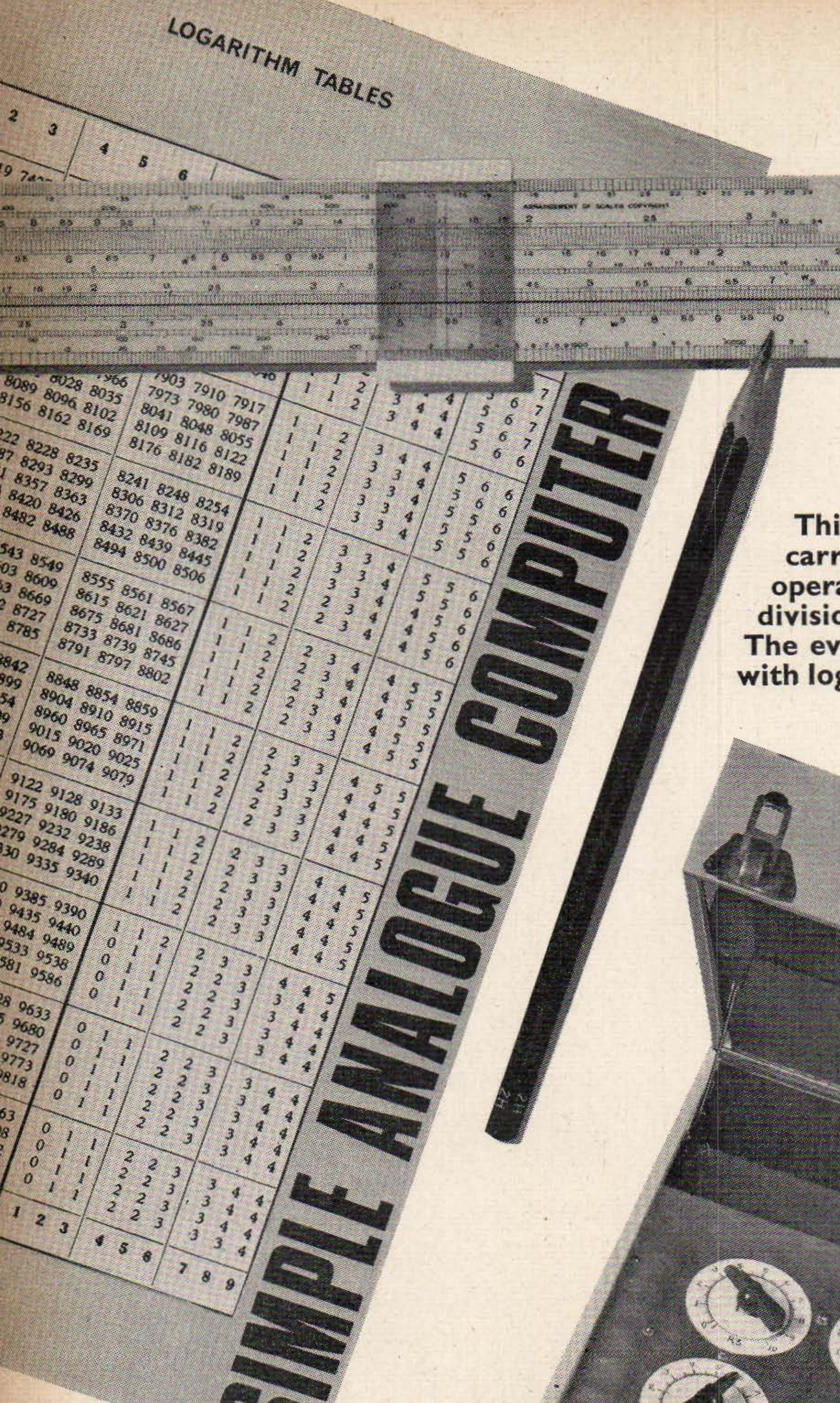


SIMPLE ANALOGUE COMPUTER

This instrument is capable of carrying out the arithmetical operations of multiplication and division with reasonable accuracy. The evaluation of powers and roots with log. scales may also be achieved.

by H. WEBSTER

ALTHOUGH popularly associated with formidable arrays of electronic instruments capable of incredibly complex calculations, computers in one form or another have been with us for a very long time. We have only to recall the familiar abacus or bead bar of our childhood to realise that our acquaintance with computers started at a very early age.

