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TRANSISTOR COUNTING-RATE METERS

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Abstract

The use of transistors in counting-rate meters has so far been restricted mainly to portable health and survey type monitors. This report points out that transistors may be used successfully in rate-meters of high accuracy and gives examples of practical circuits which may be designed to attain accuracies and linearities of better than ± 1%.

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

Scalers are, in general, preferred for precise counting work since the accuracy usually attainable is limited only on statistical grounds by the time available for counting. Ratemeters on the other hand, while limited in their accuracy by the stability of the components used, have all the advantages of analogue indication, viz. continuous output and ease of recording.

Transistors have found widespread use in portable health and survey monitors where high accuracy is not of paramount importance (Eicholtz et al. 1957, Jackson and Suran, 1957, and Goulding, 1958). More recently, considerations of reliability and low dissipation have made the use of transistors attractive in higher class nuclear instrumentation.

In this report the linearity, speed and accuracy of the two types of ratemeter circuit in common use are examined. They may be termed the "switched current" and the "switched voltage" ratemeter circuits. It is shown that the "switched voltage" type based on the well-known diode pump circuit is more advantageous and a transistorized linear ratemeter circuit is described. Logarithmic ratemeters are discussed briefly.

2. SWITCHED CURRENT RATEMETER

A standard method of obtaining a voltage or current the average value of which is proportional to counting rate is to make each pulse open a gate allowing a defined current to pass for a defined time into an averaging circuit. A transistor will fulfil the requirements of this gate very satisfactorily, and a possible circuit is shown in Figure 1.

For a counting rate of n pulses per second of width t seconds the current i_{av} measured by the meter will be

$$i_{av} = \frac{nt(V_{cc} - V_c - V_m)}{R} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

In this expression V_c stands for the voltage drop across the transistor in the "ON" condition. If the transistor is saturated this voltage may be made entirely negligible.

The factor nt requires careful consideration with respect to the random time distribution of the incoming pulses. This point is not always appreciated (Weissner, 1958). Since current is made to flow for a finite time there will be a finite dead time t, affecting the accuracy. Thus, to keep counting losses below 1% say, we should have $nt < 0.01$. This means that the transistor should be bottomed for less than 1% of the time and consequently the peak current should be at least 100 times the average metered current. It is found though that transistors are not adversely affected by heavy current pulses of short duration; e.g. OC44's with rated peak collector currents of 10 mA will not have their characteristics impaired by current pulses of 500 mA of a few microseconds width (Franklin and James, 1958).

The averaging circuit, consisting of the capacitance C across the meter of resistance R_m, will build up a voltage V_m which in the steady state is given by

$$V_m = R_m i_{av} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Thus, equation 1 on re-arranging becomes

$$i_{av} = \frac{nt\, V_{cc}}{R + ntR_m} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

It is seen that the finite resistance of the meter introduces a non-linear relationship between the measured current i_{av} and the average counting rate n. This non-linearity is very hard to avoid in circuits of this type because of the further requirement of adequate smoothing time constant R_mC which averages out the statistical fluctuations in the counting rate. (This requirement will be discussed further in Section 3.) It is apparent therefore that this type of circuit will not be very satisfactory for linear ratemeters required to operate on random pulses. However, the type of non-linear scale that results may be said to have some advantages such as a certain amount of crowding at the top end of the scale which gives an extended range without switching. Thus, if we make $R_m\, nt = 0.8\, R$ where n is the count rate at full scale, we obtain a quasi-logarithmic scale covering two decades. An example of such a scale is shown in Figure 2 for the circuit values R = 134 ohms, R_m = 53.3 K, V_{cc} = 6 V and t = 2 µsecs. At full scale nt = 0.02, i.e. 2% counting losses will occur. Suitable values of C would be between 20 and 100 µF.

There are significant departures from a truly logarithmic law and specially calibrated scales are required. Setting up is more difficult than for a linear ratemeter and the accuracy is probably poorer. Nevertheless, this system could be quite useful in health monitoring and prospecting instruments.

