The Wireless World Desk Calculator

1. Design philosophy

by Roger Alexander and Brian Crank†*

The *Wireless World* Desk Calculator is the result of close co-operation between *Wireless World* and Advance Electronics Ltd who designed the machine. The article describing this machine is divided into two parts. This month the evolution of low-cost calculators is discussed and then the circuitry and operating principles of the calculator are described. In part two of the article, next month, full constructional details will be given. These instructions will apply to a kit of parts which will be available for £39.25 plus 75p postage and packing charge. The kit is complete in every detail and includes the printed circuit board and a moulded plastics case. Details of how the kit may be ordered will be given next month.

For a long time engineers have realized that if a small automatic calculator could be produced at a fairly low price the market would be enormous. The first automatic calculators were mechanical and had no chance of achieving this ideal, for they were large and cumbersome and needed regular maintenance. Even more modern mechanical calculators could not make much impact on the potential market as they were large, noisy and expensive.

*Advance Electronics Ltd.
†Formerly deputy editor, *Wireless World*, now with T. J. Burton Associates.

In the early 1960s, with the advances being made in computer technology, electronics engineers realized that the ideal calculator was much more likely to be realized using electronic techniques. Early design work was aimed at producing an electronic analogy of the mechanical machine of the time. The reason was that the people responsible for planning argued that users would be suspicious of anything that was radically different from the norm.

The machines were constructed from the discrete components available at the time and, in general, were large, difficult to use and expensive. In fact they did not offer many advantages over the mechanical machines they were intended to replace.

When t.t.l. integrated circuits became available at low cost these were employed in calculators to great advantage; a turning point had been reached. The performance of the t.t.l. machines was better and the price came down. The main trouble was a fairly large number of t.t.l. integrated circuits was required and the amount of labour involved in constructing the machines was quite high. The result was that the price could not be reduced to the level needed to reach the mass market.

The semiconductor industry then began producing medium scale integrated circuits and it was not long before i.c. designers turned their efforts to calculators. The result was a range of calculators based on only four integrated circuits. These calculators appeared in 1970/71; they were small, compact and practical but they were too expensive for the domestic market. A stage had been reached where just about all the electronic design problems had been solved and the electronic circuitry was potentially capable of a higher performance than was really required. Who could tell the difference between a calculation time of 100 and 200ms?

Electronic calculator design was also restricted by the need for a cheap method of displaying the numerical result of a calculation. Most of the calculators used gas discharge display tubes which required complex drive circuitry, inconvenient high-voltage supplies and, of course, they did not "interface" easily with integrated circuits.

The introduction of the gallium arsenide seven-segment digital display was a major step in the right direction as far as the calculator manufacturers were concerned. The displays were small and only required low voltage, low power drive. However, they were not without their difficulties because it proved too expensive to produce the large sized displays sometimes required by office users, but, nevertheless, they were admirably suitable for the small calculators we are discussing.

Semiconductor manufacturers had by this time started producing large scale integrated circuits based on m.o.s. technology and in 1971 Texas Instruments produced a calculator on a single chip: one integrated circuit which contained all the arithmetic, control and storage functions necessary to

Fig. 1. The completed machine.

build a calculator. This represents the current state of the art, but is still not the ideal. For instance, the calculator chip will not drive the display directly, so suitable interface circuitry must be included and two power supply voltages are required.

What will happen next is a matter for conjecture but if the predictions made last month in the editorial (Electronic Calculators, p. 357) materialize the future will see a calculator based on a liquid crystal display driven directly from a c.m.o.s. integrated circuit. The whole thing would be mounted on a single substrate and would be powered by a single battery.

Whichever way calculator evolution proceeds, it is fair to assume that within a few years the price will have fallen to a level within reach of practically everybody. Calculators will probably be available with sufficient versatility to replace the engineer's slide rule at the price, say, of a small transistor radio receiver.

Once calculators are available in very large numbers, at low cost, it would be fair to ask what effect they might have on society. Will it be on a par with the computer revolution? Will it be necessary to teach arithmetic any more? The prospect certainly provides food for thought.

Wireless World desk calculator description

As mentioned earlier the *Wireless World* calculator (Fig. 1) is based on the calculator integrated circuit manufactured by Texas Instruments and employs nine gallium arsenide seven-segment displays. In addition to being able to add, subtract, multiply and divide the calculator has several other features. It will perform chain operations, which means that a number of operations can be carried out consecutively without the need to reset the machine; for instance $Y(X^2+Z)$. The machine also allows any number of calculations to be made with a constant factor which is required to be entered only once. If one needed to convert 12 and 27.5 inches to millimetres they have to be multiplied by 25.4 (the constant). The calculator is switched to the 'constant' mode of operation and 25.4 is entered on the keyboard, followed by the instruction to multiply (the calculator now stores $\times 25.4$). The first figure 12 is entered and the 'equals' key is pressed; the result of 12×25.4 is displayed. Next 27.5 = is keyed and the calculator will display the result of 27.5×25.4. There was no need to enter the 25.4 again for the second calculation or 'clear' the machine.

In a similar way division by a constant number can be performed and the machine can be made to store $\div X$, where X is a number within the range of the machine. It must be noted that the "constant" and "chain" modes of operation cannot be carried out at the same time.

The calculator will square a number automatically, will indicate an error or an overflow and it suppresses insignificant leading zeros. The brightness of the display is variable in steps and the result of a calculation can be as large as 16 digits to the left of the decimal point. With numbers as large as this the eight most significant are displayed.

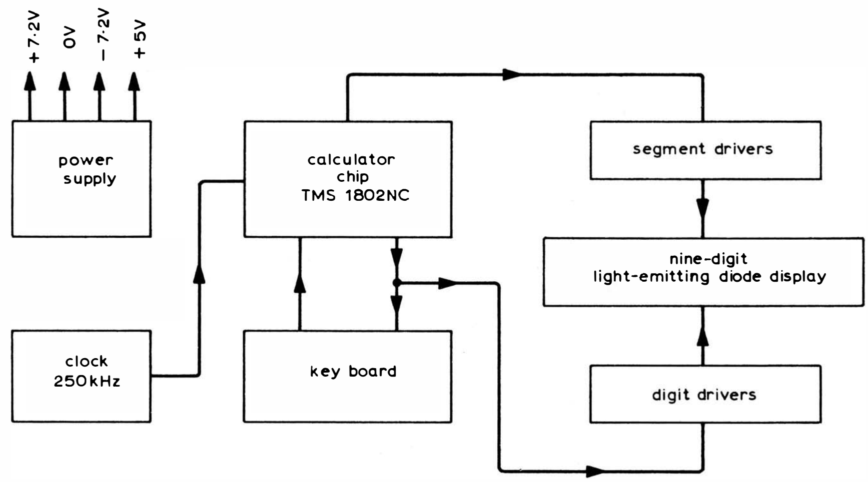


Fig. 2. Block diagram of the calculator showing the main sections.

The calculator operates in the floating point mode, that is, the decimal point can appear anywhere in the display, the least significant digit appearing at the extreme right of the display. The rest of the specification is detailed in Table 1 and a block diagram appears in Fig. 2, which should be referred to during the following description.

Calculator integrated circuit

The Texas Instrument's TMS1802NC integrated circuit is the heart of the calculator. It is a single silicon chip, only 6.56mm square, containing more than 6,000 transistors, and it is one of the most complex m.o.s. large-scale integrated circuits ever produced using the silicon nitride process.

A block diagram of the chip is shown in Fig. 3. The timing block is formed from a programmable logic array (p.l.a.). This means that an array of transistors is laid down selectively on the chip. The function this array performs is decided by the pattern of transistors laid down at a stage during the production. In other words the function that the array performs is defined by the thin oxide mask used by the second layer, in this sense, the array is programmable. The timing block contains such things as the master counter and circuitry for producing timing pulses for the keyboard and for time multiplexing the display (more about that later).

The programme read-only memory (r.o.m.) stores details of all the operation algorithms and issues them to the control p.l.a. where they are decoded and used to control the timing decoders and the arithmetic logic unit. Feedback from the control p.l.a. to the programme r.o.m. allows the programme to loop and branch within the algorithms. The data random access memory (r.a.m.) and arithmetic logic unit stores the data (numbers entered by the keyboard and results of calculations) and has all the necessary logic to perform arithmetic functions as defined by the programme r.o.m. It is interesting to note that the arithmetic unit consists of a set of logic gates and not a sequential adder, b.c.d. shift registers, etc., made up from flip flops. The output p.l.a. suppresses the leading zeros in the display and changes data which is to be displayed into a form suitable for driving the seven-segment indicators.

Table 1

Desk area	200 × 240mm
Power supply	110 or 240V a.c. at 9VA
Weight	1.1kg
Temperature range	0 to 50°C
Calculation time	<200ms

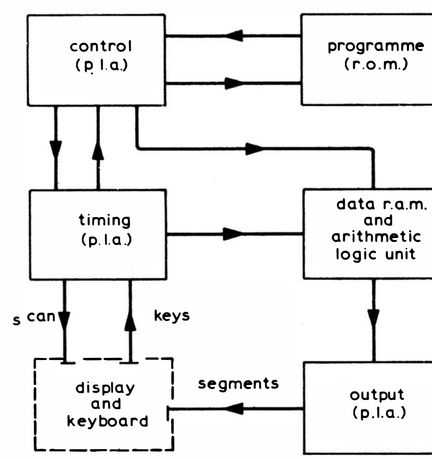


Fig. 3. Block diagram of the calculator integrated circuit.

Keyboard

The keyboard consists of 17 keyswitches and two slide switches. The key switches contain sealed reed relays and were designed and built by Alma Components Ltd to a specification produced by Advance Electronics. At the time the machine was being designed all reed key switches were very long because the reeds were mounted vertically and were actuated by circular magnets contained in the button. A "slim line" machine was needed, so radical changes had to be made to the existing key switch designs. The problem was resolved by mounting the reed diagonally, in a horizontal plane, in a square box which forms the base of the key switch. The final size of the base was fixed at $19mm^2$ and the height of the switch at 15.9mm, enabling the machine to be reduced to about 30mm in depth.