Modern computers are of two major types: the *digital*, which depend on the way we use numbers, and the *analogue*, in which numbers are represented by physical quantities such as length and current. A simple example of a digital computer is the abacus while a good example of the analogue computer is the slide rule.

Although elaborate computers are beyond the scope of the average constructor, quite simple instruments can be made using everyday components. The simple analogue computer described in this article was constructed by the author for classroom demonstration purposes. Although no originality is claimed for the design it was felt that a description of the instrument would be of interest to other constructors, particularly those engaged in teaching.

BASIC CIRCUIT

The computer is based on the familiar Wheatstone bridge network shown in Fig. 1. Such a network is commonly employed in the determination of an unknown resistance. When the bridge is balanced, for example, when the current through the galvanometer is zero, the following well known relationship holds,

$$R1 \times R4 = R2 \times R3$$

or transposing,

$$\frac{R1}{R2} = \frac{R3}{R4}$$

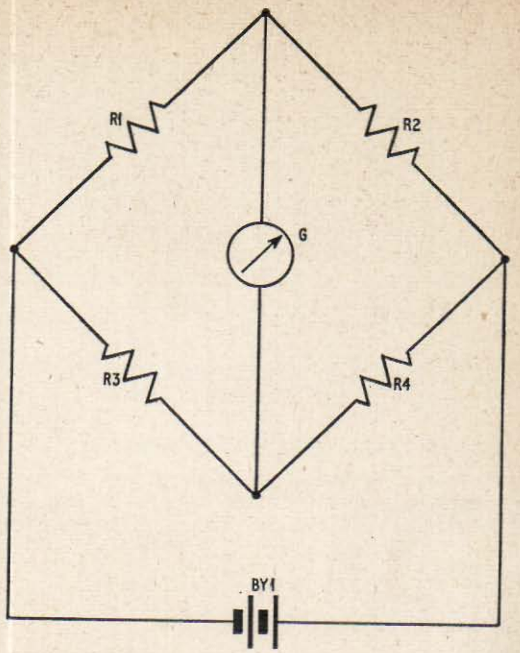
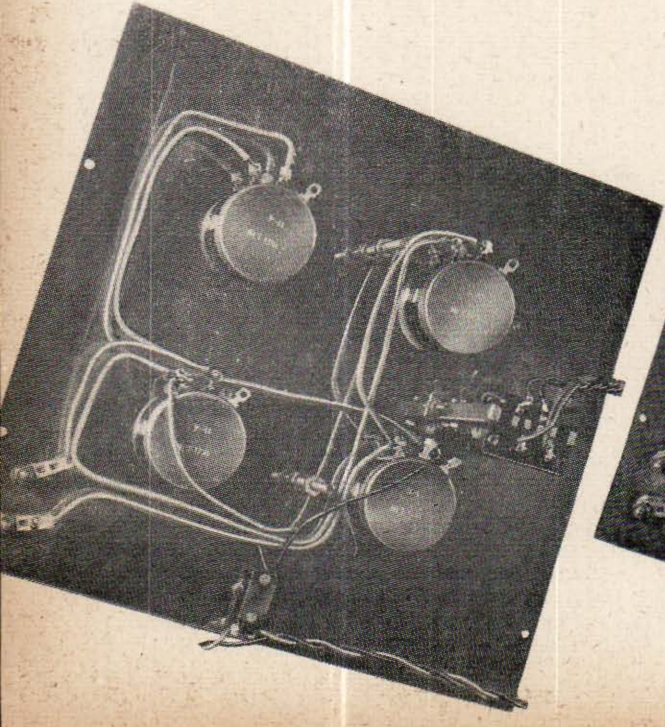
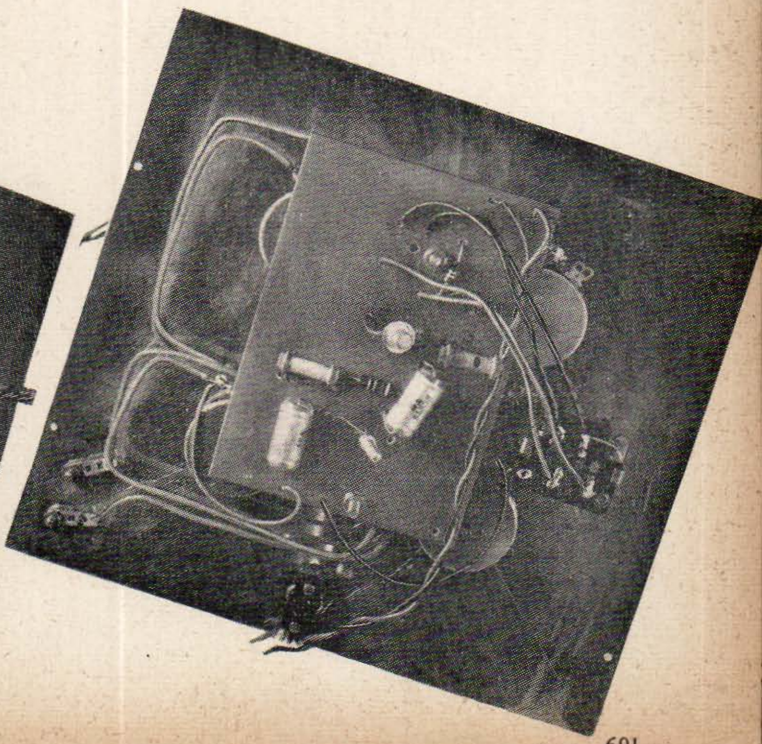