There remains the problem of defining the duration of the pulses which are to operate a ratemeter circuit of this type. The switch could be driven by a monostable multivibrator, a blocking oscillator or, for very fast rates and short pulses, by a delay line controlled, triggered pulse generator. Alternatively, the switch itself could be made to form part of a regenerative monostable circuit.

Temperature effects have not been considered in the above discussion, but it is obvious that careful attention has to be paid to this point in actual design. The circuit which defines the pulse duration requires good temperature compensation, and the effect of the collector leakage current of the current switching transistor has to be minimized. One way of doing this is to by-pass the leakage current I_{co} via a reverse-biased junction diode having similar leakage current characteristics. I_{co} will not flow through the meter then, and its variation with temperature will not be troublesome.

3. SWITCHED VOLTAGE RATEMETER

A ratemeter circuit which obviates the difficulty of careful control over the pulse duration is based on the well-known "diode pump" (Earnshaw, 1956). If a capacitance C is charged by each pulse to a well-defined voltage V, the charge per pulse will be Q = CV and the average charging current for n pulses per second i_{av} = nCV. In the circuit of Figure 3, C is charged via D_2 and discharged via D_1 by each pulse. The average current through D_1 is therefore i_{av} = nCV assuming $C_T \gg C$.

A voltage u = nVCR will, in general, appear across the tank capacitor C_T so that C will charge up to a voltage of (V-nVCR) and the average current through D_1 will be, strictly speaking,

$$I = \frac{VnC}{1 + nCR}$$

This again is a non-linear relationship between i and n, of the same general form as discussed in Section 2.

Various methods may be employed, however, to linearize the scale, the simplest being to make nCR ≪ 1. This is not always convenient and alternative methods are commonly used in linear ratemeters based on the diode pump circuit. If the point X in Figure 3 is returned to the virtual earth of an operational amplifier as shown in Figure 4 the relationship i = VnC will hold exactly if A is sufficiently large.

A method more suited to transistor circuits achieves the same result by returning the cathode of D_2 to a voltage equal to that developed at X. A sufficient approximation to this is obtained with an emitter follower connected as shown in Figure 5. Thus, with a given value of R and C_T the departure from linearity may be improved by a factor of at least 10. D_3 is a small area junction diode added for temperature compensation.

A monostable circuit may be used to feed square voltage pulses into the diode pump. The exact pulse width is not critical but limits may be set by compromising between counting losses due to long dead time for very long pulses and incomplete charging of the capacitor C for very short pulses. The period of the monostable circuit must therefore be changed on each range. In the case of a blocking oscillator drive (Franklin and James, 1956), this means that a separate blocking oscillator transformer has to be switched into the circuit to give the correct pulse width on each range. This design difficulty may be remedied by preceding the drive circuit by a scale-of-two which produces square waves the average width of which varies inversely with counting rate. This is then directly coupled to the actual driving-stage which switches the voltage across the diode pump. This driving stage must satisfy two requirements; it must produce square waves of accurately defined and stable amplitude and its output resistance must be sufficiently low to charge the feed capacitor C in a time shorter than the resolving time of the preceding circuits. The complementary saturating switch of Figure 7 is found to satisfy both these requirements.

If V is slightly larger than V_{cc} the complementary transistors will be alternately cut off and saturated. In the saturated condition the output voltage is clamped to within a few millivolts of V_{cc} which is stabilized by Zener diodes. The complementary feature allows the driving of a capacitive load with equal speed in either direction.

A typical transistorized ratemeter circuit is shown in Figure 6, a circuit accuracy of better than 1% being obtainable with careful design. The circuit responds to pulses 2 µsec. apart giving a dead time error of 2% at 10,000 counts/sec.

