ELECTRONICS June 1965. Reference to this previous article is recommended if amplification of the concise circuit descriptions which appear below is required.

The s.s.b. circuitry is arranged in two sections, the first, the S.S.B. Amplifier, is for alpha particle detection. In this application large signals are experienced not requiring high gain, and consequently a high signal to noise ratio is achieved. The Expander Stage is intended as an add-on unit to extend the capability of the combination for the detection of beta and gamma radiation.

S.S.B. AMPLIFIER

The circuit of the S.S.B. Amplifier is shown in Fig. 3.

The outer shell of the s.s.b. detector is taken to the common earth line and the collector connected via the 1 megohm load resistor R10 to a positive bias supply. The voltage pulse appearing across the load is applied to the base of TR3 which is operating as a low noise emitter follower. TR4 and TR5 are conventional voltage amplifiers with a total gain of about 500. The output from TR5 collector is fed via a differentiating network, C13, R21, and R22, to TR6 which operates as a phase splitter output stage. The purpose of this differentiation is to enhance the signal to noise ratio by limiting the bandwidth of the amplifier.

A positive output (with link between A-B) is obtained via C15 at point *F2*.

If it is not intended to add the expander stage for beta and gamma detection, an economy may be made where an instrument sensitive to negative pulses is used. The output in this case may be taken via the output capacitor C15 direct from the collector of TR5 and so obviating the need for TR6. The loss of the differentiating network making no difference in this type of operation.

EXPANDER STAGE

The circuit of the expander stage is shown in Fig. 4. It consists of an input emitter follower, a variable current discriminator/amplifier and an emitter follower output stage with a similar protecting network as in the S.S.B. Amplifier.

The positive going output from point *F6* on Fig. 3 is applied to the input of the expander stage. The input emitter follower TR7 is necessary to drive the low impedance current discriminator TR8 without upsetting the output of TR6 in the first section.

The operation of TR8 as a current discriminator is very simple. The standing base current set by VR5 and the 15 kilohm base resistor R31 is used as the negative discriminator bias which the positive going signal current from TR7 must overcome for the pulse

PORTABLE RATEMETER

SPECIFICATION...

APPLICATION	For use with wide range of G.M. and solid state radiation detectors
G.M. SENSITIVITY	100mV
S.S.B. INPUT SENSITIVITY	
Single Stage Only	Alpha particles down to 200keV
With Expander Stage	Beta and gamma radiation down to 50keV
THREE COUNT RANGES	0–5, 0–50, 0–500 counts per sec
RESOLVING TIMES	10msec, 1msec, and 100µsec respectively for the above ranges
METER	Variable time constant; set zero and calibration control
E.H.T. SUPPLY	0–300V, continuously variable

COMPONENTS . . .

Resistors

R1	22MΩ 1W	R28	120kΩ
R2	22MΩ 1W	R29	1·2kΩ
R3	22MΩ 2W	R30	100kΩ
R4	2·2MΩ	R31	15kΩ
R5	4·7MΩ	R32	10kΩ
R6	4·7MΩ	R33	120kΩ
R7	4·7MΩ	R34	120kΩ
R8	4·7kΩ	R35	3·3kΩ
R9	4·7kΩ	R36	1MΩ
R10	1MΩ	R37	10kΩ
R11	2·2MΩ	R38	3·3kΩ
R12	2·2MΩ	R39	100kΩ
R13	68kΩ	R40	68kΩ
R14	150kΩ	R41	3·3kΩ
R15	4·7kΩ	R42	330Ω
R16	47Ω	R43	68kΩ
R17	100Ω	R44	4·7kΩ
R18	150kΩ	R45	2·2kΩ
R19	4·7kΩ	R46	100Ω
R20	47Ω	R47	18kΩ
R21	68kΩ	R48	470Ω
R22	33kΩ	R49	10Ω
R23	3·3kΩ	R50	10Ω
R24	3·3kΩ	R51	430Ω
R25	1MΩ	R52	68Ω
R26	100Ω	R53	12kΩ
R27	120kΩ	R54	12kΩ

All ±10%, ½W carbon unless otherwise stated.