Fig. 1. Basic Wheatstone bridge network on which the computer is based

Generally, R1 and R2 form a calibrated resistance wire system, while R3 is a resistor of known value. R4 is the unknown resistor. When the system is balanced, the ratio R1:R2 is determined, and hence R4 can be calculated. By a reversal of this procedure, the operations of multiplication and division can be carried out.





If the resistors constituting the arms of the bridge are made variable and are accurately calibrated, the two arithmetical operations are easily performed. To multiply two numbers, R4 is set to some power of ten, the multiplicand set on R2 and the multiplier on R3. The bridge is balanced with R1 and the answer automatically read off on the R1 scale. To perform the operation of division, R4 is again set to a power of ten, while the numerator and denominator are set on R1 and R2 respectively. The bridge is balanced with R3 and the answer taken from this scale. For both arithmetical operations it is of course necessary to find the decimal point by inspection.

The scope of the bridge can be further extended by providing logarithmic scales for R3 and R4. Powers and roots may then be evaluated. This application will be discussed at a later stage.

PRACTICAL CONSIDERATIONS

In common with all other analogue computers the accuracy is limited by the precision of the components employed in the circuit. The author found that ordinary wire wound variable resistors of the type normally employed in radio work were of sufficient precision to enable quite a high degree of accuracy to be achieved.

In the original design the bridge was energised by a battery, the balance point being indicated by a sensitive galvanometer. However, since it was highly likely that the instrument would be subjected to somewhat indelicate handling, the fragile galvanometer was replaced by headphones and a simple but robust transistor audio oscillator used to energise the bridge.

CONSTRUCTIONAL DETAILS

The computer is mounted on an aluminium panel, the relevant drilling and mounting details being given in Fig. 3. Four 3¼in diameter discs cut from stiff white cardboard, and on which are described 2¼in diameter circles, are used as dials.

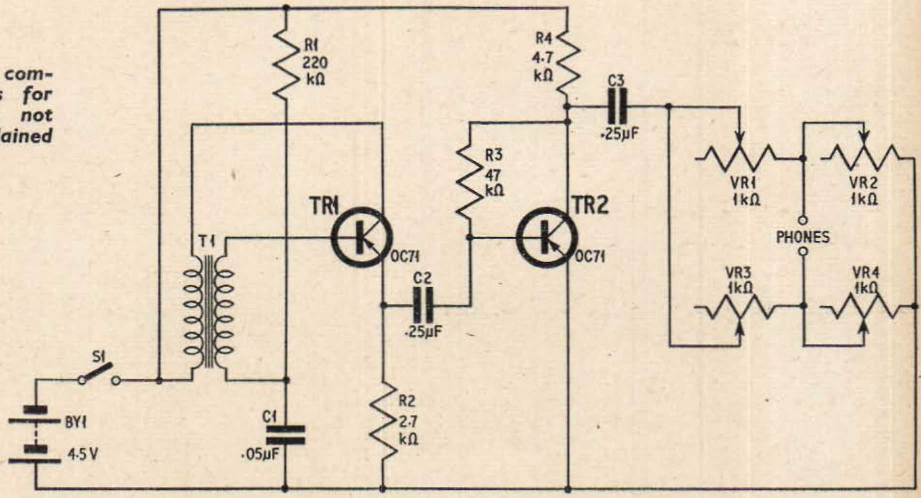
The audio oscillator is mounted on a 6in × 4in etched wiring board as shown in Figs. 4 and 5. An alternative method using Veroboard may also be used by those constructors who wish to avoid the use of chemicals. For comprehensive examples of this method the reader is referred to the April 1965 issue of Practical Electronics.

