SPECTRUM

Melbourne House

SPECTRUM Hardware MANUAL

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NEW & REVISED FOR SPECTRUM ISSUE 3

IN THE UNITED KINGDOM —
Melbourne House (Publishers) Ltd
Castle Yard House
Castle Yard
Richmond, TW10 6TF

IN AUSTRALIA —
Melbourne House (Australia) Pty Ltd
2nd Floor, 70 Park Street
South Melbourne, Victoria 3205

ISBN 0 86161 115 2

Edition: 7 6 5 4 3 2
Printing: F E D C B A 9 8 7 6 5 4 3 2 1
Year: 90 89 88 87 86 85 84

ACKNOWLEDGEMENTS

I would like to acknowledge the contributions of the many people who have provided valuable assistance and suggestions for improvements to the book. Alfred Milgrom of Melbourne House was very helpful from the start. My many friends at Cambridge, especially Mark Plumbley and Julian Bane were always prepared to discuss technical problems and provide suggestions for improvements. My brother Nigel and John Kimmitt at Churchill College proof read the book. The continuous support of both my parents was invaluable. Finally, I will be grateful to receive any further suggestions from Spectrum users for improvements to the book.

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APPENDICES

1. INTRODUCTION

The ZX Spectrum as supplied includes an introductory booklet and a Basic programming manual. These books together contain virtually no detailed information on the hardware aspects of the computer. This book fills in that gap by providing an in depth look into how the Spectrum works. For the absolute beginner who knows nothing about computer hardware, this book provides a good introduction to what makes a computer tick. For the advanced electronics wizard who is desperate to use his Spectrum to perform all sorts of weird and wonderful tasks, this book also holds the key, by providing invaluable circuit diagrams and operational descriptions.

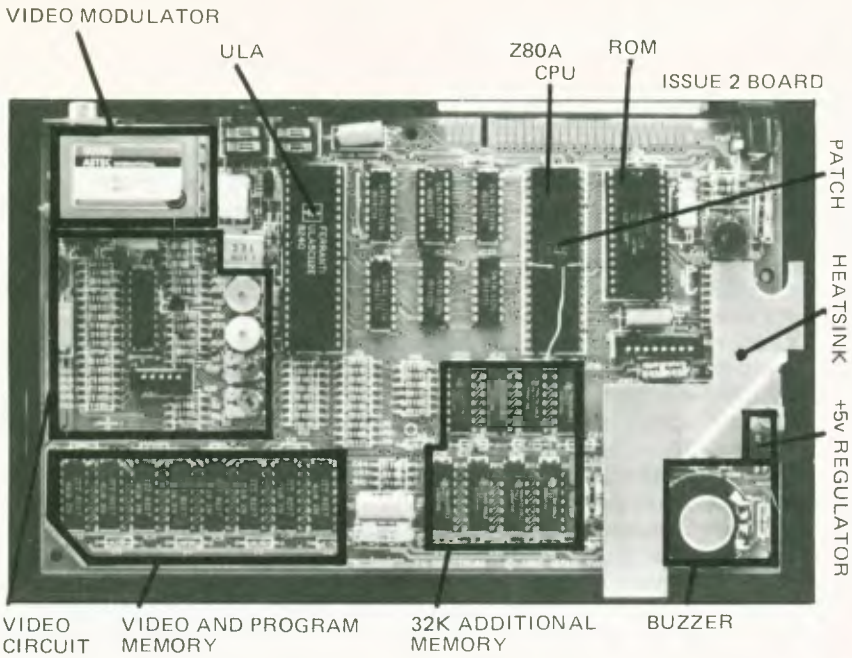
Starting off by explaining the fundamental principles behind the Spectrum's operation, the book progresses with full descriptions of how each part works and how all of the parts interrelate. After a complete explanation of all the edge connector signals, simple illustrative experiments making use of these signals are given. The remainder of the book consists of practical circuits which you can build. Constructional hints, drawings and photographs are included to help beginners with no previous experience.

All of the Spectrum circuit diagrams contain component numbers such as TR4. These are generally the codes printed by the components on the Spectrum circuit board. There is a full layout diagram of the Spectrum board together with marked positions for each component in Appendix D. The complete circuit diagram can be found in Appendix E. You should refer to these appendices if you wish to find the position of any components. The component codes given for the additional hardware projects refer to the parts list for the project, not to the main Spectrum parts list.

There are currently three different versions of the Spectrum in circulation. The first 60,000 machines were 'Issue 1', the next half-a-million were 'Issue 2', and all new machines are 'Issue 3'. Earlier editions of the Hardware Manual dealt with the Issue 1 Spectrums. This edition only deals with Issue 2 and Issue 3 Spectrums. Whilst the differences between these two types of Spectrums are in most areas minor, certain features on the Issue 2 are no longer present on Issue 3's. Major differences are described in the relevant chapters as they occur. Some minor differences, such as a new capacitor or resistor are not included on all of the circuits throughout the book. However, the full circuit diagrams in Appendix E show all of these differences.

Before we start delving deeper into the intricacies of hardware, a few words of warning will be given. The Spectrum contains a lot of sensitive and expensive chips. These will not be damaged provided that you take adequate precautions. If you are adding any kind of interface to the Spectrum, always switch off all power supplies before making the connection to the Spectrum. Always switch on the Spectrum before or simultaneously with any external power supplies. Finally, if you are testing various voltages inside the Spectrum or on its edge connector, take care not to short any pins together by mistake. Check and double check everything you do!

PLEASE NOTE — whilst every effort has been made to ensure that all information given in this book is correct, no responsibility can be accepted for any errors which may have occured. All Spectrum circuits are the copyright of Sinclair Research Limited. Other designs and programs are the copyright of the author.



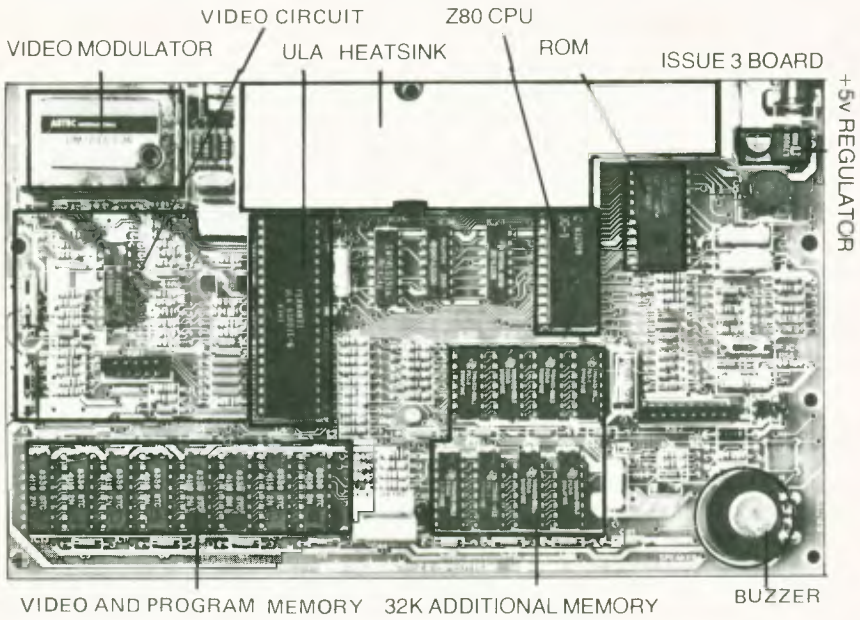


PLATE 1 – PHOTO OF MAIN SPECTRUM BOARD & ANNOTATIONS

2. GENERAL OVERVIEW OF THE SPECTRUM

This chapter is essentially in two parts. The first part aims to introduce the basic concept of binary numbers. The second part explains each of the main sections of the Spectrum in a general way.

