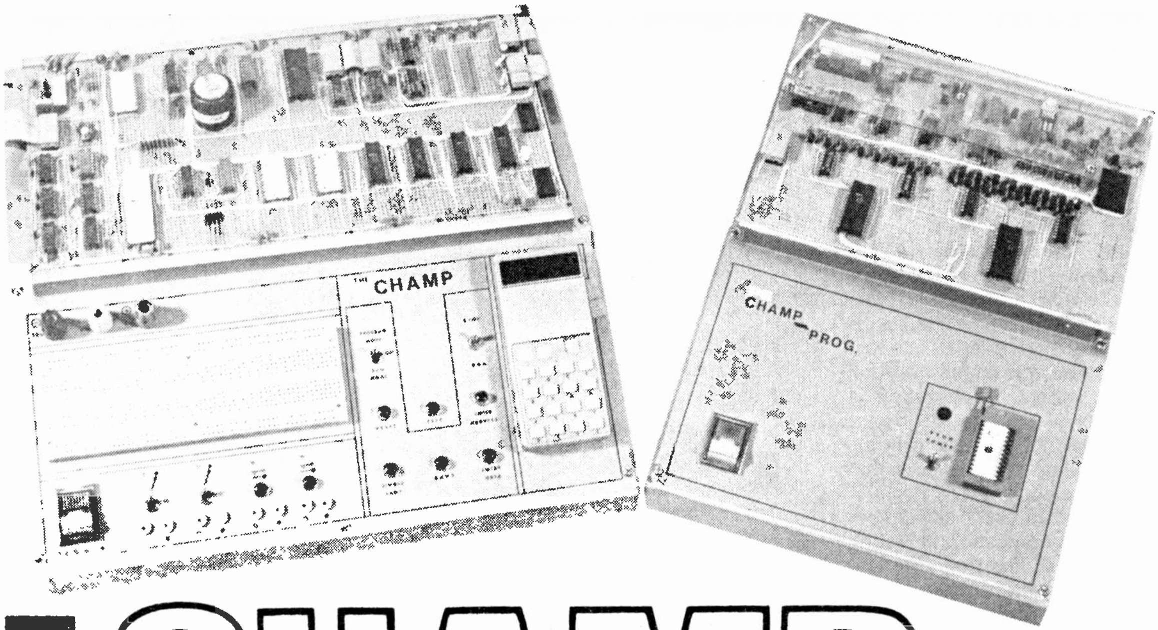

PE CHAMP PART FIVE

R. W. COLES
B. CULLEN

THE only language that CHAMP is programmed to understand is hexadecimal, and therefore to be able to talk to *it* a hexadecimal keyboard is required, and for it to talk *back*, a hexadecimal display is required. Hexadecimal is a base 16 number system which we human beings represent with 16 separate characters, namely 0 to 9 and A to F; and which CHAMP represents with a four bit binary word from 0000 to 1111 (0000 = 0, and 1111 = F). Every time we press a single key therefore, we enter a four bit word or "nibble" into CHAMP's internal registers, two presses being necessary to enter a single instruction word of eight bits, and three presses being necessary to enter a single address word of 12 bits.

The hexadecimal notation is useful because it enables us to enter data much quicker than would be possible with binary notation, and because codes for the various instructions in the 4040 instruction set are much easier to remember and use in this format. This makes program writing and debugging much simpler than would be possible if binary, or even octal were employed. The hexadecimal character set can also be represented on the cheap and freely available seven segment l.e.d. display devices, albeit in a stylised form.

CALCULATOR

As the basis of our hexadecimal keyboard/display unit we need 16 separate keys and several seven segment display digits, and of course, this combination is handily available in the form of any cheap four function calculator, making the use of such a unit the natural choice. The advantages of using a calculator rather than building from scratch are that firstly, all the case and hardware construction has been done already, and secondly, it is unlikely that you can buy a 16 digit keyboard and an eight digit display, with drivers, for the price! Cheap "throw away" calculators can now be found for less than five pounds, and there are numerous first generation machines no longer in use, and left lying around gathering dust. For CHAMP we chose to use one of the early Sinclair Cambridge machines which were produced in very large numbers, and the result was a very compact and economical keyboard/display unit at very low cost.