On statistical grounds, the integrating time constant, RC_T is determined by the allowable meter fluctuations due to the random pulse spacing, the r.m.s. value of which is given by

$$\text{r.m.s. fluctuation} = \frac{100}{\sqrt{2nRC_T}} \%$$

A compromise is usually required between the allowable fluctuations and the speed of response, but the value of R is usually such that with a tank capacitor C_T of reasonable size (up to a few thousand uF, say) a linearizing circuit is required since nRC cannot be made $\ll 1$. Hence the use of the linearizing emitter follower.

4. LOGARITHMIC RATEMETER

It has been shown by Cooke-Yarborough and Pulsford (1958) that by combining the outputs of several diode pump circuits each having the non-linear characteristics derived in Section 3 an excellent approximation to a logarithmic scale may be obtained. For example, five diode pumps with constants RC differing by factors of ten may be combined to give a five decade logarithmic ratemeter with departures of less than 0.3% from a true logarithmic scale over most of the range. The bistable circuit and complementary driver stage of Figure 7 may be applied directly to the design of logarithmic ratemeters based on multiple diode pumps. The range may be extended considerably by employing separate pre-scalers and driving circuits for the decades corresponding to higher counting rate.

5. CONCLUSION

Using transistor-driven diode pumps it has been shown that the accuracy of linear counting ratemeters may be made to depend entirely on the stability of a reference voltage and the accuracies of passive components.

6. REFERENCES

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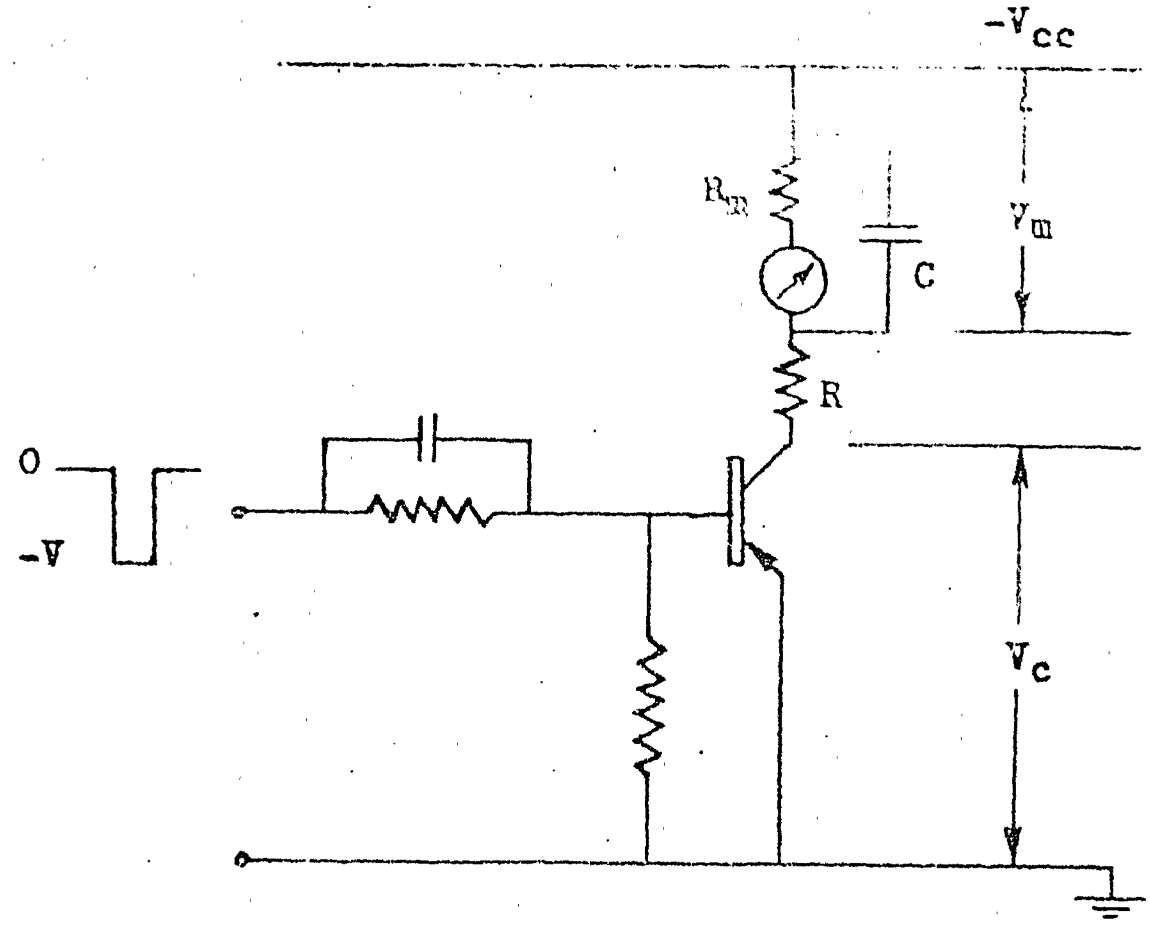