SECTION A

Computers are essentially two state devices. They rely upon logic to operate. This logic can be in one of two states only. For convenience, these two states are usually represented by a 0 and a 1. At its simplest level, the computer manipulates 1's and 0's to produce the answers. Consider for example the simple operation of addition. This could be represented by a black box with two inputs, A, B and two outputs C, D. A and B could be added together to produce their sum represented by C and D. The addition would be carried out by several simple transistors inside the black box. The addition function would be defined in binary as follows:

A	+	B	=	D (sum)	& C(carry)
0	+	0	=	0	0
0	+	1	=	1	0
1	+	0	=	1	0
1	+	1	=	0	1

Note that 1 + 1 cannot equal 2 because in the binary number system, only 0 and 1 can be used. The carry bit here is similar to that in the decimal number system. If we added 8 + 9, this would give 7 carry 1 in the decimal number system. The difference is that a carry in binary represents 2, whereas it represents 10 in decimal.

SECTION B

In the following descriptions of the various sections within the Spectrum, you will find it helpful to refer to the overall block diagram in fig 1.

The central processing unit (CPU) is, as its name implies, central to the operation of the Spectrum. It is connected to other parts of the computer by data, control and address buses (more about these later). The CPU in the Spectrum is a Z80A and lives inside the large chip IC2 at the centre of your Spectrum board. This processor is an 8 bit device which means that there are 8 separate connections in its data bus. The CPU can send information to other devices in the Spectrum along this data bus and the other devices can send data back to the CPU via the same bus. Because there are eight connections, each one of which can be either a logic 0 or a logic 1, any number between 0 (all 0's) and 255 (all 1's) can be sent via the data bus ($255 = 2^8 - 1$).

You may wonder how the CPU can understand very large decimal numbers or words typed at the keyboard when it is using BASIC. After all, if you type HELLO at the Spectrum keyboard it might be difficult to see how this can be represented by a number between 0 and 255. In fact, the answer is not very difficult. The CPU only deals with a small part of the operation at a time. To understand HELLO, the CPU first deals with the H (seen by the CPU as 72 decimal), then it deals with E

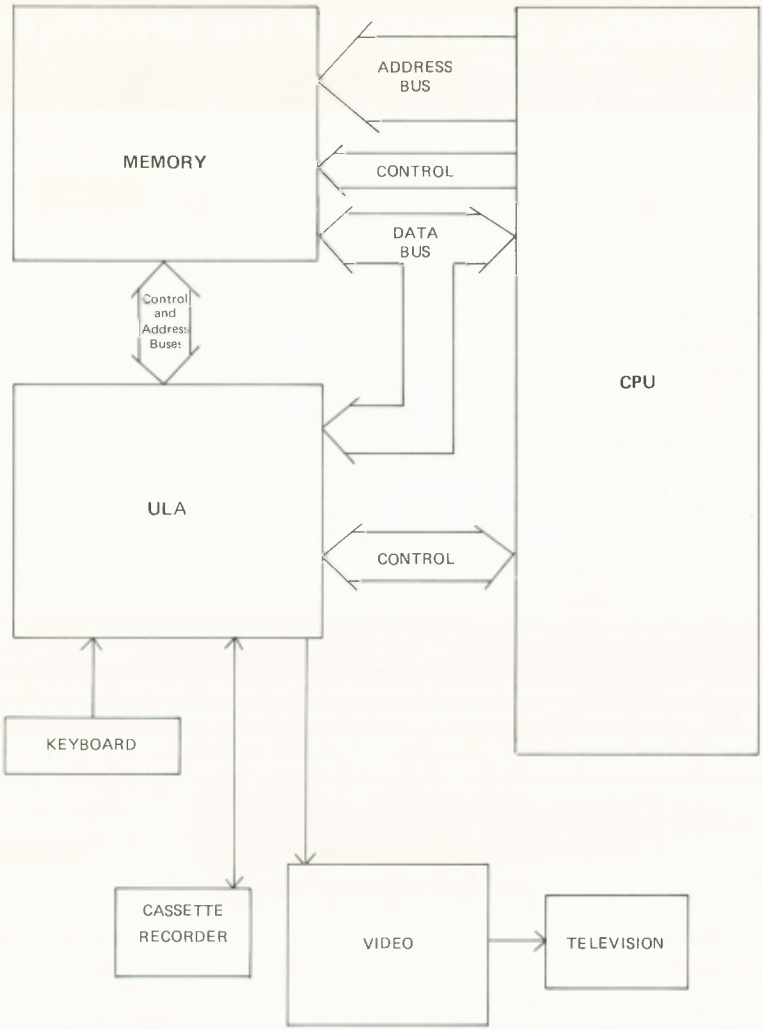


FIG 1 – SPECTRUM BLOCK DIAGRAM

(seen as 69 decimal) and so on (see Appendix A of your Spectrum BASIC manual for a complete list of characters and their decimal equivalents). Large decimal numbers are dealt with in a similar way. Each decimal number is stored in the Spectrum in 5 bytes of memory. Chapter 24 of the BASIC manual explains how these bytes are used.

Before the CPU can actually start doing anything, it must be instructed what to do. The instructions for running BASIC are held in memory. The BASIC operating system program contains all of the information required by the CPU to understand BASIC. This operating program is written in machine code and starts to run when you switch the Spectrum on. The actual program is stored in the read only memory (ROM) chip IC5. Read only memory cannot be modified by the CPU and the program remains fixed in the memory chip even when the power is switched off.

The BASIC programs which you enter into the Spectrum go into random access memory (RAM). Unlike the ROM, this type of memory can be changed by the CPU. When the power is switched off, RAM forgets everything that was stored inside it. You therefore have to save your programs on a cassette before switching off. If you do not, the program will be lost forever.

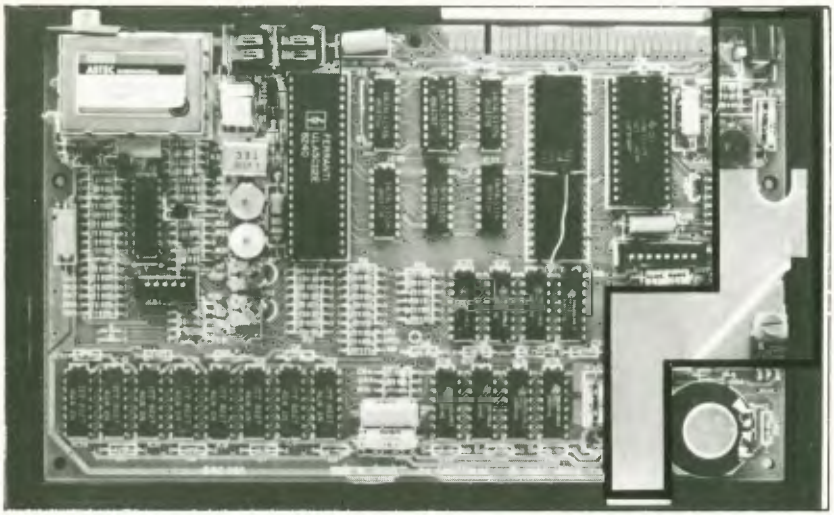
Having found what to do from the program in ROM, the CPU must get inputs from the keyboard or cassette and send outputs to the video display or cassette. The uncommitted logic array (ULA) helps the CPU to interface with the outside world. The ULA gets information directly from the keyboard and cassette inputs. This information is then sent to the CPU. When the CPU wants to record a program on cassette or buzz the buzzer, it tells the ULA to do it. Output to the television is rather more complex. The ULA copies the screen output from the video memory to the video output circuit 50 times every second. This creates the illusion of a continuous display. All that the CPU has to do when it wants to output to the TV display is to put the video information into the video memory. The ULA then does the rest.

