AD-A041 604 ROYAL AIRCRAFT ESTABLISHMENT FARNBOROUGH (ENGLAND) F/G 14/3
A PRECISION VOLTAGE REFERENCE UNIT FOR CALIBRATING AIRBORNE DAT--ETC (U)
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UDC 681.327.8 : 621.316.722 : 629.13.074

ROYAL AIRCRAFT ESTABLISHMENT

Technical Report 76164

Received for printing 9 December 1976

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D. Thomas

CORRIGENDUM

Page 18	'16 μs' should be '16 s'
Figs.3 and 4	'16 μs' should be '16 s'
Fig.6	'1 μs/cm' should be '1 s/cm'.

Departmental Reference: IT 151

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(18) DRIC

(19) BR-56069

(12) 32p.

SUMMARY

A precision voltage reference unit is described which enables the accuracy and precision of flight data acquisition systems to be measured under operational conditions. Two versions have been designed having outputs of 8mV and 4V which simulate 80% of the full scale output respectively, of low level (10mV) and high level (5V) transducer outputs, and a range of source impedances is also simulated. The voltage stability of the units is better than 0.01% for the high level version and 0.1% for the low level version, over the temperature range -40 to +80°C. The design is such that the magnitude of a number of error sources (e.g. common mode voltages, system input impedances, and offset voltages and currents) can be determined.

Departmental Reference: IT 151

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CONTENTS

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1 INTRODUCTION

Flight test instrumentation involves the multichannel measurement and recording of various parameters on board an aircraft, either during prescribed manoeuvres or throughout the whole sortie. These physical parameters are translated into electrical signals by transducers whose output voltages are usually conditioned by electronic amplifiers to provide a common full scale value for all channels. Improvements in accuracy may be obtained and the data may be more easily and rapidly analysed if it is converted into digital form before recording on tape and many modern measurement systems employ this technique. In such a digital data acquisition system, due to the high cost of sample and hold amplifiers and analogue to digital convertors, the signals from many channels are switched in turn by an analogue multiplexer to a single sample and hold amplifier and analogue to digital convertor, so producing a single serial digital stream which is then coded and recorded on magnetic tape. The bandwidth of the signal may be restricted, if necessary, to reduce any aliasing errors which may arise from the sampling mechanism of the analogue multiplexer and sample and hold circuit.

The accuracy of such a flight test data acquisition system may be measured for differing environmental conditions and various differential and common mode input voltages in the laboratory, using laboratory standard voltage sources which are neither small nor transportable. However, in order to establish confidence in the system and to assess the level of interference signals present in actual installations, the accuracy must be checked during flight.

A general purpose airborne digital data acquisition system[1,2] has been developed for flight test applications for MOD(PE), and an accurate voltage reference unit was required so that the performance of the acquisition system could be measured during the initial flight trials of the equipment. This Report describes a reference unit which has been designed to meet this requirement, and has novel features which assist in locating the source of any errors which are measured.

2 DEFINITION OF REQUIREMENT

2.1 System errors

As previously indicated, a typical digital data acquisition channel consists of a transducer, differential input amplifier, filter, analogue multiplexer, sample and hold amplifier, and an analogue to digital convertor. This is shown diagrammatically with probable error sources in Fig.1. Errors can occur in each stage due to circuit imperfections, and there is much detailed published work[3,4] describing these error sources.

In the systems referred to above[1,2] one switch position of the analogue multiplexer is dedicated to an internal reference source which is alternatively a voltage near full scale or zero. This allows the dc errors introduced into a typical channel by the analogue multiplexer, sample and hold amplifier, and analogue to digital convertor to be determined and used to correct signal channels during the ground based analysis of the flight tapes (as long as the errors are small compared with the dynamic range of the system). The amplifier and filter are then the only sources of errors in the system which cannot be removed on analysis. Errors due to filter amplitude and phase characteristics have been described elsewhere[8] and their effect will not be discussed in this Report, although dc voltage offset errors, which are considered, may include components due to filters.

The errors associated with the differential amplifier are due to the inherent limitations of amplifier back or bias current flowing through the transducer, voltage offset, gain stability and finite common mode input (which causes common mode signals to be converted into differential signals when there is an imbalance in the source impedance). The magnitude of these errors, and hence the accuracy and stability of measuring channels, may be determined from the performance of a channel or channels dedicated to calibration, the input signals being obtained from external voltage reference units mounted in typical transducer locations and simulating transducer output characteristics. This is especially important when transducers must be fitted in locations which are both electrically noisy and environmentally hostile. A suitable reference unit must be robust, independently powered and small enough to be fitted in any typical transducer location. In order that the magnitude of the errors present may be determined, the electrical properties of the device must be representative of those of typical transducers and these are discussed in the next section.

2.2 Target specification

Published reports[6,7] and manufacturers' literature reveal a wide range of transducer types and much variation in device characteristics. The majority of the physical quantities measured by flight test systems are steady or quasi-static, and most transducers used may be simulated by a dc generator capable of providing voltage output levels of zero, about 10mV (simulating, for example, strain gauges), and about 5V (typical, for example, of control movement potentiometers), and having source impedances in either one or both output lines which can vary between 0 and 2.5kΩ (for low level (10mV) outputs) or between 0 and 5kΩ (for high level (5V) outputs).

Overall system requirements indicated the need for a stability of about 0.01% of full scale for high level signals and 0.1% for low level signals, over a temperature range of -40 to +80°C, with a calibration accuracy at +25°C of the same magnitude. The voltage levels from the reference unit must be near the full scale input of, but should not exceed the dynamic range of, the acquisition system. The output voltages of the reference unit were therefore chosen to be +4V (high level) and +8mV (low level), each representing 80% of full scale positive input when used with amplifier gains of X1 and X500 respectively, the latter being the maximum gain available in the data acquisition system used; it was not considered necessary to provide the corresponding negative voltages as well as the positive ones.

The specification for the reference voltage units is given in Table 1.

3 ANALYSIS OF REQUIREMENTS

3.1 Voltage reference unit

The requirements defined in the previous section can be realised by the arrangement shown schematically in Fig.2, which shows a reference unit connected to a differential input amplifier. A stable voltage generator with an output V alternately switches between 0 and 8mV (low level) or 0 and 4V (high level), and has resistors R_1 and R_3 in the output lines which may be selected to have a range of values between 0 and 2.5kΩ (low level) or 0 and 5kΩ (high level). Having defined such a reference unit which corresponds to a generalised transducer, the errors which are introduced by the imperfections of both the data acquisition channel and the transducer installation must be considered.

3.2 Error sources in signal measurement

The error sources in a data acquisition channel may be subdivided into two categories, as follows:-

(a) Errors due to the short comings of the amplifier. These include voltage offset (v_0) leakage (i_1 and i_2) and bias (I_1 and I_2) currents, the finite size of, and imbalance between, the common mode input impedances (R_2 and R_4), and gain variations (see Fig.2).

(b) Errors due to the installation. These include sources of common mode voltage (V_c), the finite impedance of the common mode generator (R_c), imbalance in the transducer source impedance, leakage due to cable etc, noise and interference signals.

In Appendix A equations have been derived for the output voltage of a differential input amplifier when connected to the prescribed voltage and resistance combinations produced by the voltage reference unit. The various error sources and their magnitudes, whether due to the amplifier (e.g. R_2, R_4, $i_{1\ max}$, $i_{2\ max}$, v_0) or to the installation (e.g. V_c, R_c) may be determined from these equations, which may also be used to assess the accuracy of other measurements where transducers are in a similar environment to the voltage reference unit.

4 DESIGN OF THE VOLTAGE REFERENCE UNIT

4.1 General scheme

The voltage reference unit defined in the previous section is realised by providing a stable source and buffer amplifier, into the output lines of which various precision resistors are switched using semiconductor switches controlled in a set sequence by TTL logic. The accuracy and stability of the voltage reference unit is dependent upon the voltage source, buffer amplifier, precision resistors and switches, and also on the accuracy of the measuring system with which it is used. Diagrams showing the switching sequence are given in Figs.3 and 4 for the low level and high level units respectively. A simpler resistor switching is used for the low level unit in order to reduce thermoelectric voltage errors which can cause significant errors at the 10mV level. This phenomenon is discussed in section 4.3. The practical circuit details of the units are given in Appendix B.

