Servicing Sinclair Microcomputers

Part 1

Ken Taylor

Mike Phelan's series "The Lid off Microcomputers" last year evoked considerable interest among readers. It's clear that many of you are keen to get to grips with these devices which seem to be taking over the electronics world. They come in quite a lot of different types and forms. The single-chip types used in VCRs, washing machines and cars are special-purpose devices: they are not ideal subjects for an initial assault even if the wife would let you at them. So forget these and Head Office's IBM main-frame computer. In this series we're going to deal with some of Sir Clive's products, which happen to be among the cheapest, simplest and most abundant to have been put on the market. They have the added advantage that spares are readily available, which must appeal to anyone used to the problems of the TV servicing trade.

Servicing Equipment

One of the first thoughts that will probably cross your mind is the cost of the servicing equipment required. Perhaps, like me, you've wandered round the exhibitions looking at £2,000 plus scopes and sneaking envious glances at the logic analysers – "no self-respecting computer repair organisation should be without one". I often wonder whether I'd have the time to learn how to use one of these even if I could afford it. But fear not. The most I recommend, in addition to the usual TV servicing equipment (scope, multimeter, bench PSU etc.), is a logic probe. Even this could be made from one of the many circuits that have been published if you wish to keep the initial expenditure down.

In some ways a logic probe duplicates a scope, which can be used instead. It's very much quicker and easier however to use a device with an in-built indicator when checking for pulses along the pins of an i.c.: you don't have to look up and check each response on the scope. The signals you'll be looking at are generally TTL ones (0-5V), so if you use a scope for the purpose its sensitivity need be no greater than that required for TV work, though the essential high-impedance probe does reduce the signal a bit. The crystal oscillator used in a microcomputer often runs at about 14MHz, i.e. rather higher than the basic frequencies encountered in a TV set, but there's rarely need to study waveforms at this frequency and the more critical system clock frequency is in the 2-4MHz range.

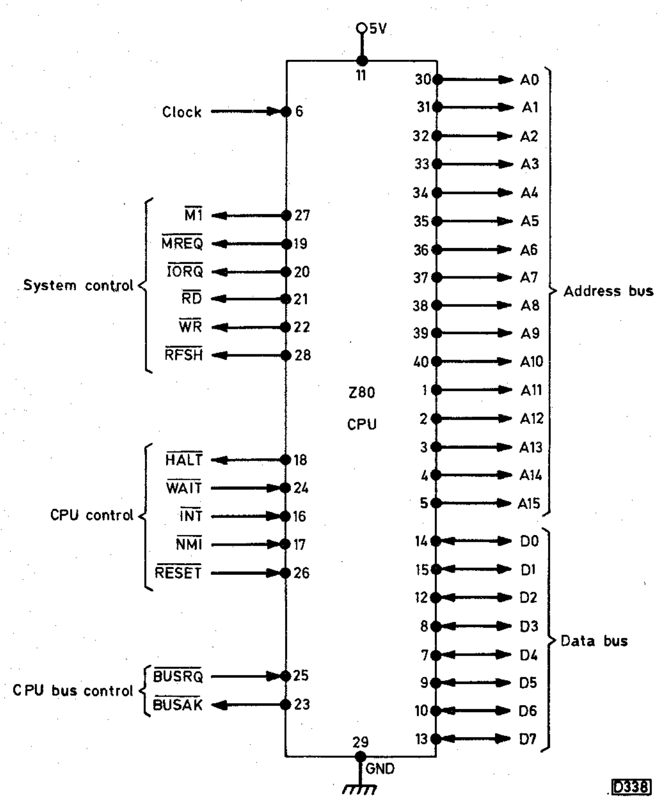


Fig. 1: Z80 CPU (microprocessor) pin connections.

The Central Processing Unit

The system clock frequency just mentioned depends on the type of central processing unit (CPU, i.e. microprocessor) used in the microcomputer. Sinclair use the Z80 family: the Z80 runs at a clock frequency of 2MHz, the Z80A at 4MHz and the Z80B at 8MHz. The Z80A, which is used in all the microcomputers we'll be considering, is housed in a 40-pin package – Fig. 1 shows the connections. Some of the names used may be new to you, so we'll briefly run through the pins and their functions.

Note that the address and data bus lines are the only "active high" ones: all the rest go low (to 0V) when operative and should thus be written as $\overline{\text{RESET}}$ for example (= not reset when high, i.e. 5V).

Designation	*Function*
5V, GND	Chip's 5V supply and chassis connections.
A0-A15	Address bus outputs which are tri-state, active high; i.e. either high (active) = 5V, low = 0V, or open-circuit (high impedance) – this latter state allows other devices to control the line without loading problems. A0 is the least significant bit. These 16 lines can address 64K binary addresses (65,536 in decimal as 1K = 1,024 decimal, i.e. 64 × 1,024).
D0-D7	Data bus lines (in/out), again tri-state, active high. D0 is the least significant bit. These eight lines carry the data to and from the CPU. They represent 1 byte in binary (256 decimal).

The CPU generates signals on the following six lines to inform and control the other devices in the system. When the lines carry signals from the rest of the system the CPU output is tri-state.

$\overline{\text{M1}}$	Machine cycle one, active low. Used by the CPU to signal that a particular loading cycle is being carried out.
$\overline{\text{MREQ}}$	Memory request, active low, tri-state. Indicates that the address bus holds a valid

address for a memory read or write operation.

$\overline{\text{IORQ}}$ Input/output request, active low, tri-state. Indicates that the lower half of the address bus holds an address for use by an input/output device.

$\overline{\text{RD}}$ Memory read, active low, tri-state. Signals read to a memory or input/output device.

$\overline{\text{WR}}$ Memory write, active low, tri-state. Signals write to a memory or input/output device.

$\overline{\text{RFSH}}$ Refresh, active low. Indicates that memory refresh is taking place. Every address in a dynamic memory has to be refreshed at 2msec intervals. This line signals that a refresh is taking place. More on this when we come to memories.

The remaining lines are used by the system to initiate action or to indicate that action has been taken.

$\overline{\text{HALT}}$ Halt output, active low. CPU output signal indicating that it has obeyed a software halt instruction.

$\overline{\text{WAIT}}$ Wait input, active low. Allows external devices to halt the CPU. Must be of short duration because refresh is stopped.

$\overline{\text{NMI}}$ Non-maskable interrupt input, active low. Allows an external device to interrupt the CPU and make it carry out a special software program.

$\overline{\text{INT}}$ Interrupt request input, active low. Similar to $\overline{\text{NMI}}$ but disregarded when instructed by the program running.

$\overline{\text{RESET}}$ Reset input, active low. Resets the CPU to the start address (0000 Hex). Takes place automatically at switch on. Refresh stops and dynamic memory is cleared.

Clock System clock input. This signal controls the speed of the system and all the CPU's operations are synchronised to it. The frequency depends on the CPU but is usually 2-4MHz.

$\overline{\text{BUSRQ}}$ Bus request input, active low. This line is activated by an external device when it requires control of the system. The CPU outputs other than $\overline{\text{BUSAK}}$ go to the open-circuit state and refresh ceases.

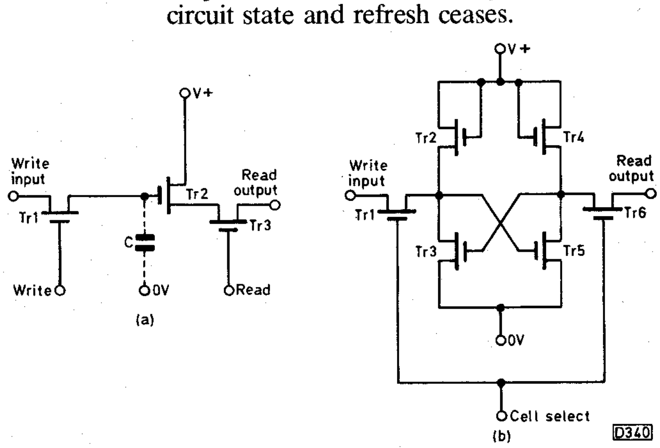


Fig. 2: Examples of basic MOS dynamic RAM (a) and static RAM (b) memory cells. In the DRAM cell the data bit is stored as an electrical charge by the capacitor shown as C – in practice this is Tr2's input capacitance. The SRAM cell uses a bistable circuit for storage (Tr3/5, with Tr2/4 as loads): the cell selection line enables data to be written in or read out. The DRAM memory cell is much simpler, giving greater storage per square area of silicon chip, but requires refreshing every 2msec.

$\overline{\text{BUSAK}}$ Bus acknowledge output, active low. Reply signal to $\overline{\text{BUSRQ}}$.

It's not necessary to worry too much about the precise function of each of the above lines: the important thing is whether a high, low or a dynamic signal is to be expected. For instance the $\overline{\text{RESET}}$ line has to be high (except at switch on) or the CPU ceases to function. Many other lines, particularly the address and data lines, are continually changing even when the computer is apparently doing nothing. At all times the refresh system is putting out addresses and indicating their presence via the $\overline{\text{RFSH}}$ line. Although this dynamic action is rarely cyclic and often produces a meaningless pattern on an oscilloscope we shall see later that it can be turned to advantage when fault finding.

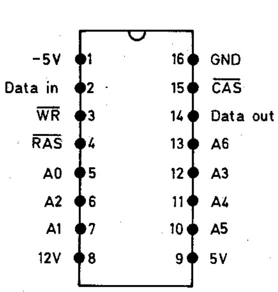
Programming Knowledge

After dismissing the need for a detailed knowledge of the operation of the CPU this is perhaps an appropriate time to stress the need for some knowledge of programming. Unlike other electronic systems the computer is controlled by the software program and the program resident in the ROM. To expect to be able to carry out fault diagnosis without an understanding of how to program the machine is naive, and a knowledge of how the system is designed and functions can be a great help. Most home computer handbooks give instructions on programming – usually in the "universal" BASIC (Beginners' All-purpose Symbolic Instruction Code) language. Unfortunately however there are different BASIC systems. Sinclair BASIC is one of the most way-out, and although devotees swear by it the differences between it and others are considerable. So too are the computer start-up sequences, and it's a great help if one knows what ought to happen when the machine is switched on. To sum up, I'd not advise anyone to attempt repairing a machine before obtaining practice and experience of its operation. More on this when we come to the ZX81 next month.

Memory Chips

While discussing the CPU we mentioned dynamic memories. We'd better next look at the memory family. As you probably know by now there are two basic types of memory, ROM (read only memory) and RAM (random access memory). The former are preprogrammed and non-volatile, i.e. they contain the manufacturer's program for operating the machine/system: this program is permanent and unchangeable. The memory in a RAM can be changed however and is used to store the data produced by the computer system. It's volatile in that all the data is lost if the supply voltage fails, but some RAMs are even more vulnerable. These are the dynamic memories (DRAMs) that require constant refreshing. With these each binary bit of every data word is stored as an electrical charge at the input of a high input-impedance transistor. This charge leaks away in about 2msec. So each bit – and there may be as many as 64K bits – has to be recharged every 2msec. A daunting task you may think.

It's not quite as bad as it looks however since another feature of the dynamic RAM helps. We said earlier that sixteen address lines are required to count up to 64K. So a DRAM is going to be a multi-pin device with probably



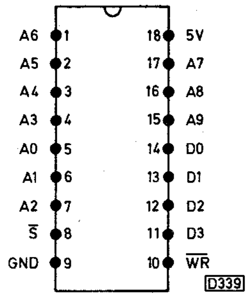


Fig. 3 (left): 4116 dynamic RAM pin connections.
Fig. 4 (right): 2114 static RAM pin connections.

over twenty pins. In fact it has sixteen. This is achieved by matrixing the address lines. The address matrix is formed of rows and columns and a system built into the chip switches eight of the pins first to one and then the other. Externally the sixteen address lines are also switched, first to one set of eight addresses then to the remaining eight. Both these switching operations are synchronised by the CPU: the data appears on the data bus at a precise time and is read by the CPU or the memory in sync with the switching.

Back to our refresh problem. The internal circuitry that does the row/column switching also assists with the refresh by recharging all the column bits each time a row is addressed. It's necessary to refresh only the rows therefore to refresh the memory completely. The number of refresh operations is thus reduced from 64K to less than 256.

Fig. 3 shows the pin connections for the 4116 DRAM. The $\overline{RAS}$ (row address strobe) and $\overline{CAS}$ (column address strobe) pins are used to synchronise the switching. This is a 16K by one bit (serial bits enter at pin 2 and leave at pin 14) memory. Despite requiring three voltage supplies (12V at pin 8, 5V at pin 9 and −5V at pin 1) it's still only a 16-pin device. Seven lines (A0-A6) are used for the addresses. The other pins are chassis (16) and $\overline{WR}$ (3) – read/write select. Compare this with the 2114 static RAM – see Fig. 4. Static RAMs use flip-flops to store the bits. This device has only one supply and has a 1K by four bit memory, i.e. it can store 1,024 four-bit numbers. Its storage capacity is a quarter of that of the 4116, yet 18 pins are required.