So far, transfer of information between the CPU, memory, ULA, keyboard etc. has been taken for granted. How is it actually done? All data is transferred via the data bus. The type of transfer being carried out is defined by various control signals on the control bus. For example, the CPU sends out a read signal if it wishes to read some data from the ULA or memory. This tells the ULA or memory to send some data to the CPU. If the CPU wishes to output something to be stored in memory, it sends out a write signal. This tells the memory that it must store the data from the data bus. So that the memory knows where it should store the data, the CPU also supplies an address on the 16 bit address bus. The address bus therefore allows the CPU to send or read data from up to $2^{16} = 65536$ different memory locations.

The buses can only deal with the two logic states 0 or 1 on each of their lines. In practice, these logic states are represented by voltages. By convention (so that most modern computer integrated circuits are compatible with one another), logical 0 is represented by a voltage between 0 volts and 0.8 volts. Logical 1 is represented by a voltage between +2 volts and +5 volts (the maximum supply voltage for logic chips). If the voltage is between 0.8 volts and 2 volts, the signal is in the process of changing from 0—1 or 1—0. All logical data transfers occur within these voltage limits. The chips are designed so that they are not reading data at times when it may be changing.

You should now have a basic understanding of the blocks which make up the Spectrum. The following chapters explain each of these blocks in much greater detail. Each block is considered in isolation, but you should always try to remember how it is connected into the rest of the system. The full circuit diagram of the logic systems which make up the Spectrum can be found in Appendix E. You can refer to this diagram if you have any difficulty in seeing how the individual circuits interconnect.

ISSUE 2 BOARD



ISSUE 3 BOARD

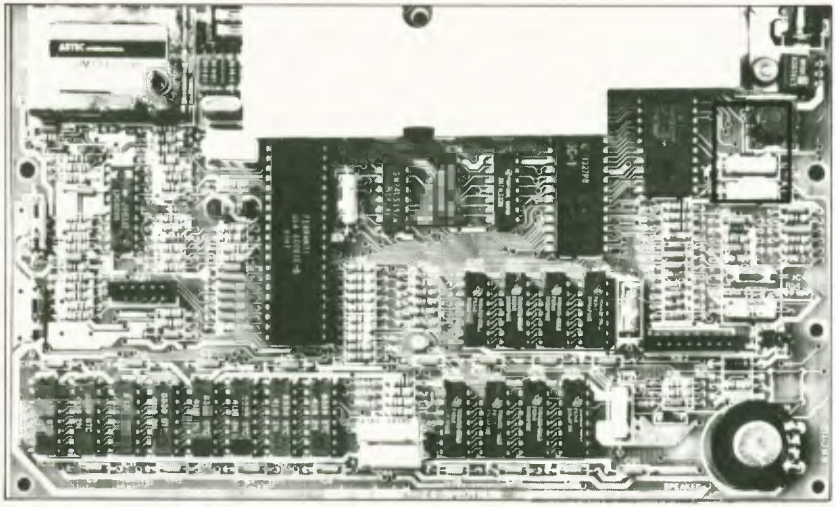


PLATE 2 – PHOTO OF MAIN SPECTRUM BOARD
WITH POWER SUPPLY OUTLINED

3. THE POWER SUPPLY

The power supply of any computer is probably the piece of circuitry most often overlooked by the user. The computer is connected to the mains supply and it comes to life. It is just taken for granted that the correct currents and voltages will be generated. If you are going to add on your own hardware however, a complete understanding of the power supplies is necessary. This chapter therefore takes a close look at that forgotten piece of circuitry and its limitations. The chapter explains how to make the most of your Spectrum power supply. It also provides circuits for additional power supplies for use with your external circuits.

In the Spectrum, all of the power comes in at +9 volts at a current of up to 1.2 amps. This is supplied from a ZX Mains Power Supply. Unfortunately, none of the chips in the Spectrum use a 9 volt supply. Most of the logic, including the CPU operates from a +5 volt supply. The video circuit requires +12 volts supply as well. The video memory chips are most awkward of all, requiring +12v, +5v and −5v all at once!

The problem isn't simply one of producing a supply that is roughly constant at roughly the right voltage for most of the time. The +5 volt supply must be within 5% of +5 volts and the +12v and −5v supplies within 10% of their nominal value all over the circut all of the time. Even a microsecond's drop in voltage could spell disaster. How are these constant voltages produced?

THE +5 VOLT SUPPLY

This is the major supply in the Spectrum. In the 48K version it is really stretched to its limit supplying a full 1 Amp of current. Looking at the regulator, you will see that it is bolted onto a large piece of aluminum. The little +5 volt regulator integrated circuit with only three connections to the outside world, contains complex regulation circuitry.

Referring to fig. 2a, the 7805 regulator accepts +9 volts at its IN pin. The internal regulation circuitry then reduces this to +5 volts at the OUT pin. The fact that the input is +9 volts is irrelevant (except for the amount of dissipated power). It could equally well have been anything from +7 volts to +25 volts, the output would still remain at a steady +5 volts. You might wonder where the lost 4 volts has gone to. It is dissipated as heat by the aluminum heatsink. When the regulator is supplying 1 amp, 4 watts have to be dissipated by the heatsink (about one quarter of the heat from a small soldering iron!). That's why the Spectrum soon gets quite hot after it is switched on.

THE +12 VOLTS SUPPLY

The 5 volt supply was relatively easy to produce. 4 volts were simply dropped by the regulator. Producing the +12 volts with only +9 volts available is rather more complex. Referring to fig 2b, TR5, TR4 and their associated components produce the 12 volt supply. TR5 forms a current feedback for the oscillator formed by C43, R61, L1 and TR4 (the main power drive transistor). Operation of the circuit relies upon the induced reverse voltage across L1 which occurs on every cycle of oscillation. This reverse voltage pushes the collector of TR4 up above 9 volts to a maximum of about +13 volts. At this level, D15 conducts to charge up the +12 volt supply capacitor C44. C44 then discharges to provide a constant

+12 volts to the memories and video circuit when D15 is not conducting. If the +12 volt supply starts to fall too low, this causes TR5 to conduct more. The oscillation frequency of the oscillator then increases, boosting the voltage back up to its original level.

THE −5 VOLT POWER SUPPLY

Again refer to fig 2b. The −5 volt part of the circuit consists of C46, D11, R55, D12, D16, R54 and C47. This circuit operates on the "charge pump principle". Remember that the collector of TR4 in the 12 volt circuit is oscillating rapidly between about +13 volts and 0 volts. When rising up to 13 volts, C46 is charging via D11 up to a maximum of about 12 volts (0.7 volts are dropped across all silicon diodes during conduction). When the collector of TR4 drops to 0 volts, this pushes the negative plate of C46 down to −12 volts. C47 then charges via D12 and R55 from C46. The voltage across C47 is held constant at −5 volts by the zener diode D17. C46 is then charged up again on the next oscillator cycle and so on.