We realise that you may not be able to lay your hands on such a machine, and if this is the case it should be possible, using the design and notes presented in CHAMP-5, to adapt most cheap four function calculators to suit, or even to build from scratch if you prefer.

HOW THE DISPLAY WORKS

Referring back to Fig. 2.3, you will see that there are two 75491 i.c.s (top right,) and these drive the segments of the seven segment display in the calculator. The eight inputs for the 75491 (seven segments plus decimal point) are provided by the 4265 programmable I/O chip which uses ports X and Y for this purpose. The CHAMP display is an eight digit unit and is of course driven in multiplex fashion, and this requires an additional eight control lines to select the currently active digit.

Rather than produce these digit strobes on the CHAMP board itself, a shift register controlled by only two wires from CHAMP, is used instead. The shift register, along with other circuitry, is situated inside the calculator case.

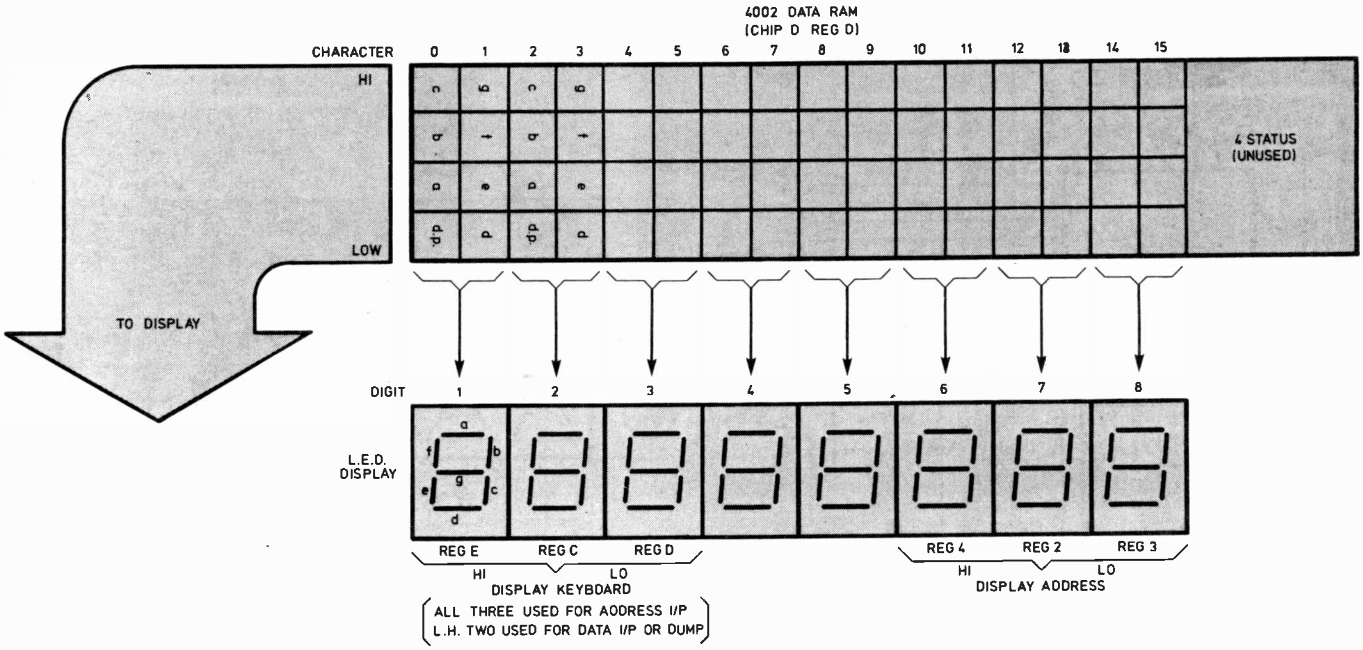

Fig. 5.1. Method of driving the display direct from RAM. A "replica" of the energised segments is stored, so that no decoding i.c.s. are necessary. Logic 1 in 4002 = Lo'. Logic 1 on 4265 o/p = Hi' = segment "on"

The CHOMP display/driver software loads a single logic 1 into the shift register, and then clocks it along to enable each digit in turn. When the logic 1 "drops off the end" of the shift register it is replaced, at the correct time, by a new one at the data input to the register.