The Z80 is an eight-bit microprocessor, these eight bits being known as one byte. It connects with an eight-line data bus and when it addresses a memory location it

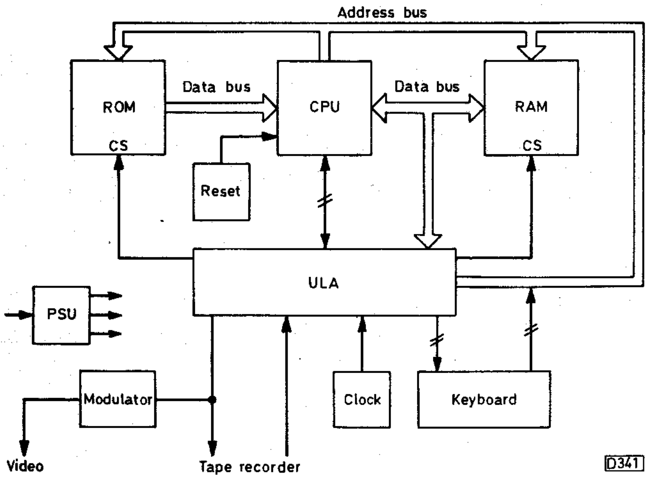


Fig. 5: Simple microcomputer block diagram.

expects to receive an eight-bit instruction to direct its operation. The memory chips are arranged to meet this requirement: in the case of the 4116 eight of these devices would be used, providing a 16Kbyte memory; as the 2114 is a four-bit memory two of these would provide a 1Kbyte memory.

When memories are assembled in this way the address lines are common to all the memory chips. If there is more than one memory group with the same address pins confusion would exist if they all unloaded their data together. To overcome this problem memories are generally provided with chip select (CS or S) or chip enable (CE) pins – often more than one. These switch the memory on only when they are active.

Suppose for example that four 2114 memories are paralleled on the address bus to provide 2K × 8 bits of memory. If an address in the 0-1K range is required the first two memories will be enabled whereas for an address in the 1-2K range the decoder detects the higher number (usually the next binary address line) and enables only the second memory pair. The data pins are tri-state and remain in the high-impedance state until the memory is enabled.

Complete Microcomputer System

It's time to look at the computer system as a whole. Fig. 5 shows a block diagram for a simple computer using the absolute minimum of components. We've already dealt with most of the important items – in fact the only major item remaining is the ULA (Uncommitted Logic Array). This is a collection of logic circuits assembled to the computer manufacturer's specification, replacing the many standard and special logic chips that would otherwise be required. In this example it would provide the address decoding, produce the clock pulses, decode the keyboard, condition the analogue tape input signals and control the output of data to the tape recorder and video modulator. Some of these tasks are carried out by the ULA alone, some are controlled by the CPU.

The clock oscillator for example is driven and divided automatically and the chip select signals are continually produced by the ULA logic alone. The output to the video modulator however is a complex signal consisting of screen character pixels and sync signals: the CPU is needed to sequence these correctly. The CPU and ULA also combine to carry out the keyboard decoding. Electrically the keyboard is organised in matrix form, one set of contact connections running from top to bottom and the other along the rows of keys. Signals are sequenced in the vertical lines via the ULA, a key producing a pulse on the address line. This pulse can then be decoded in a time sequence to find the key pressed.

We've now covered the major components in this simple example of a microcomputer. But we haven't finished with Fig. 5 because it's not a fictitious example. In fact it's a block diagram of the ZX81, the simplest Sinclair computer produced. Because of its many limitations this model has become obsolete and has little marketable value. As a result ZX81s can be purchased second-hand for as little as £10. They make ideal initial practice machines. Anyone contemplating microcomputer servicing would, if he doesn't already have a machine, be well advised to buy one of these for both the software and hardware experience.

Next month we'll look at the ZX81 in detail and start to establish a fault-finding procedure.

Servicing Sinclair Microcomputers

Part 2

Ken Taylor

Last month we considered some of the i.c.s used in microcomputers and ended with a block diagram of the simplest computer possible. It had just a Central Processing Unit (CPU – the microprocessor), a Read Only Memory (ROM) that contained the operating instructions, a Random Access Memory (RAM) for storing the program and data and an Uncommited Logic Array (ULA) for doing all the hardware jobs, including interfacing with the TV modulator and the tape input/output ports. Fig. 5 last month was in fact a block diagram of the Sinclair ZX81 microcomputer which is probably the simplest possible home computer design. We'll now examine this model as an introduction to computer servicing.

In producing such a simple computer Sinclair Research introduced several features which make both the circuitry and operation rather different from that of the more usual type of microcomputer. For instance, where have all the other chips one might expect to find gone? The ones that generate the TV display signals and the decoder chips that decide whether it's the ROM or RAM you want? Or the special that looks after the keyboard? They all seemed to be essential in the Amstrad machine described in this magazine last year. In the ZX81 these jobs are all shared between the CPU and the specialised circuitry in the ULA, the timing and decision making being carried out by the former. There's a penalty to be paid for doing things in this simplified way however: the time the CPU has available for processing the program is severely limited. In fact whenever there's a display present the CPU is free only for the period of the field flyback – for the rest of the time it's producing the line sync and display details!

Sinclair ZX81 Circuit

So when you study the ZX81's circuit details (Fig. 1) remember that this is a very specialised machine with a component count unlike most other microcomputers, though it does have a standard CPU and a system that functions in the same way despite looking so different.

Further examination of Fig. 1 will help to explain some of the differences and clear up many of the problems described above. You'll see that the ULA chip is connected to the TV and tape circuits directly at pins 16 and 20. It can decode the address lines and then enable either the RAM or the ROM via one of the Chip Select (CS) lines at pins 12 and 13. It also assists the CPU in reading the keyboard, via the KBD0-KBD4 lines. These link the ULA to the keyboard via a five-pin socket (KB1) that's not shown in the diagram. This PCB-mounted socket connects the keyboard "tails" to these lines while an eight-pin socket (KB2), also not shown, connects the other keyboard tails to diodes D1-8. The ULA also produces the 3·25MHz clock signal from the 6·5MHz ceramic filter (X1) connected to pin 35.

The machine has only 1Kbyte of RAM fitted to the board. Provision is made for this to consist of either one 4118 memory chip or two 2114 chips. There's also provision for fitting a 2Kbyte RAM for the export model. The usual memory extension consists of a 16K unit which plugs into the edge connector at the back of the machine. Fitting an extension memory disables the internal 1K memory however – the following test procedure assumes that only the internal memory is in use.

The data lines to the ROM and RAM and some of the ROM address lines incorporate buffer resistors. These enable the lines to be used by more than one device without conflict. They are very useful in a fault situation for determining which device is still functioning satisfactorily. Lines downstream of these resistors are given an identifying accent, e.g. A1'. The edge connector also has these identifications on some of the contacts to show which side of the resistors link up with them.

There have been at least three versions of the PCB. Fig. 1 represents the issue one board but I've experienced no difficulty in identifying the circuitry on later boards. They vary a little in layout but the component numbers on the boards seem to be the same. One of the only differences on the issue three board is the use of individual resistors in place of packs RP1 and RP3 – R35-42 and R43-47 respectively. There's a photograph of an early version of the issue one board, without component numbers, on page 162 of the ZX81 BASIC Programming Book that was supplied with every machine. This photograph shows all the i.c.s mounted in sockets, which certainly isn't the case with later boards. Note also that the ULA is called the "Sinclair Computer Logic" which is a less standard but perhaps more sensible name.

The power supply unit is separate from the computer and connects to it via a 3·5mm jack plug. It's not shown in Fig. 1 but is a simple d.c. unit that gives very little trouble – except for the moulded jack. If you have one that's been changed, make sure that the tip is positive.

Initial Checks

When the computer is first switched on the display should consist of a white-on-black K (inverse K) cursor at the bottom left of the screen.

If it doesn't, carry out the following simple checks. Remove any extension memory plugged into the rear connector. Check the power supply – the plug should provide an open-circuit voltage of about 14V, tip positive. If the plug has been changed for a solder-on type it's easy to check the on-load voltage which should be about 11V. This will show whether an overload or open-circuit con-

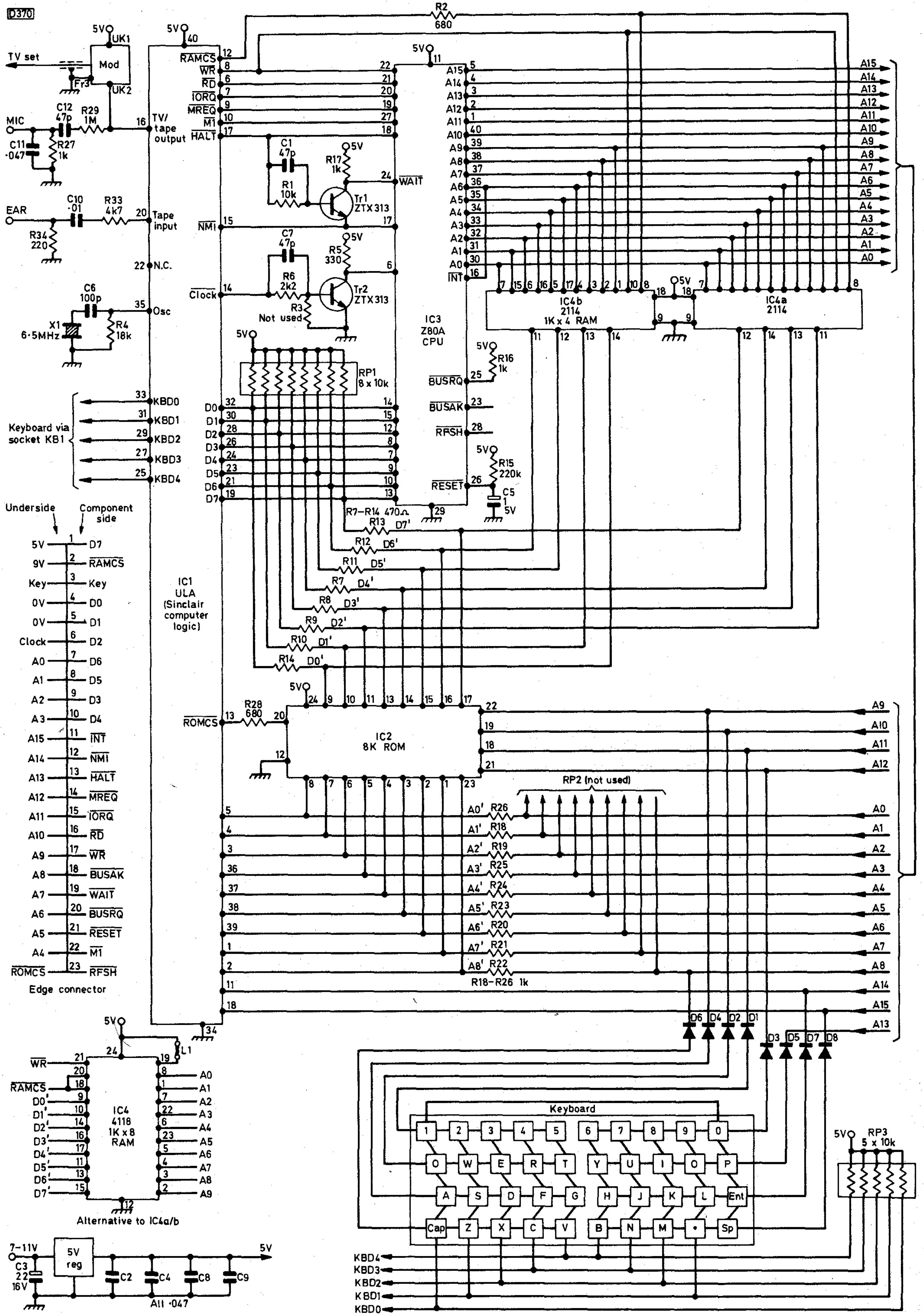


Fig. 1: Basic circuit diagram for the Sinclair ZX81 microcomputer.

dition is present in the machine. In the latter case suspect that the plug has at some time been connected with reversed polarity – this often blows the 5V regulator and saves the rest of the circuitry.

Check the tuning. The modulator is usually set to channel 36 quite accurately, but sweep the band in case the tuning has moved or been altered. If there's no output signal from the ULA the modulator's output will consist of carrier only, devoid of even sync signals. In this case the indication on the TV screen will be negligible.