4.2 Precision voltage source

The most accurate and stable voltage source which may be used over a wide temperature range and under conditions of severe vibration is the precision zener reference diode, although monolithic voltage sources having extremely low voltage variation have been reported[9,10]. Zener diodes have temperature coefficients of voltage which may cause the zener voltage of 6.4V nominal to vary by as much as ±3mV over the temperature range -40 to +80°C, which is not good enough to provide the accuracy specified for the voltage reference unit. However, the characteristic curve of voltage offset against temperature can be modified by varying the zener current. A typical family of curves (Fig.5) illustrates how the variation of zener voltage with temperature is dependent upon the value of zener current, and is a minimum for a particular value of zener current. For this particular diode a voltage change of only ±250μV over the temperature can be obtained if the zener current is selected to be 4.5mA. The zener current which gave the smallest variation of zener voltage with temperature was determined for each zener diode used in the voltage reference unit and even then some selection of devices was found necessary.

The slope impedance (variation of zener voltage with zener current) of the zener diode is approximately 10Ω and is in series with the current defining resistor which is typically 2kΩ, so that approximately 0.5% of any supply voltage change appears across the zener diode. In order to maintain an overall accuracy of 0.01%, the total error from all sources must be less than 500μV, and the error due to the slope impedance must be a small proportion of this. The slope impedance error allocation is chosen to be 20% or 100μV and then the supply voltage must not change by more than 20mV, necessitating the use of a high performance stabiliser to provide this supply voltage. An operational amplifier is necessary in the reference unit to buffer and convert the 6.4V zener diode voltage to the 4V required for the high level unit, and also to provide a low output impedance. If the error allocation of this amplifier is also allowed to be 20% then its voltage offset must be less than 100μV over the temperature range. The low level voltage is obtained by dividing down the high level voltage with a pair of precision resistors.

4.3 Switch and resistor requirements

The performance of the switches and resistors used in the low level reference unit is considered first since the requirements of this unit are the most demanding. There are many types of switch which can be used but most of them have considerable disadvantages, especially electromechanical devices with their questionable reliability, and semiconductor switches offer the best solution. CMOS switches with on-chip drivers are recommended for low level switching applications and have attractive features e.g. low ON resistance, no offset voltage across the semiconductor switch, low leakage currents and the ability to interface with standard logic voltages.

Laboratory measurements, however, have revealed voltages of 100-200μV across the switch leads of a CMOS device. The cause of these voltages was found to be the generation of thermo-electric emfs arising from temperature differences between the Kovar header leads and the aluminium interconnect on the clip. The thermo-electric emf generated between Kovar and most other metals is $40\mu V/^{\circ}C$, which makes it an unfortunate choice for low level applications; however, Kovar has the same coefficient of expansion as glass and for this reason is almost universally used in devices of this type. The arrangements made to minimise the effects of these thermo-electric emfs are described in Appendix B.

Thick metal film resistors were used for the potentiometer and source impedances in the reference unit because of their extremely low temperature coefficient of resistance and excellent stability. The leads of the resistors are fabricated from Kovar and they must be mounted in a constant temperature enclosure to reduce the thermo-electric emfs to tolerable levels. With these precautions the offset voltages can be reduced to a few μV (see Fig.6).

In the case of the high level unit, the thermo-electric error voltages introduced by the CMOS switches and the precision resistors are much less significant in relation to the performance requirements, and the CMOS switches can be used directly to switch the voltage and resistors; a separate temperature controlled enclosure was not required.

5 PERFORMANCE OF UNITS

5.1 Laboratory measurements

The accuracy of the voltage measuring equipment used to calibrate the voltage reference unit at the high voltage level was 0.002% of reading (Dynamco, digital voltmeter type 2010), and of the resistance measuring equipment, 0.001% of reading (Julie resistance measuring system PRB205S). The measuring equipment was regularly tested and certified by the Services Electrical Standards Centre, Aquila, Bromley.

A total of 16 different voltage reference units was tested (13 high level and 3 low level). The mean output voltage at room temperature (+20°C) was:-

(a) 4041mV with a standard deviation of 24mV (high level).

(b) 8034μV with a standard deviation of 26μV (low level).

The variation of the mean output voltage over the temperature range −40 to +80°C itself had a mean of:-

(a) 685μV with a standard deviation of 325μV (high level).

(b) 2.5μV with a standard deviation of 0.5μV (low level).

The best devices (high and low level) had output voltage variations of less than ±200μV (±0.005%) and ±2μV (±0.025%) respectively, and the worst devices less than ±1200μV (±0.03%) and ±3μV (±0.04%) respectively. The variation of output voltages due to thermo-electric effects in the switches and resistors for the low level units was typically less than 2μV. A set of photographs showing the voltage variation with temperature of a low level voltage reference unit in the 0V condition is given in Fig.6. The variation of voltage from zero for various resistance values in the output lines is caused by the input bias currents of an amplifier when connected to the voltage reference unit; these were 1.2 and 1.6nA in the positive and negative leads respectively.

5.2 Flight trials

The voltage reference units were used in the proving of the digital data acquisition systems[1,2] developed for MOD(PE), at A & AEE, Boscombe Down and at RAE, Bedford, and the results have been reported elsewhere[11,12]. The use of the units enabled confirmation to be obtained that systems met their performance specification in flight conditions. The units were also successful in revealing a design malfunction in the acquisition system which was speedily corrected. Photographs of a typical aircraft installation as used aboard a VC10 aircraft at RAE, Bedford are shown in Fig.9.

6 CONCLUSION

The design features of a precision voltage reference unit having either a high level (4V) or a low level (8mV) output voltage, stable over a wide temperature range, have been discussed. The manner in which the device, with its novel voltage and resistance switching capabilities, may be used to calibrate an airborne data acquisition system in flight, and indicate the magnitude and source of errors, has been described. The shortcomings of present semiconductor devices and the features necessary to produce stable voltage references have been indicated. It has been shown that a very stable reference unit can be provided, which has proved useful in airborne measurement systems.

Appendix A

DERIVATION OF THE OUTPUT CHARACTERISTICS OF AN AMPLIFIER WHEN THE INPUT IS CONNECTED TO A VOLTAGE REFERENCE UNIT

The symbols used throughout this Appendix are indicated on Fig.2. Errors due to the presence of an active filter are small and will be disregarded in this analysis. The following assumptions have been made:-

(a) The source impedance of the reference voltage (R_s) is relatively small and can be neglected.

(b) The differential input impedance (R_D) is much greater than the common mode input impedances (R_2 and R_4).

(c) The common mode source impedance (R_c) and the switched voltage reference unit resistances (R_1 and R_3) are small compared with the common mode input impedances (R_2 and R_4).

By applying Kirchhoff's Laws to the networks ABCDE and ABFE the following relationships may be obtained. The voltage across R_2 ,

$$V_2 = \frac{V_c R_2}{(R_c + R_1 + R_2)} - \frac{R_2 R_c}{(R_c + R_1 + R_2)}\left(\frac{V_c - (V + v_0)}{(R_c + R_3 + R_4)} - \frac{i_2 R_3}{(R_1 + R_3 + R_4)}\right) - \left(\frac{i_1(R_c + R_1) - i_2 R_c}{(R_c + R_1 + R_2)}\right) R_2 \quad . \quad (1)$$

The voltage across R_4 ,

$$V_4 = \frac{(V_c - (V + v_0))R_4}{(R_c + R_3 + R_4)} - \frac{R_4 R_c}{(R_c + R_3 + R_4)}\left(\frac{V_c}{R_c + R_1 + R_2}\right) - \left(\frac{i_2(R_c + R_3) + i_1 R_c}{R_c + R_3 + R_4}\right) R_4 \quad . \quad (2)$$

The differential voltage across the inputs of the amplifier,

$$V_{diff} = V_2 - V_4$$

and the output of the amplifier,

$$V_x = GV_{diff}$$

where G is the differential gain of the amplifier.