The display driver software is responsible for making sure that the correct segment information is presented to the display at the correct digit time. It achieves this by keeping a replica code for the required display in the 4002 data RAM; reading out the data for each segment in turn to the 4265, and then going back to do it again when digit eight has been displayed, and a fresh logic 1 has been presented to the register.

The display replica is held in 4002 chip zero, register zero, where the available 16 four bit characters are used in pairs to hold the complete eight digit by eight segment display readout. This can be seen more clearly by referring to Fig. 5.1, which shows how the RAM characters map onto the display digits. Notice that the replica is already in seven segment code when stored in the RAM by CHOMP. Because the replica is not in binary, no external decoder chips are necessary to drive the display. The decoding is executed using software by means of a "look-up" table, and this will be examined in detail next month.

One advantage of driving the display in this fashion is that user programmes can drive the segments in any way they please. For example, as decimal digits only, as a full alphabet of characters (which can just about be done with some improvisation), or simply as a "0" and "1" binary display.

When CHOMP is running, only six of the possible eight display digits are used, the left-most three being used for address or data entries and dumps, and the three right-most digits being used to show the current value of the address pointer maintained by CHOMP. User programmes can of course employ all eight digits, and there is no need to write any display driver software because the CHOMP subroutine DDRV handles all eight digits, and can be called by a user programme when required.

HOW THE KEYBOARD WORKS

By using a four bit output port, a four bit input port, and some software, the 4040 chip can easily encode and debounce a 16 key keyboard, and even has a special instruction, KBP (keyboard process), available to make the job simple. Despite this, CHAMP does not use software for this purpose, and uses instead a hardware keyboard encoder and debounce circuit; so perhaps a word of explanation is called for. During the CHAMP design process it was realised that the addition of software for keyboard purposes would make the use of *two* 4702A chips necessary to house CHAMP, and for economy reasons this was not desirable. In addition, the two four bit ports required would not be available on the 4265 and so some extra port hardware would be necessary, which could either be an extra 4265 or some TTL to do the same job. These two things together made the apparently simple software solution untenable in this *particular* case, and this constitutes, we think, an interesting example of the hardware/software trade off which is necessary in any microprocessor system design.

The hardware encoder/debouncer is in fact quite simple, and requires just four TTL packages, three of which are housed in the calculator case itself. Two 74148 eight input priority encoders with their active-low outputs NORed together by a 7400 gate provide the 16 key to four bit binary encoding function, and the debouncing is achieved with the aid of a 74123 dual monostable.

KEYBOARD/DISPLAY CIRCUIT

Figure 5.2 shows the internal circuitry of the keyboard and display and also covers the interface of this unit to the CHAMP main board. This circuit is intended for direct use by those who have a Sinclair Cambridge calculator of the correct type, but can also be used by those with a similar calculator, and by those who intend to build a unit from scratch. All that is in fact required from the calculator is the eight digit seven segment display