Dismantling the ZX81

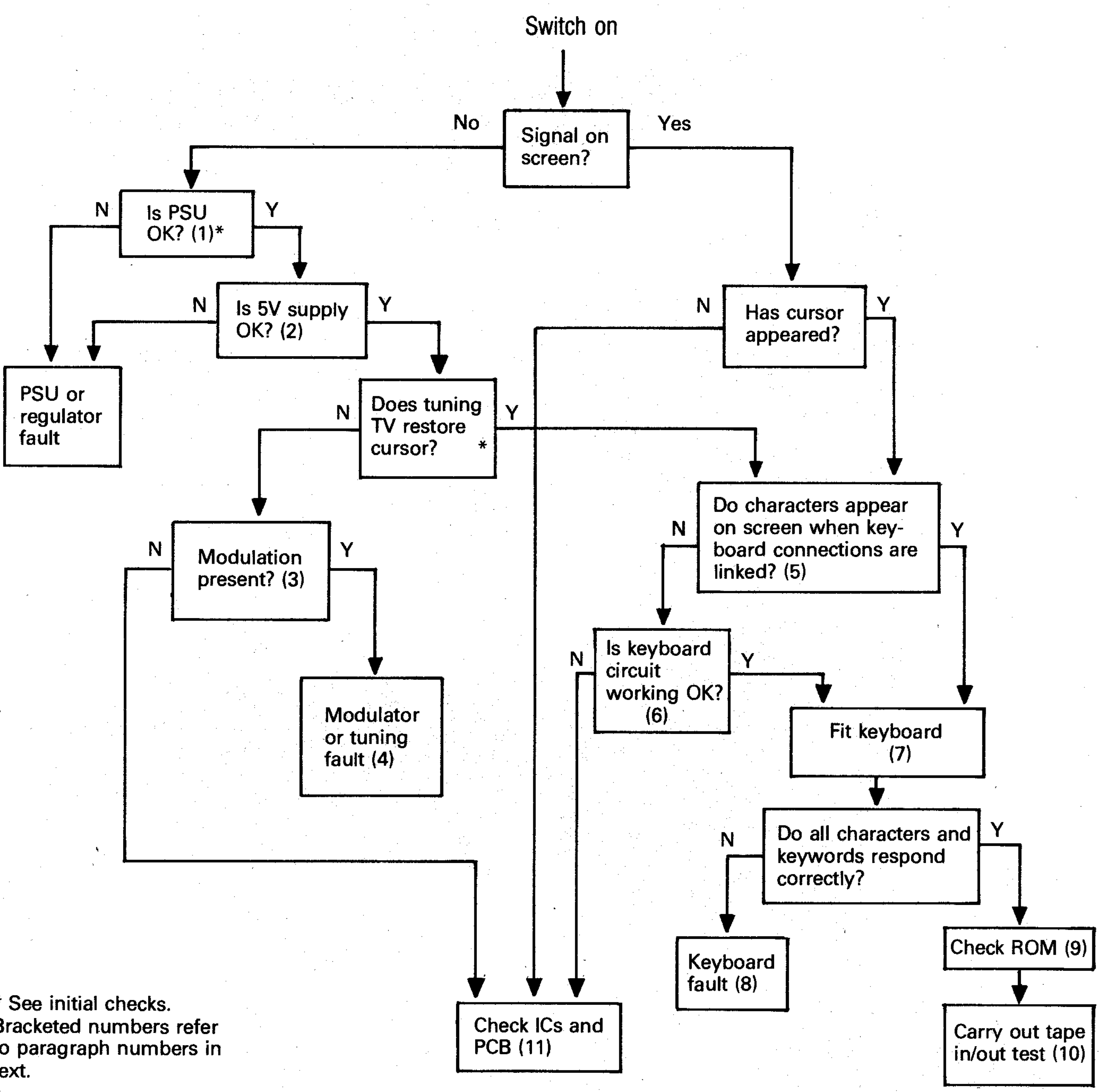
If you haven't found the fault by now you'll have to make internal tests. This means dismantling the unit. First remove the four screws from the base. Three of these should be hidden under rubber feet – if these are still there (the two at the front and the one at back left). Lift off the base and remove the two screws securing the PCB. If you turn the board over towards the front the keyboard tails can be removed from the two sockets. Treat these plastic strips with the utmost care – they are very easily damaged (more about this later).

With the board completely removed the TV and power supply leads can be reconnected. Initialisation of the computer to give the inverse K cursor display occurs without the keyboard being connected, so we can leave it disconnected until the fault has been found.

Fault Finding

Table 1 provides a quick fault-finding sequence: the numbers refer to the following paragraphs which give details of the procedure. Remember that there can often be more than one fault present, so repeat the sequence if necessary.

Table 1: ZX81 fault-finding sequence.



* See initial checks. Bracketed numbers refer to paragraph numbers in text.

(1) The power supply should provide about 11V at 400mA on load. Less than 7V will be insufficient for the regulator to function correctly. An excessive current reading indicates a fault on the board.
(2) The regulator should deliver 5V to each of the i.c.s on the board. Its heatsink normally runs hot to the touch, but not unbearably so.
(3) The signal from pin 16 of the ULA chip to the modulator should give a 'PH' indication on the logic probe (see Table 2). An oscilloscope should display a signal of 2V peak amplitude from the peak to the bottom of the sync pulses. Inverse K will produce a very faint signal near the end of the field trace.
(4) If the modulation signal is present but the TV output is absent check the modulator's supply voltage and the tuning adjustment screw – this should be approximately 3mm down inside the former.
(5) If the cursor is present, connect one of the contacts of the small keyboard socket KB1 to a contact on the large socket KB2. Check whether a character or keyword appears on screen. Don't worry about shorting more than one connector in either of the sockets as this won't cause any damage to the computer – but it won't produce a display either as the software checks that only one key (apart from the shift key) is being pressed before it produces a screen display.
(6) Two faults that can affect the keyboard circuit are shorts between the lines or open-circuit lines or diodes. They can be identified by their effect on the system. Open-circuits affect only the keys they connect (see Fig. 1). A short effectively holds one key on, disabling the whole keyboard. Faults can occur anywhere in the circuit, from the address bus side to the diodes to the ULA chip's KBD pins. Check for shorts where the PCB tracks run obliquely under socket KB1. The resistance between these KBD tracks should be a few thousand ohms.
(7) The keyboard connection tails are very vulnerable, so to avoid unnecessary work make a thorough check that the computer is working satisfactorily before reconnecting the keyboard. Connect each contact on the small five-pin socket KB1 to at least two contacts on eight-pin socket KB2, checking the screen entries. Finally make sure that the tails are not splitting across (see following paragraph) and that the metallised contacts at the ends are in good condition. Then reconnect the keyboard by turning the case face down, front towards you, with the PCB laid component side up on the case so that the edge connector is at the front left: loop the tails over and push them carefully into the sockets, with a slight rocking movement. Don't push too hard or the plastic will buckle and split. When both tails have been fitted turn the PCB over on to its screw pillars and secure with two short screws.
(8) Often one bank or row of the keyboard fails to operate. This is usually due to cracks across the plastic tails severing one or more of the tracks. If the crack is near the end of the tail a clean square cut can sometimes be made, removing the fault. If not too short the tail can then be refitted. As mentioned above the end contacts of the tails should be checked to make sure that there's a good contact for the connectors. If the ends look a little dirty don't be tempted to apply a liquid solvent cleaner – some of these attack the plastic (they don't soften it, they completely disintegrate it!).

If a satisfactory repair proves to be impossible a new keyboard will have to be fitted. These are readily obtainable and are easy to fit to the case with the self-adhesive backing.
(9) Here's a simple ROM check to establish that all the bytes of memory are being read correctly. Although it's unlikely that a ROM fault could continue to be present at this point in the test sequence without being detected the check will set your mind at rest. Enter and run the program below – it takes just over a minute to run. Check that the answer printed out is 855106. If the answer is 854885 the ROM is an early version. To prove this enter: PRINT SQR ·25 (square root of a quarter). An answer of 1·359 instead of ·5 proves that the ROM is an early type which has a few faults. Any other answer to the program indicates a ROM error. Here's the program:

```
10    FAST
20    LET L = 0
30    FOR N = 0 TO 8191
40    LET L = L + PEEK N
50    NEXT N
60    PRINT L
```

(10) At this stage it remains only to check the tape save/load operation and box up the computer. Put in a short program – the one above will do – and save it on tape. Switch off the machine to clear it, then restart and load the program. These operations are both described in Chapter 16 of the BASIC Programming Book supplied with the ZX81.

If the tape tests o.k. the case can be assembled, the four screws fitted and the rubber feet restuck in their sockets.
(11) This is the stage you'll probably end up at if the computer has suffered major damage. You've proved that the fault lies in one or more of the chips or on the PCB.

First check whether the computer has been repaired previously. If you find evidence of modifications or soldering, check the board carefully for solder splashes, shorted tracks etc. Where Sinclair Research fitted i.c. sockets originally I've found that they fitted them to all the i.c.s. So if you find a board that has sockets for some of the i.c.s treat it with suspicion – it's probably been modified.

I don't intend to tell you how to extract a suspect i.c. but let me tell you one of the pitfalls of the method I use in order to illustrate an elusive fault condition. I use a sucker on each pin of the i.c. and having removed most of the solder finally free each pin with a pair of pliers and if necessary the use of solderwick. This often leaves the odd pin still slightly secured in the hole: as the i.c. is carefully removed it's important to free any such pins before they lift and break the print. It's very easy to end up with a print crack on the top of the board and if undetected this crack will be covered when the socket is fitted. So if you have a particularly difficult fault, make sure that this hasn't happened. Check the signals at the i.c. pins and at the line end (the next component) to ensure track continuity.

Checking the ICs

Next, i.c. checks. Table 2 lists the conditions at each pin of the i.c.s. The readings were taken using the Tandy Micronta logic probe featured in last November's issue of *Television*. The computer was at the inverse K cursor stage and the supply for the probe was taken from the 5V rail – I always fit a short wire with a small loop to the 5V plated-through hole near the regulator.

To simplify checking, the pins are listed in numerical order in Table 2 though quick checks at selected pins might speed up the testing. For example I always make an initial check on the 5V and chassis pins of all the i.c.s, then the reset line and memory request pins of the CPU and the cell select and read pins of the ROM and RAM chips. But this is only my own view of what are the more important checks or those most likely to lead to a fault indication. All the pin signals are listed, even those directly connected to the pins of other i.c.s, as this makes for easier checking. As mentioned earlier when describing the circuit some data and address lines incorporate buffer resistors between the i.c.s. These can be very useful as failure of an i.c. at one end of a resistor won't affect the i.c. at the other end, so you can establish with certainty which i.c. is faulty.

It's often easy to locate a fault or anomaly in the signals on the lines but very difficult to establish the reason. The unnecessary removal of a 40-pin i.c. is a non-profitable pastime to be avoided if possible. Other approaches can be adopted. One that has been with us since the earliest days of printed circuits is to cut the track. This is useful for tracing shorts, the computer equivalent of which is the loss of a logic signal. When deciding where to make the cut remember what was previously said about track cracks under sockets and try to avoid making any cut that would subsequently be covered by a socket. Another method of checking a suspect i.c. is to mount a good one on top piggy-back fashion: the legs should be sprung in and care taken to ensure that there's contact at all the pins of the suspect i.c. This doesn't always work but it's worth a try when you have two or three suspect soldered-in i.c.s. The method complements track cutting as it's particularly effective with open-circuit chips.

One last tip. When you suspect that ULA chip and don't have a spare – I usually suspect the item for which I don't have a replacement – remember that the TV screen will be bright if the ULA is all right, even if all the other chips are defective. So a bright screen without a cursor usually means that you should look elsewhere for the fault.

Table 2: Signals on the i.c. pins.

Pin	*IC1 (ULA)*	*IC2 (ROM)*	*IC3 (CPU)*	*IC4a/b (RAM)*
1	P	P	P	P
2	P	P	P	P
3	P	P	PL	P
4	P	P	P	P
5	P	P	P	P
6	P	P	P	P
7	PH	P	P	P
8	PH	P	P	P
9	P	P	P	L
10	P	P	P	P
11	P	P	H	P
12	P	L	P	P
13	P	P	P	P
14	P	P	P	P
15	PH	P	P	P
16	PH	P	P	P
17	P	P	PH	P
18	P	P	P	H
19	P	P	P	
20	L	P	PH	
21	P	P	P	
22	OC	P	PH	
23	P	P	H	
24	P	H	PH	
25	H		H	
26	P		H	
27	H		P	
28	P		P	
29	H		L	
30	P		P	
31	H		P	
32	P		P	
33	H		P	
34	L		P	
35	H		P	
36	P		P	
37	P		P	
38	P		P	
39	P		P	
40	H		P	

P = pulse, high and low LEDs lit.
PH = pulse and high LEDs lit.
PL = pulse and low LEDs lit.
H = high LED lit.
L = low LED lit.
OC = no LED lit (open-circuit).

Spares

The above paragraph reminds me that I mentioned in the introduction to this series last month that Sinclair spares are readily available. The supplier I use is PV Tubes, 104 Abbey Street, Accrington, Lancs BB5 1EE – 0254 36 521 or 0254 32 611. I find that when in a hurry a phone call quoting my Access card number will rush a spare to me – sometimes by the following morning. (Editorial note: the full address of CPC, mentioned in Roger Burchett's letter last month, is CPC Electronic Component Distributors, 194 North Road, Preston, Lancs – 0772 555 034).

This concludes the notes on servicing the ZX81. Next month we'll start on the Spectrum and Spectrum Plus.