Thus

$$V_x = G\left(\frac{(V + v_0)R_4}{(R_c + R_3 + R_4)} + V_c\left(\frac{R_2}{(R_c + R_1 + R_2)} - \frac{R_4}{(R_c + R_3 + R_4)}\right) + i_2R_3 - i_1R_1\right) . \qquad \ldots . (3)$$

In the operation of the voltage reference unit the following resistance and voltage states apply:-

$$\left.\begin{array}{ll} a & R_1 = R_3 = 0 \\ b & R_1 = 0 \;,\; R_3 = R \\ c & R_1 = R \;,\; R_3 = 0 \\ d & R_1 = R_3 = R \end{array}\right\} \begin{array}{l} \text{for values of} \\ V = 0 \quad \text{and} \quad V = V_A \;. \end{array}$$

By substituting the above values in equation (3) the following equations are obtained; subscripts a , b , c and d refer to the particular resistance configurations denoted above, and 1 and 2 refer to the voltage configurations $V = 0$ and $V = V_a$ respectively,

$$V_xa_1 = G\left[\frac{v_0R_4}{(R_c + R_4)} + V_c\left(\frac{R_2}{(R_c + R_2)} - \frac{R_4}{(R_c + R_4)}\right)\right]$$

$$V_xa_2 = G\left[\frac{(V_A + v_0)R_4}{(R_c + R_4)} + V_c\left(\frac{R_2}{(R_c + R_2)} - \frac{R_4}{(R_c + R_4)}\right)\right]$$

$$V_xb_1 = G\left[\frac{v_0R_4}{(R_c + R + R_4)} + V_c\left(\frac{R_2}{(R_c + R_2)} - \frac{R_4}{(R_c + R + R_4)}\right) + i_2 R\right]$$

$$V_x b_2 = G\left[\frac{(V_A + v_0)R_4}{(R_c + R + R_4)} + V_c\left(\frac{R_2}{(R_c + R_2)} - \frac{R_4}{(R_c + R + R_4)}\right) + i_2 R\right]$$

$$V_x c_1 = G\left[\frac{v_0 R_4}{(R_c + R_4)} + V_c\left(\frac{R_2}{(R_c + R + R_2)} - \frac{R_4}{(R_c + R_4)}\right) - i_1 R\right]$$

$$V_x c_2 = G\left[\frac{(V_A + v_0)R_4}{(R_c + R_4)} + V_c\left(\frac{R_2}{(R_c + R + R_2)} - \frac{R_4}{(R_c + R_4)}\right) - i_1 R\right]$$

$$V_x d_1 = G\left[\frac{v_0 R_4}{(R_c + R + R_4)} + V_c\left(\frac{R_2}{(R_c + R + R_2)} - \frac{R_4}{(R_c + R + R_4)}\right) + i_2 R - i_1 R\right]$$

$$V_x d_2 = G\left[\frac{(V_A + v_0)R_4}{(R_c + R + R_4)} + V_c\left(\frac{R_2}{(R_c + R + R_2)} - \frac{R_4}{(R_c + R + R_4)}\right) + i_2 R - i_1 R\right]$$

The input amplifiers used in the data acquisition system[1,2] referred to in this Report have facilities which enable the screens of the input cables to be driven by the common mode voltages present at the input of the amplifier, in order to reduce capacitive effects. This common mode voltage output is

$$V_Y = \tfrac{1}{2}(V_2 + V_4)$$

$$= \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R_1 + R_2)} + \frac{R_4}{(R_1 + R_3 + R_4)}\right) - \frac{(V + v_0)R_4}{(R_c + R_3 + R_4)} - 2R_c(i_1 + i_2) - i_1 R_1 - i_2 R_3\right]$$

By substituting the values of R_1 , R_3 and V as defined above for the various states of the voltage reference unit, the following equations may be obtained:-

$$V_Y a_1 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R_2)} + \frac{R_4}{(R_c + R_4)}\right) - \frac{v_o R_4}{(R_c + R_4)} - 2R_c(i_1 + i_2)\right]$$

$$V_Ya_2 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R_4)} + \frac{R_4}{(R_c + R_4)}\right) - \frac{(V_A + v_0)R_4}{(R_c + R_4)} - 2R_c(i_1 + i_2)\right]$$

$$V_Yb_1 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R_2)} + \frac{R_4}{(R_c + R + R_4)}\right) - \frac{v_0R_4}{(R_c + R_4)} - 2R_c(i_1 + i_2) - i_2R\right]$$

$$V_Yb_2 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R_2)} + \frac{R_4}{(R_c + R + R_4)}\right) - \frac{(V_A + v_0)R_4}{(R_c + R + R_4)} - 2R_c(i_1 + i_2) - i_2R\right]$$

$$V_yc_1 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R + R_2)} + \frac{R_4}{(R_c + R_4)}\right) - \frac{V_0R_4}{(R_c + R_4)} - 2R_c(i_1 + i_2) - i_1R\right]$$

$$V_yc_2 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R + R_2)} + \frac{R_4}{(R_c + R_4)}\right) - \frac{(V_A + v_0)R_4}{(R_c + R_4)} - 2R_c(i_1 + i_2) - i_1R\right]$$

$$V_yd_1 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R + R_2)} + \frac{R_4}{(R_c + R + R_4)}\right) - \frac{v_0R_4}{(R_c + R + R_4)} - 2R_c(i_1 + i_2) - R(i_1 + i_2)\right]$$

$$V_yd_2 = \tfrac{1}{2}\left[V_c\left(\frac{R_2}{(R_c + R + R_2)} + \frac{R_4}{(R_c + R + R_4)}\right) - \frac{(V_A + v_0)R_4}{(R_c + R + R_4)} - 2R_c(i_1 + i_2) - R(i_1 + i_2)\right] .$$

By combining and simplifying various of these equations the following relationships may be obtained:-

$$R_4 = \frac{R}{GV_A\left(\frac{1}{(V_xb_2 - V_xb_1)} - \frac{1}{(V_xa_2 - V_xa_1)}\right)}$$

$$R_c = \frac{GV_AR_4}{(V_xa_2 - V_xa_1)} - R_4$$

$$R_2 \simeq -\frac{RV_c}{2(V_y c_1 - V_y a_1)}$$ (if i_1 is known the value of R_2 can be found more exactly)

$$V_c = \frac{2V_Y a_1}{\left[\dfrac{R_2}{(R_c + R_2)} + \dfrac{R_4}{(R_c + R_4)}\right]} - v_0 \frac{R_4}{(R_c + R_4)}$$

$$= V_Y a_1 - v_0$$ if R_c is small

$$v_{0\ \max} = \frac{(R_c + R_4)}{GR_4} V_x a_1$$

$$i_{1\ \max} = \frac{(V_x c_1 - V_x a_1)}{RG}$$

$$i_{2\ \max} = \frac{(V_x b_1 - V_x a_1)}{RG}$$

(These last three equations give the maximum possible values of v_0, i_1 and i_2 assuming the common mode voltage is negligible.) Using these equations the values of the various error sources can be estimated from the variation of output voltage of an amplifier (connected to a reference unit) which occurs when the sequence of resistors and voltages are switched.

Appendix B

PRACTICAL CIRCUIT DETAILS

Two versions of the voltage reference unit have been provided, one with a low level (8mV) output and the other with a high level (4V) output.

They have the same reference voltage source and logic circuits, but for practical reasons discussed below, they have different switching and resistor arrangements. The circuit diagrams of the units are shown in Figs.7 and 8 and the circuit numbering used below refers to these figures.

The unit derives its power from one phase of the 400Hz aircraft power supply via purpose-made transformer and dc stabiliser units mounted in separate boxes; these provide ±18 to ±21V outputs with the stability needed to meet the voltage reference unit specification. Units may be mounted where convenient and are shown in Fig.9.

The input voltage regulator N1 is an integrated circuit type SG1501T which provides the ±15V needed for the CMOS switches and operational amplifier employed. The regulator output voltage is extremely stable and varies by only ±10mV over the full temperature range and for an input variation of ±10%, providing the accuracy necessary for the precision zener diode supply.

A simple resistor and zener diode arrangement (R1, DZ1) provides the +5V necessary for control logic circuits. The control logic consists of a clock oscillator employing an operational amplifier type LM211 (N5) and an RC network (C9, R18), which produce a 32Hz square pulse waveform. This pulse train is connected to the clock input of a ÷16 divider circuit (N6), whose output is connected to further dividers (N7, N8) controlling the resistor and voltage switching.

The stable voltage source consists of a precision zener diode type 1N829A (DZ3) which derives its current from the +15V supply line through resistor R3. The optimum current for the lowest temperature coefficient of voltage for each zener is determined by temperature cycling the devices in the laboratory and R3 is adjusted to set this optimum current. The voltage across the zener diode is divided down to provide 4V at the input of the operational amplifier type 725 (N2) which is chosen for its low noise and small voltage offset change with temperature. The amplifier (N2) is stabilised by components C7, C8, R14 and R15.

The output arrangements are different for the high and low level units as the magnitude of the thermo-electric voltages in the CMOS switch would introduce an unacceptable error in the output voltage of the low level unit. In the high level unit (Fig.7) the operational amplifier (N2) is connected for unity gain and provides a low output impedance. The positive output terminal of the unit (L) is connected through two resistors (R8, R9), which can be shorted out by CMOS switches (N3), and then through further CMOS switches (N5) either to the output terminals of the operational amplifier (N2) or to ground. The negative output (M) is connected to the ground line through resistors (R10, R11), which can be shorted by CMOS switches (N4). The ground terminal (GND) is connected to the nearest aircraft earth. The sequence of switching is determined by the logic control.