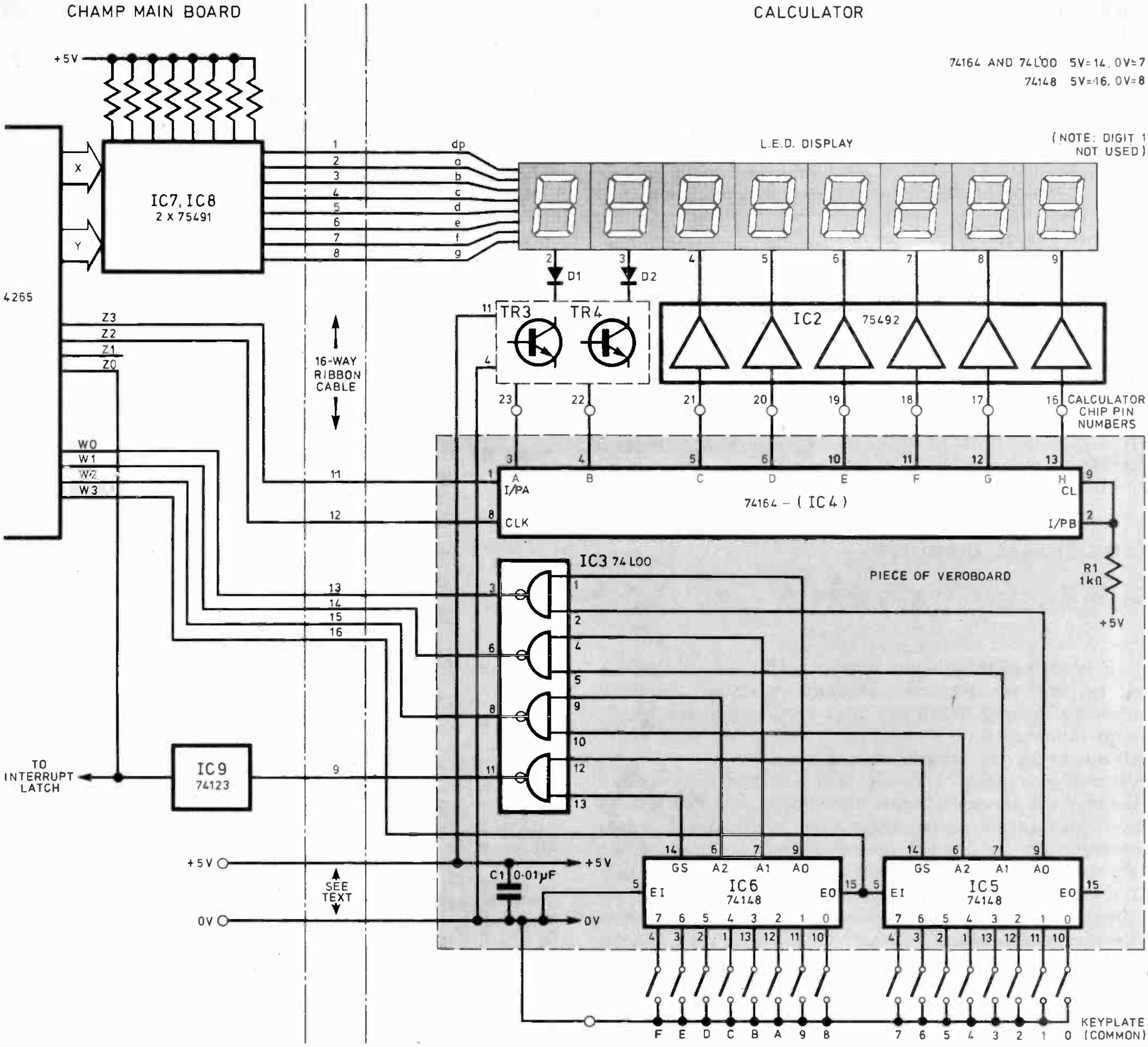

Fig. 5.2. Complete keyboard/display system showing the interconnections to CHAMP board. The shaded area shows which components are mounted on the Veroboard within the calculator case

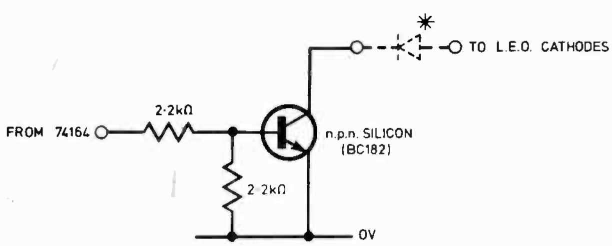

Fig. 5.2a. Driver circuitry for 0·125 inch l.e.d. display digits. The diode (1N4148) is only required when some of the cathodes are driven by a 75492 i.c.