The switch plunger houses a small magnet which actuates the reed switch, and herein lay a problem. The low overall height limited the plunger traverse to about 3.2mm and there was a danger that the reed would not open when the plunger was at the top of its travel because of the close proximity of the magnet. This problem was solved by incorporating a metal keep at the top of the plunger travel which effectively removed the magnetic field from the reed. It also gives a bonus which Advance Electronics call negative feel. A small force is required to start the plunger moving because the magnet is in contact with its keep. This resistance disappears as soon as the plunger moves, giving a very pleasant feel to the keyboard.

The plunger has a tapered top, onto which are pushed double-shot moulded key tops in black and white. The base of the key switch contains the two contacts for printed circuit board mounting and two orientation pips. This allows the switch to be mounted in one plane only so that no interaction occurs between adjacent switches.

Two slide switches are mounted directly on the printed circuit board; they are the constant-mode switch and the brightness level adjustment. The constant-mode switch is single-pole, two-position and the brightness switch single-pole, three-position. These switches are operated through the case top via moulded switch tops, engraved with the operating function.

The key switches are connected in a matrix as shown in Fig. 4; one has to imagine a contact operated by each button which connects a horizontal wire to a vertical wire. Fig. 4 shows all the keys which can be connected to the calculator chip; not all these keys are used in the *Wireless World* calculator.

The calculator i.c. produces 11 timing signals which appear at the 11 pins one after the other. These pins on the i.c. are connected to points D1 to D11 on the keyboard diagram (Fig. 4). The calculator i.c. is also connected to the points KN, KO, KP and KQ. Let us assume that the ÷ button is pressed. During timing signals on D1 and D2 there will be no output from the various K outputs to the i.c. but during the time a signal is present on D3 there will be an output on KO. When there is an output at KO during this time the i.c. interprets it as an instruction to divide. In a like manner, when any button is pressed the i.c. can determine which one it is.

The calculator i.c. has an input sensing programme which provides protection against transient noise, double entry (two buttons pressed at the same time) and switch bounce.

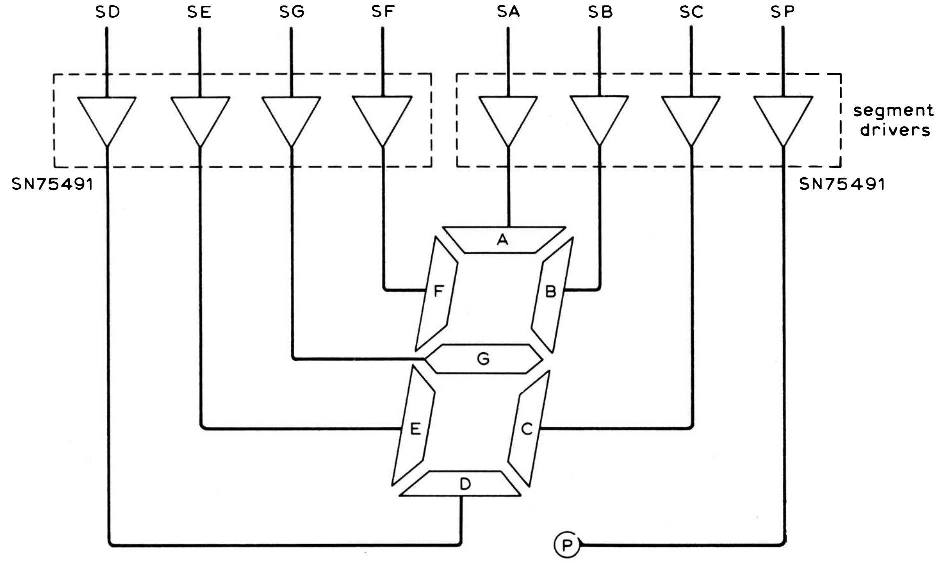


Fig. 5. Layout of the light-emitting diodes in one indicator. The segment lettering A, B, etc., corresponds to the calculator i.c. outputs SA, SB, etc.

While the calculator is switched on but is not being used, the calculator i.c. goes into an "idle" routine. It sequentially scans the KO and KN lines, "looking" for a non-quiescent condition. When such a condition is detected the i.c. waits 6.8ms and goes into a routine called TPOS which again scans the input to determine if the signal was the result of a keystroke or was just transient noise. If the latter was the case the i.c. reverts to the idle condition.

If the TPOS routine proves a keyboard entry the i.c. responds accordingly and performs the task demanded of it. The i.c. then enters a programme called TNEG, which scans the keyboard looking for a non-quiescent condition; if this test is successful the i.c. returns to the idle condition.

If the TPOS routine discovers a KN input the programme jumps to the 'NBR' (number) routine and the data are entered into the random access memory. If a KO input had been detected the programme would have jumped to 'OPN' (operation) and the calculator would have executed the instruction. Keys must be pressed or broken for a minimum of 25ms.

Display decoding and driving

The result of calculations is presented on gallium arsenide seven-segment indicators

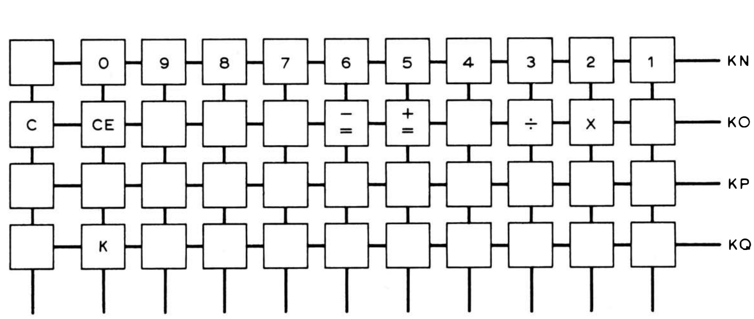


Fig. 4. The keyboard matrix. Timing signals from the calculator i.c. are fed to the matrix at D1 to D11. The calculator i.c. scans the K outputs and can determine which key has been pressed because each key will provide an output for a unique combination of timing signal and K output.

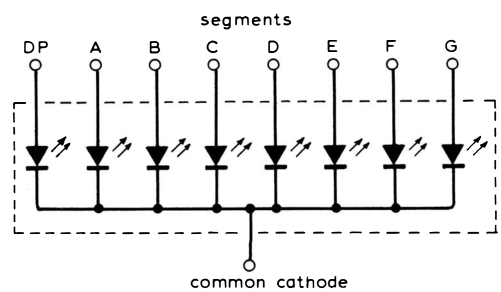


Fig. 6. The circuit of one of the gallium arsenide indicators showing how the eight light-emitting diodes are connected.

of the form shown in Fig. 5. Each segment (numbered A to G) and the decimal point (P) is formed by a light-emitting diode. All eight diodes are mounted on a substrate and are connected as shown in Fig. 6. In the calculator the display packages measure about 6.9mm high by about 5.6mm wide with a digit height of 3mm. The displays are magnified to provide a final digit height of approximately 5mm.

The calculator chip has eight outputs, each output intended to illuminate one of the light-emitting diodes so as to form a complete figure as shown in Fig. 7. The letters SA to SG and SP represent the outputs of the calculator i.c. and SA is the output which drives segment A (as defined in Fig. 5) in an indicator and SB drives segment B, and so on. Fig. 7 serves two functions. It shows which segments have to be illuminated to form the various numerals and symbols, and it also shows which outputs from the calculator i.c. are needed (indicated by the thin bars) to form those numerals and symbols.

There are 9 indicators (8 for numerals plus an indicator for symbols), each containing 8 light-emitting diodes, and yet there are only eight outputs from the calculator chip. One would have thought that, as each indicator requires 8 inputs, one would need 8×9 outputs from the calculator chip. However, if one thinks about it, 72 output leads from one i.c. would not be practical.

What happens in the calculator is this. Each indicator is selected in turn and the calculator provides the correct combination of output signals necessary to drive that particular indicator. Therefore only one indicator is illuminated at a time. However, the circuitry switches from one indicator to the next so quickly that to the eye all the indicators appear to be illuminated continuously.

It was mentioned earlier that the calculator i.c. could not supply enough power to drive the indicators directly. Integrated driver amplifiers are therefore used to interface the calculator i.c. with the indicators. These same drivers also allow the indicators to be switched on and off sequentially, or to be time multiplexed as the technique is known. We still need a means of knowing when to switch a particular indicator on and still need some sort of control signal to do it. In the calculator the timing signals on D1 to D11, which were used to scan the keyboard, are employed to select the correct indicator as well, as shown in Fig. 8. Notice that D9 and D10 are not used.

Two kinds of indicator driver are used. One type, known as digit drivers, are used to select the individual indicators and are therefore driven by the timing signals on D1 to D11. The second type, segment drivers, are connected between the SA to SG and SP outputs of the calculator and the individual indicator segments.

All the drivers are housed in four dual-in-line bipolar integrated circuits. The segment drivers employ two type SN75491 i.cs, each i.c. containing four Darlington circuits cap-

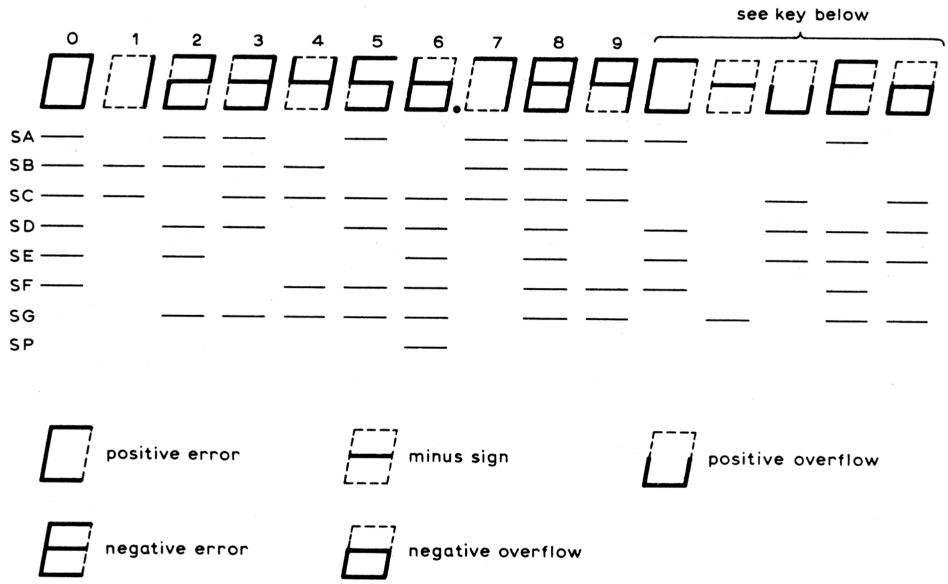


Fig. 7. The display font and how the various numerals and symbols are made up from the light-emitting segments. The bars opposite the letters SA, SB, etc., represent outputs from the calculator chip. The symbols appear only in the ninth, extreme left-hand, indicator of the calculator and inform the user of several fault conditions and also give the sign of the indicated result.