Fig. 1 Switched Current Ratemeter

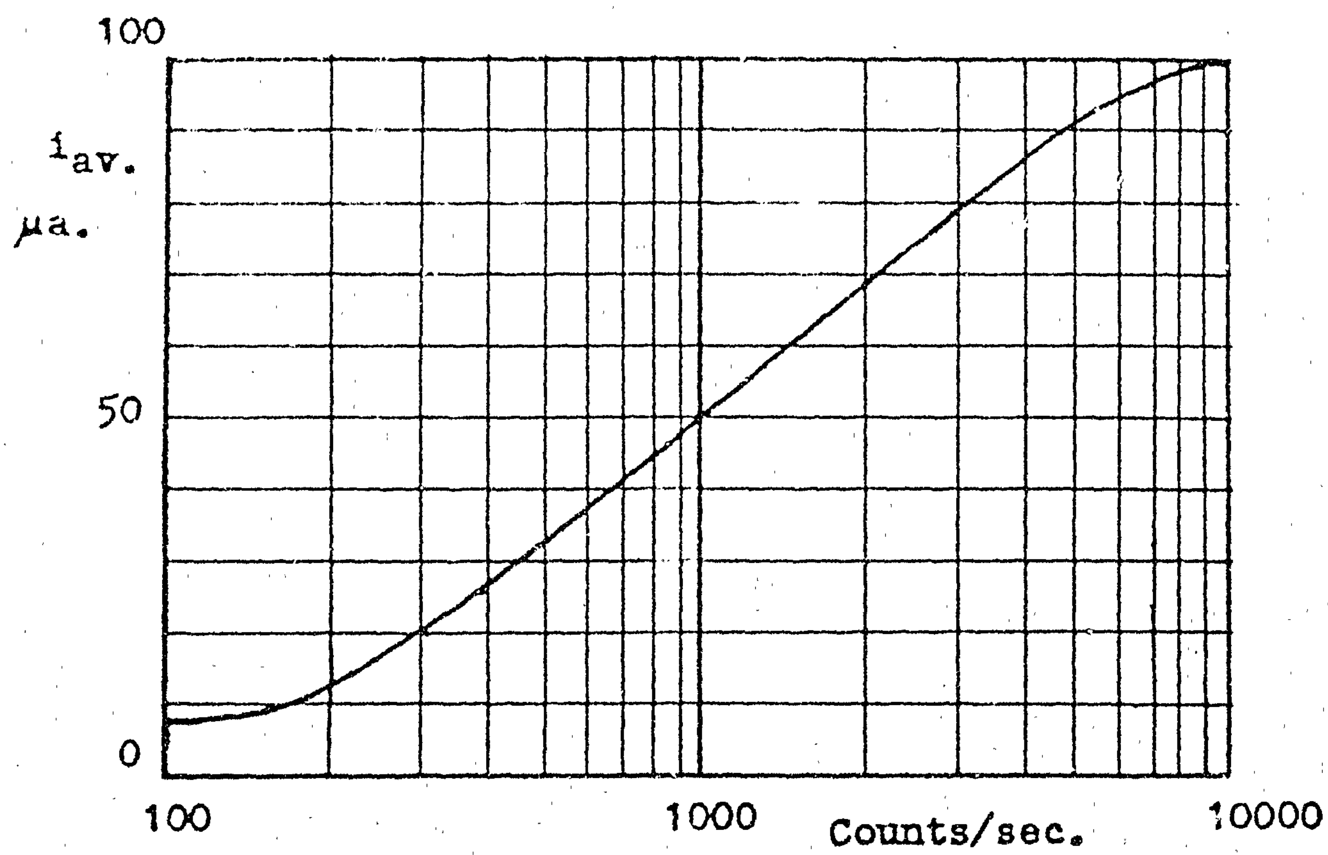


Fig. 2 Approximation to Logarithmic Scale with the Circuit of Fig. 1 (see text)