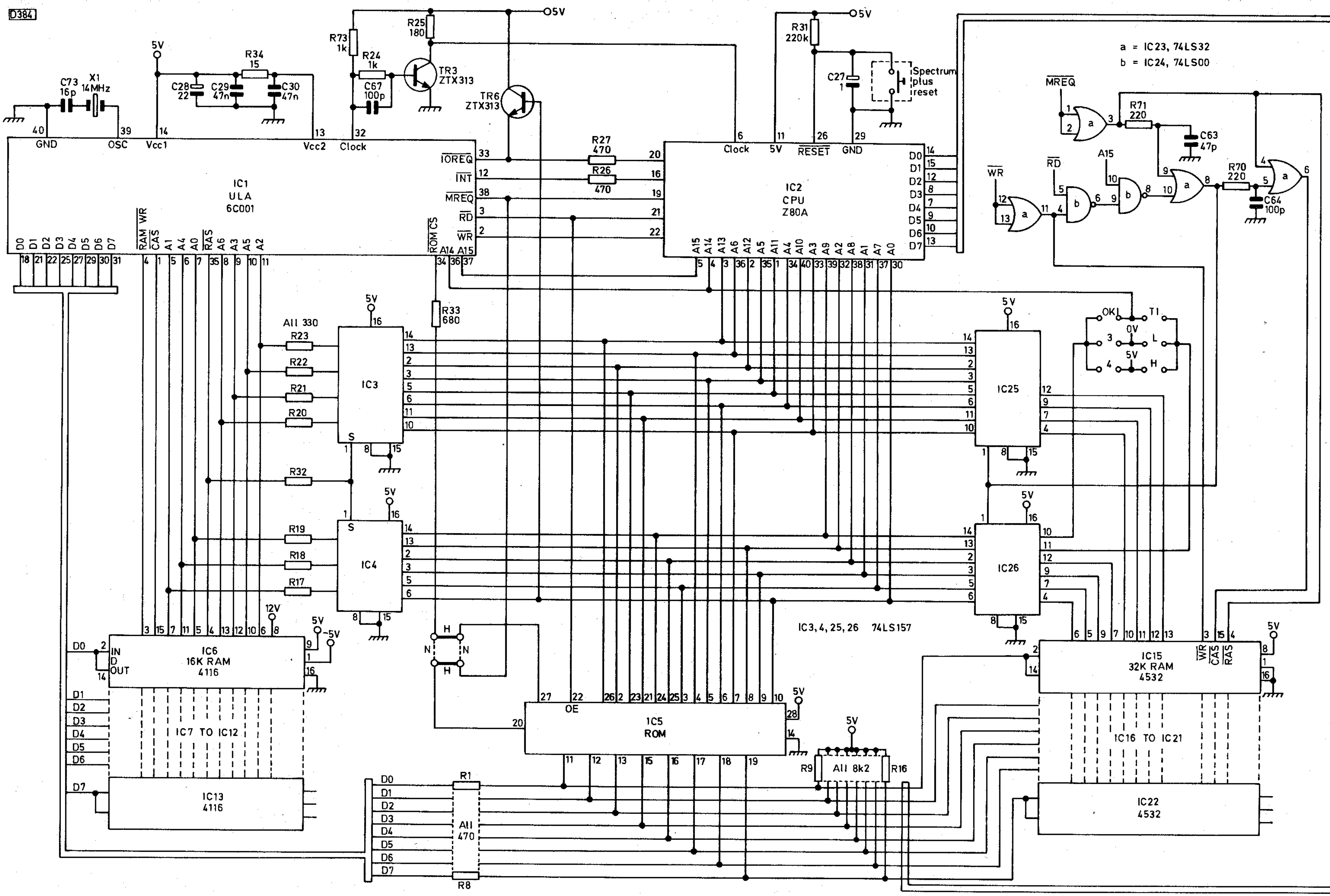


Fig. 1: The basic digital computing circuitry used in the Sinclair Spectrum microcomputer, issue 3 version.

Servicing Sinclair Microcomputers

Part 3 **Ken Taylor**

This month we start on the Spectrum. Let's first take a quick look at the development of this machine over the past few years. There have been four standard PCBs marked issue 1, 2, 3 and 3B. After each change a few modifications were generally required to make the new design operational or to implement further improvements – even the 3B board has now been modified. It's often possible to determine the issue number without opening the case. The clues are as follows:

(1) If the rubber keys are a light fawn colour it's an issue 1 board.

(2) If the keys are dark grey, look into the edge connector slot to see whether an aluminium heatsink is visible – especially at the power socket end. If you don't see the heatsink it's an issue 2 board which has the heatsink near the forward corner of the board, under the keyboard.

(3) If the heatsink is visible it's an issue 3 or 3B board – there is very little difference between them.

The Spectrum Plus usually has an issue 3B board, but watch for earlier models that have been fitted with a Spectrum Plus keyboard kit – this can now be obtained separately.

In this write-up I shall be dealing primarily with issue 3 and 3B models, though I hope to mention the earlier models where the differences are important.

Circuitry

The Spectrum differs from the ZX81 (see last month) in two major respects. First it's designed to carry the full memory (48K RAM) on the PCB. Secondly the TV display is serviced automatically by the ULA chip and a dedicated i.c. (type LM1889) which also provides the video output in colour. This latter arrangement explains why with an otherwise dead machine a vertical striped pattern of "bricks" flickers up and down the screen and goes on working even when the CPU has been removed.

Which reminds me – I haven't explained why we're not providing a block diagram for the Spectrum. I don't see that this would be of much advantage. Apart from illustrating the two differences I've just mentioned it would be much the same as the block diagram given for the ZX81. Instead I'm showing most of the circuitry, which by now should be fairly self-explanatory.

The first circuit section is shown in Fig. 1. This includes the basic digital computing circuitry. For clarity, most of the decoupling and smoothing capacitors have been omitted. The input/output circuitry, including the TV output, tape input and output and the keyboard connections have also been omitted: these will be shown later.

Fig. 2 shows the layout of the issue 3 Spectrum to enable you to find the main components as we refer to them. The differences between this and the issue 2 board are not very great. Because of the changed position of the heatsink, the keyboard socket at the right-hand side of the board has been moved slightly rearwards and the regulator is in the middle of the right-hand edge. Most of these features become obvious when you compare an earlier issue board with the layout shown in Fig. 2.

Access

You can't do that however till you open up the machine, so here goes:

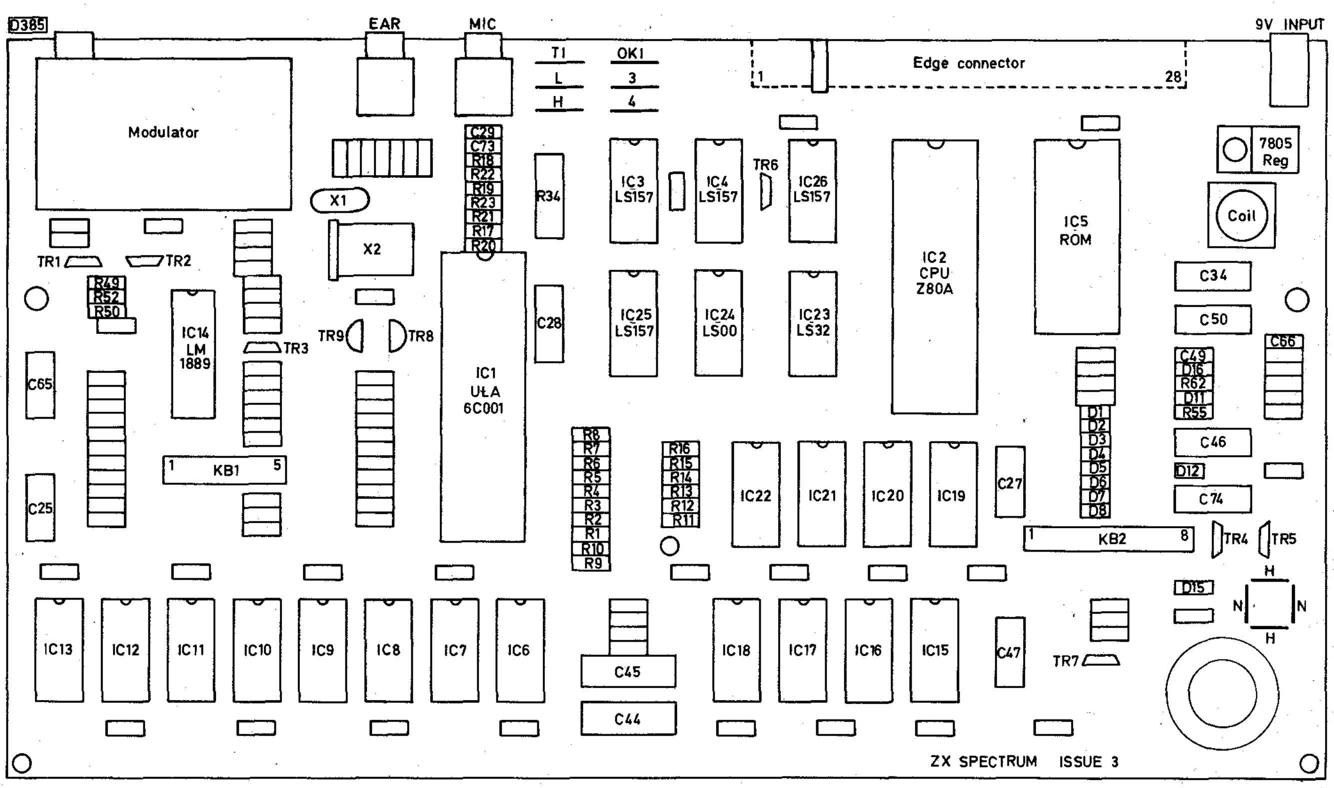


Fig. 2: Layout of the issue 3 Spectrum panel.

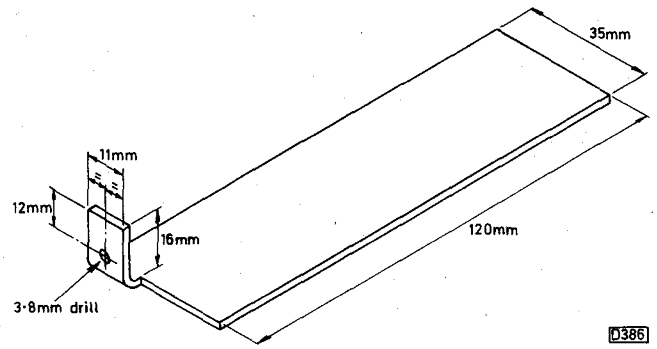


Fig. 3: Temporary heatsink for use when carrying out servicing work on the Spectrum.

(1) Turn the machine over and remove the five screws – eight with the Spectrum Plus.
(2) Turn it back, carefully holding the two parts together. Lift the top, tipping it on to its rear edge so that the keyboard tails can be removed from their sockets. Remember what we said when dealing with the ZX81 about the fragile nature of these tails: the Spectrum is just as vulnerable in this respect.
(3) As with the ZX81, the machine should still initialise when the keyboard has been disconnected, and on start up should display "c 1982 Sinclair Research Ltd." on the bottom line. The keyboard can be left disconnected until this has been achieved.
(4) Before much serious work can be undertaken the heatsink must be removed to provide access to the components beneath. This is even more important with issue 3 and 3B models which have a larger heatsink that covers many of the more important components. The temporary heatsink I use when working on any Spectrum board is shown in Fig. 3. Don't worry if you cannot find a piece of copper or aluminium exactly the right size – the only important section is the little bent-up end which has to fit under the regulator. Even here, if your metal is too thin you can stick another shim of metal to the back so that the regulator legs are not distorted when you screw the heatsink underneath it.

Fault Finding

The internal voltage generator circuit is shown in Fig. 4. This is one of the circuit areas that often suffers when a fault develops. It consists of a 5V regulator and a blocking oscillator (TR4) whose output is rectified to produce the 12V and −5V lines required by the 4116 memory i.c.s that provide the initial 16K of RAM. An interesting regulation technique is used: the blocking oscillator's timing capacitor(s) are charged by the constant-current transistor TR5 whose base is controlled by feedback from the 12V line. The outputs are taken to the edge connector and perhaps this is the problem. It seems that TR4 dies when there's the slightest extra load. This is often caused by a joystick interface being removed or fitted while the machine is switched on and probably shorting out one of the supplies. But the 4116 memory i.c.s sometimes develop shorts and then the problems start.

I've shown the oscillator current in Fig. 4. It's often necessary to supply the board from a bench supply and monitor this current. With a supply provided for the 5V rail, wind up the supply to the oscillator slowly from zero. Monitor the current drawn by the oscillator: if the reading exceeds 300mA switch off quickly and remove one/some of the memory i.c.s or cut the 12V supply tracks to pins 8. Finding the faulty memory or memories is very hit and miss but if you've a good record at pontoon or the football pools you may be lucky!

Earlier circuits were slightly different from the issue 3/3B circuit shown but the differences were often only in the component values and it's worth noting that all issues use the same component reference number for components in the same circuit position.

One more point. Because of the omission in earlier versions of the asterisked 22μF electrolytic capacitor, unless you have the 3B version the 12V line will be at about 11V even when the oscillator is not working. This can present a very confusing situation, so ensure that your first check is always on the −5V line, which will be absent if the oscillator isn't working. The frequency of oscillation, which isn't very critical – or stable – is about 6·6kHz.