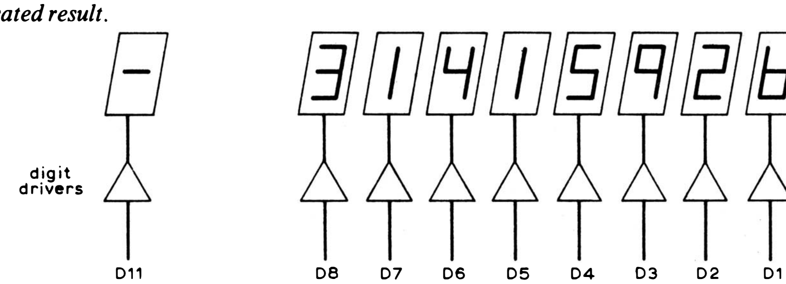


Fig. 8. How the timing signals that were used to scan the keyboard also feed the digit driver amplifiers so that only one digit at a time is illuminated. Timing signals D9 and D10 are not used for display purposes.

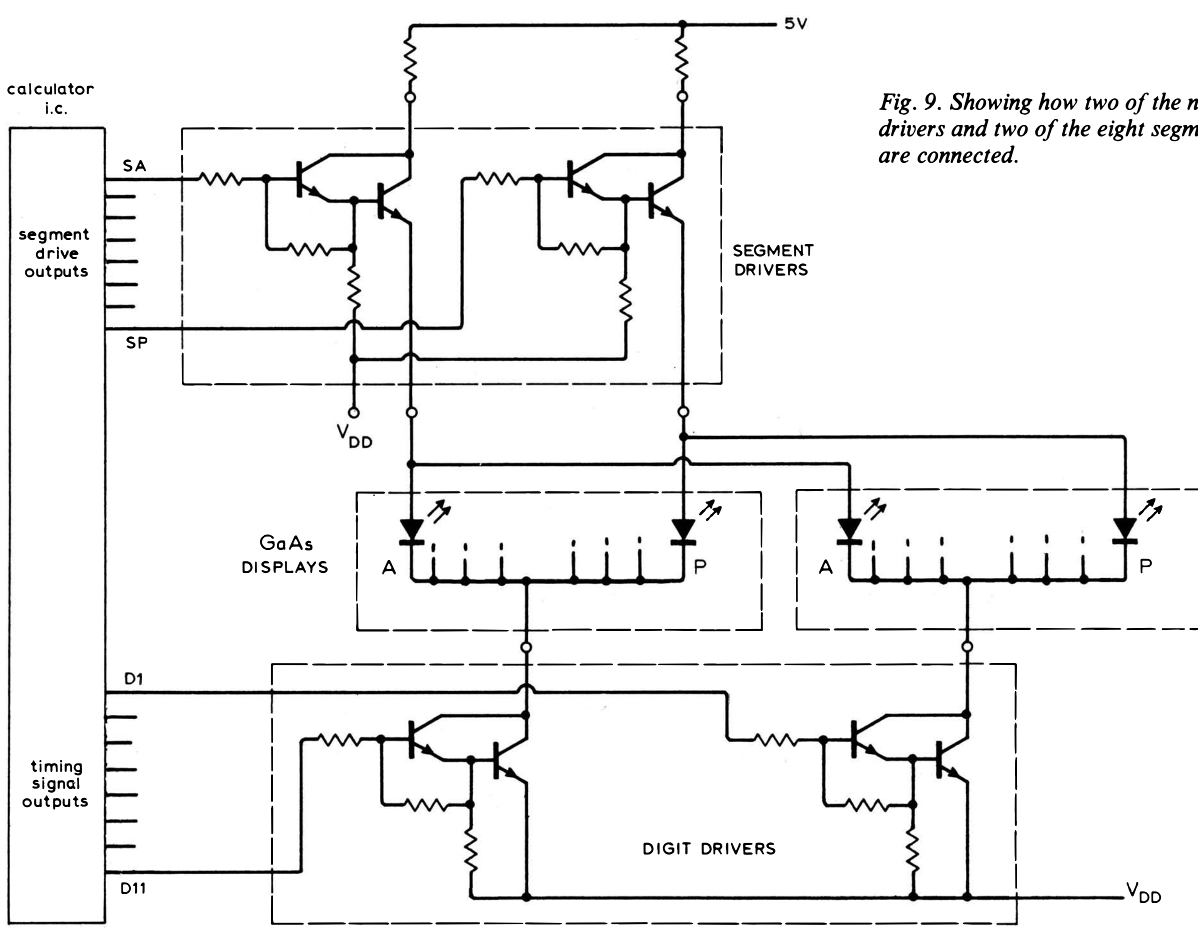


Fig. 9. Showing how two of the nine digit drivers and two of the eight segment drivers are connected.

able of switching 40mA with a maximum 800mV drop across them. These take care of the seven segments and the decimal point. The digit drivers employ two type SN75492 i.cs, each i.c. containing six Darlington circuits capable of switching 320mA with a maximum 900mV drop across them. There are 12 digit drivers in the two packages and, as we require only nine, three are left spare.

Fig. 9 shows the circuit for two of the eight light-emitting diodes in two of the nine indicators. The indicator on the left-hand side of the calculator display is the one which is used for symbols as it is driven by the D11 timing pulse. The right hand digit is the least significant and is driven by the timing pulse on D1. In Fig. 9 the segments are A; the decimal point shown being driven by SA and SP.

Clock generator

The clock generator needed to drive the calculator i.c. is a hybrid thick film integrated circuit, which makes for easy construction and reliability; it measures only 25×12×3.5mm. The internal circuit of the i.c. is given in Fig. 10; operating frequency is 250kHz.

Power supplies

The circuit of the power supply is given in Fig. 11. Two bridge rectifiers connected to two separate secondary windings on the mains transformer provide the inputs to two voltage stabilizer integrated circuits. The output of the 15V regulator has a zener diode and a 220Ω resistor in series across its output to provide outputs of plus and minus 7.5V relative to the zero line for the calculator i.c. The second stabilizer provides a +5V output. Both the stabilizers exhibit excellent transient response.

If one of the transformer secondaries is short circuited the fuse in the primary circuit will blow. This is to ensure that the calculator will meet the British Standard Specification for office equipment which requires that the transformer should not reach more than 100°C when the secondary is short-circuited. The two 1.8nF capacitors and the two coils L_1 in the transformer primary circuit protect the calculator from pulse interference in the mains. The coils consist of four turns each on the same toroid core.

The two transformer primaries are connected in series for 240V operation and in parallel for 110V operation. The fuse size is 50mA for 240V and 100mA for 110V supplies.

The power supply has a much higher capacity than needed for this particular calculator because it was designed as a standard sub-assembly for a range of machines.

Because of the extensive use of integrated circuits construction of the calculator is a simple matter.

Full constructional details will be given in the concluding part of this article next month which will also describe operating procedures with worked examples.

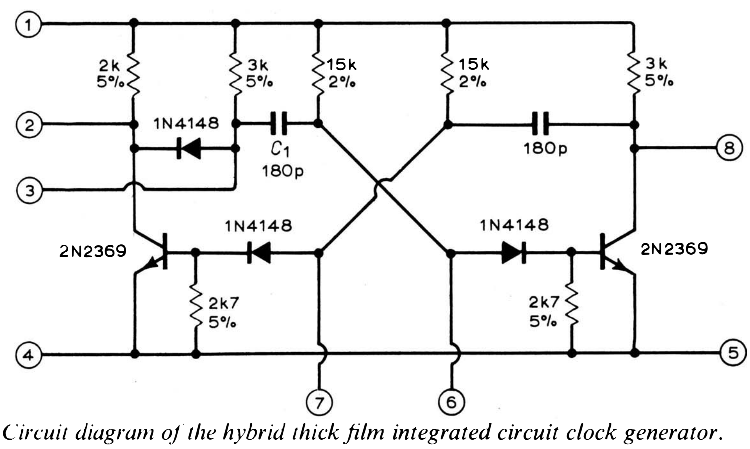


Fig. 10. Circuit diagram of the hybrid thick film integrated circuit clock generator.

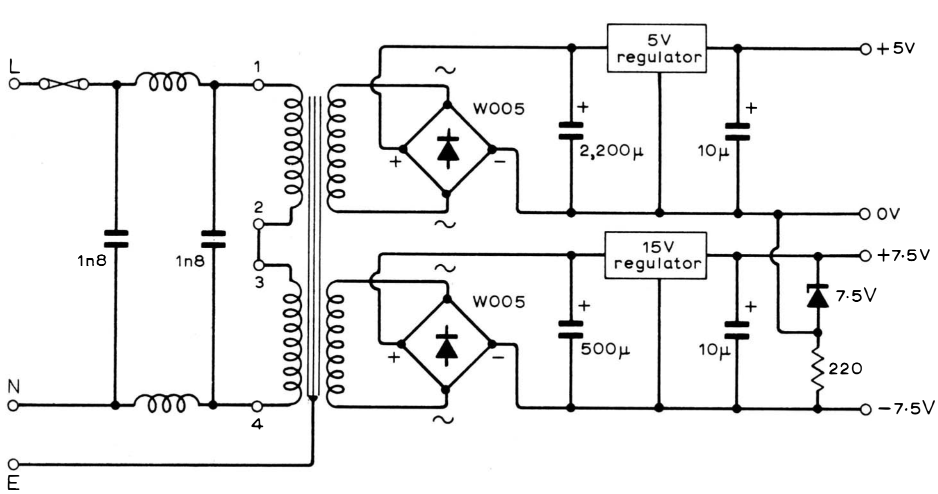


Fig. 11. Power supply circuit diagram.