Potentiometers

VR1	10kΩ linear	VR5	10kΩ log
VR2	10kΩ linear, preset	VR6	500Ω linear
VR3	2MΩ linear	VR7	2kΩ linear, preset
VR4	10kΩ linear	VR8	5kΩ skeleton preset

Capacitors

C1	2,500pF paper 500V (T.P.C.)
C2	0·025μF paper 500V (T.P.C.)
C3	0·25μF paper 500V (T.P.C.)
C4	100μF elect. 6V (Sub mins)
C5	5,000μF elect. 6V (Sub mins)
C6	500μF elect. 25V (Tubes)
C7	1μF paper 250V (T.P.C.)
C8	470pF ceramic (1,000V)
C9	5,000pF ceramic (500V)
C10	0·5μF elect. 15V (Sub mins)
C11	8μF elect. 15V (Sub mins)
C12	0·5μF elect. 15V (Sub mins)
C13	1,000pF ceramic 500V
C14	50μF elect. 15V (Sub mins)
C15	0·1μF plastic 250V (Polyesters)
C16	0·1μF plastic 250V (Polyesters)
C17	0·1μF plastic 250V (Polyesters)
C18	0·1μF plastic 250V (Polyesters)
C19	0·1μF plastic 250V (Polyesters)
C20	0·1μF plastic 250V (Polyesters)
C21	250μF elect. 25V (Tubes)
C22	0·1μF plastic 250V (Polyesters)
C23	22pF ceramic
C24	47pF ceramic
C25	1μF elect. 15V (Sub mins)
C26	2,000μF elect. 25V (Tubes)
C27	0·05μF elect. 500V (T.P.C.)
C28	1μF elect. 250V (T.P.C.)
C29	0·05μF elect. 500V (T.P.C.)
C30	0·1μF elect. 1,000V (T.P.C.)
C31	0·1μF elect. 1,000V (T.P.C.)
C32	2,000μF elect. 25V (Tubes)
C33	2,000μF elect. 25V (Tubes)

Note: Information in brackets is the form of coding used by Radiospares Ltd.

Switches

S1	Midget wafer 4-pole, 2-way
S2	Toggle, s.p.d.t.
S3	Wafer, 4-pole, 4-way
S4	Toggle, d.p.d.t.
S5	Toggle, s.p.d.t.

Transformers

T1 Mains transformer, 200-250V tapped primary. Secondary 16·3V 0·3A centre tapped

T2 Mains transformer, 200-250V tapped primary. Secondary 6·3V 1A centre tapped

Transistors

TR1-TR13 OC44 Mullard (13 off)

TR14-TR17 OC81 Mullard (4 off)

Diodes

D1	Silicon	OA202 Mullard
D2	Silicon	OA202 Mullard
D3	Zenner	6·8V OAZ244 Mullard
D4	Silicon	125V r.m.s. 500mA Radiospares REC50
D5	Zenner	6·8V OAZ244 Mullard
D6	Silicon	800 p.i.v. 500mA International Rectifier SD98 or 985
D7	Silicon	800 p.i.v. 500mA International Rectifier SD98 or 985
D8	Silicon	125V r.m.s. 500mA Radiospares REC50

Plugs and Sockets

PL1	Coaxial free plug	P.E.T. type 101
SK1	Coaxial fixed socket	P.E.T. type 101
PL2	Coaxial free plug	Belling Lee
SK2	Coaxial fixed socket	Belling Lee
PL3	Mains input fixed 3-pin plug	Radiospares
SK3	Mains input free 3-pin socket	Radiospares

Miscellaneous

BY1	9V battery 2X Exide H30 4·5V
BY2	9V battery Ever Ready PP9
FS1	Fuse cartridge, 1A
LS1	Loudspeaker 3in, 35Ω speech coil
M1	Moving coil meter, 100μA f.s.d., 2½in, panel mounting

Sundry Items

Chassis: 18 s.w.g. aluminium 6½in × 8¾in × 3in. Battery clamps: 18 s.w.g. aluminium. Component board cradle and retaining strip: ¼in thick s.r.p.b. Case: 10in × 7in × 7in (Tele-Radio). Carrying handle. Seven knobs. Four stand-off insulators. One fuse holder. Screened lead (single miniature microphone cable). Veroboard.