unit (which must be a small common cathode l.e.d. unit), the digit drive circuitry (which may be discrete transistors or a 75492 chip), and the keyboard array itself (which must be capable of being rewired as 16 single keys with one common connection). The calculator MOS chip and all other circuitry is not required and can be removed. Some more recent calculator designs drive the digit lines directly from the LSI chip without separate digit drivers, and if you have one of these, then the required drivers can be added by using either a pair of 75492s or eight silicon n.p.n. transistor stages of the type shown in Fig. 5.2a. Anyone building from scratch (why not build it on the breadboard?) can use the Fig. 5.2a driver circuitry, and must add their own l.e.d. display. In this case it is important *not* to use the 0·3in or 0·6in type of discrete l.e.d. because these have a voltage drop which is "too high for comfort" on the 5V supply scheme employed here. *Only small 0·125in common cathode arrays are suitable.*

Those using other calculators, or building from scratch, may also find it necessary to alter the value of the current limiting resistors R51 to R58 on the main board to achieve a satisfactory display intensity.

ADDITIONAL CIRCUITRY

Returning to Fig. 5.2, display, drivers, and keyboard components can be identified which form part of the original calculator, and also the additional components which must be mounted inside the calculator case.

Four integrated circuits are added to the calculator, as we shall see later, and these are mounted on a small piece of Veroboard which may be housed in the battery compartment of the Sinclair Cambridge. The digit drive shift register is formed by IC4, with its A data input driven by output Z3 of the 4265, and its clock input driven by output Z2, under the control of the CHOMP software. The eight outputs of the 74164, are the digit strobes and are applied to the display via digit drivers which in the case of the Sinclair unit, are already available on the calculator p.c.b. The 75492 driver has only six stages, and to make this up to eight, Sinclair have added two discrete transistor stages, but this poses a small problem when working from 5V supplies because the difference in voltage drops between the two types of driver causes a difference in l.e.d. digit brightness. This was easily cured in our keyboard unit by adding silicon diodes in series with the *discrete* driver outputs. Anyone who used all 75492 drivers, or all transistor drivers, should of course omit these diodes.

Integrated circuits IC3, IC5 and IC6 form the keyboard encoder, where IC5 and IC6 are 74148 eight input priority encoders, which give a three bit binary output code corresponding to the active input line with the highest numerical weighting. To get a full 16 line encoder, two 74148 devices are cascaded using the OUTPUT ENABLE and INPUT ENABLE facility provided on these chips. Chip IC3 provides the final three low order BCD bits and the common "group strobe" which is present when any key is pressed, the high order BCD bit being taken directly from the ENABLE output of the 8 to F encoder. This encoder scheme is simple and very effective, having the advantage of requiring a very simple switching array of 16 s.p.s.t. keys with one side of all of these wired common to 0V. This overcomes a major obstacle when using a cheap calculator keyboard, because almost any design can be rewired into this configuration from the "row and column" matrix usually employed. The type of matrix used in a calculator design varies a great deal, but a little careful thought should be enough to enable a CHAMP builder to adapt any design to suit this simple new requirement.

As you can see, a total of 17 connections are required between the keyboard unit and the CHAMP main board, which poses a bit of a problem because 16-way sockets have been chosen as Standard. The solution was to carry the 15 logic signals using the standard 16-way ribbon cable connection system, and to add two extra wires for the 0V and +5V power supply to the keyboard. As you can see in the photographs, these two extra wires were the two "outers" of an 18-way ribbon cable connection, and were terminated at the CHAMP end by means of sleeved Soldercon pins which can be pushed on to terminal pins adjacent to SK3 on the main board. This arrangement has worked well in practice, and allows the keyboard to be disconnected easily when required.

KEYBOARD CONSTRUCTION

From now on, we will be considering the keyboard design used with the CHAMP prototype, and this means that details which follow relate *only* to a particular version of the Sinclair Cambridge which uses the Texas Instruments' TMS0801 calculator chip. This type of Cambridge can be recognised by the fact that it has a CE button between the C button and the ON/OFF switch, whereas some others have a K button.