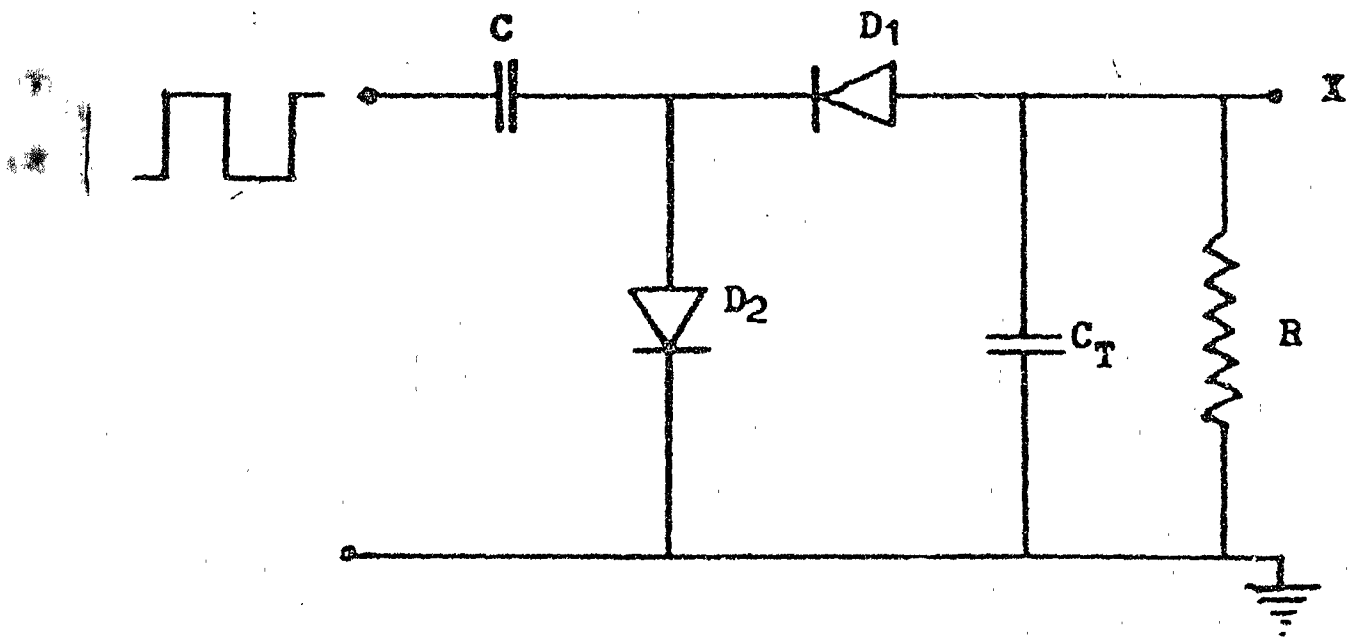


Fig. 3 Diode Pump Circuit