Having eliminated faults in the voltage generator circuit and hopefully in any of the 16K RAMs, why doesn't the thing work? Assuming that you are still getting the flickering vertical columns the ULA and the TV video generator chip appear to be o.k., so what else? Remember that your check on the memory i.c.s, made whilst

Table 1: Signals on the i.c. pins

Pin	*IC1*	*IC2*	*IC5*	*IC6*	*IC15*
1	P	P	OC	L	L
2	PH	PH	PH	P	P
3	P	P	P	PH	PH
4	PH	P	P	P	P
5	P	P	P	P	P
6	P	P	P	P	P
7	P	P	P	P	P
8	P	P	P	H	H
9	P	P	P	H	H
10	P	P	P	P	P
11	P	H	P	P	P
12	PH	P	P	P	P
13	H	P	P	P	P
14	H	P	L	P	P
15	P*	P	P	P	P
16	P*	PH	P	L	L
17	PH	H	P		
18	P	H	P		
19	H	P	P		
20	H	PH	P		
21	P	P	P		
22	P	PH	P		
23	H	H	P		
24	H	H	P		
25	P	H	P		
26	H	H	P		
27	P	P	P		
28	L	P	P		
29	P	L			
30	P	P			
31	P	P			
32	P	P			
33	PH	P			
34	P	P			
35	P	P			
36	P	P			
37	P	P			
38	P	P			
39	†	P			
40	L	P			

P = pulse, high and low LEDs lit.
P* = pulse LED only lit.
PH = pulse and high LEDs lit.
H = high LED lit.
L = low LED lit.
OC = no LED lit.
† = display affected.

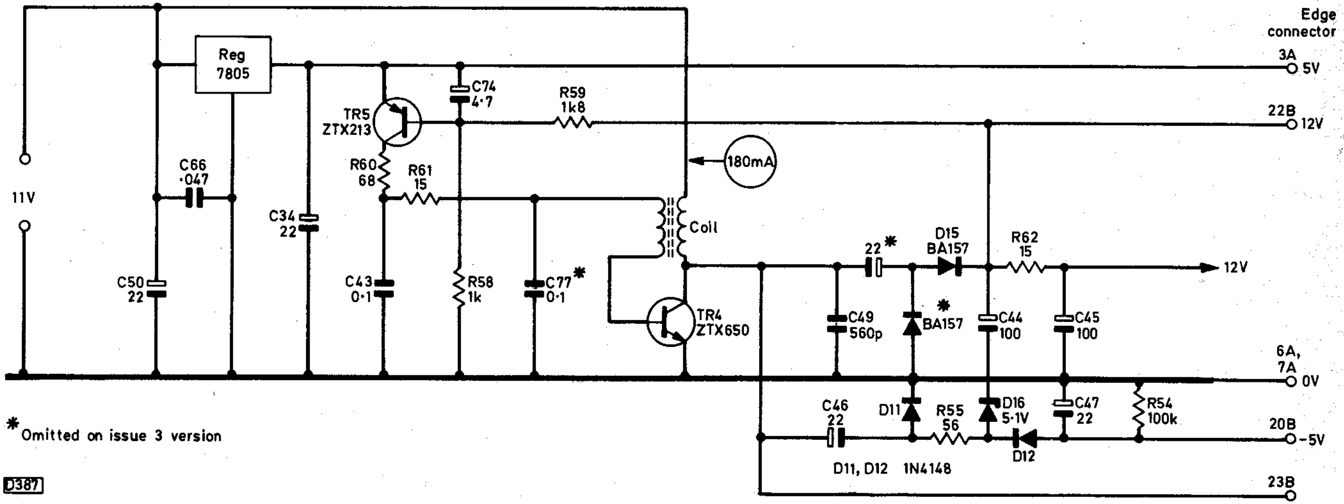


Fig. 4: Voltage generator circuit used in the Spectrum – issue 3B version. With the issue 3 version R60 is 270Ω, C49 is 47nF and the asterisked components are omitted. Edge connector numbers suffixed A are on the underside of the board, those suffixed B are on the component side (top). The input from the power supply is approximately 11V on load (650mA).

repairing the voltage generator (if necessary), detected only those i.c.s taking excessive current, not those with other faults. So first try the piggy-back check I suggested for the ZX81 last month. Clip a good 4116 on top of each of the remaining original memories and see whether this makes a difference. If the extension memory chips (IC15-IC26) are fitted they can be turned off either by removing the memory chips or IC25 (one of the 74LS157 multiplexer chips). Alternatively the 5V supply track to pin 16 of this i.c. can be cut, but this is not easy with the issue 3 board as the track is thicker than usual.

The 4116 memories are also addressed via the 74LS157 multiplexers IC3-4. You may recall our earlier comment that dynamic RAMs such as the 4116 are addressed by a row/column sequence so that only half the theoretically required number of address pins are needed. The internal system stores the first half of the address and then combines it with the second half to provide the full 16-bit address. The ULA has this facility built in, so it doesn't require multiplexers to address the RAMs.

Note the buffer resistors in the address lines between the ULA and multiplexers IC3-4. These allow the ULA to take control of the address bus when the screen needs updating, irrespective of the demands of the CPU. These buffer resistors are very useful when you are fault finding. Any loss of signal tends to be isolated to one side of the buffer, enabling the faulty i.c. to be detected. In this case, if the fault is on the ULA/RAM side removing the ULA or cutting the track will usually pinpoint the fault.

If you still have a fault, it's probably in the CPU or the ROM and a full check on the circuit will be necessary. Table 1 shows the signals that should be present at each pin of the main i.c.s, with the keyboard disconnected and the Sinclair logo displayed, when monitored using a logic proble (a Tandy Micronta was used). This should enable you to isolate and replace the faulty i.c.

Next month we'll look at the rest of the circuit and some of the variations and modifications.

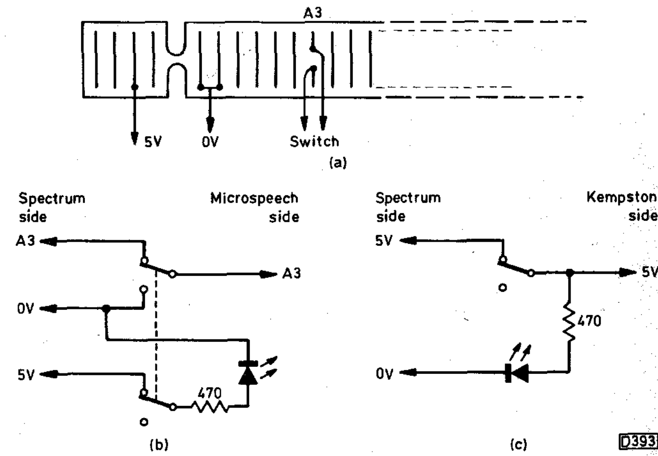


Fig. 3: Modifications for use with Spectrum add-ons.

SPECTRUM ADD-ONS

Quite a lot on the Spectrum microcomputer has appeared in *Television* recently. Some add-ons can cause the computer to either crash or not work with various games. The Currah Microspeech and the Kempston interface are but two examples. Both of these can be successfully, easily and cheaply modified to work with all games however. First the Microspeech. Some games won't work because the game and the Microspeech try to occupy the same section of memory, so the computer crashes. The cure is to earth line A3: the Microspeech stays connected but the Spectrum ignores it. As this is a dead-ended device with no through connector most people who want to use more than one add-on will use some form of extender, the usual sort being a 56-way socket to fit the Spectrum's rear connector and two or more sockets on the end of a piece of ribbon cable. These extra sockets will require a printed circuit "back-to-back" to connect them to whatever accessory is being used. It's this piece of back-to-back that's modified. This has several advantages, the main ones being that modification can be done without connection to either the computer or the Microspeech, so that a careless solderer won't do any damage, and that neither the computer nor the Microspeech has to be dismantled so no guarantees are nullified.

Back to the Microspeech. Break the A3 line. Counting from the double-earth connections (taking these as one and two) at one side of the keyway A3 is the seventh – see Fig. 3(a). Fit a double-pole, two-way toggle switch with sufficient wire to enable it to be taped to the side of the Microspeech's case. Two poles are used – see Fig. 3(b) – so that one pole can be used for a LED to indicate on or off. The slider of one pole goes to the A3 line for the Microspeech, the fixed contacts going to earth and the A3 line from the Spectrum respectively. The other pole is used to connect a LED with a resistor of about 470Ω in series between the 5V line (the second edge connector from the keyway on the same side as the double earth) and 0V. Irrespective of whether the Microspeech is on or off the Spectrum sound will come from the TV set's speaker – and so sound a lot better than the Spectrum's own feeble beep.

The next device is the Kempston interface for joysticks. You'd think that games designers would take this into account as it has become an "industry standard" joystick interface, but no. The game "Chickin Chase" (their spelling, not mine!) will crash if the Kempston is connected. This modification – see Fig. 3(c) – is very simple. Just switch off the 5V supply to the interface and the Spectrum will ignore it. Although it's a bit late now the game "Ghostbusters" will, despite having a Kempston option in the menu, crash if the Kempston is connected – unless you moan to Activision who will replace the game with a Kempston compatible one (and also refund your postage if you ask nicely). To test the Kempston interface use the following short program:

```
10 PRINT IN 31;:PRINT "  ";:PAUSE 25: GOTO 10
```

With the interface switched off the answer should be 255. With it switched on you should get the following: up 8; down 4; left 2; right 1; fire 16 – or combinations thereof.

I know that the alternative to these modifications is to keep unplugging the devices but I feel sure that the Spectrum's rear connector was not designed for constant plugging and unplugging. I hope that Amstrad, having taken over Sinclair's computer range, will repackage the 128K and 48K with a built-in joystick interface.

Michael Harris,
Cheadle, Cheshire.

Servicing Sinclair Microcomputers

Part 4

Ken Taylor

Last month we dealt with the main parts of the Spectrum, including the CPU, ROM, ULA and 16K RAM. Fig. 1 showed the main computing circuitry (issue 3 version) while Fig. 4 showed the voltage stabiliser and generator circuits. Fig. 5 this month completes the Spectrum circuit: it covers the tape recorder input and output and sound sections, and the video circuits. You'll find several references to Figs. 1-4 in this month's article: these refer to last month's diagrams.

The 32K Extension RAM

Before looking at these new areas of the circuit there are a few points that remain to be dealt with concerning last month's circuitry. The first of these is the extension memory. This section, using IC15-IC26, extends the RAM memory from the initial 16K to 48K. It was originally an optional extra, with sockets provided to enable these i.c.s to be fitted later. So you sometimes find that these i.c.s can be easily removed for checking or for eliminating a possible source of trouble. The extension memory chips are IC15-IC22 and may be Texas TMS4532 or OKI MSM3732 chips – the memory chips must all be of the same type. These are both 64K DRAMs with only 32K of serviceable area. This area is sometimes in the address range zero to 32K and sometimes in the range 32K to 64K. This is why there's a link panel on the printed board (between the MIC socket and the edge connector – see Fig. 2 last month). The connections required for the various memory permutations are as follows:

Memory chip	*Links required*
Texas TMS4532-3	TI and 3
Texas TMS4532-4	TI and 4
OKI MSM3732-H	OKI and H
OKI MSM3732-L	OKI and L

The pin connections for these chips are shown in Fig. 6. Pin 9, which is normally the A7 address connection, is here referred to as AR – high/low memory address select: it's connected to either 5V or 0V depending on whether the useful memory area is high or low.

The other chips associated with the extension memory

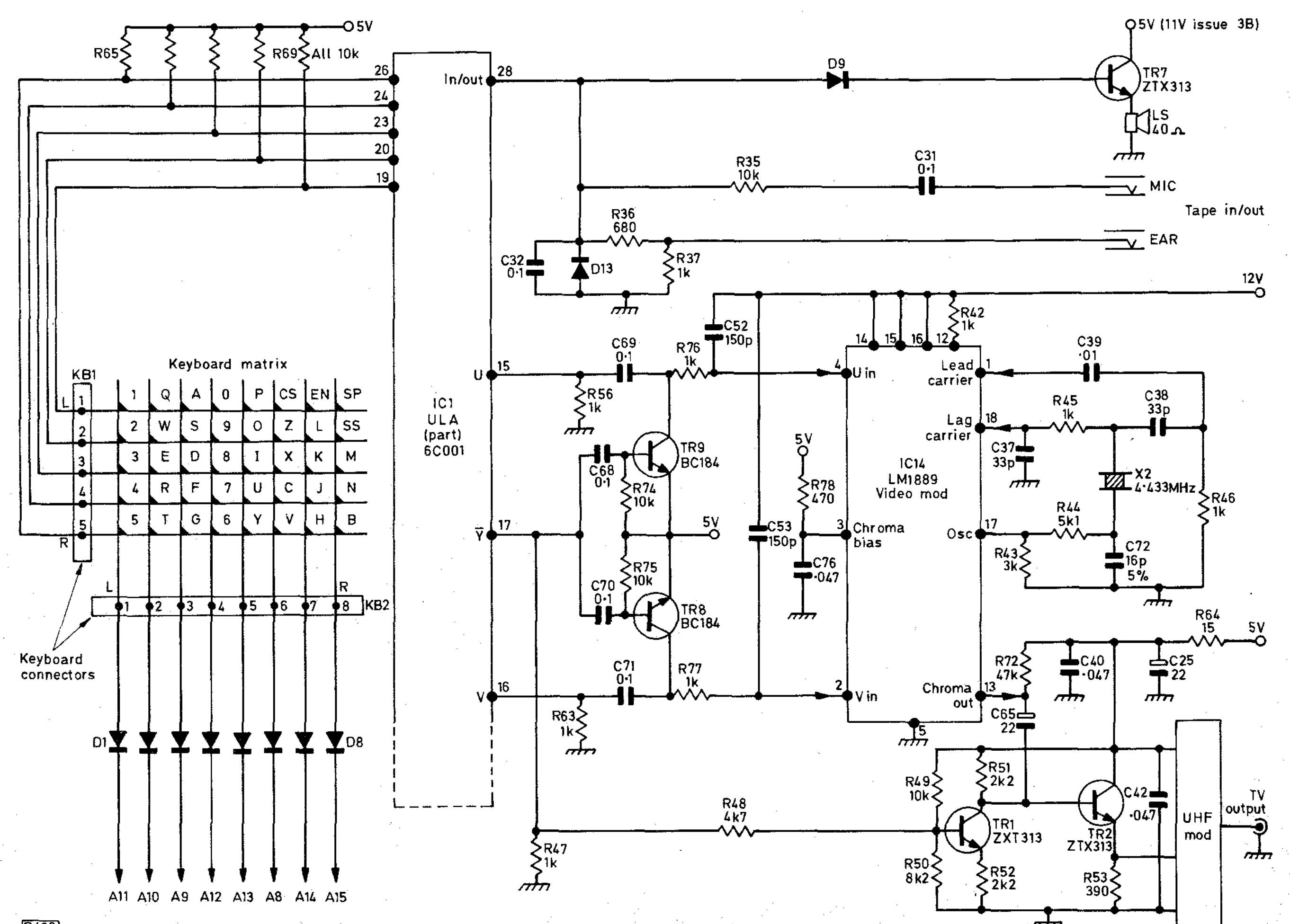


Fig. 5: Final part of the Spectrum issue 3 circuit diagram, showing the keyboard matrix, the tape input and output and the video and TV output circuitry. Note that C65 is 0·1µF in some issues of the Spectrum, also that to simplify the circuit many of the supply line decoupling capacitors have been omitted, also the edge connector connections (see Table 3). R47, R56 and R63 were 220Ω in early versions: C72 is present in issue 3B versions. Some pin numbers were missed off IC3/4 last month: R23 goes to pin 12, R22 to pin 4, R21 to pin 7, R20 to pin 9, R19 to pin 12, R18 to pin 4 and R17 to pin 7.