For the low level reference unit (Fig.8) the operational amplifier (N2) is connected for unity gain, by the CMOS switch (N3) when it is closed, and by R8 when N3 is open. This is necessary to maintain the output of N2 free from transients and to ensure that errors due to the switches do not appear across R6 and R7. This resistor chain is either connected between ground and the 4V output of the operational amplifier (N2), or is open circuited at R6. The switching produces either 8mV or 0V across R7, which is used as the low level voltage source. The positive output terminal of the reference unit (L) is connected through a resistor R11 to the junction of R6 and R7. The negative output terminal of the unit (M) is connected to the ground line through R12. Resistors R11 and R12 may be short circuited by FET switches TR2 and TR1 respectively when required by the control logic, operating through the CMOS switches (N4). The ground line is brought out and must be connected to the airframe at the nearest convenient point. All critical resistors used are thick metal film types manufactured by Vishay. These can be obtained with very accurate nominal values and have temperature coefficients of resistance of a few parts per million.

Table 1

SPECIFICATION FOR VOLTAGE REFERENCE UNITS

Parameter	High level unit	Low level unit
Nominal output voltage	4V	8mV
Output voltage accuracy	±2%	±2%
Voltage stability	±0.01% (±400μV)	±0.1% (±8μV)
Output impedance	< 0.1Ω	10Ω
Resistive unbalance in each arm	0, 1, 1.5, 2.5kΩ	0, 2.5kΩ
Nominal sequence time of resistance switching	16μs	16μs
Leakage current	<0.1nA	< 0.1nA
Temperature range	Performance to be met from −40 to +80°C	
Size	25.4 × 64 × 60mm	
Weight	0.17kg	
Power requirements	+18 to +22V at 50mA −18 to −22V at 15mA	
Vibration environment	BS 3G 100. Part 2, section 3, sub-section 3.1 category 5	

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No.	Author	Title, etc.
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3	A. Pool D. Bosman	Basic principles of Flight Test Instrumentation Engineering. AGARDOGRAPH No.160 (1974)
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5	R. Morrison	Grounding and shielding techniques in instrumentation. Wiley (1967)
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9	E.P. Thoma	IBM Technical Disclosure Bulletin, Vol.17, Part 8. 1975
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Fig. 1

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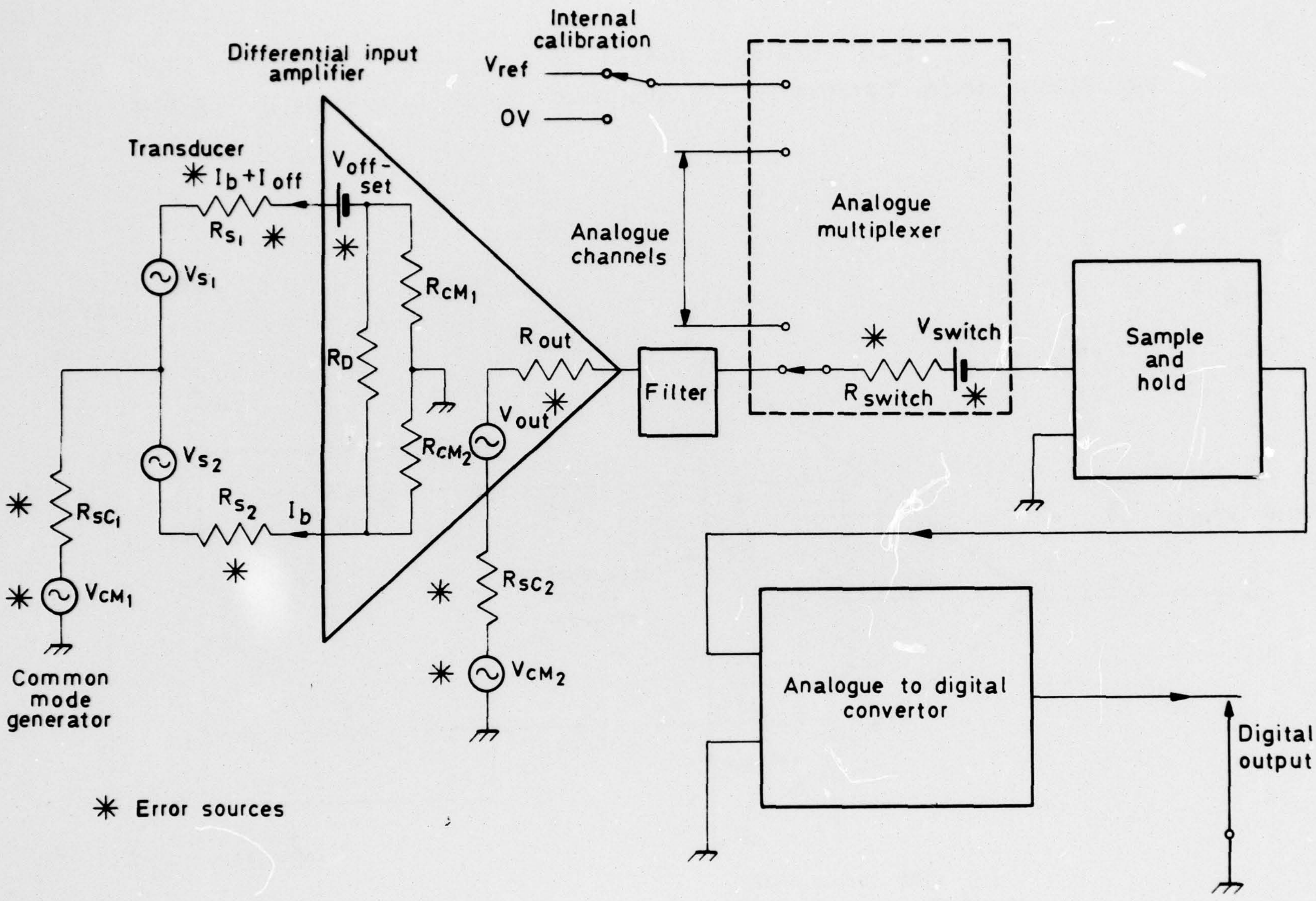