ETCHED WIRING BOARD

The copper laminate is polished with metal polish and then washed in warm soapy water. After rinsing and drying, the circuit pattern shown in Fig. 4 is drawn out with cellulose paint of the car "touch up" type. The paint is allowed to dry for approximately 30 minutes and the laminate immersed in a 30 per cent w.v. solution of ferric chloride. This solution is prepared either by dissolving 75gm of the anhydrous salt or 92gm of the hydrated salt in 200ml of water containing 3ml of concentrated hydrochloric acid. The resulting solution is made up to 250ml. For complete dissolution of the unwanted copper a reaction time of roughly 30 minutes at 40 degrees C is required. The etching is done by gentle agitation of the solution.

The prepared board is washed with water to remove all traces of the iron salt and the cellulose paint removed by swabbing with cotton wool soaked in acetone or other suitable solvents.

Fig. 2. Circuit of the simple computer. Additional resistors for calibration (R5-R10) are not shown here but are explained later in Figs. 6, 7, and 10



CIRCUIT DESCRIPTION

The circuit diagram of the computer is given in Fig. 2. Four 1,000 ohm wire wound potentiometers (VR1–4) form the arms of the bridge. The transistor oscillator is of the Hartley type. Oscillation is maintained by feedback in the correct sense through the primary of the audio transformer T1. Although the output of the oscillator may be taken via C2 from the emitter of TR1, an additional stage of amplification may be found advantageous, particularly where noisy background levels are encountered.

Holes are drilled at the points shown in Fig. 5. Wiring of the board is straightforward and the customary heat shunt precautions are observed when the transistors and other closely clipped components are soldered in position.

The audio frequency transformer is temporarily connected to the appropriate points on the board and a check made on the correct functioning of the oscillator. It may be found that the leads to the primary of the transformer require reversal to ensure feedback in the correct sense.

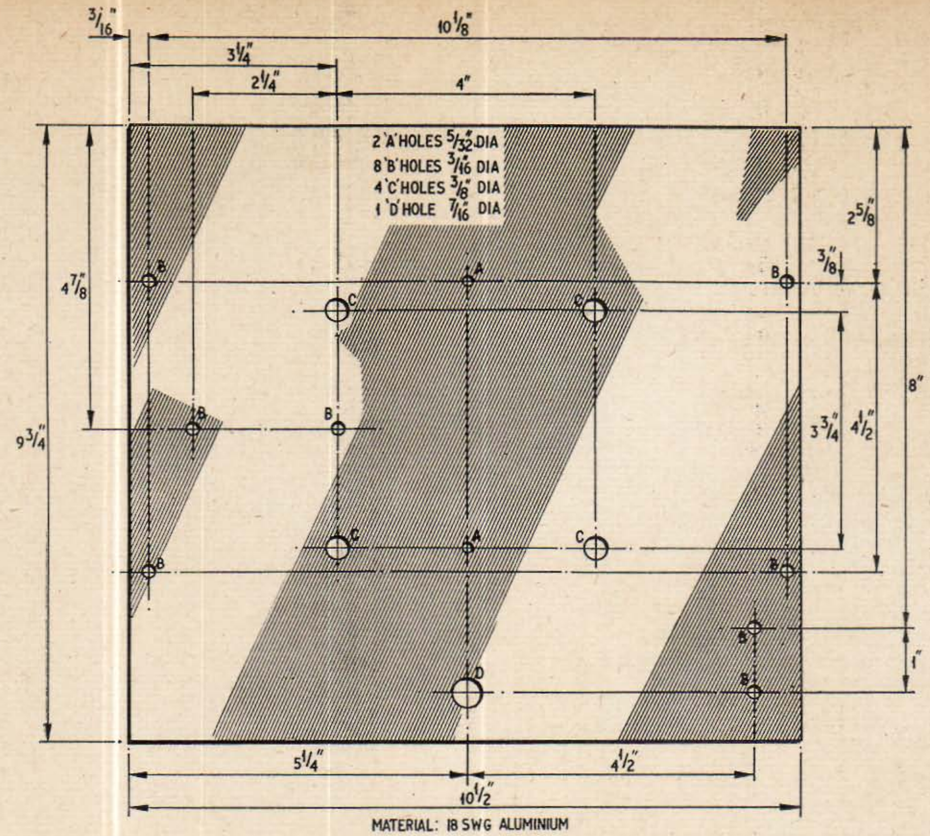


Fig. 3 (above). Drilling details of the aluminium panel to hold the potentiometers