are the address decoders (IC23 and IC24) and the row/column multiplexers (IC25 and IC26). The decoders activate the memory only when the A15 address line is high, thus setting the address range from 32768 (decimal) upwards.

While we're discussing addresses it's worth noting the memory map for the Spectrum. The 16K ROM starts at address zero and is followed at 16K (16384 decimal) by the 16K RAM (the 4116 chips). This continues to address 32767 and is followed by the 32K extension memory which carries on to the final address of 64K (65535). The model description – 16K or 48K Spectrum – indicates the size of the RAM. The 48K model often has a label on the underside.

RAM Checks

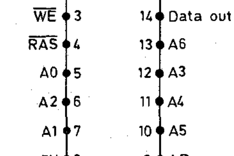
When you've finished a repair, especially when it has involved removing the extension memory, it's good practice to check that the entire memory is operational. This is a simple matter since one of the tasks in the initiation program is to determine the maximum usable memory available. This data is needed by the computer and is therefore stored in one of the system variables. Access is by entering the following line:

PRINT PEEK 23732 + 256 * PEEK 23733 (Enter)

Note that print and peek are words on the keys. The printout should be 65535, or 32767 if it's a 16K model. Any shortfall indicates that there's a memory fault that will have to be traced. If it's simply a defective memory chip diagnosis should be possible using the computer, because each i.c. is responsible for the same binary data bit at each of its addresses. If we can find the faulty bit in the data word and we know which i.c. handles which bit we shall be home and dry.

The above check will have told us that the faulty address is the one beyond the printout address number. We now need to find out which bit at this address is wrong. To do this we put 85 at this address, using the command poke. If you remember your binary you will know that 85 is 01010101. We next read what is in the address, using peek, and see if there's an error. If there is we can tell which i.c. is responsible because we know which data line goes to which i.c. (see Fig. 1). We also know that D0 is the least significant digit – the one at the right-hand end – and D7 the most significant digit, the first figure on the left.

So there we are. Except that an error may not show if the faulty cell registers the same digit we've put into it. In this case try again, this time putting in 170 which swaps the bits to 10101010. This must reveal the culprit.



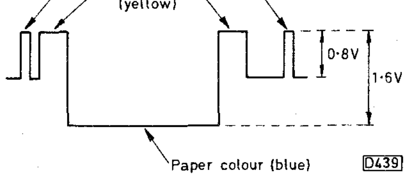


Fig. 6 (left): Pin connections for the 32K extension memory chips. Pin 3 is write enable, pin 4 row address strobe, pin 9 high/low address select, pin 15 column address strobe.

Fig. 7 (right): The TV line waveform at pin 18 of the edge connector when the computer is displaying a yellow border, blue paper and no characters.

Table 1: RAM check procedure.

The following routine will isolate a fault at one address of the RAM:
(1) Enter the following:
PRINT PEEK 23732 + 256 * PEEK 23733
(2) If the result is other than 65535 or 32767 (16K version) there's a fault.
(3) Add one to the faulty result. Let's say it was 54321. Enter:
POKE 54322,85 (Enter)
then:
PRINT PEEK 54322 (Enter)
Use your result + 1 in place of the example quoted above.
(4) If the answer returned is 85, repeat step (3) using 170 instead of 85.
(5) One of the answers should differ from the 85 or 170 entered. Provided there is only one faulty i.c. at the address, Table 2 will indicate which one it is. Find the line with the wrong data bit then refer to IC6-13 if the address is below 32768 or IC15-22 if the address is above 32768.
(6) Repeat step (1) after the repair to ensure that there isn't another fault.

Table 2: Identifying the faulty chip.

Wrong answer obtained from procedure given in Table 1	*Wrong data bit*	*Defective chip 16K*	*32K*
84 or 171	0	IC6	IC15
87 or 168	1	IC7	IC16
81 or 174	2	IC8	IC17
93 or 162	3	IC9	IC18
69 or 186	4	IC10	IC19
117 or 138	5	IC11	IC20
21 or 234	6	IC12	IC21
213 or 42	7	IC13	IC22

If you don't want to exercise your binary skills, Table 1 lists the check procedure and Table 2 the faulty i.c. against the number read out. Remember that the system works only for a single fault at an address, though it's unlikely that there will be more than one when all the rest of the memory is operational. But there may be a fault at a higher address, so repeat the procedure until the correct final address has been obtained.

ROM Check

The program given below will enable you to verify that the ROM is satisfactory:

```
 10 LET 1=0
 20 FOR n=28003 TO 28033
 30 READ a
 40 LET 1=1+a
 50 POKE n,a
 60 NEXT n
 70 DATA 17,0,64,62,0,33,0,0,1,0,0,134,48,2,3,63,35,
    29,32,247,21,32,244,50,96,109,237,67,97,109,201
 80 IF 1=2033 THEN GO TO 110
 90 PRINT "Error in Data"
100 STOP
110 RANDOMIZE USR 28003
120 PRINT PEEK 28000 + 256 * PEEK 28001 + 65536 *
PEEK 28002
180 STOP
```

This will work with either make of ROM and should return the number 1926175. If "Error in Data" appears you've entered a wrong number in line 70. Incidentally if you remember that the ZX81 ROM check took over a minute to run you may be surprised at the speed of this one. Although the ROM is twice the size the check uses machine code, giving an almost instantaneous result. This is a measure of the difference between BASIC and machine code: when you consider that apart from all the addressing procedures etc. over 16000 additions have been made in the time you can see the potential speed of the CPU.

A connection link similar to that for the RAM is provided for the ROM. It provides for fitting a chip of either NEC or Hitachi manufacture. The link is no longer used since current ROMs work with either set of connections.

The Keyboard

Like the ZX81, the Spectrum's keyboard is of membrane construction wired in matrix form with decoding by the CPU. The keyboard (see Fig. 5) is scanned by sequentially putting a low on each of the address lines A8 to A15 and monitoring the data lines D0 to D4. If a key is pressed the appropriate pin of the ULA chip is pulled low: this is transmitted to the relevant data line via an inverter in the ULA.

Fault diagnosis is straightforward – the usual faults are in the tails that connect the membrane to the sockets. A fault here affects either a row or column of keys. It's a simple task, with the aid of the diagram, to determine which tail is at fault. If the whole keyboard is dead a quick check is to make connections across from one socket to the other in place of the keyboard. This can also be done quite safely when the keyboard is removed for servicing the computer. No damage will be done even if more than one socket contact is shorted.

The Spectrum Plus keyboard has an extra complication. In order to simulate the pressing of two keys by operation of one of its special keys it has a double-layer membrane. The connections between these are made by clamping the tails together, print side to print side, using a plastic clamp. This is not entirely satisfactory and can lead to some unexpected characters appearing. Replacing the Spectrum Plus keyboard is much simpler than with the earlier model however since it's assembled with screws instead of double-sided adhesive tape.

Keyboards are relatively cheap and as they often take a lot of punishment it's expedient to replace any that give trouble.

Tape and Sound Circuits

The tape recorder input and output and the speaker are always operated independently so only one pin of the ULA is used for all three. This combined circuit also provides a sound output from the speaker when the recorder is loading. There are few components in this area and it should be a simple matter to check that the circuit is working correctly. As a guide, a 5V peak-to-peak signal at the EAR socket should give a 2V p-p signal at the ULA. With almost all such tests however the best guide is to compare the suspect signal with that in a good machine. In this particular case, if the signal is o.k. but there's no

Table 3: Connections to edge connector pins.

Pin	*Component side (top)*		*Underside*	
1	A15	(1)	A14	(1)
2	A13	(1)	A12	(1)
3	D7	(1)	5V	
4	NC		9-11V	
5	Slot		Slot	
6	D0	(1)	Chassis	
7	D1	(1)	Chassis	
8	D2	(1)	Clock. ULA pin 32	
9	D6	(1)	A0	(1)
10	D5	(1)	A1	(1)
11	D3	(1)	A2	(1)
12	D4	(1)	A3	(1)
13	$\overline{\text{INT}}$. CPU pin 16		$\overline{\text{IORQULA}}$. ULA pin 33	
14	$\overline{\text{NMI}}$. CPU pin 17	(2)	Chassis	
15	$\overline{\text{HALT}}$. CPU pin 18	(2)	U.H.F. modulator input	
16	$\overline{\text{MREQ}}$. CPU pin 19		Y. ULA pin 17	
17	$\overline{\text{IORQ}}$. CPU pin 20		V. ULA pin 16	
18	$\overline{\text{RD}}$. CPU pin 21		U. ULA pin 15	
19	$\overline{\text{WR}}$. CPU pin 22		$\overline{\text{BUSRQ}}$. CPU pin 25	(2)
20	−5V		$\overline{\text{RESET}}$. CPU pin 26	
21	$\overline{\text{WAIT}}$. CPU pin 24	(2)	A7	(1)
22	12V		A6	(1)
23	−12V	(3)	A5	(1)
24	$\overline{\text{MI}}$. CPU pin 27	(2)	A4	(1)
25	$\overline{\text{RFSH}}$. CPU pin 28	(2)	$\overline{\text{ROMCS}}$. ULA pin 34	(4)
26	A8	(1)	$\overline{\text{BUSAK}}$. ULA pin 23	(2)
27	A10	(1)	A9	(1)
28	NC		A11	(1)

Notes: (1) These pins connect directly to the CPU address or data lines.
(2) Some CPU control lines are used in the Spectrum, some are not. The latter connect only between the CPU and the edge connector and are not shown on our circuit diagrams.
(3) Sinclair refer to this as −12V. It actually connects to TR4's load coil (see Fig. 4). TR4's collector waveform superimposed on a d.c. voltage is present at this pin.
(4) This pin does not connect directly with pin 34 of the ULA: it goes to the ROM side of R33, at its junction with the ROM link (see Fig. 1).

loading the ULA must be at fault. From bitter experience I'd recommend that you make this test before quoting for the job: the ULA is the most expensive item in the computer, costing over eight pounds at present, so it's not the sort of pricing detail to overlook.

The tape output at the MIC socket should be sufficient to produce a clean recording on a standard mono tape recorder. As this level is rather low the easiest check is to save a simple one or two line program then check that it loads.

Colour and Video Circuits

The colour and video section is where you come into your own. At least you can work on signals you recognise, even though they are being assembled into a composite video signal rather than being decoded from it.

The initial organisation of the display is carried out by the ULA, which every fiftieth of a second reads the display file – the memory area that holds the display details – and produces U, V and inverted-Y output signals. The U and V signals are fed to pins 4 and 2 respectively of the LM1889 video modulator chip IC14 which produces a standard PAL chroma output signal at pin 13. The chip incorporates a 4·43MHz oscillator which, in conjunction with the external crystal network, produces phase-shifted subcarriers at pins 1 and 18. The inverted-Y output from the ULA is inverted by TR1 and added to the chroma signal at the base of TR2. The resultant composite video output is then fed to a standard Astec u.h.f. modulator which produces an output on channel 35.

If the sound output works all right but there's a problem with the display you'll need to check the circuit with a scope. One of the best points for making checks, if you have a suitable socket, is at the edge connector (see Table 3). Pin 15 on the underside of the connector is the u.h.f. modulator's video input, pin 16 carries the inverted-Y signal from pin 17 of the ULA while pins 17 and 18 carry the ULA's V and U outputs. With the computer initiated, i.e. switched on, and no key pressed pins 17 and 18 will carry only the sync pulses. These are positive-going and of 0·8V p-p amplitude. If a colour border, or paper, is displayed blocks appear between these sync pulses. Fig. 7 shows a typical waveform but you must appreciate that the amplitude and polarity of the signal, i.e. whether it's above or below the sync base line, changes with the colour.