Fig. 1 Typical data acquisition channel with probable error sources

Fig. 2

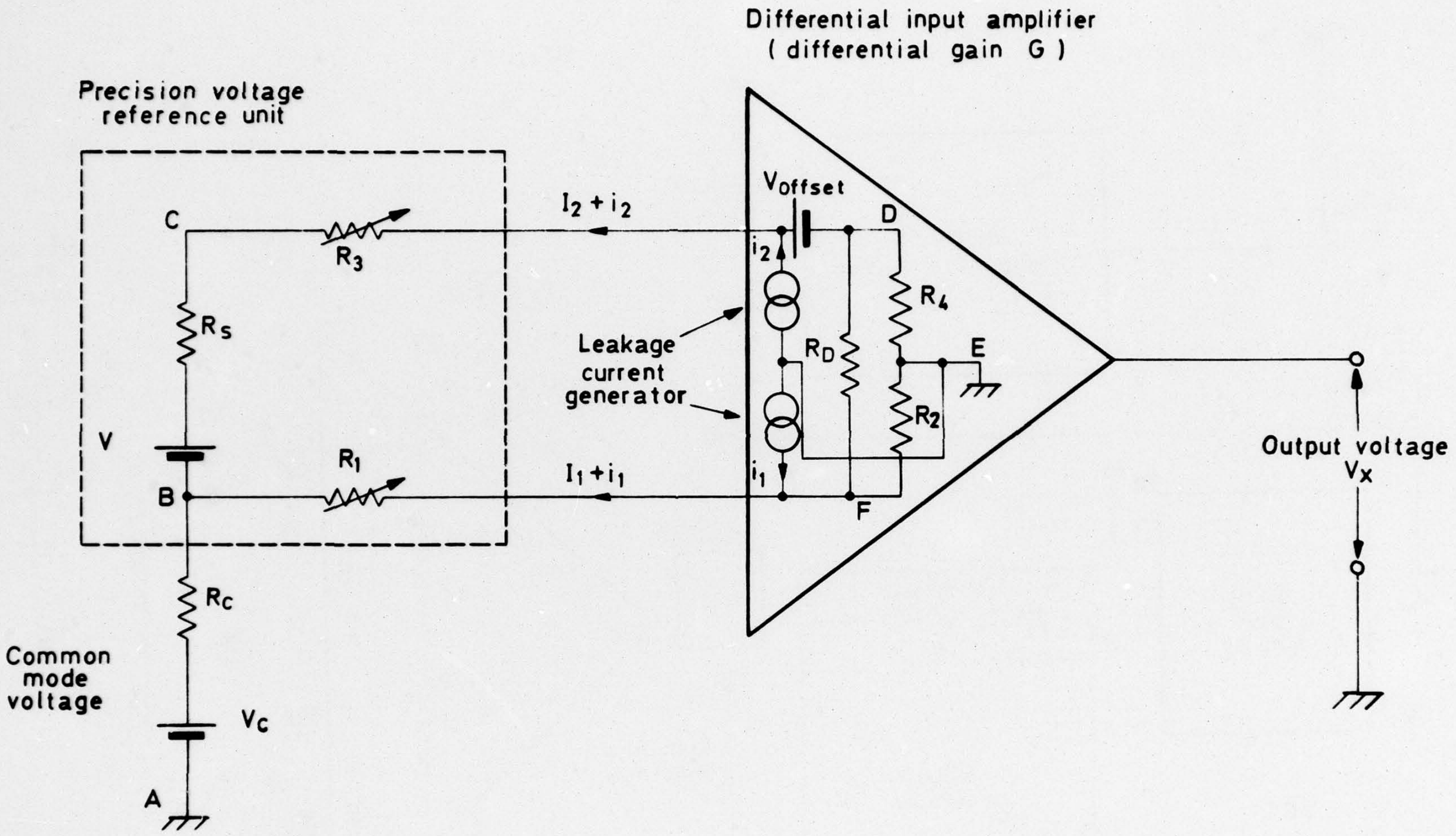
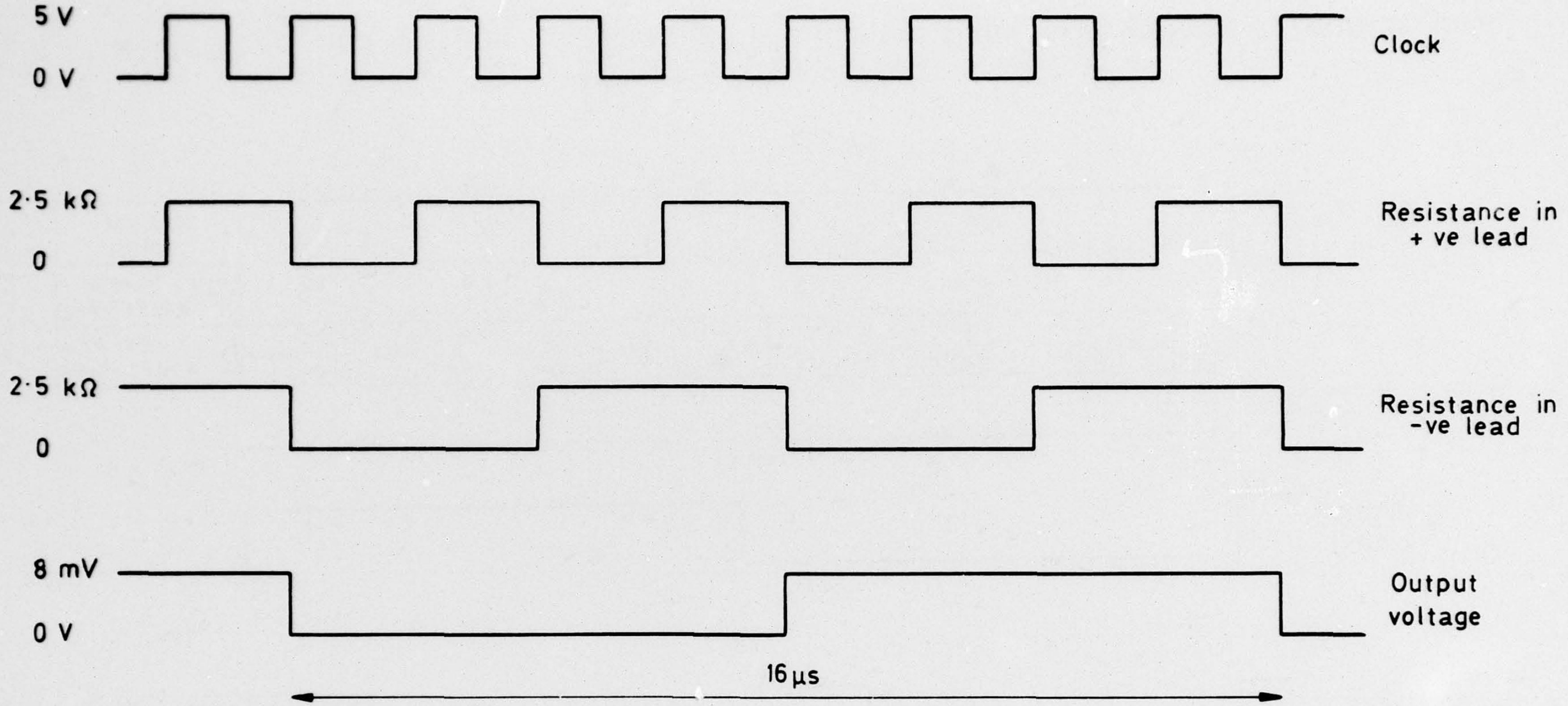


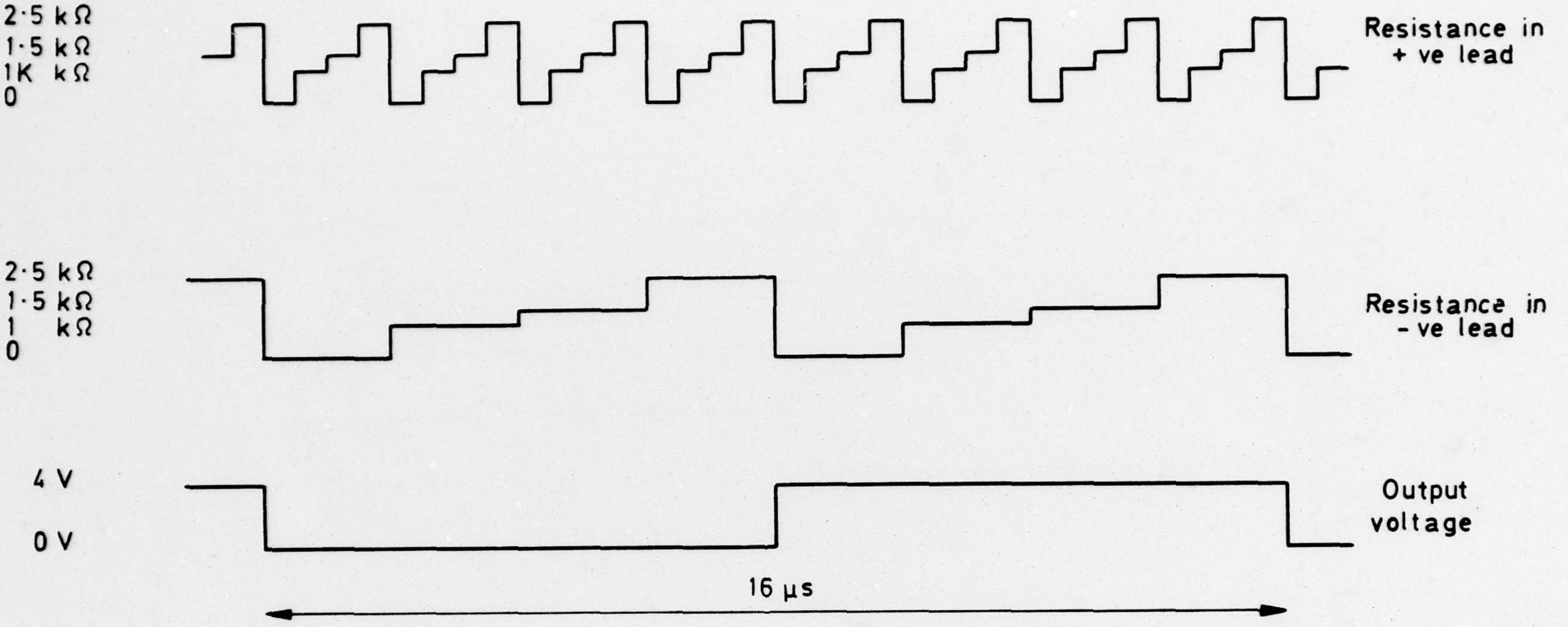
Fig. 2 Differential input amplifier configuration when connected to a voltage reference unit



Resistance in +ve lead (kΩ)	0	2·5	0	2·5	0	2·5	0	2·5
Resistance in -ve lead (kΩ)	0		2·5		0		2·5	
Output voltage	0				8 mV			

Fig. 3 Resistance and voltage variation with time for low level voltage reference unit

Fig. 4



Resistance in +ve lead (kΩ)	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5	0	1	1·5	2·5

Resistance in - ve lead (kΩ)	0	1	1·5	2·5	0	1	1·5	2·5
Output voltage	0V				4V			

Fig. 4 Resistance and voltage variation with time for high level voltage reference unit