The Wireless World Desk Calculator

Part 2: Construction and operation

by Roger Alexander and Brian Crank†*

Most of the constructional articles in *Wireless World* leave room for the reader to exercise his own expertise and imagination. We would not normally give detailed instructions unless there was some aspect which was particularly critical from the electrical performance point of view. With this desk calculator the situation is somewhat different. A kit of parts, complete to the last detail, is available and the object of this articles is to explain how the kit should be assembled. Each and every part in the kit has only one correct place in the finished calculator, therefore this article must of necessity comprise a very detailed list of instructions.

At the end of the article operating instructions are included in the form of worked examples, including a few typical electronics calculations.

The kit for the *Wireless World* Desk Calculator can be obtained from Advance Electronics Ltd, Calculator Division, Raynham Road, Bishop's Stortford, Herts, price £39.25 plus 75p postage & packing. Send a crossed cheque, postal or money order for the full amount with your order. The kit is supplied packed in polystyrene mouldings with all the individual components neatly laid out in a polystyrene tray. An internal view of the calculator giving the positions of the majority of components is shown in Fig. 12 and the finished machine in Fig. 13.

Points to watch

The two large expanded polystyrene mouldings and the cardboard box in which the kit is packed should not be discarded as they are designed to protect the completed calculator during storage or in the post should there be any need to return the calculator for servicing.§

There are two very critical aspects of the construction, one of which must be understood by the constructor *before the kit is unpacked.* It will be noticed that the calculator integrated circuit (TMS1802NC) is

*Advance Electronics.

†Formerly deputy editor *Wireless World*, now with T. J. Burton Associates.

§The calculator kit is fully guaranteed against defective parts. If inspection reveals faulty components, they should be returned to Advance Electronics with the appropriate description and part numbers and they will be replaced under the guarantee. If the completed calculator should fail to function properly and attempts to find and cure the trouble prove ineffective, then the instrument may be returned to Advance for repair. A small service charge will be made where the defect is not covered by the terms of the guarantee included in each kit.

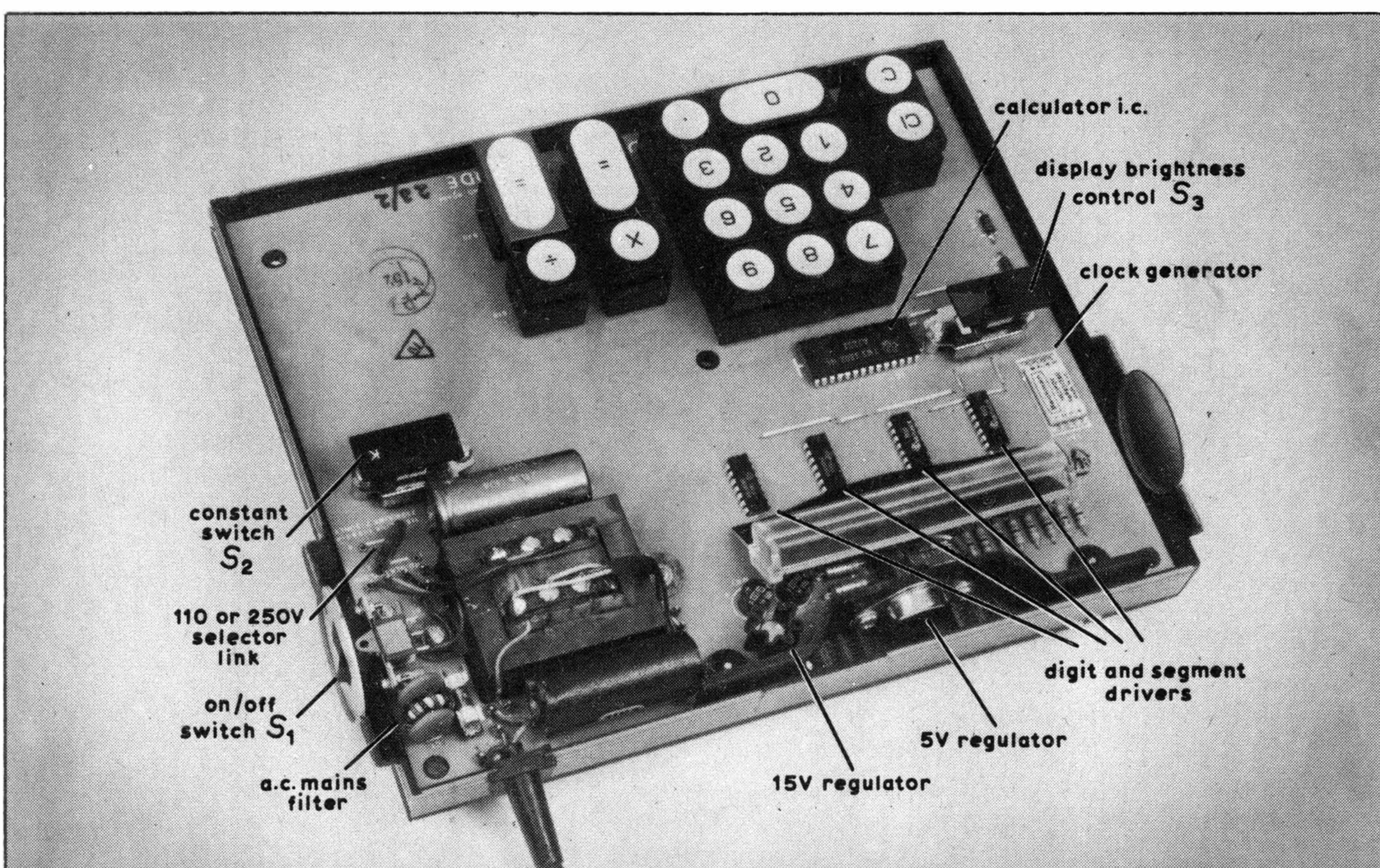


Fig. 12. Internal view of the calculator.

supplied with its leads embedded in what looks like ordinary black plastic foam material. The foam is in fact impregnated with a highly conductive material which short circuits all the leads during transport and handling. The reason for this is obvious when one considers the construction of the m.o.s. transistors in the i.c. The gate electrode of each m.o.s.f.e.t. is formed from a small metalized area insulated from the silicon chip by a very thin layer of silicon oxide. The impedance of the gates is extremely high and it is very easy to connect to the gate leadout wires a source of high voltage sufficient to puncture the oxide layer and destroy the i.c. Such voltage sources include static charges on nylon clothing or even bodily static charges. Anyone who has lived with a nylon carpet will know that such bodily static charges can be considerable, especially when one touches an earthed object or some object at a lower potential. Other sources of destructive high voltage can arise from capacitive coupling to the mains or, most important, unearthed soldering irons. Any attempt to solder the TMS1802NC calculator i.c. into the printed circuit board with an unearthed soldering iron will result in the instant destruction of the i.c. The TMS1802NC is by far the most expensive single item in the kit and to ensure it is not damaged the following precautions must be observed:

- Do not remove the black foam until the i.c. is to be soldered into the circuit board.
- Before removing the i.c. from the foam touch some earthed object to discharge any personal static charges.
- Grip the plastic package between the thumb and forefinger without touching the leadout wires.
- Only use a soldering iron of the highest quality which is connected to a *reliable* earth.

We apologize to readers with experience in handling m.o.s. l.s.i.cs for labouring these points, but, as such devices may not be commonly used by some constructors, they will be the first to realize the importance of strictly adhering to the rules above.

The second critical point concerns the l.e.d. numerical displays. There are nine display packages which have to be mounted side-by-side on a small printed circuit board which plugs into the main mother board. Each package measures about 6.9 by 5.6 mm and has nine leadout wires. This means that 81 soldered joints have to be made in a space 55 × 13mm (2.2 × 0.52 inches). This requires a steady hand and a soldering iron with a bit diameter not greater than 1 or 2mm; if it has a chisel head so much the better. This should not present a problem as a larger bit can be turned down to the correct diameter in an electric drill and finally shaped with a file.

There are two other requirements for the soldering iron: it must have a fairly long bit if some of the wires are to be connected without melting the insulation on others and it must be of low wattage to prevent damage to the very narrow tracks on the circuit boards. About 15W is ideal.

If you are in any doubt at all about your soldering iron, buy a new one as it will cost you less than £2.

All components, including the i.cs, should be mounted as tightly to the board as possible if the proper performance is to be achieved. It is a good plan *not to* bend component leads over by 90° on the soldering side of the printed circuit board as this is not necessary for good connection and makes component removal very difficult during servicing or during the correction of mistakes.

Access to the individual components packed inside the two case halves is by removing the single screw at the centre of the base of the bottom half of the case.

In the detailed instructions which follow open parentheses ( ) have been placed before each item for the constructor to tick as each task is completed as an *aide mémoire*.

Assembly

Upper case half (Fig. 14)

( ) Remove the five strips of self-adhesive packing foam fitted inside the upper half of the case and discard.