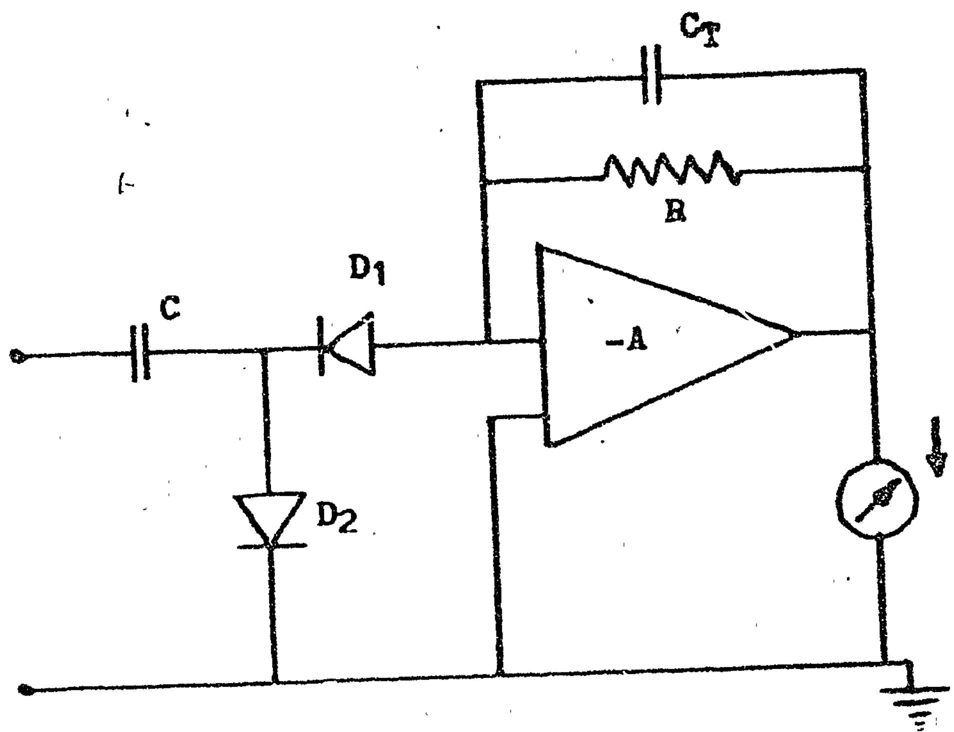


Fig. 4 Linearization of Diode Pump