With a full-screen display the inverted-luminance signal at pin 16 is a normal looking TV line signal of 2·5V p-p with no colour burst. The colour burst is very pronounced at pin 15, which carries the u.h.f. modulator's input signal. The overall signal here is only 1V p-p however.

The Edge Connector

Having just referred to the edge connector, this seems a good point at which to provide the details of this output port. It's a double-sided 28-pin board-edge connector – sockets to mate with it are readily available. Every useful line in the computer is brought out to a pin and the connector provides a ready means of linking the computer to the outside world. Rather too ready at times since, as I've said before, my belief is that most of the damage to these machines occurs when devices are fitted or removed without first switching off.

Next month we'll review some of the differences between earlier and later versions of the Spectrum.

Servicing Sinclair Microcomputers

Part 5

Ken Taylor

Previous treatment of the Spectrum in this series has related specifically to the issue 3 and 3B versions. There has however been continuous development of the machine since its introduction in 1982. The range now extends from the initial issue 1 version to issue 6A, covering a total of eight models with six PCB changes. It's time we looked at some of these variants, starting with the earlier models.

The issue 1 and 2 versions have a lot in common. They both have the early zigzag shaped heatsink, and both have small trimmer capacitors and preset potentiometers for setting up the colour generator circuits. The issue 2 board layout is shown in Fig. 8. The issue 1 differs only in the design of the original 32K extension memory, which isn't assembled on the main board as with all later versions. Instead, it's built on a plug-in board that carries the memory i.c.s and the decoders and multiplexers. This daughter board plugs into two DIL sockets at the rear of the main board and extends right across from the modulator to the coil. To accommodate this, the CPU and the multiplexer chips IC3/4 are moved towards the front of the main board along with the ULA and ROM chips, leaving a clear space into which the extension memory board fits. If this space isn't filled the machine isn't worth very much, since the extension is no longer available and without it the majority of the commercial programs cannot be used.

Another distinctive feature you will find on some issue 1 boards is the "spider". Due to a timing error in the 5C102 ULA chip it was necessary to fit an extra 74LS00 i.c. Because this was added retrospectively there wasn't room for it on the board, so the i.c. had to be mounted on its own small board suspended above the main board by the connecting wires. When the later type 5C112 ULA was introduced the spider was no longer required. The initial issue 2 board used the same 5C112 ULA but a further modification was fitted: this was the addition of TR6 which replaced the previous diode/resistor network – see Fig. 9. As you can see from Fig. 8, TR6 is mounted across the top of the CPU i.c. Later versions of the issue 2 board have the current 6C001 ULA chip: this necessitated some resistance changes which are detailed in (4) of the issue 2 modification instructions.

The following modifications should be added whenever a Spectrum is dismantled for servicing. First, issue 1 versions.

Issue 1 Modifications

(1) When National 4116 RAM i.c.s are fitted, remove R57 (330Ω) – connected to pin 28 of IC2 – and fit a 1kΩ resistor between the $\overline{CAS}$ line and the 12V rail and another 1kΩ resistor between the $\overline{RAS}$ line and the 12V rail. These resistors are best fitted on the underside of one of the memory chips IC6-13. C54 (at pin 28 of IC2) can also be removed – but it must be left in circuit when the 4116 RAMs are of NEC manufacture.

(2) When a type 5C102 ULA is fitted, add a 100pF capacitor between the $\overline{RAS}$ line and chassis.

(3) C46 (1μF electrolytic) should be replaced with a high-temperature capacitor as it's mounted beneath the heatsink.

(4) Axial capacitors should be fitted in place of all the disc ceramic capacitors. The following capacitors *must* be replaced: C41 (ROM pin 14 to pin 28) and C49 (between the collector and emitter of TR4) – these capacitors are both 47nF.

(5) If there's insufficient colour difference between white and yellow, fit a 47kΩ resistor between pin 13 of IC14 (LM1889) and chassis.

(6) To improve the reliability of the voltage generator the circuit should be modified to correspond with Fig. 13. A minimum would be to change the value of R60 and fit a 4·7μF electrolytic (C74) between the emitter and base of

TR5. See the notes on this section of the circuit in Part 6 next month.

(7) Finally, if you want to use the Spectrum to operate a Z80 PIO, or if you find that some machine code software doesn't run satisfactorily, check that the following modifications have been made.

(a) Change TR3's base circuit as shown in Fig. 10, i.e. replace D14 with C67, change R24 to 1kΩ and add the pull-up resistor R73.

(b) Change R27 from 680Ω to 470Ω or shunt it with a 1·5kΩ resistor (ULA pin 33 to CPU pin 20).

Issue 2 Modifications

Now to issue 2 boards. Like the modifications given for the issue 1 version these should be made whenever possible. Fig. 8 shows the positions of the components.

(1) Replace all disc ceramic capacitors with axial ones. Especially change C41 and C49 (47nF) – as with issue 1 boards – and change C43 (100nF) in the voltage generator circuit. This, together with modification (3) below, will update the circuit almost to issue 3 standard.

(2) To improve the colour, change R48 to 2·2kΩ, R49 to 8·2kΩ, R50 to 4·7kΩ, R72 to 10kΩ and C65 to 22μF. These components are all associated with the luminance/chrominance drives to TR1 and TR2 (see Fig. 11).

(3) Carry out the same modifications as those listed under (6) and (7) for issue 1 boards.

(4) The only currently available ULA is type 6C001. When this is used to replace an earlier type the following modifications should be made: change R47 to 1kΩ, R49 to 10kΩ and R56 and R63 to 470Ω.

(5) There's no need to change the speaker circuit from that shown in Fig. 5 to that shown in Fig. 11. The modification is very simple however if increased sound output is required.

Servicing Aspects

From the servicing point of view the advice given for issue 3 versions applies in general to issue 1 and 2 versions. There's one exception. There are four presets (TC1, TC2, VR1 and VR2) that may need setting up if any changes have been made. Their positions are shown in Fig. 8 and their functions are as follows.

TC1 sets the frequency of the 14MHz crystal that controls all the computer timing, including the 50Hz field sync signal. You might think that this would provide an easy means of setting up this control, but in many cases the range of adjustment is too small to enable the 50 Hz to be locked. The control is used only to alter the frequency slightly, to eliminate any objectionable colour patterning on the screen.

TC2 sets the frequency of the colour subcarrier oscillator and unlike TC1 Sinclair advise precise adjustment using a frequency counter. I've personally had no problems with the setting of this control but if a check is required it should be possible to compare the results with the frequency obtained from a TV set locked to a transmitter.

VR1 and VR2 are the only controls that may present difficulties. They affect the phasing of the colour-difference signals and are interactive in their effect on the display. Take particular care when dealing with issue 1 models because although the controls are in the same positions and are marked as shown in Fig. 8 the connec-

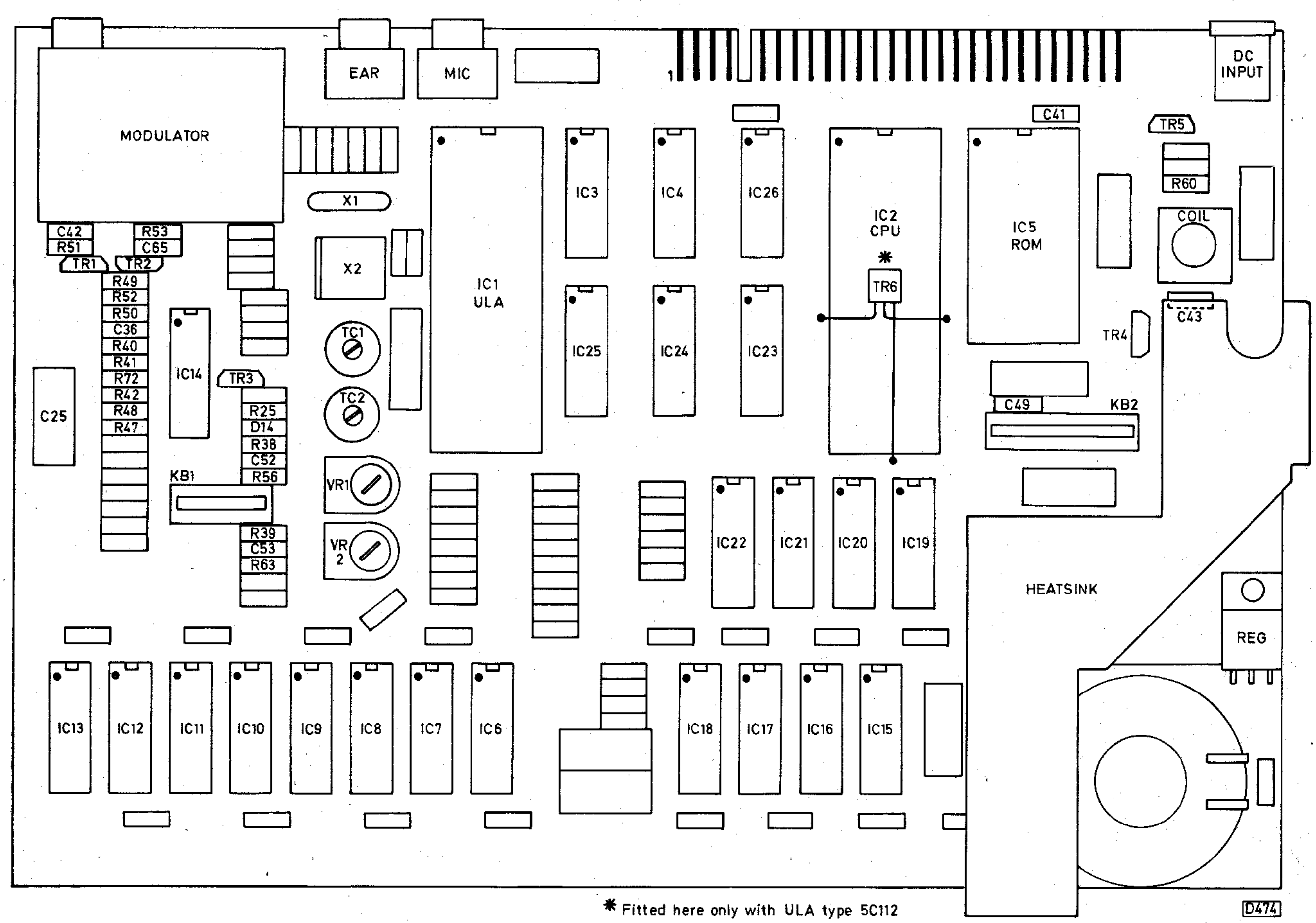


Fig. 8: Layout of the issue 2 board.

tions between them and IC14 are reversed.

A colour display is necessary for setting and checking these controls. The following short program will display colour bars, enabling the effect of any changes to be seen across the colour spectrum. It's advisable to save this program to make it easier to load when the top case and keyboard are lifted to reach the presets.

```
10  FOR N = 0 TO 7
20  FOR M = 0 TO 3
30  PAPER N : PRINT "    ";
40  NEXT M
50  NEXT N
60  GOTO 10
```

This will display the Spectrum colours corresponding to keys 0 to 7, i.e. black, blue, red, magenta, green, cyan, yellow and white.

If there's no colour on the screen when this program is entered and run, check the TV set's tuning and colour controls. If there's still no colour the controls will have to be set up. The procedure suggested by Sinclair is as follows.

(1) Switch on and initialise the computer. Do not enter a program.
(2) Using TC2, set the colour subcarrier frequency to 4·433619MHz ± 50Hz.
(3) Using VR1, set the voltage at pin 4 of IC14 to 50mV +0mV/−5mV relative to pin 3.
(4) Using VR2, set the voltage at pin 2 of IC14 to −50mV +5mV/−50mV relative to pin 3.

These settings are designed so that pins 2 and 4 will be at zero with respect to pin 3 when the computer is at its operating temperature. In the factory however they set pin 4 to 130mV ± 20mV and pin 2 to −75mV ± 20mV, so you can take your choice which values to use.

Personally I prefer the following method of setting these controls. It may seem very complex at first sight but it's actually quite simple. A word of explanation. Those of you who are long in the tooth – and short of hair – may remember ion traps. These could be set in a few seconds but it took you twice as long even to read the Mullard instructions. This procedure is similar. As the settings aren't critical – about the same as the average hold control – getting the colour correct is easier than reading the instructions. So here they are:

(1) Load the program above and run it.
(2) Assume that the subcarrier frequency is o.k. and set VR1/2 to mid-travel.
(3) Slowly sweep VR1 until colour is displayed. If no colour shows during the full travel of VR1, move VR2 slightly and try again.
(4) Keep moving VR2 in steps of about 20° to 30°, sweeping VR1 slowly back and forth until colour has been obtained, or the whole range of both potentiometers has been covered.
(5) If no colour can be obtained at any settings, mark the position of the vanes of TC2 and move it approximately 30°. Repeat (3) and (4) above. At worst it should take only about four-five repeats to get some indication of colour.
(6) When some colour is displayed, move the presets one at a time until the full eight colour bars are present, in their correct colours. Finally, find the optimum position for each adjustment, going over TC2, VR1 and VR2 at least twice.