Radiation Detectors

G.M. tube	Type G10H	20th Century Electronics
558 detector	Type 55NO3K or 55N05K	20th Century Electronics

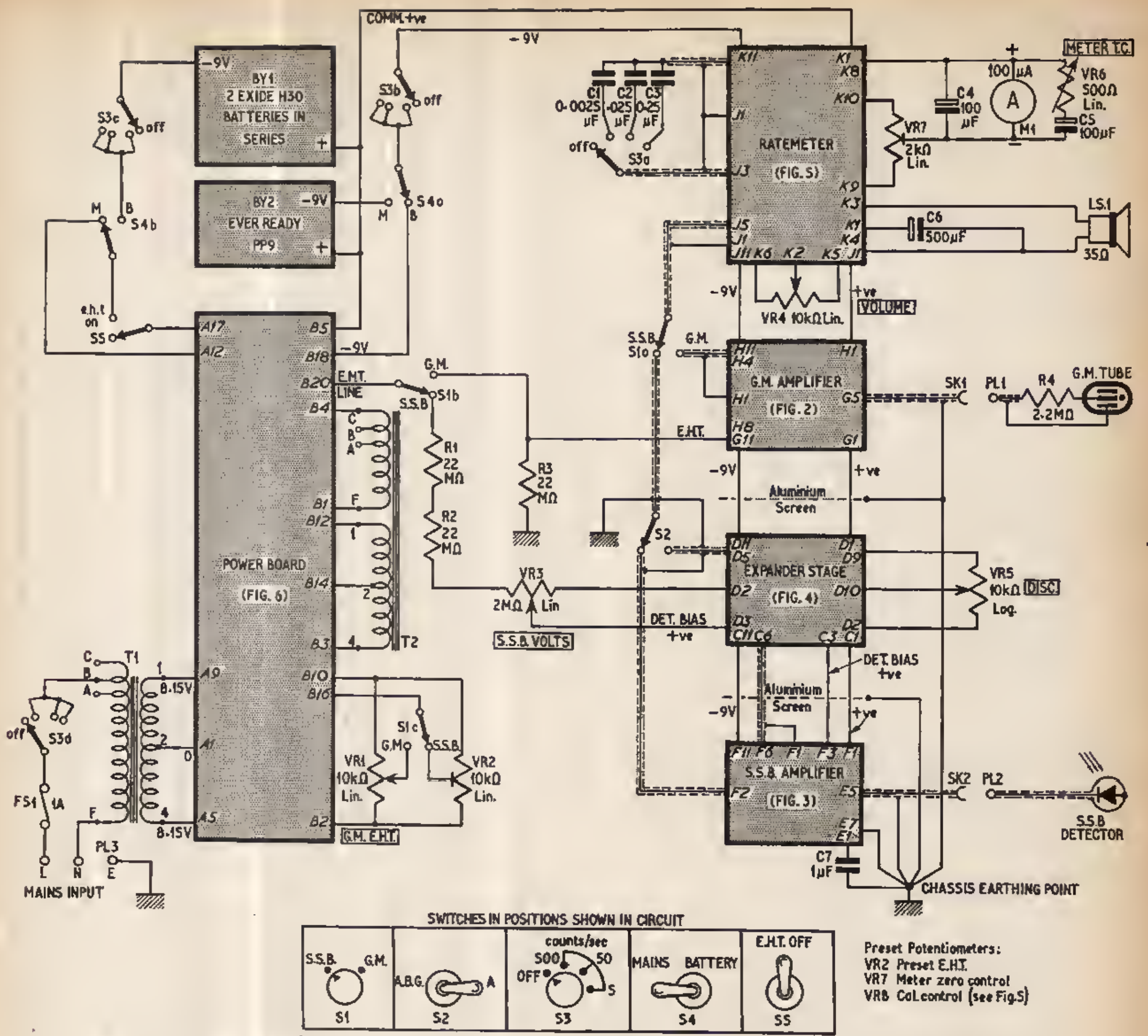
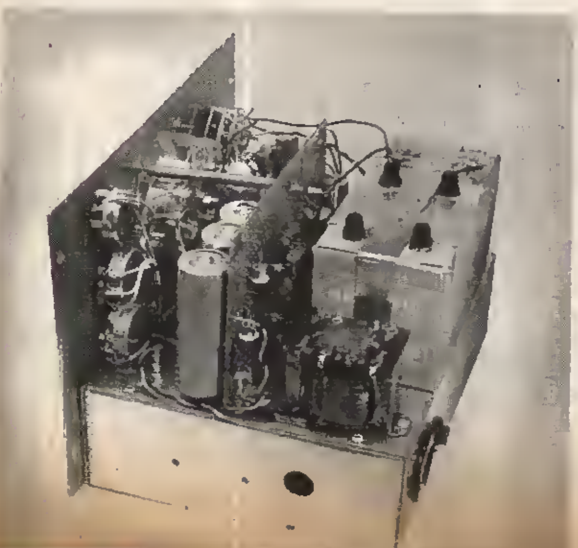