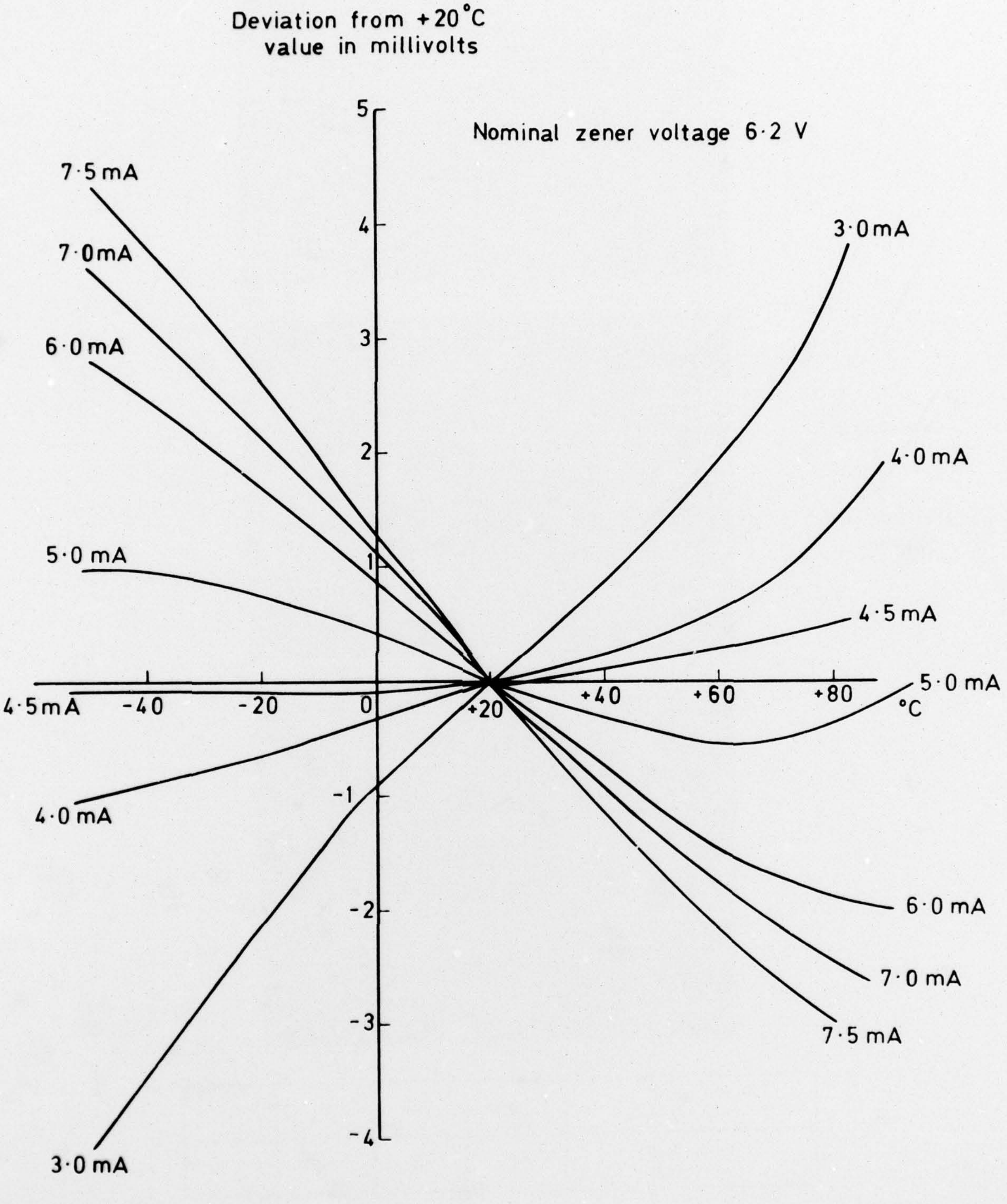
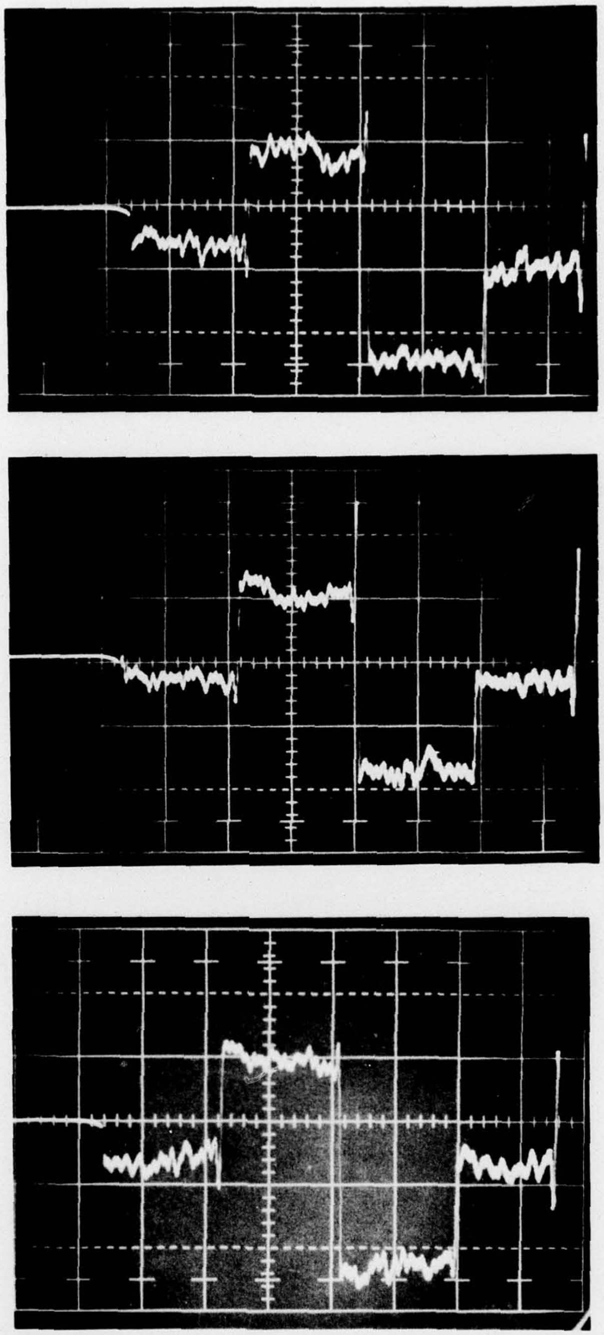


Fig. 5 Variation of zener diode voltage with variation of current and temperature

Fig.6



Resistance in +ve lead (kΩ)	0	2.5	0	2.5
Resistance in −ve lead (kΩ)	0	0	2.5	2.5

Fig.6 **Output voltage variation of low level voltage reference unit with resistance change and temperature variation**

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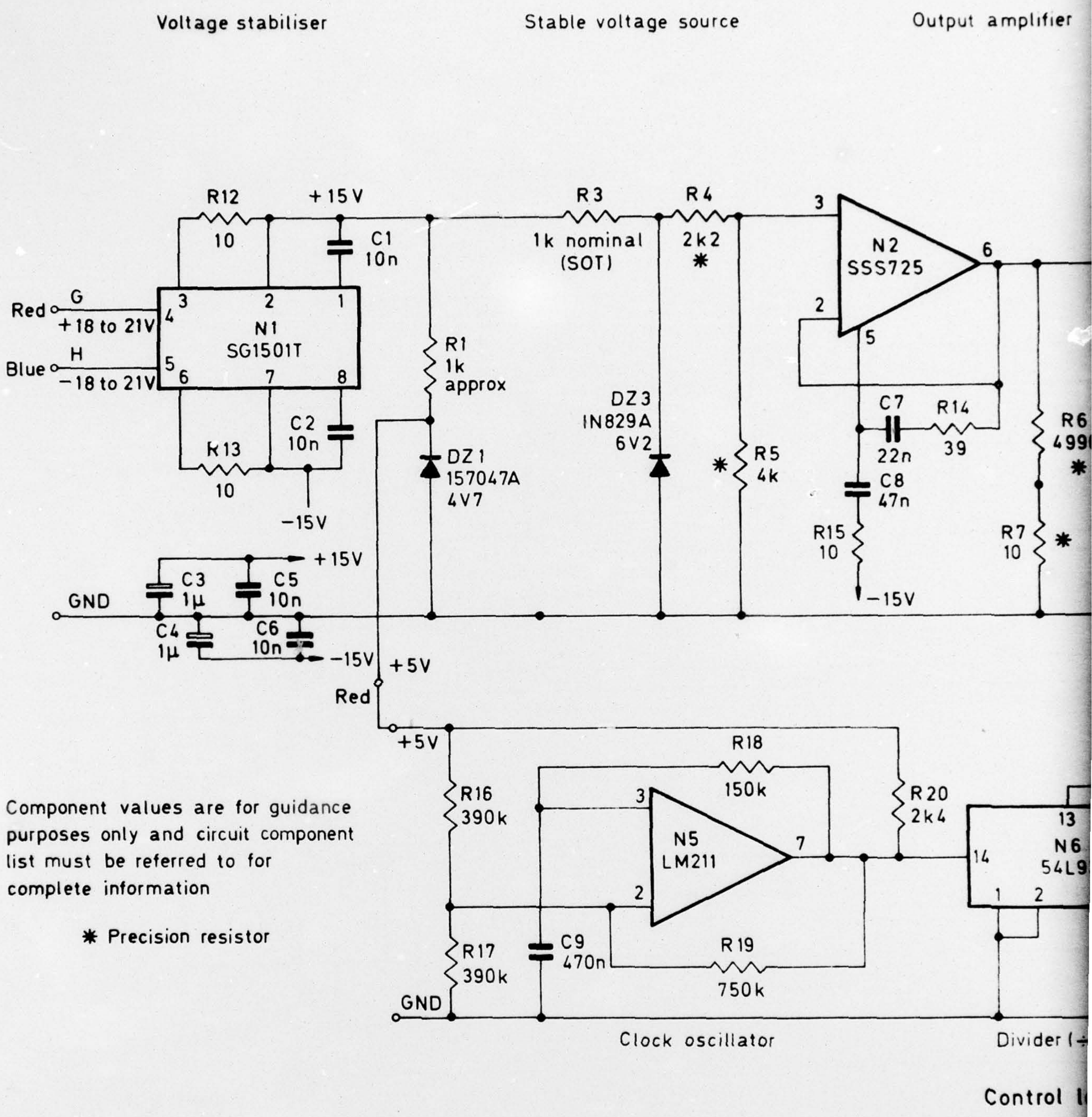