CURRENT LIMITS

Currents which can be drawn from the Spectrum's own internal power supply for use by external circuits are fairly limited. For the 16K Spectrum, about 300 mA extra can be taken from the +5 volt supply. The absolute maximum limits are rather difficult to define. Generally, the more you take from the power supplies, the worse the regulation becomes. Bad regulation can cause the computer to crash more frequently, but shouldn't cause any damage provided that you stay within the limits recommended above. For 48K Spectrum owners, it is advisable to add an extra +5 volt supply for all external circuits. The current limits on the other supplies are similar to those for the 16K version.

THE −12 VOLT SUPPLY

You may now be wondering what has happened to the −12 volt supply. It is shown on the edge connector in the Sinclair BASIC manual. However, it isn't shown on the main circuit diagram. In fact, it doesn't exist. The '−12 volt' connection was wrongly labelled. It should really be 'unregulated +12 volt', since it is connected to the collector of TR4. Luckily, it is very easy to use this oscillating +12 volt supply to produce a −12 volt supply, with the addition of a few common components.

Referring to fig 2c, you will almost instantly recognise a circuit very similar to that for the −5 volt supply in the Spectrum. It works on exactly the same charge pump principle. No zener diode has been incorporated in this circuit, because the 33 uF capacitor charges up to 12 volts anyway and is therefore at the correct voltage. Regulation of this type of circuit is never very good under load. The voltage will rise to about −10.5 volts if you take 20mA from the circuit, so this is the recommended maximum current. If you decide to build the circuit then make sure that the two capacitors are rated at 16 volts or above. Apart from this, none of the component values are critical.

EXTRA +5 VOLT SUPPLIES

For all but very low current circuits on the 48K Spectrum (such as the simple resistor and switches type of experiments in this book), you will have to add an external power supply. The same will apply to the 16K version if you want to draw more than 300 mA from the +5 volt supply. In either case, you have two options:

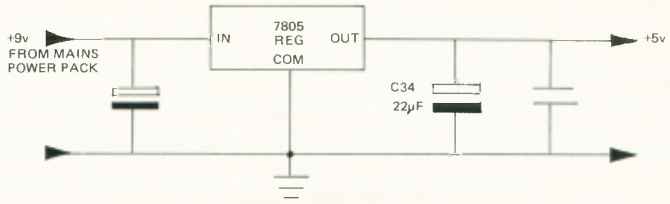


FIG 2a – +5volt POWER SUPPLY CIRCUIT DIAGRAM

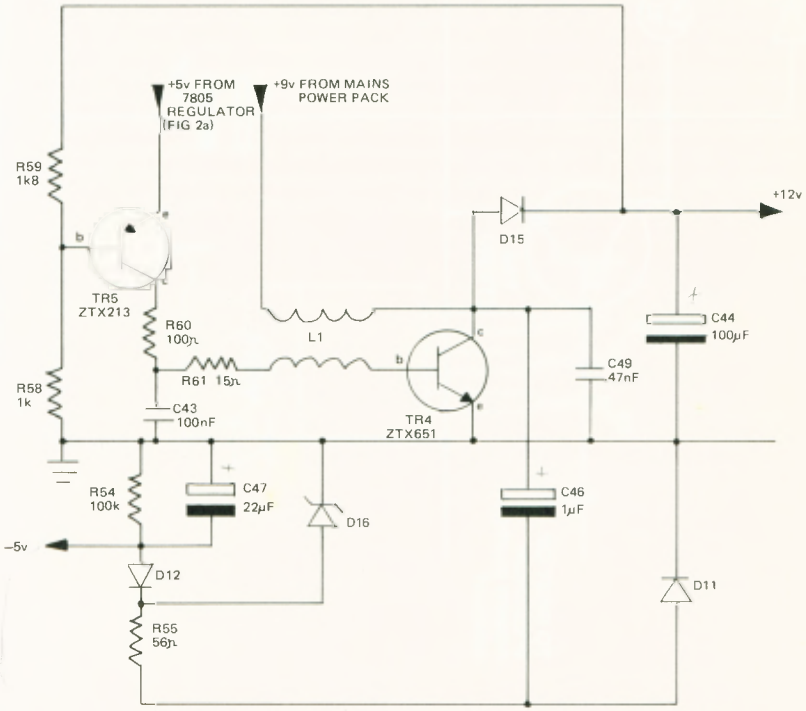


FIG 2b – +12volt AND–5volt POWER SUPPLY CIRCUIT DIAGRAM

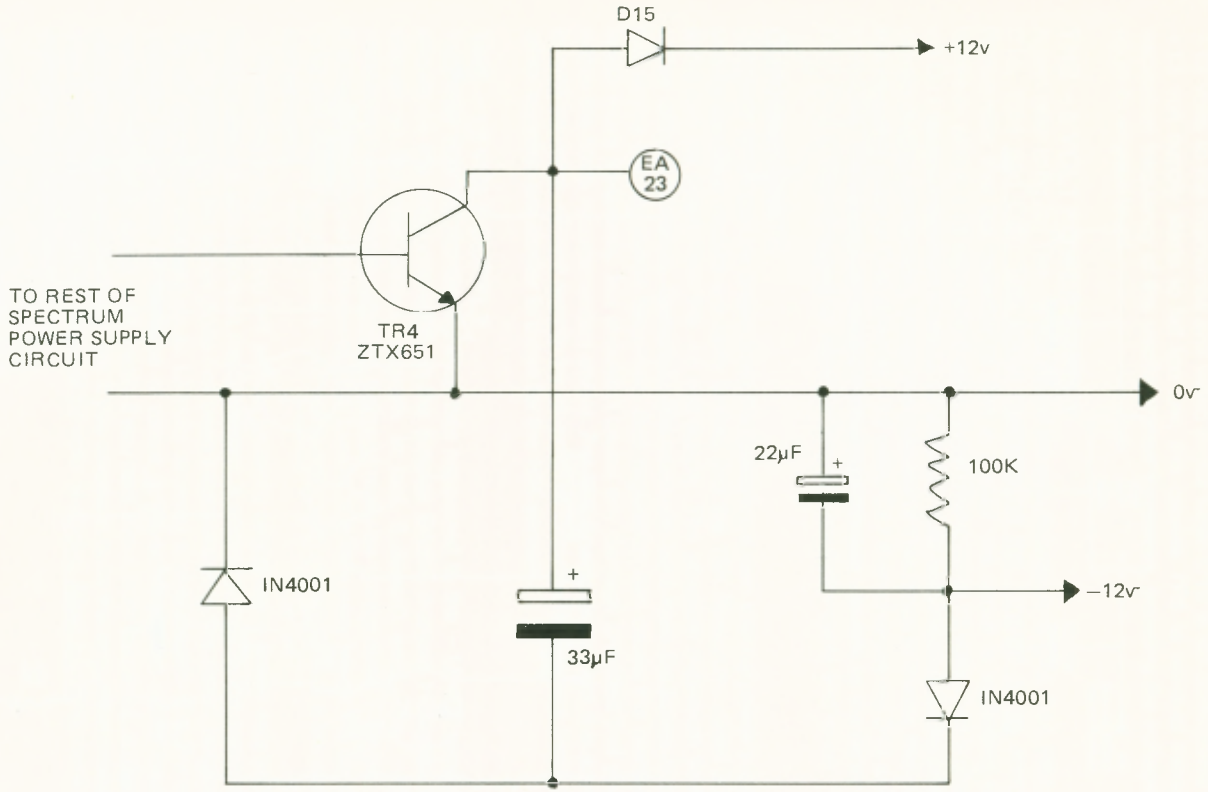


FIG 2c – ADDITIONAL CIRCUIT FOR −12v SUPPLY

1. Using the ZX Power supply

There will be some extra current capacity available from your +9 volt Spectrum supply, especially if the +12 volt supply is not fully loaded. The author found it quite acceptable to obtain up to 500 mA more from the ZX supply. The circuit for doing this is shown in fig 2e. Only that part of the circuit to the right of the figure is required. This circuit is basically identical to the one used inside your Spectrum. Connect the 7805 regulator as shown in fig 2d, its input pin being connected to +9 volts. This pin diagram shows a view looking down onto the black plastic part of the regulator, which has the device number stamped on it.

Do not forget to bolt a heatsink onto the regulator. Small vaned heatsinks of a suitable type are available from most good electronic stores. A cheap alternative is to bolt a piece of aluminum onto the regulator. A piece similar in size to that in the Spectrum will do nicely. C1* in fig 2e should be included to help regulation. 22uF at 16 volts will do. Another 22 uF capacitor should also be included across the output. It is advisable to scatter some 0.1 uF decoupling capacitors around as well. About one for every two chips should be sufficient. The +5 volts provided by this circuit should not be connected to your main Spectrum +5 volt supply rail. Only the 0 volts connection should be made to all chips.

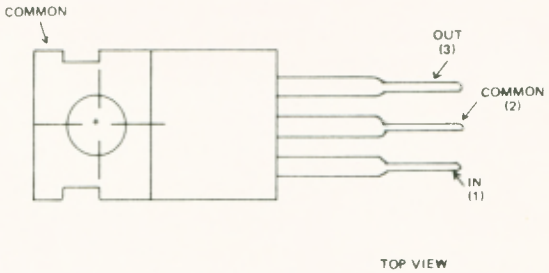


FIG 2d – 7805C 1 AMP/5 VOLT REGULATOR PIN CONNECTIONS

2. Using an extra mains supply unit

The full circuit is shown in fig 2e and will provide up to 1 Amp at +5 volts. Instead of connecting pin 1 of the regulator to the Spectrum +9v supply, as in the previous example, it should be connected to the new +9 volt supply. This extra +9 volt supply consists of a 240v to 9 volt at 1 amp mains transformer, a 1 amp bridge rectifier (BR1) and a large 1000uF +25 volt smoothing capacitor C1. You must ensure that the mains transformer is safely wired up. Build it into an earthed metal case. The 7805 can then be bolted to the case, which will act as the heatsink. Accessible mains connections must be avoided to eliminate the possibility of an electric shock. Apart from the differences mentioned above, the circuit is identical to that described in section 1.

You should ensure that the mains supply is connected to your extra power supply at the same time as the Spectrum. If power is not applied simultaneously, some chips could be damaged, because they don't like to have voltages applied to any of their pins without power being applied to them.

DECOUPLING CAPACITORS

The power supplies are distributed all over the main Spectrum board. Therefore, if a chip on the far side of the board from the power supply suddenly requires extra current, a localised drop in voltage could occur. If the voltage drops too low (even for a microsecond), it could be enough to destroy essential data and programs stored in memory. Supply 'decoupling capacitors' are therefore placed at strategic positions around the board. They are able to smooth out the supply by providing large currents for short periods of time. The voltage is therefore held approximately constant. C1—C8 around the memory chips are there for this reason, as are the other capacitors around the board connected across the supply rails. You should put some around any external circuits which you build as well. One 0.1uF capacitor for every two chips should be enough.

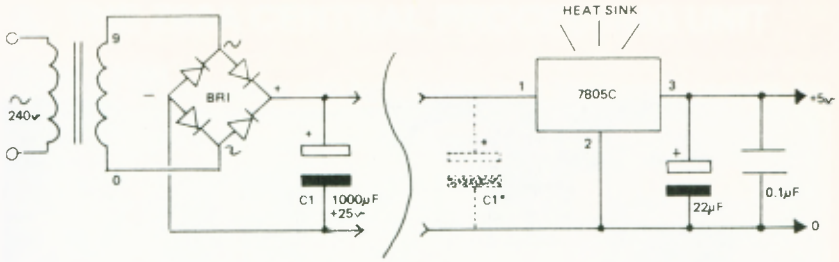
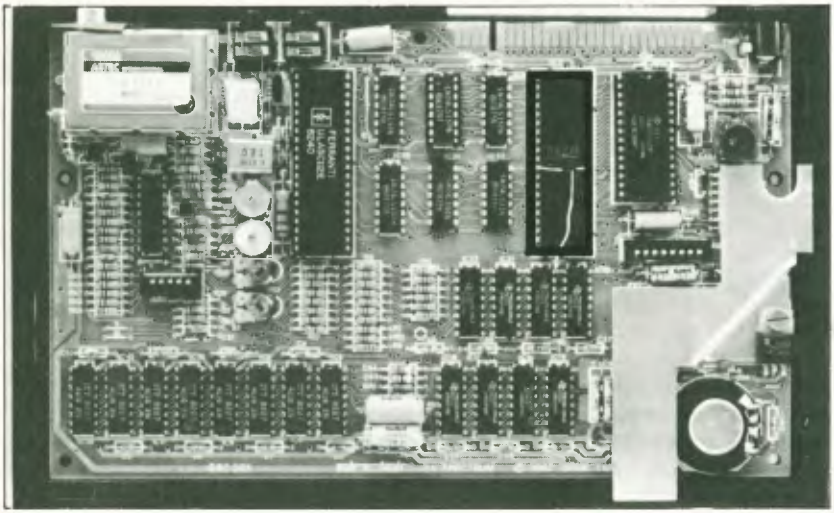


FIG 2e — ADDITIONAL +5 VOLT POWER SUPPLY

ISSUE 2 BOARD



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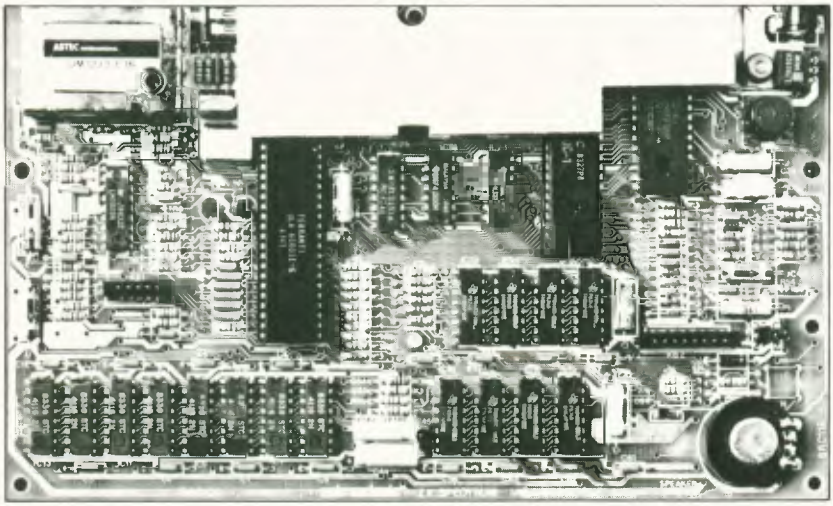