( ) Place a piece of gauze over the slots on the inside at the rear of the case and fix in position by *lightly* touching it at about 50mm (2in) intervals with the tip of a soldering iron. The idea is to melt a small portion of the plastics case just below the gauze so that the gauze is held in position

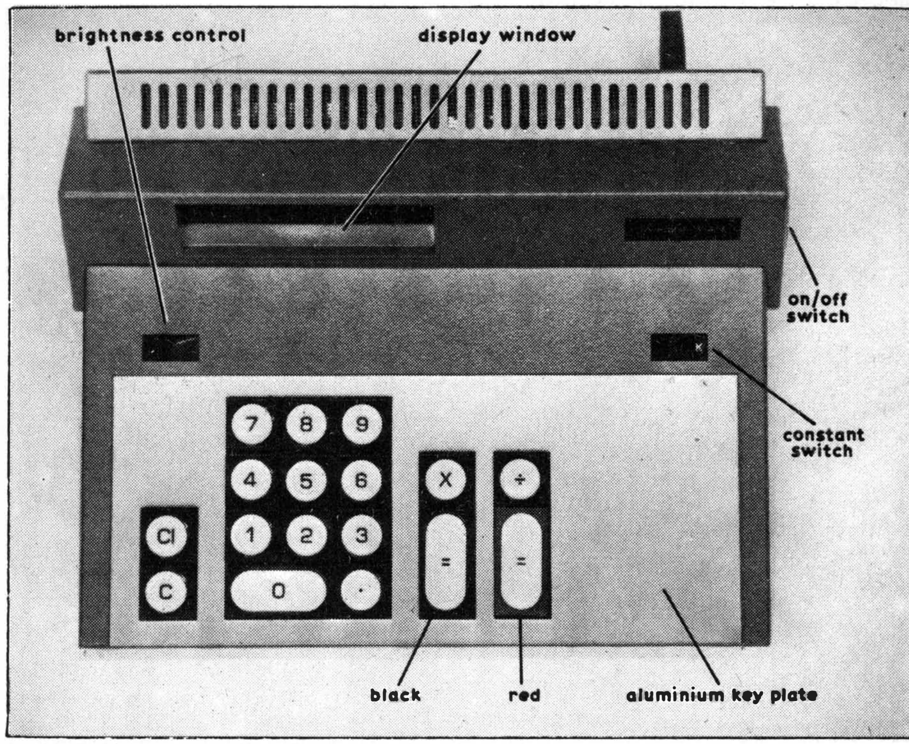


Fig. 13. The completed calculator showing the positions of the various keys and switches.

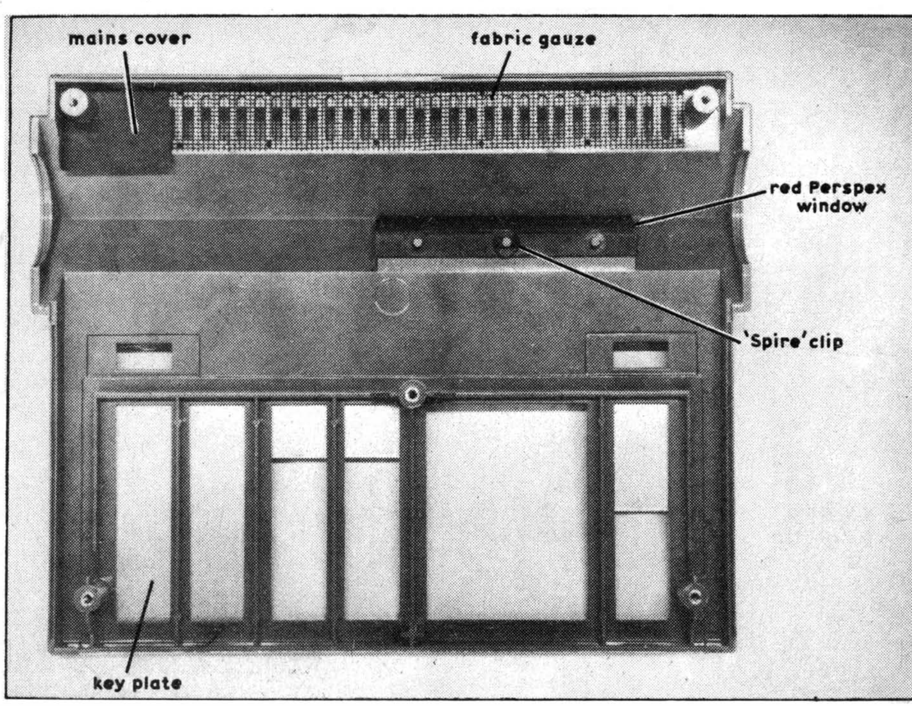


Fig. 14. Upper case half. The mains cover is not fitted until a late stage in the assembly procedure.

when the plastic sets. The emphasis is on the word lightly.

( ) Push the red Perspex window on to the three lugs and retain in position with a Spire clip on the centre lug. The concave side of the clip should face downwards.

( ) Remove the backing paper from the self-adhesive label 'Wireless World' and place in position in the indentation on the right-hand side of the case front (Fig. 13).

( ) Remove the backing paper from the large aluminium self-adhesive key plate and fit into position on the top of the case half. The best way to do this is to hold the plate at an angle of about 45° relative to the top of the case, locate the rear edge of the plate into the groove, and then bring the plate down into position. Press the plate down firmly to ensure good adhesion. *The plate has a thin protective layer of plastic; do not remove this until construction is completed.*

Lower case half (Fig. 15)

( ) Fix a piece of gauze over the slots on the inside of the case half in the same manner as before. This time remove a small piece of gauze from around the bulge in the case.

( ) Attach the self-adhesive serial number label to the indentation on the underside of the case half.

( ) Attach the self-adhesive lower plate (a piece of angle aluminium) to the case without removing the protective film.

( ) Push the two small rubber feet into the slots underneath the case with a small screwdriver.

5V regulator and heat sink sub-assembly (Fig. 16)

( ) Referring to Fig. 16 fit the 5V regulator (L005) to the heat sink (it will fit only one way) and bolt into position using two 6.32, 9.5mm ($\frac{3}{8}$in) long screws, using a plain washer and nut on one side and a solder tag, wavy washer and nut on the other. With the heat sink in the position shown in Fig. 16 (mounting lugs downwards) the solder tag should be on the left hand screw.

( ) With the heat sink in the position described, solder a red wire to the top lead out, a black wire to the bottom lead out and a yellow wire to the solder tag.
(Please observe the colour coding as the task of the engineers at Advance Electronics will be made easier should your calculator ever need servicing).

( ) Insulate each connection with one of the small sleeves supplied (do not use the large sleeve).
Place the heat sink assembly on one side.

Mains switch sub-assembly (Fig. 17)

( ) Mount the switch to the bracket using two 8BA, 6mm ($\frac{1}{4}$in) long, screws using plain washers, shake proof washers and nuts. The photograph shows the exact method of assembly.

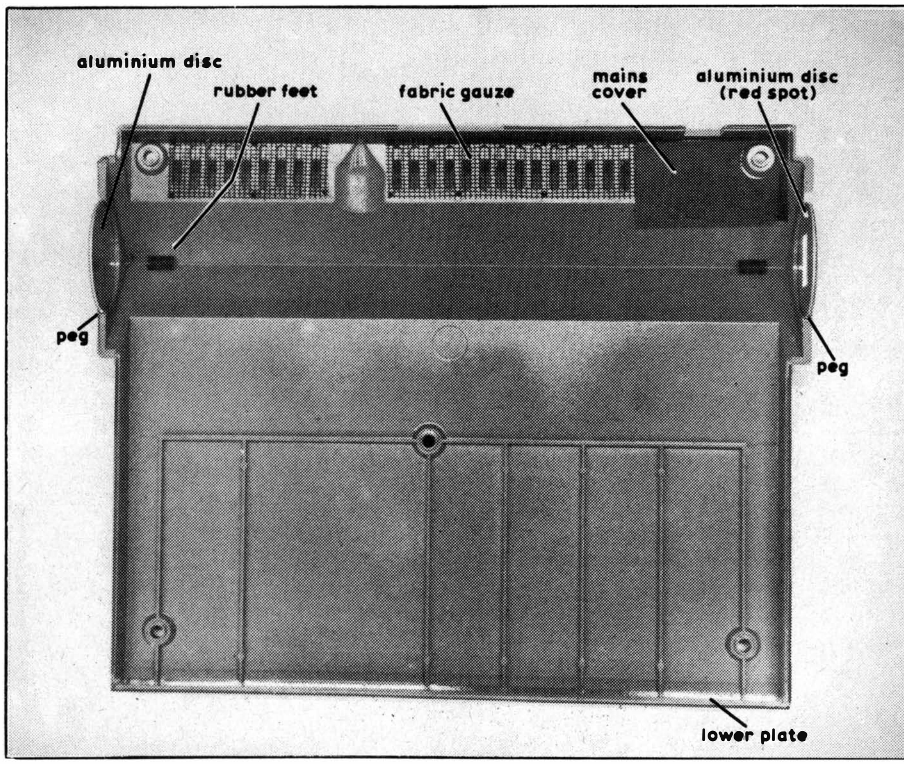
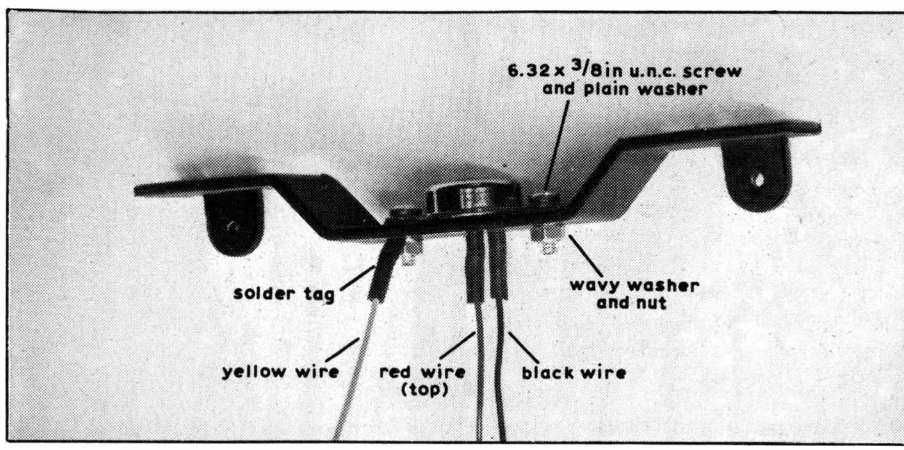


Fig. 15. Lower case half. Note the position of the cut-away in the gauze.



( ) Solder red wires to the terminals indicated in the photograph.
Place the assembly on one side.