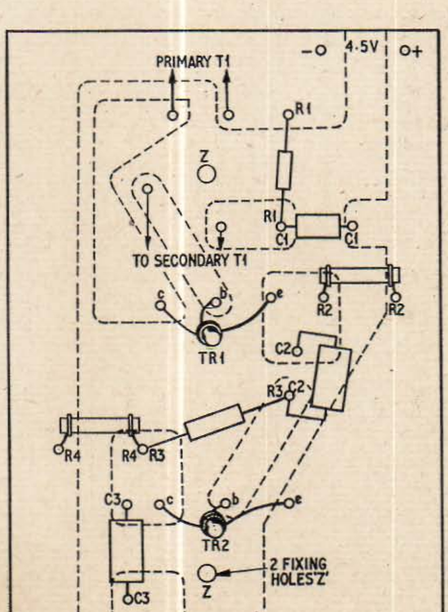


Fig. 4. Component layout on the printed circuit board

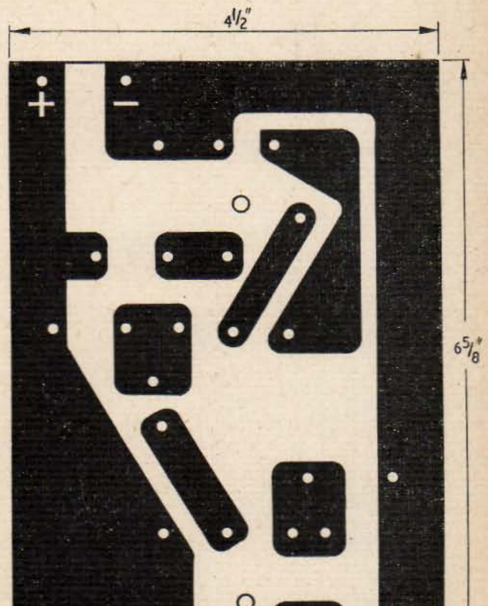


Fig. 5. Plan of the printed circuit board shown half scale

Before the completed audio oscillator is mounted on the main potentiometer panel, the potentiometers are calibrated by the following procedure.

CALIBRATION OF BRIDGE

A careful calibration of the four potentiometers is essential if accurate results are to be obtained. Although calibration is simplified if a resistance box calibrated in 10 ohm and 100 ohm steps is available, it is possible to use close tolerance fixed resistors as calibration standards. The construction of such a standard is shown later in Fig. 10.

Both calibration methods will be described, the resistance box method being dealt with first.

VRI CALIBRATION

Two close tolerance resistors, R9 and R10, each of 1,000 ohms, are wired with VR1 and the decade resistance box as shown in Fig. 6. The audio oscillator and headphones are connected to the appropriate points. With the decade box set at 100 ohms, VR1 is adjusted until the null point is observed. The dial of VR1 is carefully marked with pencil at this point. Repetition of the process with the decade box set at 200, 300, 400 ohm etc., followed by balancing with VR1 gives a series of points separated by 100 ohm intervals up to 1,000 ohms. If the decade box is calibrated in 10 ohm steps intermediate points may be filled in.