PLATE 3– PHOTO OF MAIN SPECTRUM BOARD
WITH Z80A CHIP OUTLINED

4. THE Z80A CENTRAL PROCESSING UNIT

This is the microprocessor chip itself. Housed in its 40 pin plastic package, this chip is the computing centre of your Spectrum. It is the big chip labelled IC2 in Appendix D. The CPU is able to perform several basic functions. These are:

Read data from memory
Write data to memory
Read data from an input/output (I/O) device
Write data to an I/O device
Perform arithmetic and logical operations on data

What the Z80A does at any particular time is determined by the instructions which it obtains from memory. There are 158 different types of instructions which the Z80A can understand. Programming the Z80A in machine code is a complete subject in itself. You should look at a specialised book on programming if you wish to know more.

You may have seen other computers using the Z80 chip, and wondered what the difference between it and the Z80A is. Both are identical in their operation. The only difference is that the Z80A can operate at speeds up to 4MHz whereas the Z80 can only operate at speeds up to 2.5MHz. More recently, a new chip called the Z80B has been introduced. This is still the same as the Z80 chip, but can operate at speeds up to 6MHz.

As was mentioned earlier, the Z80A is an 8 bit microprocessor. It transfers data 8 bits at a time. The first microprocessor chips were 4 bit devices, but now some microprocessors are 16 bit or even 32 bit devices. They tend to be rather faster than the 8 bit ones because they can transfer more information in the same time. However, they are much more expensive, so the 8 bit micros are more popular in home computers.

The Z80A clock signal runs at 3.5 MHz (except when accessing video/program memory — see chapter 8) in the Spectrum. All CPU operations are referenced relative to this clock signal, so the 0—1 and 1—0 transitions must be very fast to ensure that all operations start each cycle at exactly the same point. This is why TR3 and its associated resistors and diode are required. The 3.5 MHz clock signal from the ULA does not have a sufficiently fast logic 0 to logic 1 transition. Since all internal CPU circuits may start at slightly different voltages in the +0.8 volt to +2 volt range, if the time for the clock signal to go from +0.8 volts to +2 volts is significant (in nanoseconds!), different parts of the internal circuitry may start at different times. If there is a difference in start times, the Z80A may malfunction. TR3 ensures that the transition at the CPU clock pin is fast enough.

Z80A CPU PIN DESCRIPTIONS*

A0 — A15 The address bus — tristate outputs (ie 0 or 1 or floating. When floating, another device can provide the address bus instead of the CPU). This bus provides 2^{16} = 65536 different addresses for memory data exchanges or 2^{8} = 256 input/output device addresses (the lower eight address lines are used during I/O). The CPU can also refresh memory (see refresh pin) by providing

*note that signals with a bar over them such as $\overline{RD}$ are 'active low'. This means that a read is occuring when $\overline{RD}$ = 0. Normally, 1 = true and 0 = false but all Z80A control signals with a bar over them are inverted so that 0 = true and 1 = false.

valid refresh addresses on the lower 7 bits of the address bus.

D0 — D7 The data bus — these eight tristate bidirectional lines are used for data input and output transfers with the CPU. Transfers take place between memory or peripheral devices and the Z80A.

$\overline{M1}$ Machine cycle one — Output active low. The signal means that the CPU is currently getting the Op-code for the next instruction to be executed from memory. $\overline{M1}$ also occurs with $\overline{IORQ}$ to indicate an interrupt acknowledge cycle.

$\overline{MREQ}$ Memory request — tristate output, active low. This signal indicates to the memory that the address bus now contains a valid address for a read or write operation. This signal is required to distinguish between a memory or input/output operation. For example, $\overline{MREQ}$, $\overline{RD}$ and $\overline{ROMCS}$ must all be active before a read from the BASIC ROM can take place (see fig 5).

$\overline{IORQ}$ Input/output request — tristate output, active low. Indicates that the lower half of the address bus holds a valid I/O address for an I/O read or write operation. This signal is required to distinguish between an input/output or memory operation. Note that $\overline{IORQ}$ and $\overline{MREQ}$ will never be active at the same time.

$\overline{RD}$ Read — tristate output active low. Indicates that the CPU wishes to read from memory or an I/O device. The addressed device should use this signal to put the relevant data onto the CPU data bus.

$\overline{WR}$ Write — tristate output, active low. Indicates that the CPU data bus holds data to be stored at the addressed location, or output to the selected I/O port. Memory should use this signal to store the data from the data bus.

$\overline{RFSH}$ Refresh — output active low. Indicates that the lower 7 bits of the address bus contain a refresh address for dynamic memories. This is required by dynamic memory chips so that they do not forget. If they are not fully refreshed at least once every two milliseconds, there is a danger that memory will be lost. When this signal is present, the upper 8 address bus lines contain the CPU I register contents. This leads to a fault in the Spectrum hardware. By setting the I register to any value between 64 and 127, interesting contention for the video RAM occurs. A15 and A14 from the CPU are selecting the 16K of RAM which the ULA normally has priority over. In this case, although the relevant address occurs with $\overline{MREQ}$ active, no $\overline{RD}$ or $\overline{WR}$ signal occurs because it is a refresh. This combination of signals seems to confuse the ULA so that it doesn't stop the CPU clock properly. A BASIC program which will illustrate this problem is included in chapter 8 on the ULA.

$\overline{HALT}$ Output active low. Indicates that the CPU has executed a software HALT instruction. It awaits an interrupt from another device before it will continue operation. There is a simple experiment illustrating the operation of a HALT in chapter 14.

$\overline{WAIT}$ Input active low. Used by slow memory or I/O devices to tell the CPU that they are not yet ready for a data transfer. The CPU sits back doing nothing until the slow device indicates that it is now ready.

$\overline{INT}$ Interrupt request — input, active low. This signal can be generated by external devices to make the CPU run a special machine code program somewhere in memory. If the internal software controlled interrupt enable flip-flop is enabled, the CPU will accept and acknowledge the interrupt. A flip-flop is equivalent to one bit of memory. The CPU uses this bit of its internal memory to remember whether or not it should accept interrupts from other devices. For more details on the use of interrupts, you should refer to a specialised book on the Z80.