Main circuit board (Fig. 18)

( ) Solder eight bare tinned copper wire links into position between holes connected by continuous white lines on the main circuit board (marked L on the photograph). *Do not solder links in the places marked '+ volts', '− volts' and '5 volts'.*

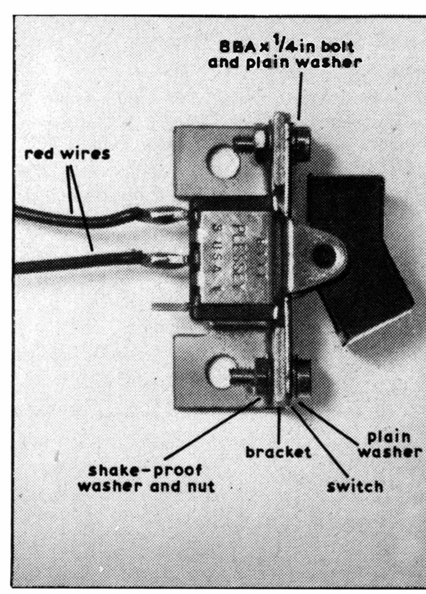
( ) Press fit the 21 miniature sockets into place and solder into position, making sure that the tops of the sockets are level with the top of the circuit board. Seventeen of the sockets (for the display sub-assembly) fit above the positions for the four d.i.l. i.cs. The remaining four are situated in the holes marked 1, 2, 3, and 4.

It will be found that all electronic component positions are marked with their reference number on the board.

( ) Fit resistor R_1, 220Ω, 0.5W.
Fit resistors R_2 to R_9, 47Ω, 0.25W.

Fig. 16. The 5V regulator and heat sink sub-assembly.

Fig. 17. Mains switch sub-assembly.



( ) Fit capacitors C_5 and C_6 (10μF, 16V). The printed circuit board has white lines to show the components' positions; the bisecting line indicates the positive end. The black line round the capacitor is the *negative* connection. The positive connection is at the end nearest R_9.

( ) Fit diodes. D_1 7.5V zener
D_2, D_3, IN4001
The white band indicates the positive end.

( ) Fit bridge rectifiers MR_1 and MR_2 (type W005). The '+' mark on the rectifier's body must line up with the '+' mark on the circuit board. (Ensure that the bridges are pushed down flush with the board.)

( ) Fit the 15V regulator IC_1 (TBA 625C). The pip on the TO-5 case must line up with the marking on the board. Make sure the bottom of the can is flat on the board.

( ) Press fit corrugated heat sink on to IC_1.

( ) Fit fuse holder into the two large holes to the left of the mounting position for C_1 and C_2.

( ) Cut, strip and tin the four wires from the toroidal coil L_1. The red wires go to the holes marked 'R' and black wires to the holes marked 'B'. The coil is mounted so that it stands upright and is flush to the board.

( ) Fit capacitors C_1 and C_2 (1.8nF marked 1800p) either side of L_1. Together C_1, C_2 and L_1 form a mains pulse interference suppressor.

( ) Fit the hybrid integrated circuit clock generator in the white package (9698 21280) so that pin 1 corresponds to the 1 marked on the board.

( ) Fit IC_3 and IC_4 (SN75491N) so that the 'horse shoe' indentation corresponds to the horse shoe marking on the board.

( ) Fit IC_5 and IC_6 (SN75492N). Each package has a horse shoe indentation which must be lined up with the board marking.

( ) Fit capacitors C_3 (2,200μF) and C_4 (1,500μF); the '+' marking on the components lining up with the '+' markings on the board.

( ) Fit the display brightness control switch S_3 (three-position slide) in the following manner: Push a 14mm ($\frac{9}{16}$in) 4.40 u.n.c. (unified coarse thread) screw through the circuit board from underneath and place a pillar, the switch and a wavy 4.40 washer on the screw in that order. Loosely secure with a nut. Repeat the procedure for the other switch mounting hole. Tighten up screws and then (*and only then*) solder the switch connections to the board.

( ) Fit S_2 (two-position slide) to the board in the same manner as S_3.

( ) Remove the tops of all the key switches by giving them a slight pull.
It will be noticed that the base of the key switches is formed from two snap-together parts which contain the magnet and reed switch assembly. These two parts of the switch are matched and must not be interchanged.
The shot-moulded key tops (with the numbers, letters etc,) are fully interchangeable.

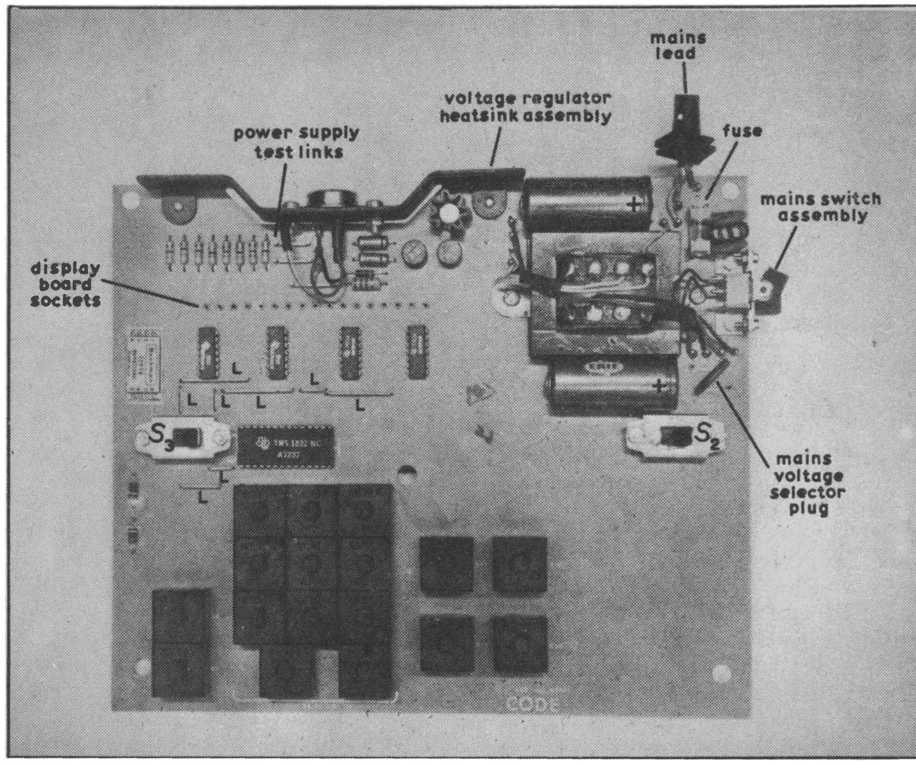


Fig. 18. Main printed circuit board showing the position of all components.

( ) Fit all the key-switch bases to the board (they will only go in one way) and carefully align them both horizontally and vertically before soldering. Pieces of card and elastic bands may be of help here. Solder the switches in position.

If any switches have become misaligned melt the solder for that switch and 'juggle' it into position.

( ) Strip and tin the three wires from the 5V regulator and heat sink assembly and solder them to the circuit board pins as follows:
Red to pin B
Black to pin E
Yellow to pin C

( ) Identify the two 'Tapex' self tapping screws (when viewed from the thread end they have a very slightly triangular cross section). The screws are 4.40 u.n.c. and are 6mm ($\frac{1}{4}$in) long. Use these screws to secure the heat sink assembly to the main circuit board.

( ) Lay the mains transformer (T_1) in the oblong cut-out in the printed circuit board with the white wire to the rear. Bolt the transformer in position using two 6.32 u.n.c. 8mm ($\frac{5}{16}$in) long screws, 6.32 wavy washers and nuts. The nuts and washers should be on the underside of the board.

( ) Cut the remaining large sleeve in two. Place one half over the blue and yellow wires and the other half over the red, black, orange and brown wires. These sleeves are to keep the wires neatly in a bundle and are not for insulating purposes.

( ) Solder the transformer lead-out wires to the marked circuit board pins as follows (all the wires are tinned and are already cut to the correct length):

blue wires,	one to each pin BL
yellow wires,	one to each pin YW
red wire	to RD
black wire	to BLK
orange wire	to ORG
brown wire	to BRN
white wire	to W

( ) Bolt mains switch to board using two 4.40 u.n.c., 6mm ($\frac{1}{4}$in) long, screws, 4.40 wavy washers and nuts. Refer to Fig. 18. The nuts and washers should be on the underside of the board.

( ) Solder the two red wires from the mains switch assembly to the two pins marked $S1$ (one wire to each pin!).

( ) Read the warning notes at the beginning of this article regarding the calculator i.c. TMS1802NC.

( ) Fit IC_7 (TMS1802NC) to the printed circuit board after removing the conductive foam. If the i.c. has a horse shoe marking the device must be fitted so that this marking corresponds with the horse shoe marking on the board. That is, nearest to the switch S_3. The i.c. may, however, have a dot on the package indicating pin 1. If this is the case the package must be fitted with the end with the dot nearest to S_3.

If the pins on the i.c. do not line up with the holes in the circuit board bend the pins by pressing them on a flat, insulating, surface. Remember not to touch the pins with the fingers.

( ) Solder the mains lead to the main circuit board pins as follows (the leads are tinned and have already been cut to the correct length):

green/yellow to pin E
brown to pin L
blue to pin N

This completes the main circuit board assembly.

Display printed circuit board assembly (Fig. 19)

The display board involves some fairly intricate soldering. The constructor must therefore have a suitable soldering iron and should preferably be working in a quiet environment to assist concentration.

The display printed circuit board is double sided and has plated through holes. It comes equipped with 17 mounted pins which have been accurately set at 45° and spaced to match the 17 sockets in the main circuit board. The alignment of these pins should not be disturbed.

( ) Solder the mounted pins to the printed circuit track on side A of the display board taking great care to prevent solder running down the pins. If this happens the solder will have to be removed before the display board will plug into the main circuit board.

( ) Insert one indicator into position LD9 on side B of the board ensuring that the type number on the package is facing in the direction indicated on the board. All the pins on the packages are accurately preformed and the package should be pushed down as far as the bends on the leads. Hold the digit in place while turning the board over. *Solder the middle pin only.* The middle pin has only a copper pad to solder to but as the hole is plated through solder will flow down into the hole and around the lead.

If necessary the solder connection should be re-heated whilst gently manipulating the indicator until the package reaches its final position. (Hard down against the bends in the leads and square).