Fig. 1. Portable Ratemeter inter-unit wiring diagram. The ratemeter is divided into five sub-units and the physical arrangement follows closely the same general pattern as this key diagram



to be detected. Once this has happened TR8 operates as an amplifier, and the resulting negative pulse is fed to the output (point *D5*) via emitter follower TR9.

Due to the action of the discriminator the output pulses are no longer proportional to the radiation energy lost into the detector.

RATEMETER

Simply expressed, the ratemeter circuit (Fig. 5) applies a constant charge to a meter for every input pulse regardless of its size or duration. The meter then reads the average current which is proportional to the count rate.

If the pulses applied to the meter were of the same short duration as those from the radiation detector then the average current on low pulse rates would be rather too low to be of great use. A more satisfactory arrangement has therefore been adopted in which the length of the pulse is artificially "stretched" by a monostable multivibrator.

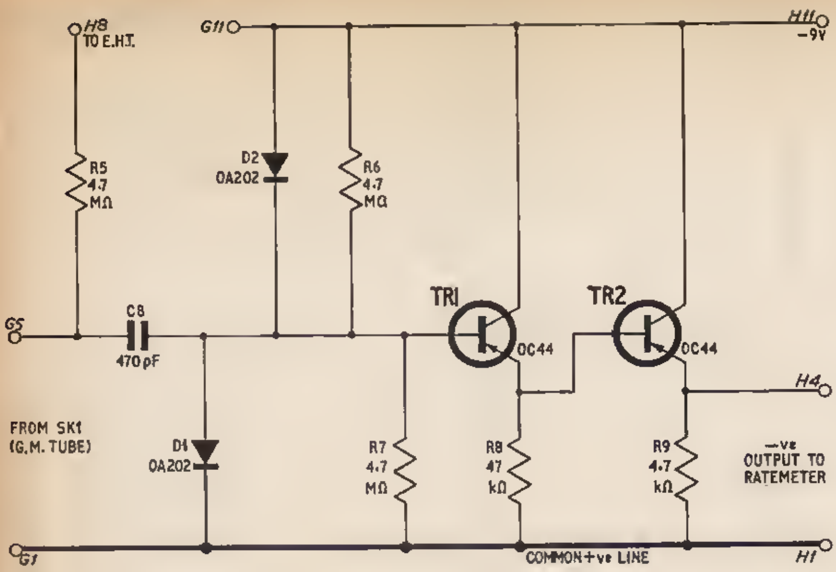


Fig. 2. Circuit diagram of the Geiger-Muller tube amplifier. The diodes D1 and D2 protect TR1 from the danger of large voltage transients

The effect of this is to magnify the charge per pulse applied to the meter while still retaining the necessary linear relationship of average current to count rate. The amount of stretching is related to the count rate range and is a satisfactory compromise between meter deflection and count losses. In other words if the stretching were too long the likelihood of pulses occurring during the insensitive period would be too high and an unacceptable counting error would result although the meter deflection would be good.

The resolving (stretching) time "T" is defined such that if one or more pulses arrive within a time "T" of a former pulse, only the former is recorded. The circuit is therefore "paralysed" for a time "T" after each registered pulse.