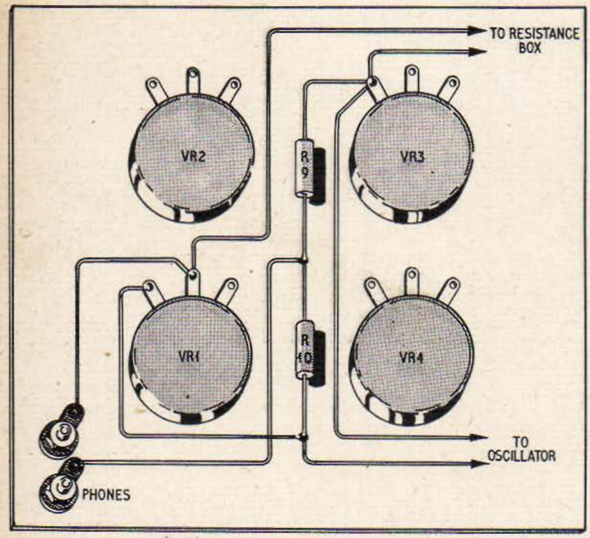


Fig. 6. VRI calibration

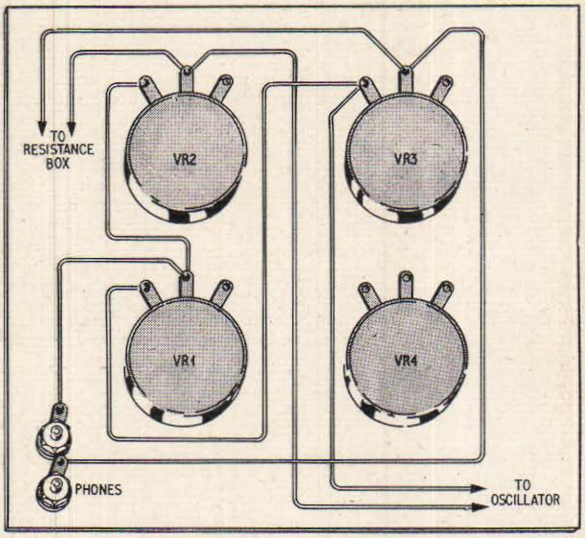


Fig. 8. VR3 calibration

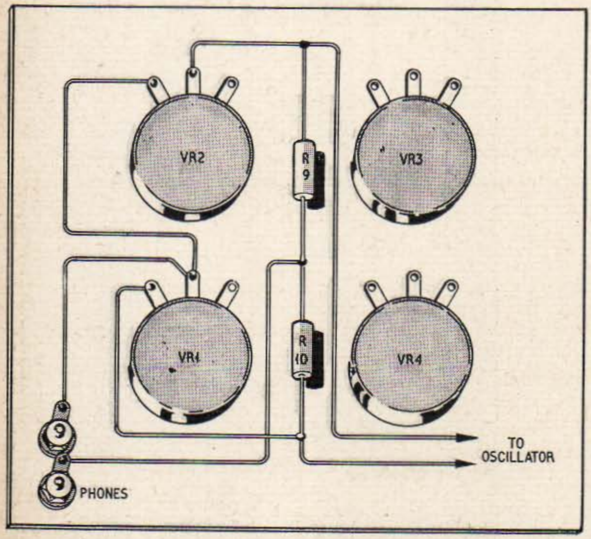


Fig. 7. VR2 calibration

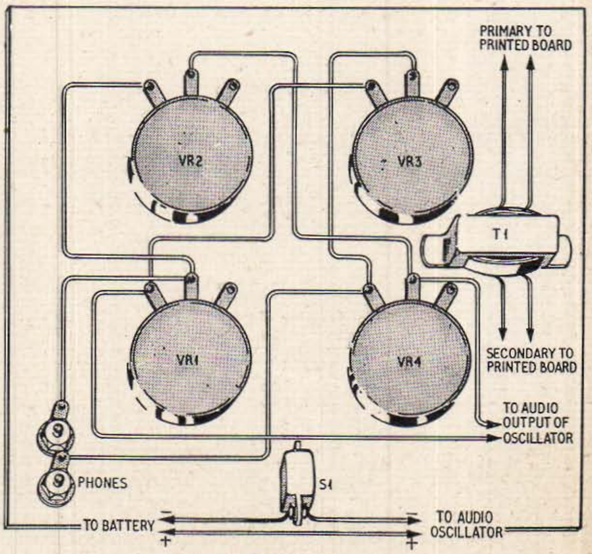


Fig. 9. VR4 calibration

Figs. 6-8. Temporary wiring of the potentiometer panel for calibration. Fig. 9. The final wiring

VR2 CALIBRATION

The decade box is disconnected and VR2 wired into circuit as shown in Fig. 7.

VR1 is successively set at each of the previously determined points and VR2 balanced against each point. In this way VR2 can be accurately calibrated in terms of VR1.

VR3 CALIBRATION

The decade box is reintroduced and R9 and R10 deleted. VR1 and VR2 are each set at 500 ohms and VR3 calibrated in 10 or 100 ohm steps against the decade box. Wiring details are shown in Fig. 8.

VR4 CALIBRATION

Prior to this final calibration the complete panel is wired as shown in Fig. 9. The audio oscillator and transformer may also be permanently attached. Two 3in 4 B.A. bolts serve as stand-off supports for the oscillator panel.