( ) This procedure is repeated for the other eight digits (LD8 to LD1) ensuring that the indicators are inserted with the type number in the right direction and that only the middle pin on each package is soldered, making sure that all the packages finally sit at the same height. This can be achieved by very carefully melting the solder round the centre pin (taking care not to overheat) and manipulating each individual indicator. All the indicators should be true and square in all three planes.

( ) Cut all the indicator leads off so they stand about 1.5mm ($\frac{1}{16}$in) proud of side A of the board.

( ) Solder all the remaining connections, taking them a row at a time and taking care not to miss any. Soldering must be carried out only on side A of the board. The other holes in the board do not need soldering as they are plated through.

( ) Examine the display printed circuit board, with a magnifying glass if available, for conductors bridged with solder and missed connections.

Power supply test

WARNING: WHENEVER THE MACHINE IS CONNECTED TO THE MAINS CERTAIN COMPONENTS AND CERTAIN CONDUCTORS ON THE PRINTED CIRCUIT BOARD ARE AT MAINS VOLTAGE. CARELESS HANDLING COULD RESULT IN A FATAL ACCIDENT. TAKE CARE.

( ) Place the main circuit board assembly in the lower case half, locating the raised lugs in the holes in the circuit board.

( ) Fit red 'plug links' for the appropriate mains supply as indicated on the main circuit board and insert a 50mA fuse in the fuse holder.

( ) Connect a suitable mains plug to the mains lead in the usual manner:

brown – live
blue – neutral
yellow/green – earth

( ) Plug the calculator into the mains socket and switch on the calculator.

( ) Measure the voltages present at the pins marked '5 volts', '+ volts' and '– volts' nearest to C_5 and C_6. The results should be as follows (use the case of the TO-3, 5V regulator as common):

5 volt pin	$5V \pm 0.25V$
+ volt pin	$+7.5V \pm 1V$
– volt pin	$-7.5 \pm 1V$

( ) Switch off and remove mains plug.

( ) If the voltage measurements were within the prescribed limits one can proceed with the construction. If they were not, locate and cure the trouble *before proceeding any further.*

( ) Solder in place three bare tinned copper wire links marked '5 volts', '+ volts' and '– volts'.

( ) Remove the printed circuit board from the lower case half and place it on a raised flat surface clearing the mains transformer protrusion.

( ) Push the key switch tops into position referring to Fig. 13.

( ) Place the constant slide switch top (S_2) into position with the 'K' marking to the right.

( ) Place the display brightness switch top (S_3) into position with the red section to the right.

( ) Plug the display printed circuit board into the 17 sockets in the main circuit board. A considerable amount of force is necessary so one must be very careful if nothing is to be broken.
(If it is necessary to remove the display board at any time carefully lever it upwards using a large screwdriver, taking care not to distort the pins).

( ) Place the main circuit board back into the lower case half as before.

Functional test

( ) Replace the mains plug, switch on, place K switch to right, and perform the tests detailed in Table 2.

If the calculator does not operate correctly examine all connections, referring to the circuit diagram (Fig. 20) and the calculator description given in the first article. If you are still unable to trace the fault complete the assembly procedure and, after carefully packing the calculator, return it to Advance Electronics for servicing.

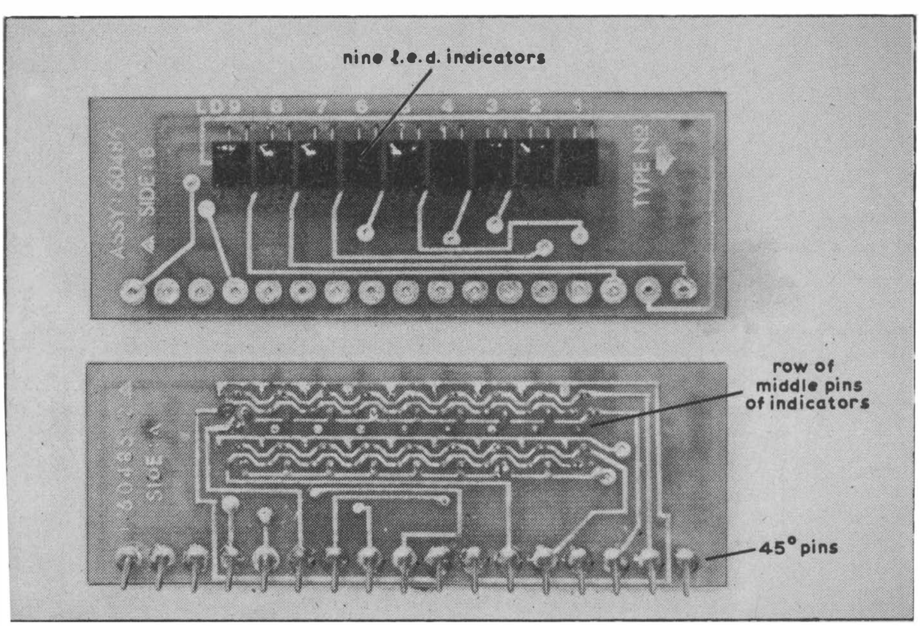


Fig. 19. Both sides of the indicator printed circuit board.

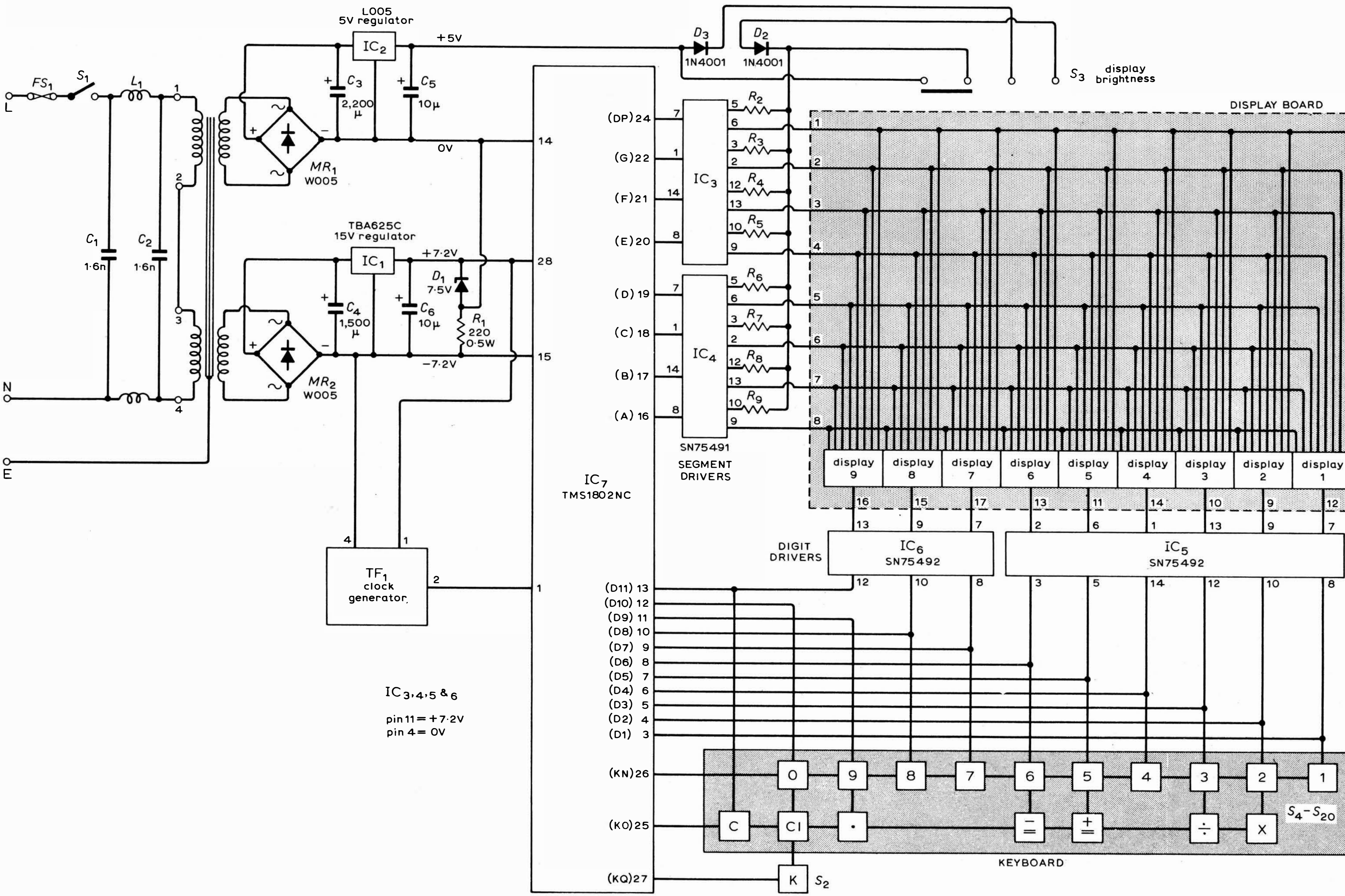


Fig. 20. Circuit diagram of the calculator.

Table 2

KEY OPERATION	DISPLAY READING
C	0.
1.2 3 4 5 6 7 9 0	C 1.2345679
Cl	0.
8 8 8 8 8 8 8 8	88888888.
X	88888888.
Black =	u 790 12344.
'K' switch to the far left (constant in)	
C	0.
.1 2 3 4 5 6 7	0. 1234567
X	0. 1234567
1	1
Black =	0. 1234567
÷	0. 1234567
.1 2 3 4 5 6 7	0. 1234567
Red =	– 1

Cl: Clears the last number entered (should an error have been made) and resets the display register to 0.
K: Enables the calculator to store the command to multiply or divide by a number which does not vary for a series of calculations.

It will be remembered (Part 1) that the extreme left-hand indicator is used to indicate if the displayed number is negative or if some abnormal condition exists within the calculator. The symbols and their meanings are repeated in Table 3.

When an entry overflow is indicated calculations can continue but the symbol will remain illuminated until the machine is cleared.

Table 3

C	entry overflow
u	answer overflow
–	negative number
6	entry overflow, answer overflow and negative number

Final assembly

( ) Cut the mains cover (a piece of black card with two holes punched in it) in the centre of the two fold lines and fit to the upper and lower case halves as shown in Figs. 14 and 15 after folding along the fold lines.