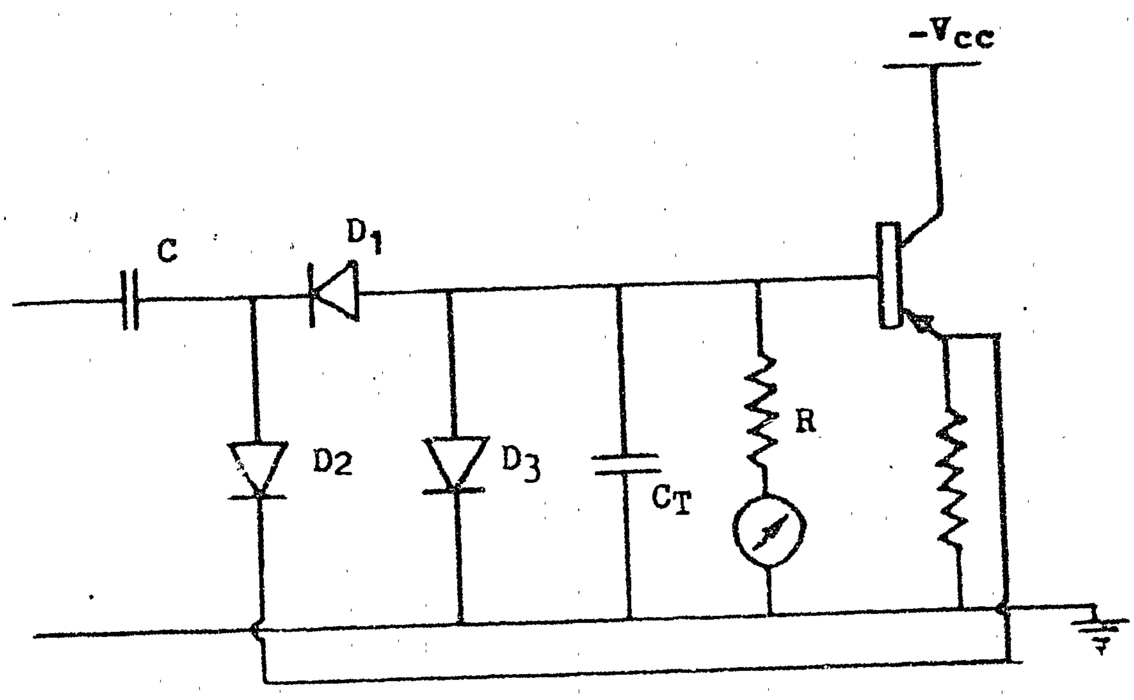
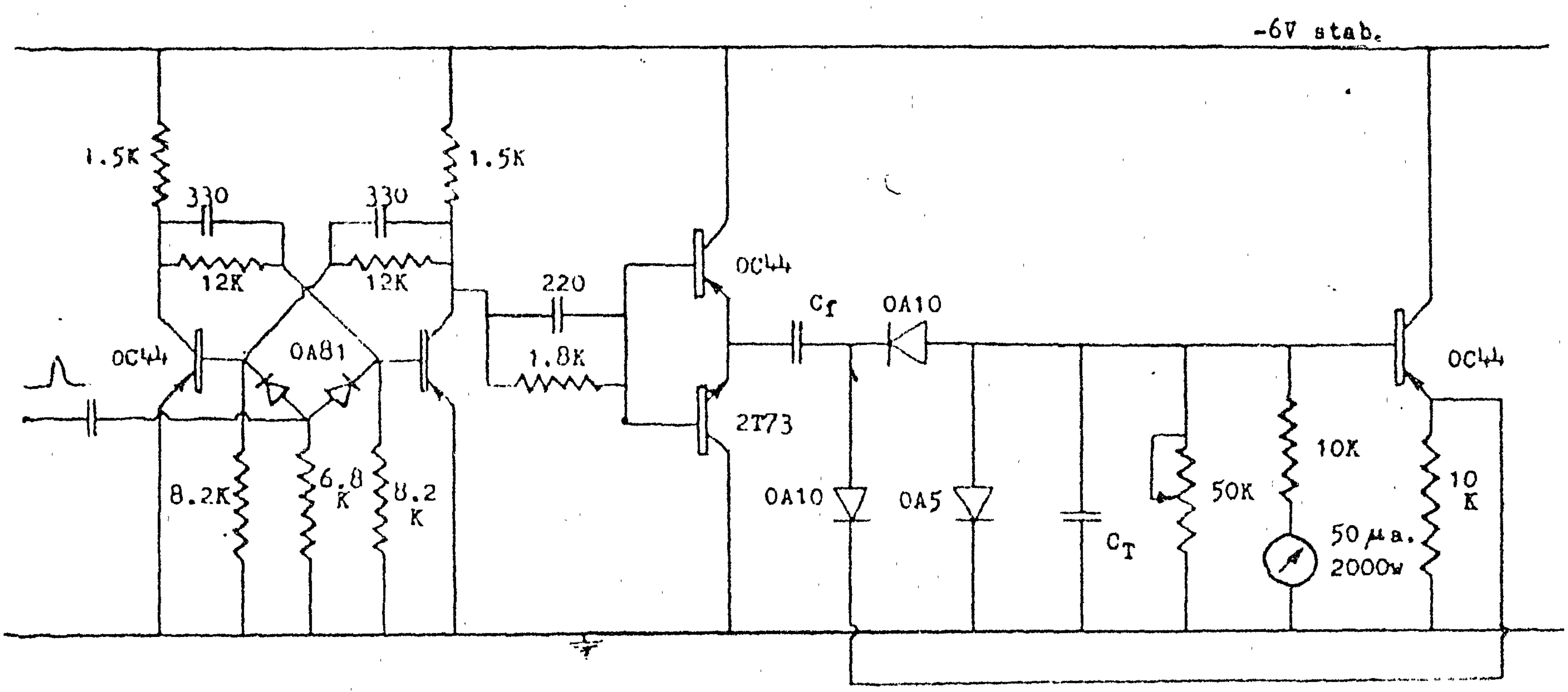