The true count rate of random pulses can be obtained from the expression:

$$N_t = \frac{N_o}{(1 - N_o T)}$$

where N_t is the true count rate
N_o is the observed count rate
T is the resolving time

For example, if our system has a resolving time of 1 millisecond and a count rate of 25c/s, is observed, the true rate will be:

$$N_t - \frac{25}{(1 - 25{\cdot}10^{-3})} = 25{\cdot}7\text{c/s},$$

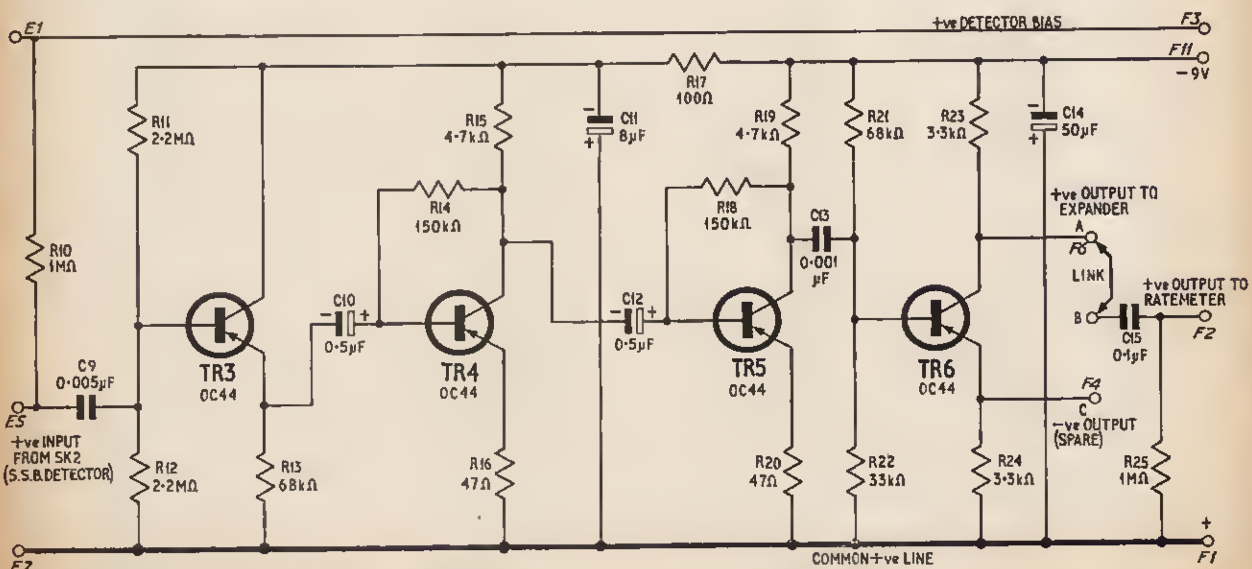


Fig. 3. Circuit diagram of the s.s.b. amplifier. The outer shell of the s.s.b. detector is taken to the common earth line via PL2, SK2, see Fig. 1