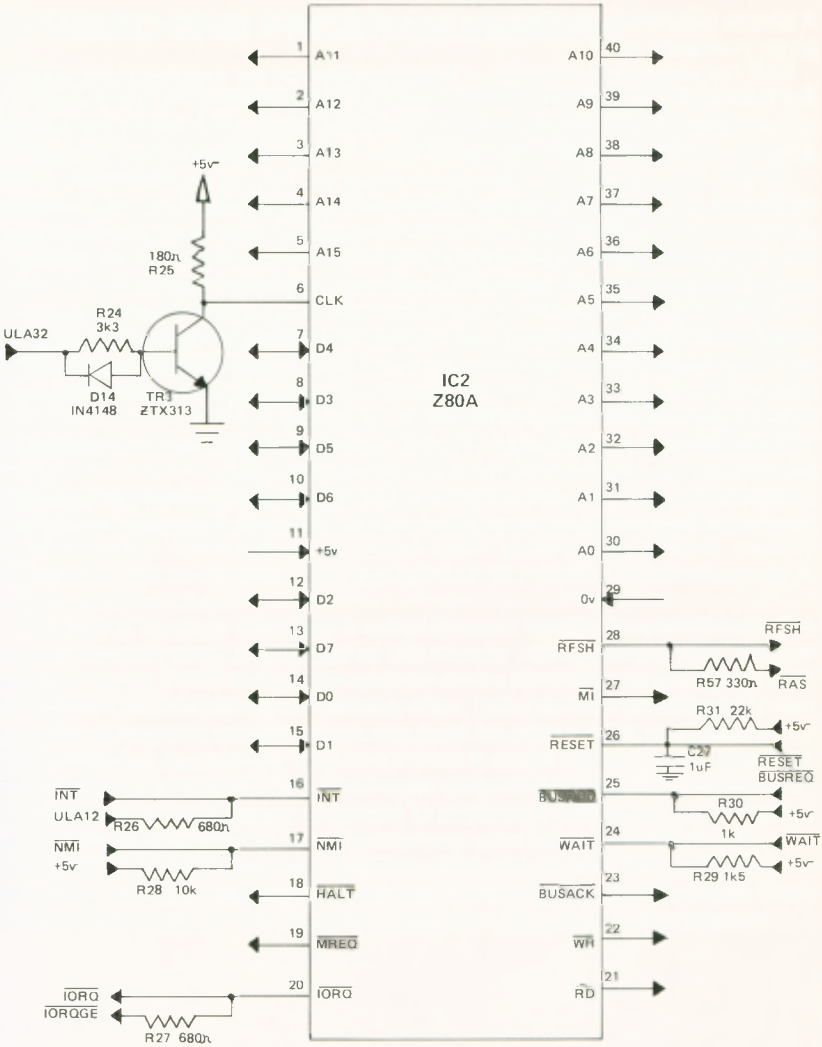


FIG 3 – Z80A CENTRAL PROCESSING CHIP

A simple experiment showing you how you can make use of the interrupt line is given in chapter 14.

$\overline{\text{NMI}}$ Non-maskable interrupt — input operated on the negative going edge of the interrupting signal. The NMI is always accepted by the CPU at the end of its current instruction. It forces the CPU to run the program in memory starting at address 102 decimal (66 Hex). See chapter 14 for a simple example of its use.

$\overline{\text{RESET}}$ Input active low. This signal forces the CPU to the reset state. In the Spectrum, when power is applied, C27 holds the reset pin low until it has charged up via R31. This allows the rest of the computer to reach an operational state before the CPU starts to run the program in memory from address zero. Details of adding a push button to reset the Spectrum are given in chapter 14.

$\overline{\text{BUSREQ}}$ Bus request — input, active low. Used by an external device to request the CPU address bus, data bus and tristate output control signals for its own use. The CPU will hand over control of all its buses as soon as the current machine cycle is terminated. To indicate to the requesting device that control can now be taken, the CPU sets its BUSACK output low.

$\overline{\text{BUSACK}}$ Bus acknowledge — output, active low. Indicates to the requesting device that it can now take full control of all the CPU buses.

More information about some of these Z80 signals and how they can be used is included in other chapters. In particular you are referred to chapters 8, 12 and 14.

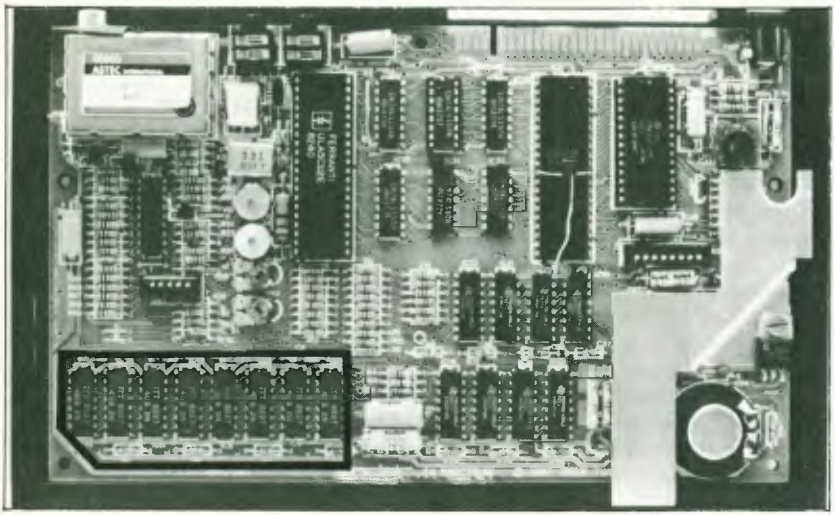
5. VIDEO AND PROGRAM MEMORY

This 16K of RAM is supplied on both the 16K and 48K versions of the Spectrum. It contains all of the data for generating the display on the television screen, the various variables required by BASIC, workspace, user defined graphics and your BASIC programs.

Now refer to fig 4. Each of the memory chips IC6 — IC13 can store 2^{14} = 16K (K just means 1024) bits of information. Eight of them are required to make up the 8 bit data bus. So that the memories can fit into smaller chips with fewer connections, the address lines are multiplexed. This means that first of all A0 — A6 are presented to the memory chip, followed by A7 —A14. These two sets of 7 bits are latched within the memory chip. The memory chip is then able to select the correct location. IC3 and IC4 do this multiplexing, the selected address lines diverted to the memory chip inputs being determined by the state of the select pin 1 on IC3 and IC4. DRAM A0 — DRAM A6 on the ULA can override the outputs from IC3 and IC4 because of the 330 ohm resistors in series with the multiplexer outputs. This override capability enables the ULA to get data for output to the video circuit whenever it is required. You may now be wondering what would happen if the CPU and ULA both wanted to access this memory simultaneously. Obviously they cannot both access two different memory locations at the same time. The resolution of this conflict will be described in chapter 8 on the ULA.

The type of memory used here is called dynamic random access memory. The internal memory array is arranged as 128 rows by 128 columns of cells. The row address strobe (RAS) and column address strobe (CAS) signals are used to latch the relevant addresses into the memory chips. Data can then be written to or read from the addressed location. Each row must be accessed at least once every 2mS otherwise the memory may forget what is stored inside it. In the Spectrum this refreshing is not a problem whilst video output is occuring, because the video memory has to be regularly accessed to produce a continuous video display. During the video field sync, when the memory is not accessed for about 5mS, the normal CPU refresh takes over. Memory which can be read from and written to, but which does not require this continual refreshing procedure is called Static RAM. In both types of RAM, the data is lost when the power is disconnected.