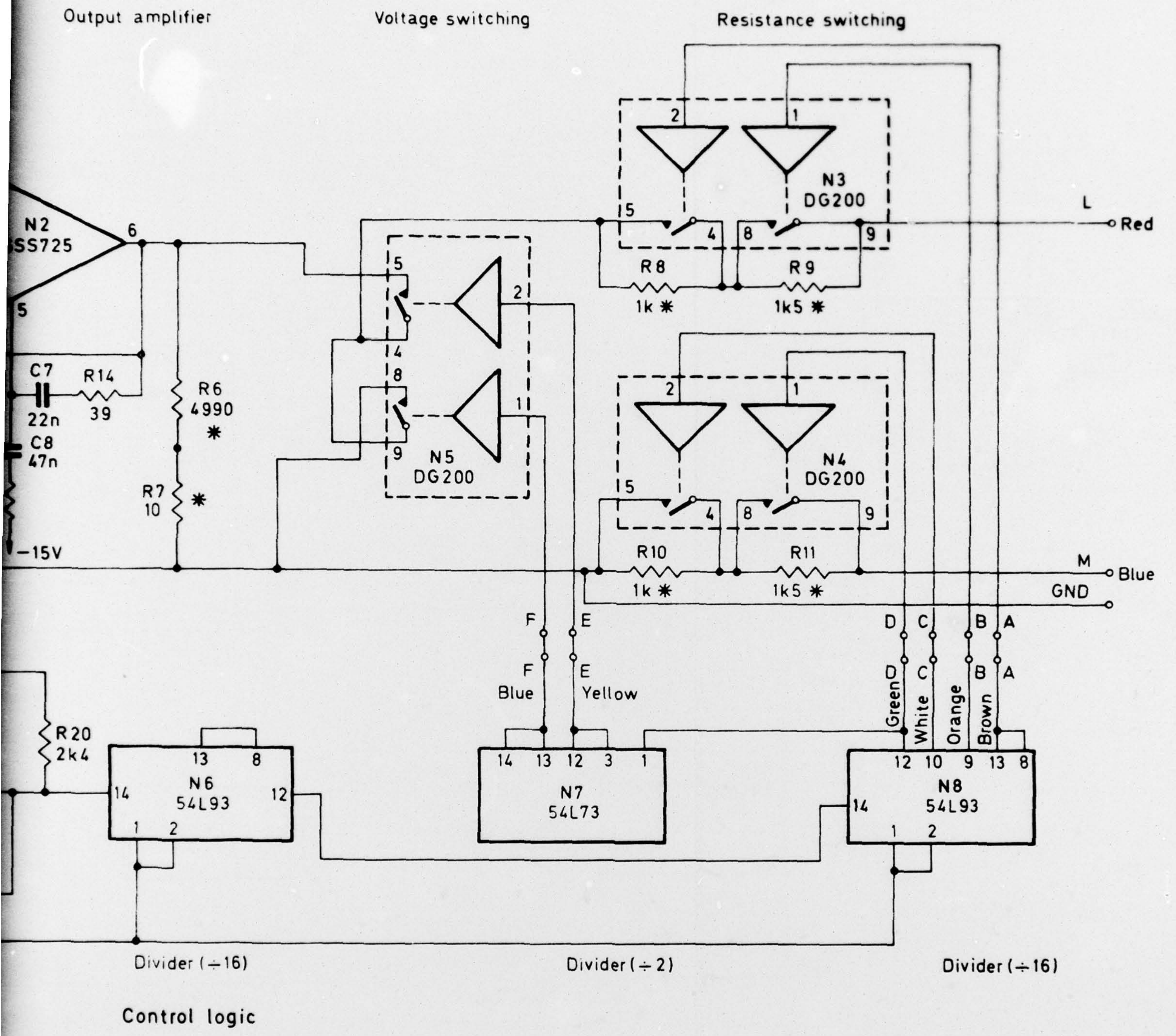
Component values are for guidance purposes only and circuit component list must be referred to for complete information