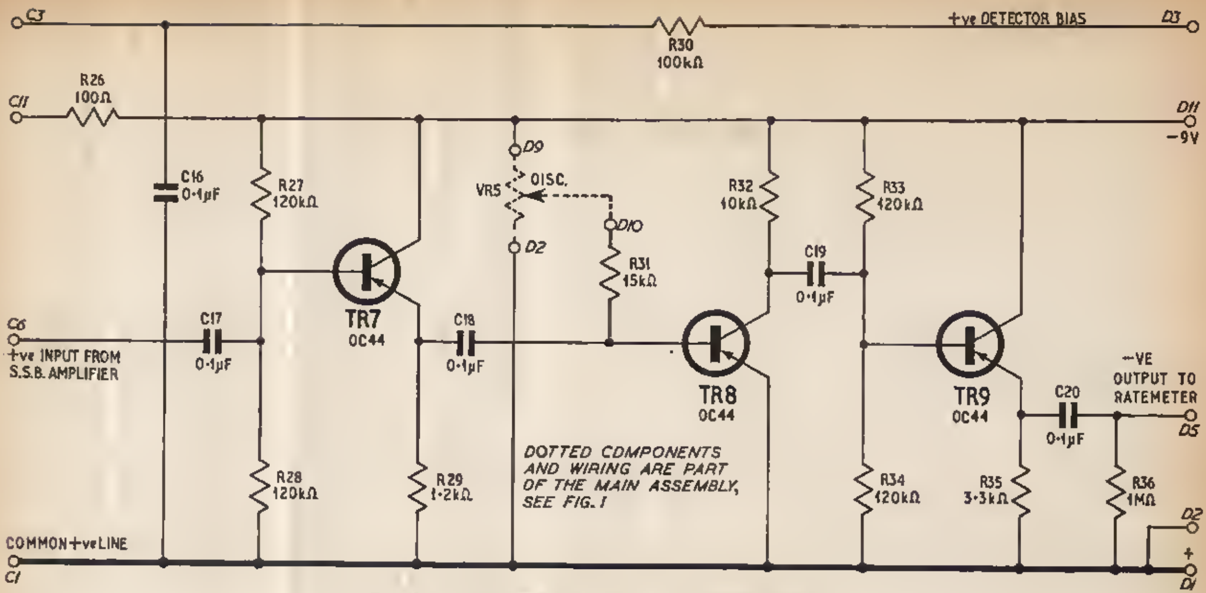


Fig. 4. Circuit diagram of the expander stage

which is near enough for most purposes. The approximate resolving times of the ratemeter on its three ranges are 10mS on 5c/s, 1mS on 50c/s, and 100μS on 500c/s. If the G.M. counter has a longer "dead" time than the resolving time of the system then this will be the governing factor. The s.s.b. detector is much faster than the G.M. tube and so will not complicate the issue in this way, although very little difference will be made in any case.

The action of the circuit (Fig. 5) is briefly as follows: A negative going input pulse greater than about 100 millivolts in amplitude will start to turn TR10 on. The positive going pulse appearing at TR10 is transferred via one of the three timing capacitors C1, C2, C3, to TR12 base. This transistor, normally held on by the current through R40, begins to turn off. The negative pulse produced at TR12 collector is fed via R39 and C23 to TR11 base and begins to turn TR11 on. The current through TR11 is in phase with the current through TR10 through R38 and therefore the action is regenerative, causing a rapid transition to the astable condition.

At the end of the duration of the input pulse TR10 cannot initiate a reversal of the action in turning off as TR11 has "clamped" TR10 collector.

The charge on the timing capacitor leaks away through R40 until TR12 begins to turn on and the circuit rapidly reverts to its original state. The duration of the astable condition depends on the value of the timing capacitor and R40.