After completing the wiring VR4 is calibrated against VR3 with VR1 and VR2 each set at 500 ohms.

CALIBRATION WITH FIXED RESISTORS

A simple calibration standard is shown in Fig. 10. Four close tolerance resistors of 100, 200, 300 and 400 ohms respectively, are wired together as shown. By shorting out the appropriate sections a selection of resistance values from 100 to 1,000 ohms may be made. Two leads which terminate in crocodile clips are conveniently used as shorting links. Resistance values obtained when the appropriate sections are shorted are given in Table 1.

TABLE 1

Resistance Ω	Short Out
100	3 & 8
200	1 & 2, 6 & 8
300	6 & 8
400	1 & 5
500	3 & 5
600	7 & 8
700	1 & 4
800	3 & 4
900	1 & 2
1,000	none

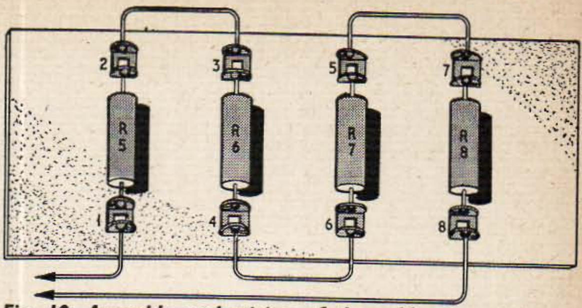


Fig. 10. Assembly and wiring of the calibration resistors. Due to the accuracy required for these resistors, it may be necessary to select and measure to within 1 per cent tolerance of the quoted values from resistors of the nearest "preferred" value available

Calibration of the bridge using this standard is carried out exactly as before, the standard taking the place of the decade box.

When calibration is complete the dials may be numbered from 0 to 10 and permanently marked with indian ink. If the calibration has been made in 100 ohm steps the intervals may be divided into ten equal parts. No great loss of accuracy will occur since it was found that over small portions of the potentiometer tracks the resistance per unit length was constant enough to warrant this procedure.

OPERATION OF COMPUTER

A discussion of the operations of multiplication and division was given in the introduction to this article. These operations are summarised at this point.

MULTIPLICATION

Set VR4 to 1 or 10. The multiplicand is set on VR2 and the multiplier on VR3. The bridge is balanced with VR1 and the answer taken from this scale.

DIVISION

Set VR4 to 1 or 10. The numerator is set on VR1 and the denominator on VR2. The bridge is balanced with VR3 and the answer taken from this scale.

COMPONENTS . . .

Resistors

R1 220kΩ 10%
R2 2·7kΩ 10%
R3 47kΩ 10%
R4 4·7kΩ 10%
} see Fig. 2

R5 100Ω 1%
R6 200Ω 1%
R7 300Ω 1%
R8 400Ω 1%
} see Fig. 10

R9 1,000Ω 1%
R10 1,000Ω 1%
} see Figs. 6 and 7

Potentiometers

VR1, 2, 3, 4 1kΩ linear, wire wound

Capacitors

C1 0·05μF paper
C2 0·25μF paper
C3 0·25μF paper

Transformer

Intervalve type, ratio 3:1

Transistors

TR1, TR2 OC71 or NKT272

Switch

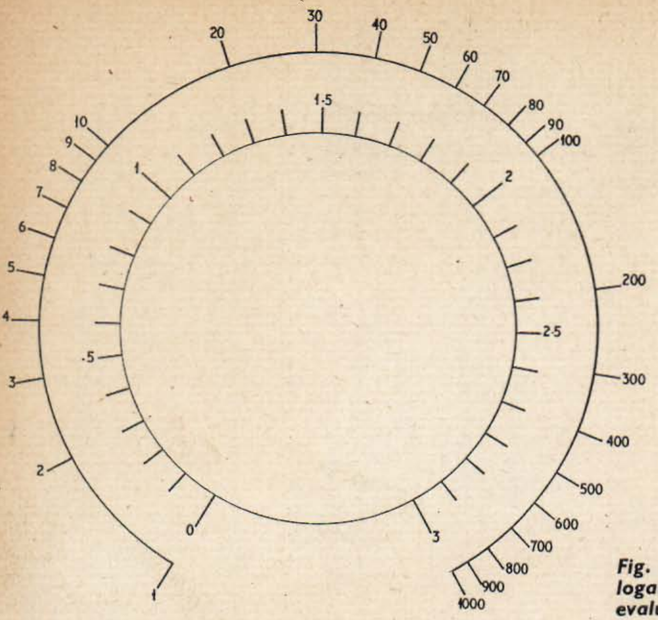
S1 Single pole on/off

Battery

BY1 4·5V battery

Miscellaneous

Aluminium panel. Copper laminate board. Four pointer knobs. Headphones. Terminals. P.V.C. insulated connecting wire.