✱ Precision resistor

Fig 7 Circuit diagram of high

Fig 7

2



iagram of high level voltage reference unit

Fig 8

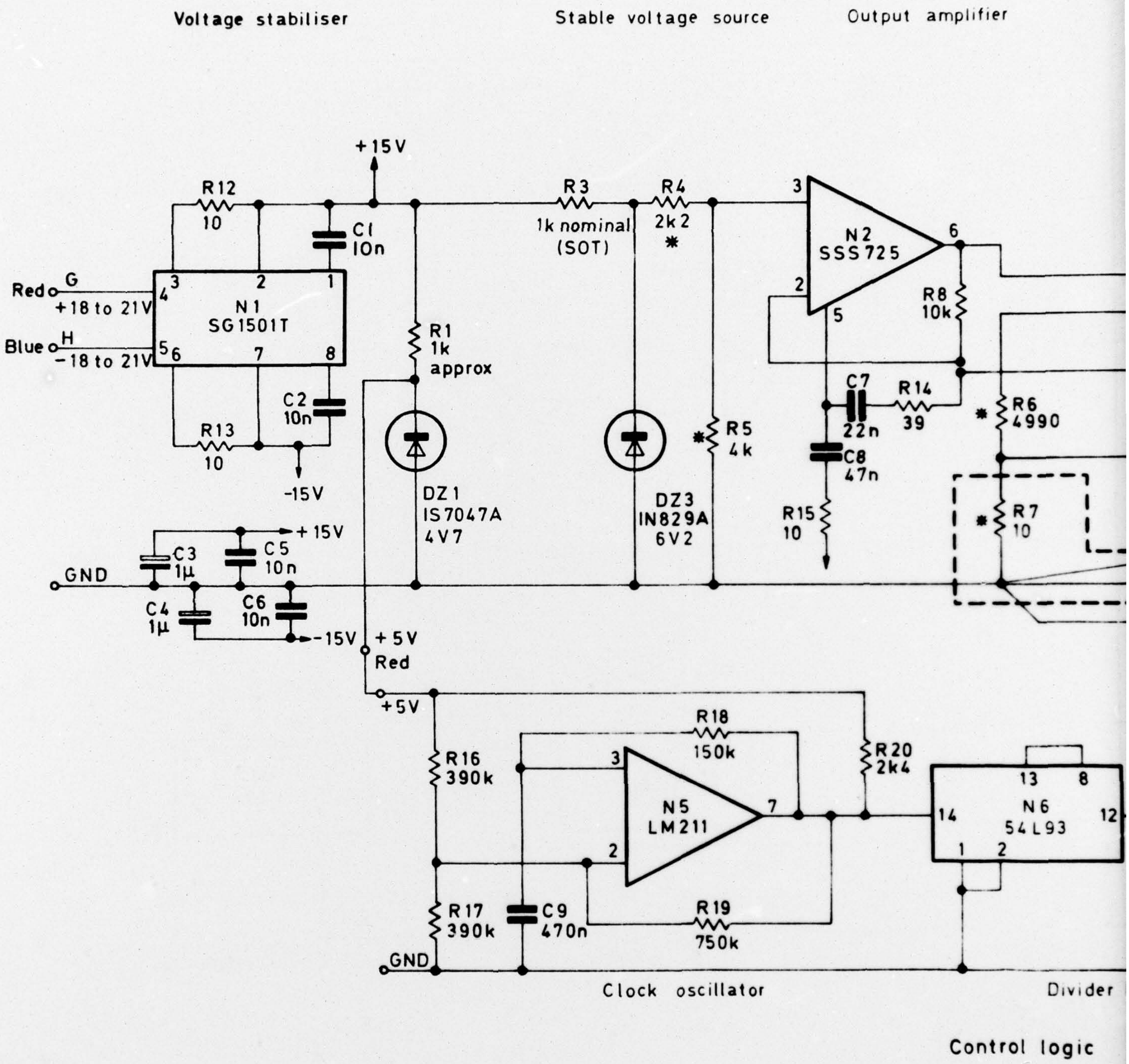
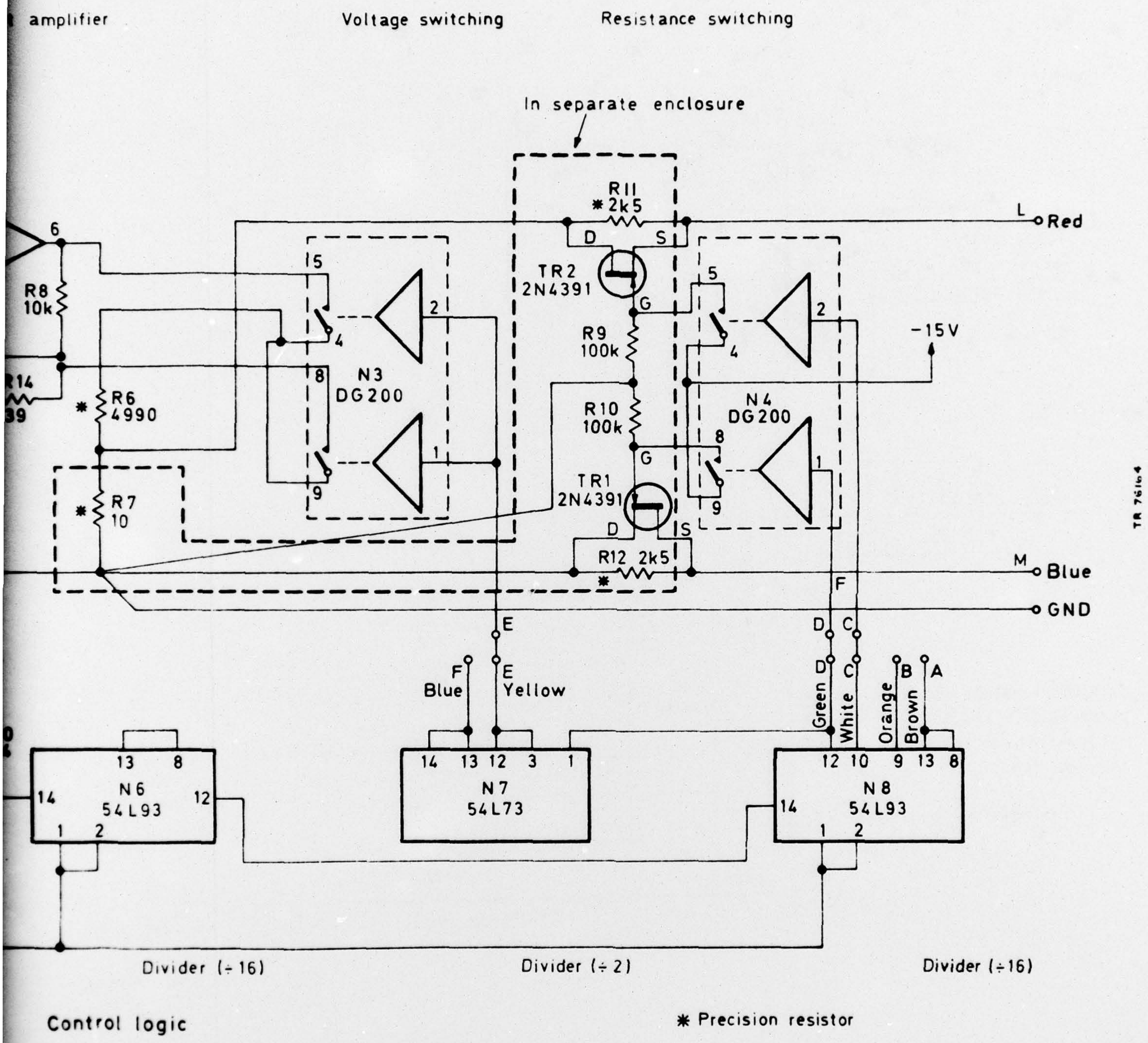


Fig 8 Circuit diagram of low level



of low level voltage reference unit

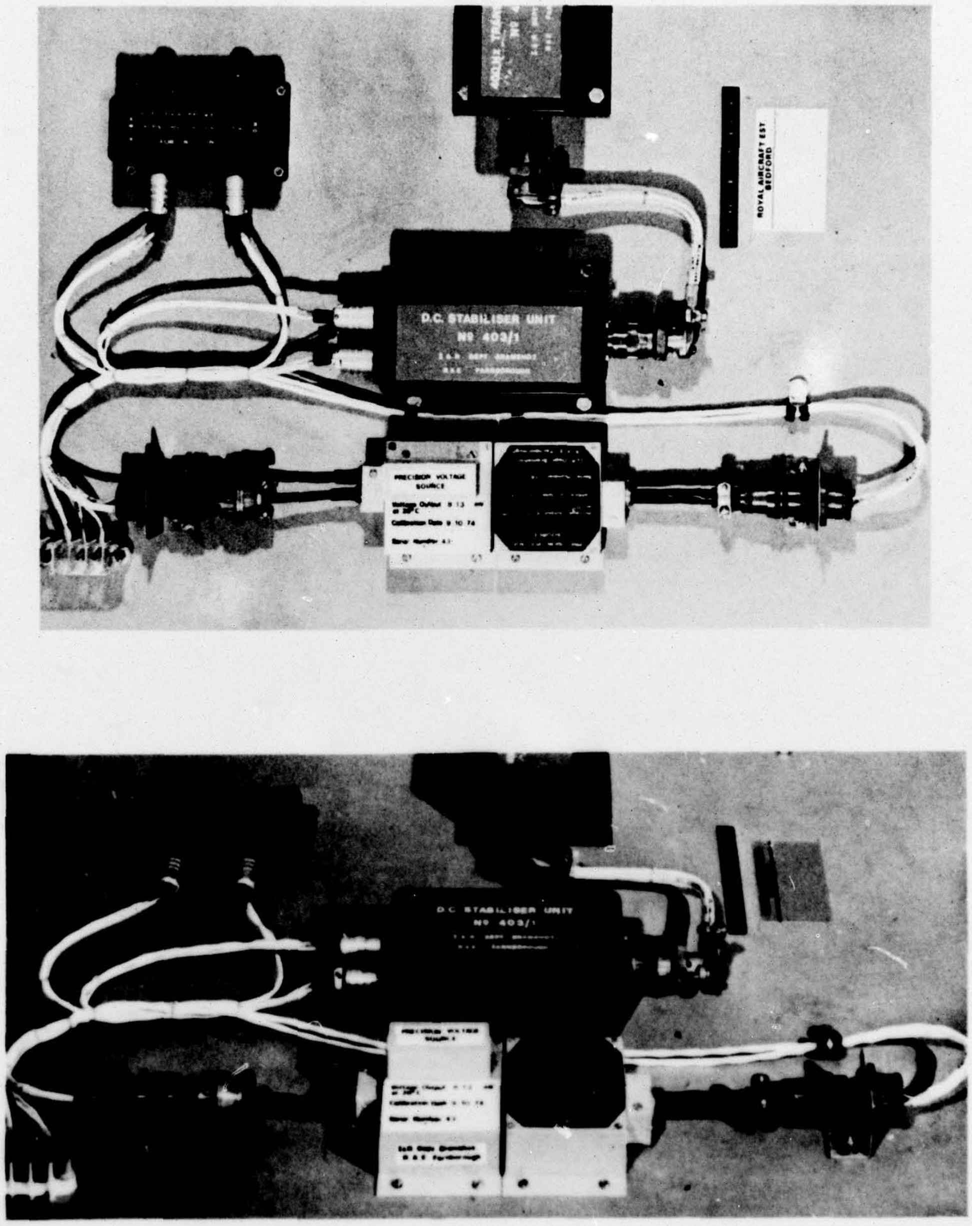


Fig.9 High and low level voltage reference units in typical aircraft installation