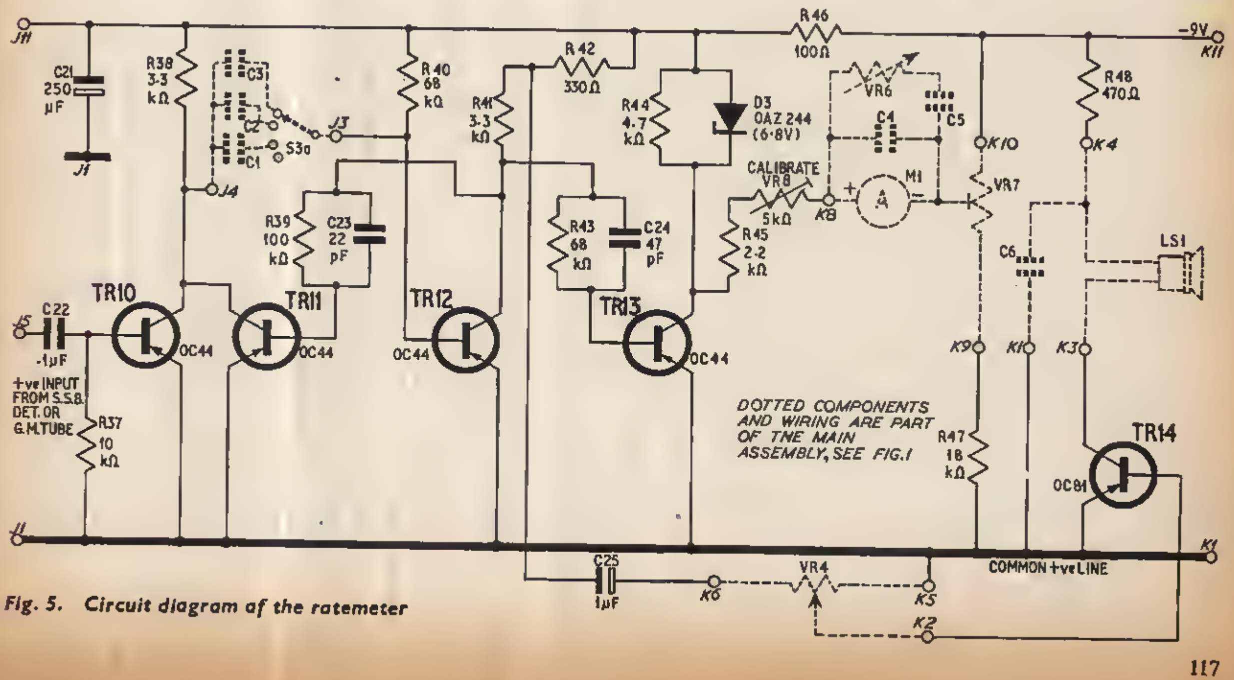


Fig. 5. Circuit diagram of the ratemeter

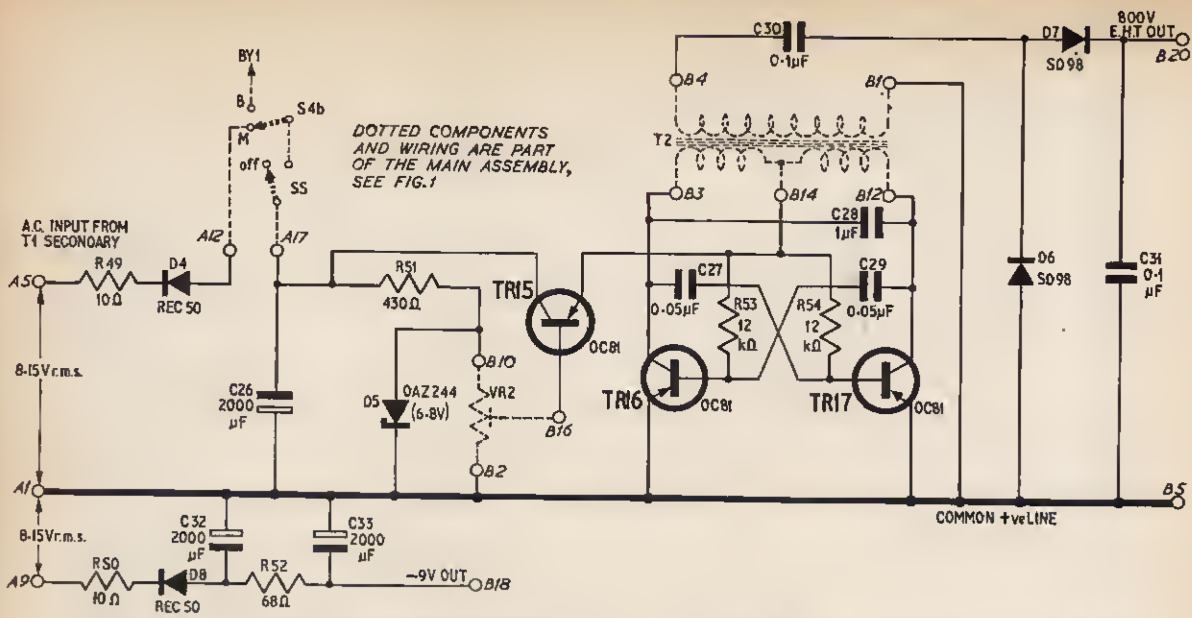


Fig. 6. The e.h.t. generator and power supply circuits. The components above the common positive line are the e.h.t. generator and those below this line form the h.t. supply circuit

The rectangular negative-going pulse appearing at TR12 collector during the astable period is fed to TR13 base via C24 and R43 turning TR13 hard on. Current then flows through the meter circuit for the duration of the pulse, causing a deflection of the pointer of M1.

METER CONTROLS

The meter time constant potentiometer VR6 ("METER T.C.") and its associated capacitors C4 and C5 are a simple arrangement provided so that the meter is slow to change its deflection on low or fluctuating count rates if desired.