The colour controls should now be set up correctly and the bars displayed in their correct colours. Check by switching channels on the TV set and making sure that the colours lock without any delay. When all is well set TC1 as described below.

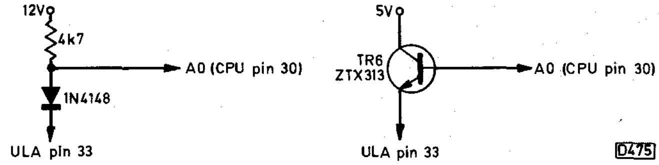


Fig. 9: Modifications associated with pin 33 of IC1: early version left, later version right.

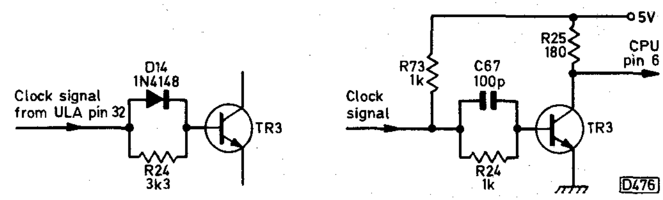


Fig. 10: Modified clock circuit. It's essential to modify the circuit to that shown on the right whenever the earlier version is found.

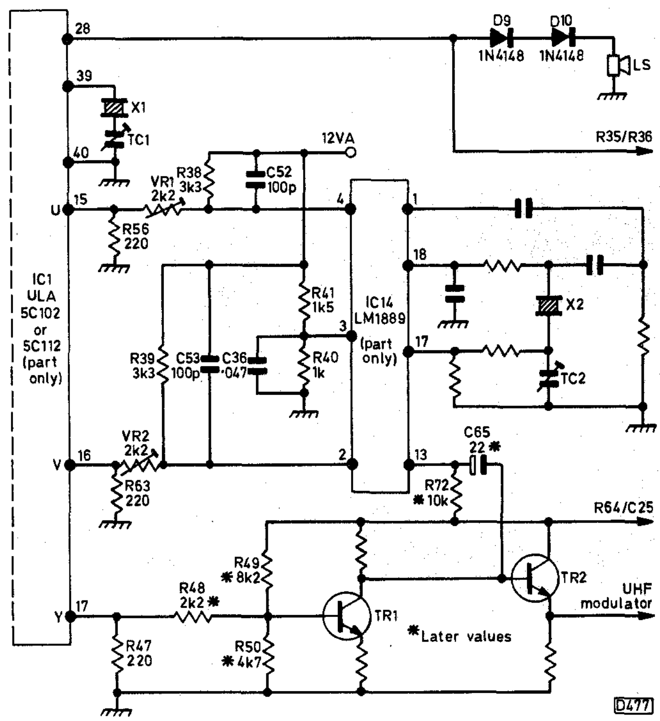


Fig. 11: Circuit variations around IC1/IC14 in earlier versions – compare with Figs. 1 and 5.

If you still have a problem there could be a fault in IC14, the associated circuitry or the signals from the ULA. The colour-difference signals can be checked either at pins 17 and 18 of the edge connector (underside) or at VR1 and VR2. Examination of the signals with and without the colour display running will show if the ULA is o.k. Check the oscillator and its frequency at pin 17 of IC14 – use a high-impedance probe when checking the frequency.

Finally, when a satisfactory colour display has been obtained put in a program giving a screenfull of characters in red ink with a background of green paper and adjust TC1 for minimum patterning. Some early machines have a hole in the bottom of the case to enable this adjustment to be carried out with the computer fully assembled.

Next month we'll deal with the 4A, 4B, 5 and 6A versions.

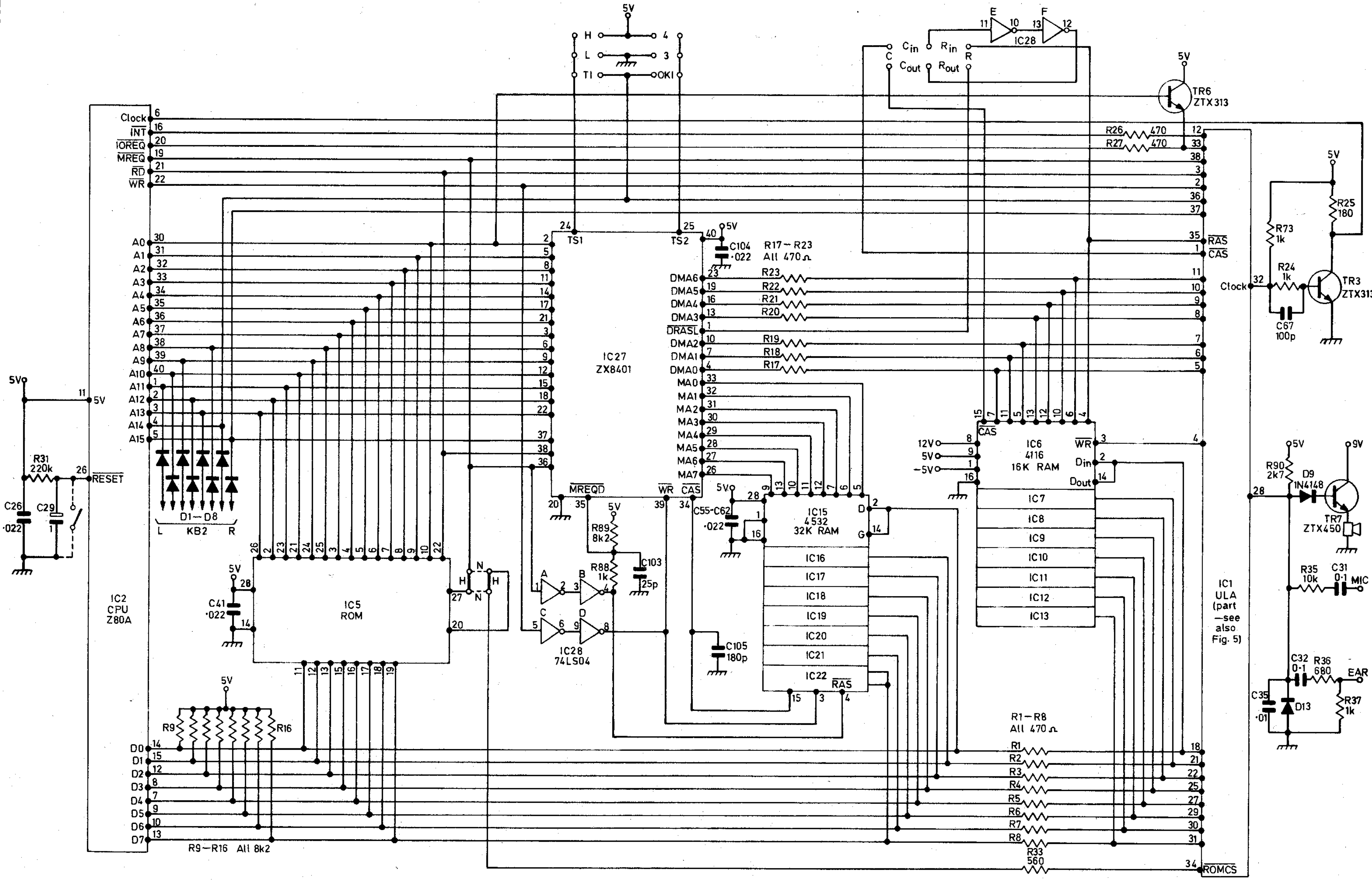


Fig. 12: Computing circuitry used in the issue 6 version of the Sinclair Spectrum microcomputer. Pins 7/11/5/13/12/10/6 of IC6 are connected to chassis via 1k resistors (R50-56). All diodes are type 1N4148.

Servicing Sinclair Microcomputers

Part 6 **Ken Taylor**

Previous instalments in this series have dealt with versions of the Spectrum up to and including the 3B. Development continued, and issues 4A, 4B, 5 and 6A subsequently appeared. With each new version the board varies somewhat from the previous one. The differences with the later versions are highlighted below. We'll deal with the voltage generator section separately because although the basic design remained the same there were a number of modifications.

The Later Spectrums

The issue 4A and 4B boards are similar to the 3B, the main exception being the use of a 6C001-7 ULA chip. This necessitated a timing modification. The two spare nand gates in IC24 are connected in series (to maintain the correct polarity) and replace R32 in the $\overline{RAS}$ line to IC3 and IC4 (see Fig. 1 part 3). Replacement ULAs must be of the −7 or later type.

A major change was introduced with the issue 5 board. The six decoder/multiplexer chips IC3, IC4, IC23, IC24, IC25 and IC26 were replaced with a Mullard ULA type ZX8401. But something seems to have gone wrong somewhere because the two gates are still needed in the $\overline{RAS}$ line and the new circuit requires an additional four. A 74LS04 hex inverter chip (IC28) provides the six inverters required. Although these changes greatly altered the appearance of the board the basic circuitry hasn't changed very much and servicing shouldn't be affected.

The issue 6 version is very similar to the issue 5, but there's now an alternative supplier of the main ULA (IC1) – Saga joins Ferranti. Certain component changes go with this (see Table 4). Fig. 12 shows the computing circuitry used in the issue 6 version – refer to Fig. 5 for the rest of the circuit. Note that for clarity some supply line decouplers have been omitted, also the connections to the edge connector (refer to Table 3 for these).

The Voltage Generator Circuit

Throughout the development of the Spectrum the circuit that's been most subject to change has been the

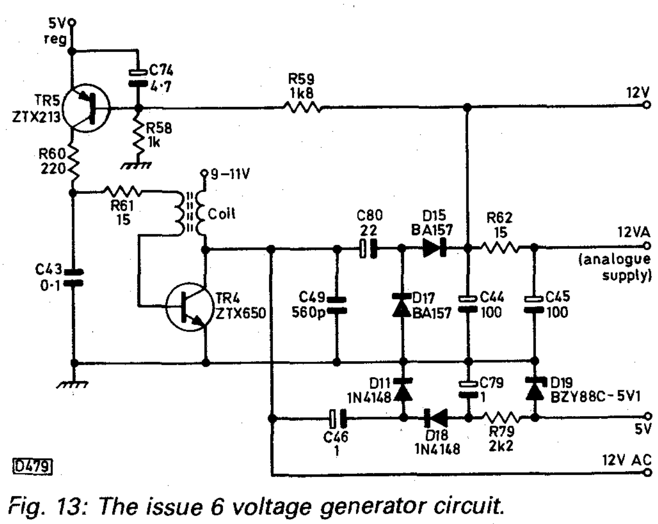


Fig. 13: The issue 6 voltage generator circuit.

voltage generator. The issue 3/3B version shown in Fig. 4 had already been substantially modified from the issue 1 version. The item that's seen most alteration has been R60, whose value has gone up and down in an almost random manner. Some of the changes are more logical. For example the introduction of the 22μF capacitor (C80) in the 12V supply: this isolates the 9-11V input from the output when there's an oscillator fault. It seems that each time the board was changed this circuit was subject to modification whether or not it improved the performance.

In the hope that they got it right by this stage the issue 6 circuit is shown in Fig. 13 (lucky for some?). If you are making any changes I would recommend that you use the values shown here, though if you compare this circuit with Fig. 3 you'll see that they differ in only a few respects. In any case, when TR4 has blown the minimum alteration I'd advise would be to change R60 to 220Ω and to fit C80 and D17 if these are not already present. Any other changes are up to you.

Correction

Note that the EAR socket circuit was shown incorrectly in Fig. 5. It should be as shown in Fig. 12 in all versions.

Alternative Components

Instructions for fitting alternative ROM and ULA chips have been given in earlier instalments. RAM chip replacements have also been dealt with. It's recommended that all replacement ceramic capacitors are of the axial type – if you can get them. Here's a list of alternatives to the E-line transistors (you may find that some are more obscure than the originals):

Table 4: Component changes when alternative ULAs are fitted to issue 6 boards.

Component	*Saga ULA*	*Ferranti ULA*
C30	Delete	22nF
C32	220nF	100nF
C35	100nF	10nF
C52/3	Delete	150pF
C67	Delete	100pF
C68-71	Delete	100nF
C76	Delete	22nF
R33	560Ω	680Ω
R34	Delete	15Ω
R48	Zero ohms	2k2
R49	Delete	10k
R50	Delete	4k7
R51	1k2	2k2
R56	Delete	1k
R63	Delete	1k
R65-67	Delete	10k
R68	Delete	6k8
R69	Delete	10k
R73	Delete	1k
R74-5	Delete	10k
R76-7	Delete	1k

Refer to Figs. 1, 5 and 12 as necessary.

Original transistor	*Alternatives*
ZTX650	TIPP31, ZTX651
ZTX313	MPS2369, MPS2713
ZTX213	BC213, BX214

Suppliers

The following firms can supply Sinclair spares and will provide a price list on application (send a stamped-addressed envelope in the case of PV Tubes and Video Vault Ltd.). It's worth comparing prices and charges which can vary quite a bit.

CPC Ltd., 194-200 North Road, Preston, Lancs PR1 1YP.

PV Tubes, 104 Abbey Street, Accrington, Lancs BB5 1EE.

Video Vault Ltd., 140 High Street West, Glossop, Derbyshire SK13 8HJ.