Fig. 5 Linearization of Diode Pump with
Emitter Follower



Range counts/sec.	C_f
0-10	2 μf.
0-100	0.2 "
0-1000	0.02 "
0-10000	0.002 "

*The value of C_T depends on the Integrating Time Constant required.

Fig. 6 Linear Ratemeter Circuit

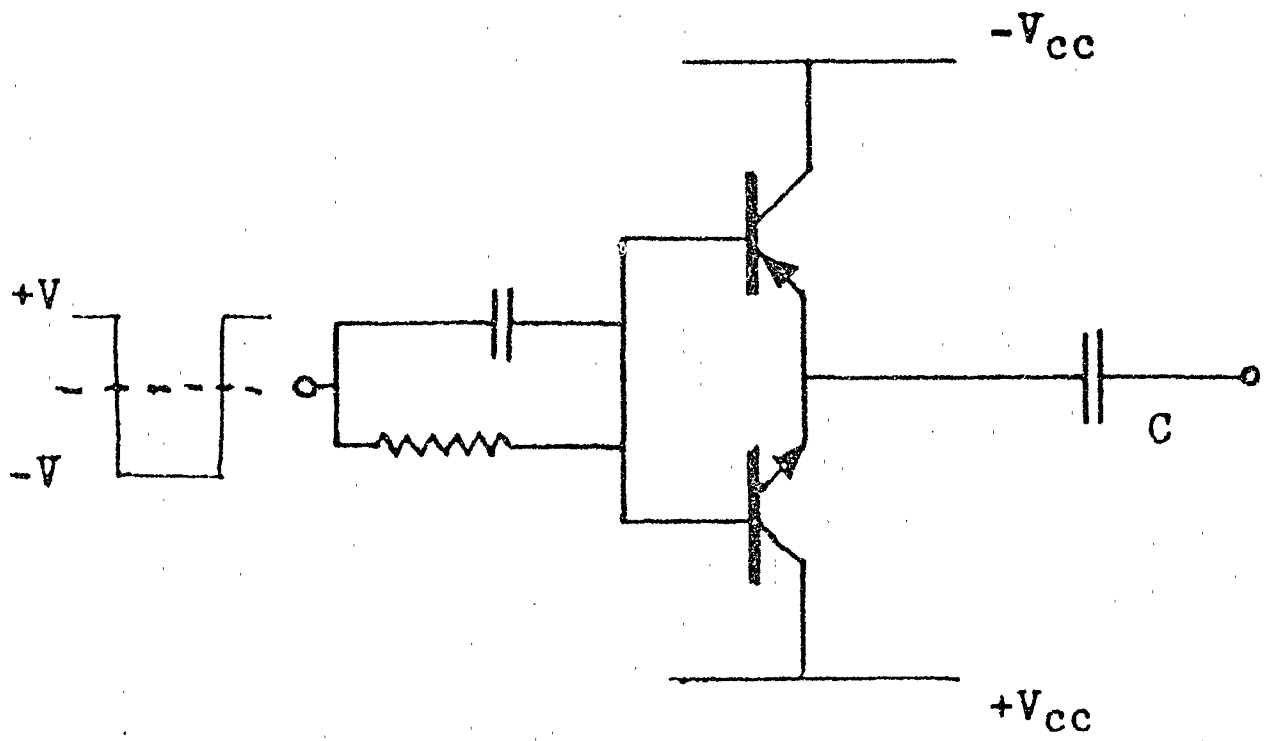


Fig. 7 Complementary Saturating Switch