Start by dismantling the case. This is achieved by locating a screwdriver in the slot around the side of the case and twisting. The buttons and keyplates are held in position by means of a plastics retaining frame which has three studs protruding through the circuit board which are welded on the component side. Lay the calculator circuit board face down on a flat surface and snip the welded studs away, then lift the circuit board off and you should be left with the key buttons and their retaining frame. The stainless steel keyplate will be left attached to the circuit board by means of the ON/OFF switch, and this should be removed, together with its thin plastics insulating spacer. Put these parts aside for later use. If you have any trouble with this part of the modification, refer to Fig. 5.3.

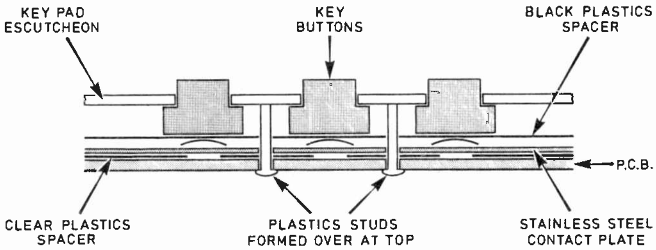

Fig. 5.3. A guide to the basic construction of the Sinclair 0801 keyboard assembly

COMPONENT REMOVAL

Using Fig. 5.4, identify and remove the following unwanted components:

C1, C2, C3, C4.
D1, D2, D3, D4.
R1, R2, R3, R4, R6.
TR1, TR2.
L1.
IC1.

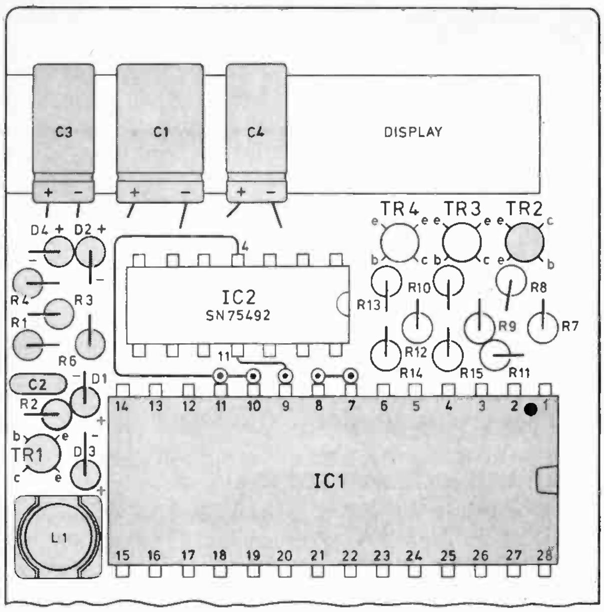

Fig. 5.4. Component layout of the Sinclair calculator. The shaded components should be removed (see text)

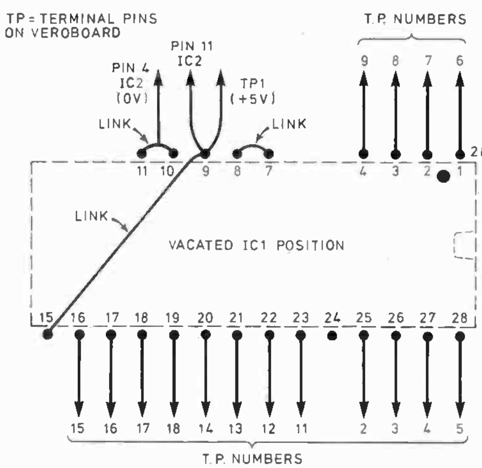

Fig. 5.5. After the calculator chip (IC1) has been removed from the Cambridge, terminal pins should be inserted through the lead holes. The vacated i.c. pad can then be wired as shown in the diagram

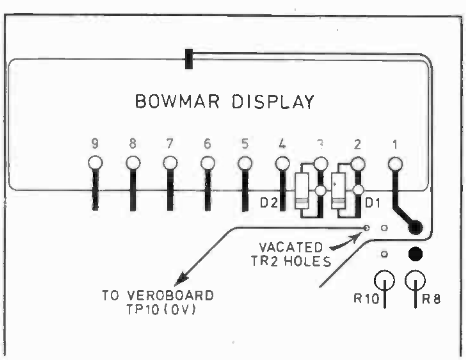

Fig. 5.6. Modifications to be made around the calculator display

The removal of IC1 in particular should be carried out with great care, since the board is double sided and uses plated-through holes. A "Solder Sucker" or de-solder braid *must* be used.