VR7 is a meter zero control for backing off current in the meter caused by leakage in TR13. In the instrument described it is a preset control mounted inside the case but it is felt that many constructors might prefer it to be a front panel control and there is no reason why this should not be so if space can be found for it. The need for this control can be eliminated at extra cost by replacing TR13 by a silicon transistor type 0C202.

The purpose of the Zener diode D3 is to stabilise the meter reading against variations caused by changes in the supply voltage.

The values used for the timing capacitors are nominally, 0·25μF for 5c/s, 0·025μF for 50c/s, and 0·0025μF for 500c/s. These ranges should suffice for most purposes but can obviously be altered to suit individual requirements.

With a fixed value of R40, the values of the timing capacitors must be fairly accurate multiples of each other for good range agreement. Adjustment can be made by "padding" where necessary with suitable value capacitors in parallel.

The calibrating control VR8 enables the instrument to be initially set up. Ideally this should be done with a pulse generator but a source of low voltage 50c/s pulses can be used for the 50c/s range and to check the corresponding point on the 500c/s range.

The split collector load of TR12 is a source of low impedance pulses for driving the audio stage TR14. The combination of R48 and C6 is to prevent excessive pulses appearing on the supply line. It will also have the effect of causing the volume of sound to decrease somewhat as pulse rate increases, particularly on the higher count ranges. This, the author believes, is a desirable feature as audible indications of counts are more useful at low rates and tend to become a nuisance at high rates.

E.H.T. GENERATOR AND POWER SUPPLIES

The circuit of Fig. 6 can be divided into two distinct sections: all that above the common positive line is the e.h.t. generator; below this line is the h.t. supply circuit. Each section is supplied from separate halves of the mains transformer secondary.

Dealing first with the e.h.t. generator: the transistors TR16 and TR17 are operated as a free running multivibrator, the load of which is the tuned 6·3 volt winding of T2. This transformer is the readily available *Radiospares* Standard Filament (6·3V) type which has a centre tapped 6·3 volt winding and is ideal for this purpose. It is drawn in dotted, since it is physically located on the main chassis (see Fig. 1). The operating frequency of the multivibrator is about 1kc/s, determined by C28, together with R53, R54, C27 and C29.

The winding on T2 which normally is the mains primary is now the secondary from which the e.h.t. voltage is obtained. This output is fed to the voltage doubling circuit C30, C31, D6, and D7, and appears as smooth d.c. at the e.h.t. output point B20. The output voltage is controlled by VR1 or VR2 which, via the transistor TR15, regulates the drive to the multivibrator. The e.h.t. voltage has a near linear relationship to the angular rotation of VR1 and use is made of this by calibrating the "G.M. E.H.T." knob in volts. Zener diode D5 stabilises the output against input supply variations.

R1, R2 and VR3 form the potential divider for attenuation and fine control of the bias applied to the s.s.b. detector. The above values should be chosen in conjunction with the setting of VR2 to suit the maximum rating of the detector. The total resistance of the chain should not be less than 20 megohm. However, this arrangement is shown only as a demonstration of possible systems where specially selected detectors are used operating at up to 300 volts and normal battery operation becomes unwieldy.

For the most popularly used detectors a maximum of 25 volts is the limit and it would obviously be more economical to obtain this voltage from a battery.

Drive voltage for the e.h.t. generator is obtained from one half of the centre tapped secondary of the mains transformer T1. The a.c. output of approximately 8·15 volts r.m.s. is rectified by D4 and applied to TR15 and so to the multivibrator.

The other half of T1 secondary provides the h.t. for the other four sub-units. After rectification by D8 and filtering by C32, R52, and C33, a d.c. output of — 9V is obtained at point *B18*.

The primary of T1 is connected to the a.c. mains supply via S3d and FS1, see Fig. 1.

BATTERIES

Two separate 9 volt batteries are incorporated in the ratemeter. These enable the instrument to function normally in the absence of a.c. mains supplies. BY1 is composed of two 4·5V batteries connected in series and is used to drive the e.h.t. generator. This supply is fed in at point *A17*. BY2 is a single 9V layer type battery and it supplies h.t. to the various sub-units.

The mains input circuit and all power supply switching arrangements are clearly shown in the inter-unit wiring diagram, Fig. 1.

The construction of the ratemeter will commence next month.