( ) Fit the circuit board into the lower case half ensuring that the lugs fit into the holes at the corners of the circuit board. It is best to align the left hand front hole first.

( ) Push the moulding on the mains lead firmly into the slot at the rear of the case.

( ) Fit the disc with the red dot into the groove at the right hand side of the case. The slot in the disc fits over the mains switch and the red dot should be towards the front of the case.

( ) Fit the second disc in its groove at the left hand side of the case (spun finish outwards) with the peg towards the front.

( ) Fit the display shield (a piece of black card with a slot cut in it) over the indicators so that it rests on the indicator leads.

( ) Slide the Perspex magnifier over the indicators, making sure that the printed circuit board and the display shield fit in the slots in the magnifier.

( ) Place the top half of the case in position ensuring that the end discs and the slide switch tops fit into their grooves and slots.

( ) Secure the two case halves together with five 6.32 u.n.c., 12mm ($\frac{1}{2}$in) long screws fitted from underneath.

( ) Remove the thin protective film of plastic from both the aluminium key plate and the lower aluminium plate.

The calculator is now complete and if it has been carefully constructed should have a long and trouble free life. Note that a dust cover is provided to protect the machine when it is not being used.

Operating the calculator

Entering a number into the calculator is simply a matter of pressing the appropriate keys, as was seen during the test procedure. For instance, to enter 15.36 one presses key 1, then key 5, then the decimal point key followed by keys 3 and 6.

The operations which the various keys perform are set out below. Some of the explanations may not be clear at this stage but they will be clarified during the practical examples.

×: Stores the command to multiply and executes a possible preceding instruction.
÷: Stores the command to divide and executes a possible preceding instruction.
= (black): Performs addition. Enters the last number keyed into the calculator (which is indicated on the display) and performs a possible preceding instruction.
= (red): Performs subtraction. Enters the last number keyed into the calculator (which is indicated on the display) as a negative number and performs a possible preceding instruction.
C: Resets the whole calculator to 0.

If the symbol appears which indicates that the result of a calculation has exceeded the capacity of the machine the answer will be correct to the eight most significant digits and the decimal point must be shifted eight places to the right to obtain the correct answer.

Some worked examples follow and it is recommended that the reader tries these to familiarize himself with the machine.

During the examples a colon (:) will be used to indicate that keystrokes have to be made.

The instruction 5.1: means press key 5 followed by the decimal point key followed by the 1 key, in other words, enter 5.1. In the same manner the following instructions are to be interpreted as follows: ×: press multiply key; ÷: press divide key; B=: press black equals key; R=: press red equals key; → K: slide constant switch to the right; ← K: constant switch to the left; and C: press clear key. The number which will appear on the display is printed in square brackets [4159659] whenever the indicated number is significant.

General arithmetic examples

Example a. 15.3+27.9
C: 15.3: B=: 27.9: B=: [43.2]

Example b. 14.8−4.12
C: 14.8: B=: 4.12: R=: [10.68]

Example c. 15−7+8
C: 15: B=: 7: R=: 8: B=: [16]

Example d. 1.3923905×400
C: 1.3923905: ×: 400: B=: [556.9562]

Example e. −3×8
C: 3: R=: ×: 8: B=: [−24]

Example f. $22 \div 7$
C: 22: ÷ : 7: B= : [3.1428571]

Example g. $5 \times (-7) \div (-3)$
C: 5: × : 7: R= : ÷ : 3: R= : [11.666666]

Example h. $\frac{4(5+7-3)}{2} - 3$

C: 5: B= : 7: B= : 3: R= : × : 4: ÷ : 2: B= : 3: R= : [15]

Example i. Convert 17.1, 19.5, and 23 inches to millimetres. There are 25.4mm to the inch.
C: ← K: 25.4: × :
The machine has now stored the instruction multiply by 25.4 in its constant register. Proceed as follows:

17.1: B= : [434.34] mm
19.5: B= : [495.3] mm
23: B= : [584.2] mm

Notice that there was no need to enter the instruction to multiply or 25.4 between each calculation, nor was there need to clear the machine.

Example j. Convert \$17.26, \$15.33 and 77c to pounds assuming that the exchange rate is \$2.55 to the pound.
C: ←K: 17.26: ÷ : 2.55: B= : [6.7686274] which would be rounded off to £6.77. The machine has now stored the instruction to ÷2.55. Proceed as follows

15.33: B= : [6.0117647] (£)
.77: B= : [0.3019607] (£)

Example k. $7^4 \times 3$
C: ← K: 7: × : 3: B= : B= : B= : B= : [7,203]

Example l. $46 \div 3^3$
C: ← K: 46: ÷ : 3: B= : B= : B= : [1.7037036]

Example m. Find $3^2, 3^3, 3^4, 3^5 \ldots 3^n$
C: ← K: 3: × : B= : [9] = 3^2
B= : [27] = 3^3
B= : [81] = 3^4
B= : [243] = 3^5 etc.

Make sure the constant switch is in the right hand position before the next example.

Example n. Find the reciprocal of 0.000081 (= 1/0.000081).
There are two ways of doing this.
C: 1: ÷ : 0.000081: B= : [12345.679]
If 0.000081 is the result of an earlier calculation and is already held in the machine it is inconvenient to use the technique above to find the reciprocal as it would be necessary to clear the calculator and enter 1÷ and the number.
The calculator holds 0.000081 as the result of a previous calculation (to simulate this enter 0.000081 followed by B= :). To find the reciprocal proceed as follows:
← K: ÷ : B= : [1] (indicated) → K: B= : [12345.679]
To prove the result repeat the operation
← K: ÷ : B= : → K: B= : [0.000081]
This technique can be used to great advantage as will be seen in later examples.

Example o. Find the square root of 35. The method uses the well known formula:

$$= \frac{1}{2}\left(\frac{x}{n} + n\right)$$

where n is an approximation and x is the number the square root of which is required. A mental approximation can be tried on the calculator and 5.9 seems reasonable
C: 5.9: × : B= : [34.81] = (5.9^2)
which is not far from 35.
To find $\sqrt{35}$ proceed as follows:
C: 5.9: B= : ← K: ÷ : B= : → K: 35: B= : 5.9: B= : ÷ : 2: B= : [5.9161015]
The result of this calculation (5.9161015) is used in place of 5.9 and the procedure is repeated. Because 5.9161015 is already in the machine the first three operations are omitted.
← K: ÷ : B= : → K: 35: B= : 5.9161015: B= : ÷ : 2: B= : [5.9160795]
The procedure is repeated with the new approximation:
← K: ÷ : B= : → K: 35: B= : 5.9160795: B= : ÷ : 2: B= : [5.9160795]
This is the same as the second approximation and the process is complete. To calculate the error, with the result still in the machine, all one need do is square 5.9160795:

× : B= : [34.999996]
R= : 35: B= : [0.000004]

which represents the error.
In general the iteration process is continued until the square root is correct to the required number of decimal places.

Some typical examples in electronics

Example p. Find the resistance R of a circuit consisting of 3.9kΩ in parallel with 5.6kΩ using the formula:

$$R = \frac{3.9 \times 5.6}{3.9 + 5.6} \times 10^3$$

This can be solved by calculating the denominator and using the constant register to store ÷(3.9+5.6) while 3.9 × 5.6 is being found:
C: 3.9: B= : 5.6: B= : ← K: ÷ : B= : → K: 3.9: × : 5.6: B= : × : 1000: B= : [2298.9472]Ω

Example q. A tuned circuit is required which will resonate at 10.7MHz; calculate suitable values of L and C using the formula:

$$10.7 = \frac{159}{\sqrt{LC}}$$

where L is in μH and C is in pF.
$\sqrt{LC} = 159/10.7$
C: 159: ÷ : 10.7: B= : [14.859813] (= $\sqrt{LC}$)

$$\sqrt{LC} = 14.859813$$
$$\therefore \quad LC = (14.859813)^2$$

(14.859813 is already in the calculator)

× : B= : [220.81404] (= LC)

If a value of 8μH is chosen for L:

$$C = 220.81404/8$$

(220.81404 is already in the calculator)
÷ : 8: B= : [27.601755]
$\therefore \quad C = 27\text{pF}, L = 8\mu\text{H}$.

As an exercise, to prove the calculation, proceed as follows: (we have already established 14.859813 as being $\sqrt{LC}$)
C: 27.601755: × : 8: ÷ : 14.859813: B= : ← K: ÷ : B= : → K: 159: B= : [10.7]

Example r. Assuming that the coil of the above example has a resistance of 5Ω calculate its dynamic resistance r_d using the formula:

$$r_d = (L/CR) \times 10^6$$

where L is in μH, R is in ohms and C is in pF

$$r_d = [8/(27 \times 5)] \times 10^6$$

C: 27: × : 5: B= : ← K: ÷ : B= : → K: 8: B= : × : 1000000: B= : [59,259.2]

$$r_d = 59{,}259.2\Omega$$

Examples. Find the Q of the coil in examples **q** and **r** using the formula:

$$Q = r_d/(2\pi f L)$$
f in MHz, L in μH

C: 2: × : 3.1416: × : 10.7: × : 8: B= : ← K: ÷ : B= : → K: 59259.2: B= : [110.17958]

$$Q = 110$$

Example t. The 3dB bandwidth of the tuned circuit (= f_0/Q) can be calculated as follows:
C: 10.7: × : 1000: ÷ : 110: B= : [97.272727]

3dB bandwidth = 97kHz

There are of course many other ways in which the calculator can be used but by now the reader should be able to discover them for himself.

V.H.F. Reception

Wireless World is collecting information for a survey on the reception of v.h.f./f.m. sound broadcasts and will be glad to hear of readers' experiences and opinions on this subject. The following topics would be of interest: design, performance and price of receivers; facilities on sets; dealers' experience in selling and installing sets; users' experience of buying sets and after-sales service; comparison of v.h.f./f.m. broadcast reception with that on medium and long waves; and interference effects from other stations (e.g. national vs. local), from man-made sources and natural sources.