With IC1 removed, refer to Fig. 5.5, insert the terminal pins and make the links (except those to PL1 and the Veroboard) as indicated.

Using Fig. 5.6, identify the Bowmar l.e.d. display and then, working from left to right, break the tracks connecting display digits 2 and 3 to the circuit board proper, and bridge the gaps with two IN4148 Silicon diodes as shown. Next, add a flying lead from the hole location shown, to act as a 0V connection to the Veroboard, to be added later. Using Fig. 5.7, which shows the component side of the calculator circuit board, make the 16 track breaks required with a sharp modelling knife or similar implement, and be sure to get rid of any swarf which may cause shorts later. The flying leads from individual keypads can now be added, and these should be of Kynar wire (or similar) left long at first, and trimmed to size when the Veroboard is added. To avoid disaster, these wires should be soldered very carefully to *avoid solder running through the plated hole to the keyplate side* where it will cause trouble.

THE VEROBOARD

The Veroboard layout is shown in Fig. 5.8, and this board can now be cut to size and assembled in the usual way. Soldercon pins were used for all four i.c.s in the prototype although this is not essential. Make sure that all track breaks, terminal pins, wire and fixing holes are correctly located, and then wire up the board with the fine wire in accordance with Fig. 5.2. Notice that PL1 does not mate with a socket, but is soldered directly to the board.

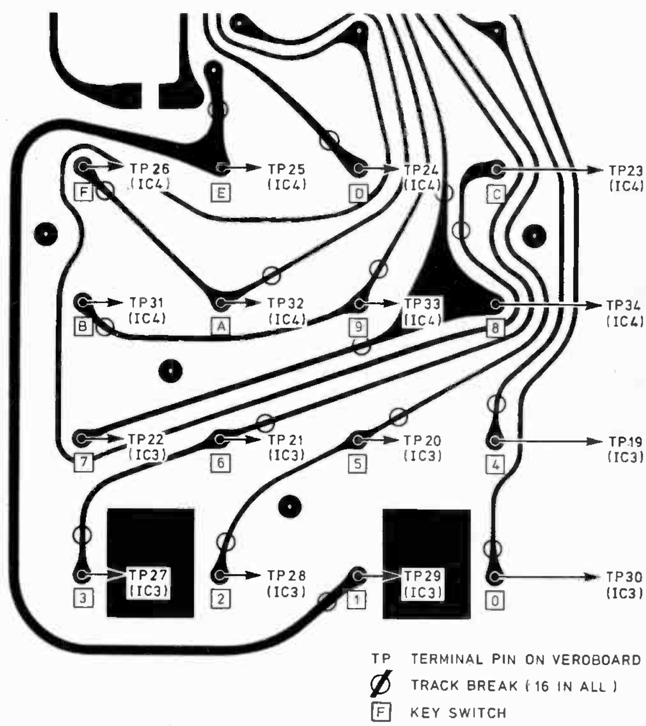

Fig. 5.7. Proprietary p.c.b. inside the Sinclair Cambridge, showing the keyboard end where track cuts are necessary

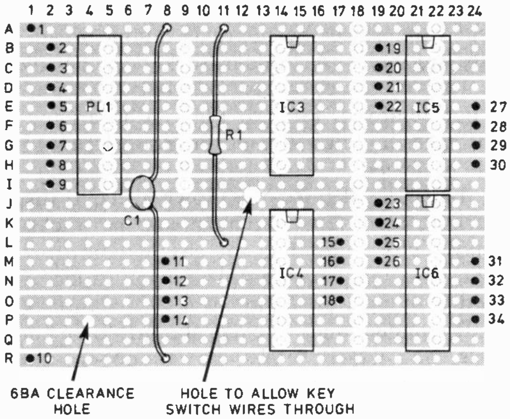

Fig. 5.8. Component layout for Veroboard to be mounted inside the calculator case

Terminal pins could be used for this termination instead of the 16-way plug, but in this case some kind of "strain relief" should be provided for the loom to prevent wires breaking during everyday use of the keyboard.