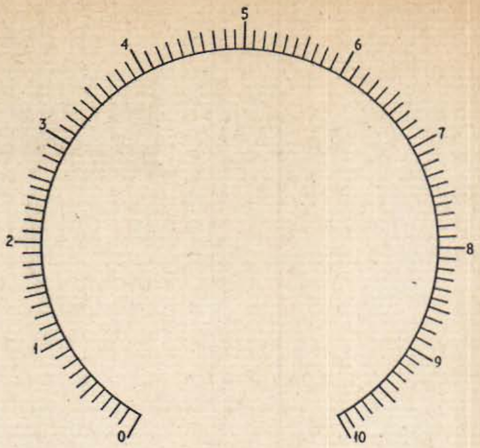


Fig. 12 (above). Example of the linear type of scale that will be produced when the four potentiometers are individually calibrated as described on page 694. This linear scale is used for multiplication and division

Fig. 11 (left). Calibration scale for VR4 drawn on a logarithmic basis to full size. This scale is used for the evaluation of powers and roots

EVALUATION OF POWERS AND ROOTS

In addition to the operations of multiplication and division, further interesting evaluations may be made if the scales of VR3 and VR4 are calibrated logarithmically.

If we let r_3 be the reading of VR3 such that $\log r_3 =$ VR3 and similarly r_4 the reading of VR4 so that $\log r_4 =$ VR4, then at the balance point, and recalling that in the basic bridge of Fig. 1, $R1 \times R4 = R2 \times R3$, it follows that

$$VR1 \log r_4 = VR2 \log r_3$$

or

$$r_4^{VR1} = r_3^{VR2}$$

or

$$r_4 = r_3^{VR2/VR1}$$

In other words we can determine the value of r_3 to the power VR2/VR1.

As a simple example consider the evaluation of 3^4. The required power VR2/VR1, is conveniently obtained by setting VR2 to 8 and VR1 to 2. VR3 is set to 3 and the bridge balanced with VR4. The answer is taken from this scale.

Roots may be evaluated using a similar procedure. For example, suppose we wish to find $\sqrt[3]{27}$ or, what is the same thing, $27^{1/3}$. VR2 is set to 1 and VR1 to 3. After setting VR3 to 27 the answer is read off the VR4 scale.

LOGARITHMIC SCALES

The logarithmic scales are prepared as follows. A 2¼in diameter circle is inscribed on a disc. Two points are marked with pencil on the circumference of the circle such that the length of the arc is the same as that of the linear scales. The arc is then divided into three equal portions which in turn are subdivided into tenths. This calibration represents the logarithms of numbers between 1 and 1,000. The resistance scale may now be calibrated by inserting the values whose logarithms correspond to the inner scale. An illustrative example is given in Fig. 11. This scale can conveniently be used for VR4.

The second logarithmic scale is prepared by calibrating VR3 in terms of VR4. To do this VR1 and VR2 are each set at a dial reading of 5 and VR3 then balanced against each point of VR4 by the usual method. Fig. 12 shows an example of this scale.

Doubtless other evaluations will suggest themselves to the mathematically-minded constructor. Circuit variations are also possible, for example, the audio oscillator may be replaced by a buzzer with a cheapening in the overall cost. As a point of interest the cost of the instrument excluding battery and phones was ust over £2. ★

Contributed Articles

The Editor will be pleased to consider for publication articles of a theoretical or practical nature. Constructional articles are particularly welcome, and the projects described should be of proven design, feasible for amateur constructors and use currently available components.

Intending contributors are requested to observe the style in our published articles with regard to component references on circuit diagrams and the arrangement of components list.

The text should be written on one side of the paper only with double spacing between lines. If the manuscript is handwritten, ruled paper should be used, and care taken to ensure clarity, especially where figures and signs are concerned.

Diagrams should be drawn on separate sheets and not incorporated in the text. Photographic prints should be of high quality suitable for reproduction; but wherever possible, negatives should be forwarded.

The Editor cannot hold himself responsible for manuscripts, but every effort will be made to return them if a stamped and addressed envelope is enclosed.