Using the circuit diagrams the Veroboard can now be connected up to the rest of the calculator circuitry. This involves:

16 connections to keypads
17 connections to IC1 (now removed)
one connection to the hole left by the emitter of TR2 (now removed).

KEYBOARD ASSEMBLY

In the prototype, the Veroboard was attached to the calculator p.c.b. by means of a countersunk 6BA screw, which made it necessary to drill and countersink a hole in the main circuit board. This had the advantage of easy dismantling should it be required, and the addition of two insulating strips act as spacers. Perhaps a better solution would be the use of double sided sticky pads.

Reassembly of the calculator can be achieved fairly easily by reversing the dismantling procedure, the separate parts of the keyboard assembly being adequately retained by the case when it is snapped together.

POINTS ARISING

BURGLAR ALARM *(May 1977)*

Constructors may find that in the GUARD condition, sufficient current can leak through LP1 and LP2 to energise WD1, (see Fig. 1). This can be overcome either by replacing these bulbs with l.e.d.s (in series with 560Ω resistors), or placing a OA47 diode in series with LP2 *only*, wired in forward bias.

In order that the TAMPER SWITCH (S3) will operate at *any* time, it should be wired between points "12" and "1" via a 330Ω resistor, and *not* points "12" and "11" as shown in Fig. 1.

FREQUENCY COUNTER/TIMER *(September 1977)*

Some readers have found that the crystal XL1, in Fig. 4, does not control the oscillator frequency as it should do. Anyone experiencing this difficulty should try reducing the value of C6 to around 330pF.

COMPONENTS...

KEYBOARD/DISPLAY UNIT

Resistors
1 off 1kΩ R1

Capacitors
1 off 0·01μF ceramic C1

Semiconductors

2 off 1N4148	D1, D2
1 off 74L00	IC3
1 off 74164	IC4
2 off 74148	IC5, IC6

Miscellaneous
Sinclair Cambridge calculator (type using TMS 0801 chip)
Stripboard, 0·1 inch matrix
Terminal pins
16-way d.i.l. plug (PL1) and ribbon cable
Kynar, or similar wire

CONSTRUCTOR'S NOTE

The keyboard/display unit, as with other system parts extraneous to the CHAMP board, can be linked using ribbon cable and d.i.l. plugs and sockets. The sockets are readily available, but the plugs may be obtained from: **P.S.P. Electronics, 228 Preston Road, Wembley, Middlesex, HA9 8PB.** The plugs are made by T & B Ansley, part No. 609-M165 (16-way).

TESTING

The keyboard encoder can be checked in isolation by wiring four l.e.d. lamps with 1kΩ resistors in series to pins 13, 14, 15 and 16 of the 16-way d.i.l. plug on the end of the flat cable. The anodes of the l.e.d.s should be connected to +5V, and the supplies should be connected to the keyboard as if for normal use. Pressing any key should generate the correct binary code on the four l.e.d.s, though in inverted form (light off equals logic 1). The strobe output on pin 9 should always be generated regardless of which key is pressed, and this can be checked with a fifth l.e.d. or by means of a voltmeter. Checking the display is more difficult, although if trouble is experienced, ohmmeter checks between the segment drive lines and the outputs of the digit drives can be carried out as a starting point.

WIDE USE

The CHAMP keyboard/display described this month is by no means dedicated only to the CHAMP system, and could, if required, be interfaced to almost any microprocessor system where its ready encoded keyboard output and flexible display format would be an advantage.

NEXT MONTH: CHOMP Firmware