ISSUE 2 BOARD



ISSUE 3 BOARD

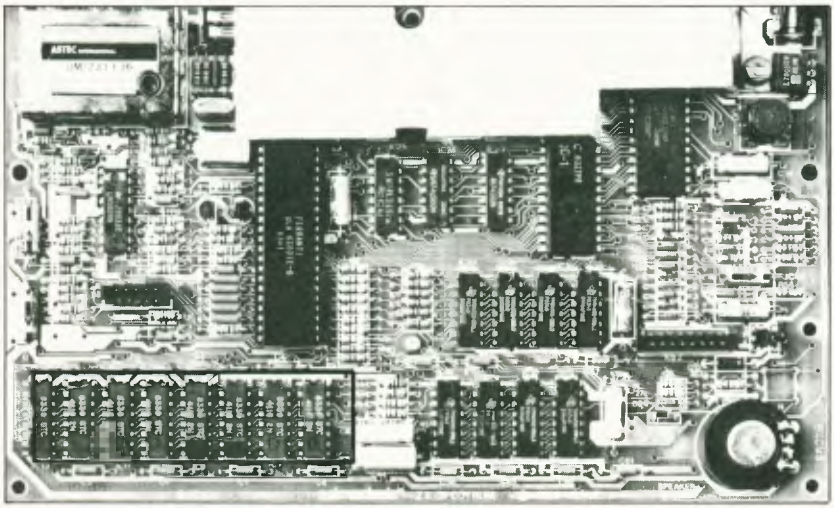


PLATE 4– PHOTO OF MAIN SPECTRUM BOARD
WITH RAM OUTLINED

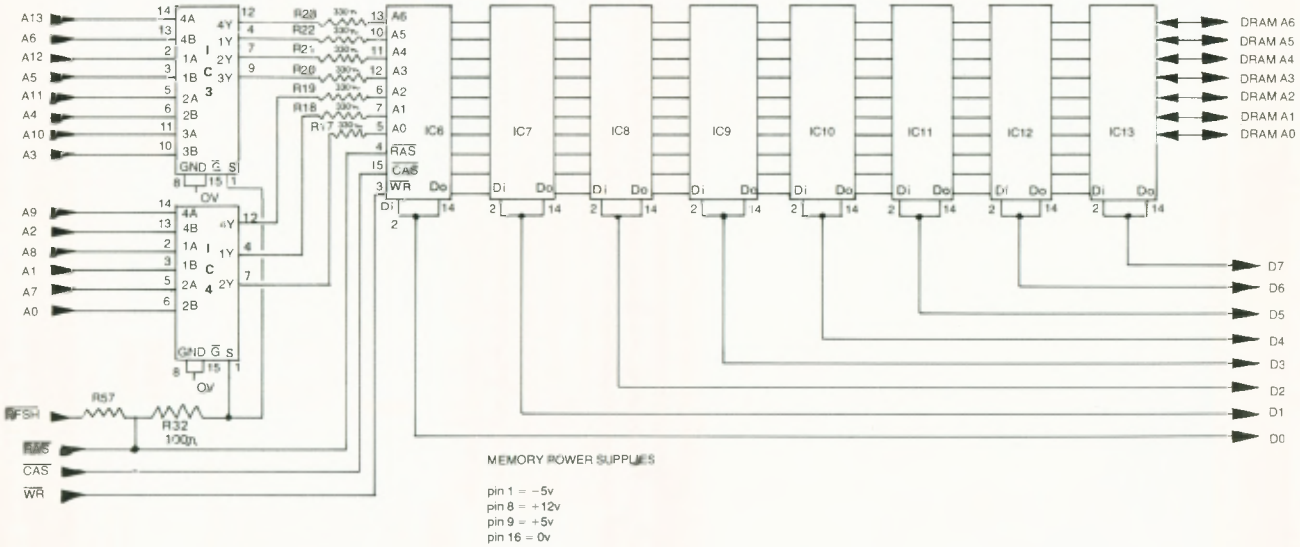
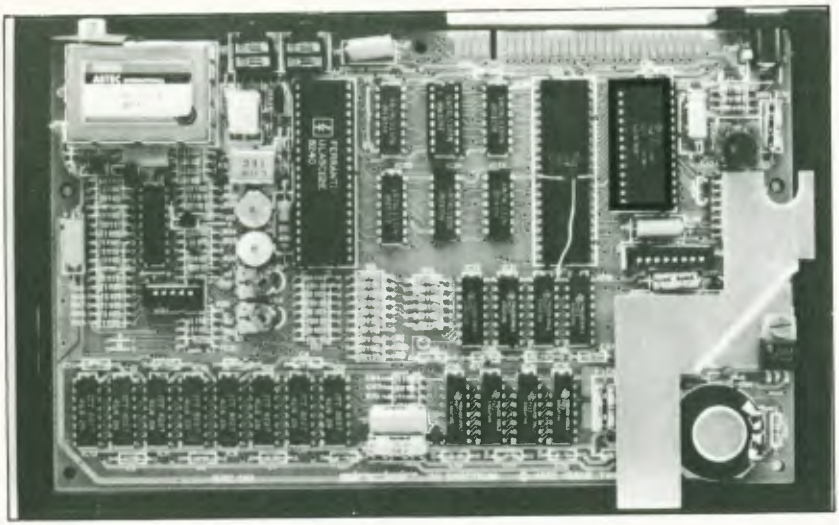


FIG 4 – VIDEO AND PROGRAM RANDOM ACCESS MEMORY

ISSUE 2 BOARD



ISSUE 3 BOARD

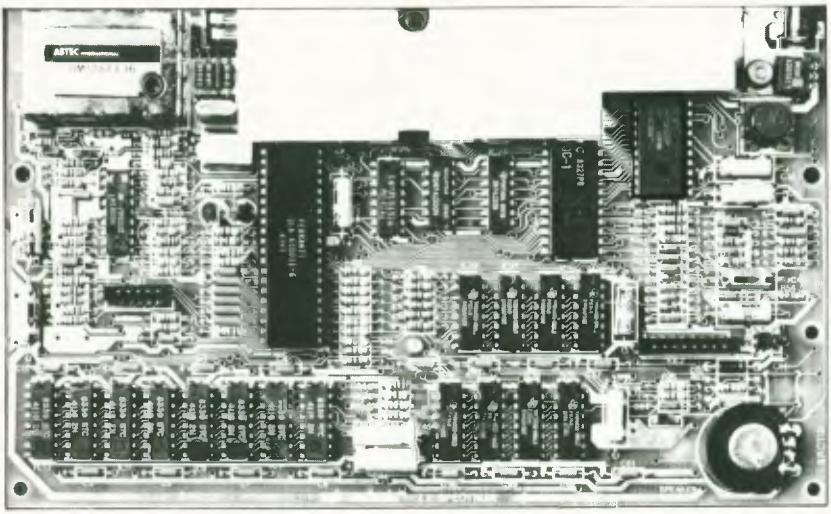


PLATE 5– PHOTO OF MAIN SPECTRUM BOARD
WITH ROM OUTLINED

6. THE BASIC READ ONLY MEMORY

IC5 is a 16K byte read only memory (ROM) chip. Housed in its 28 pin package, this chip is provided with 14 address lines, 8 data lines, two chip select pins, one output enable pin to enable data to be read by the CPU and of course the power supply connections. Its pin connection diagram is illustrated in fig. 5.

The ROM contains the program which tells the CPU how to run Sinclair BASIC. This program is embedded into the silicon structure of the chip during manufacture and cannot ever be changed. If this were not the case then BASIC would disappear whenever the power was switched off. Also, since you cannot modify the BASIC program nothing that you can do with software from the Spectrum keyboard can possibly destroy BASIC.

The ROM is positioned from address zero upwards. It has to be positioned here, because when the CPU is reset (when it is switched on), the CPU always runs the machine code program starting from address zero.

The $\overline{\text{ROMCS}}$ connection on the rear edge connector can be connected directly to +5 volts to disable the BASIC ROM. The $\overline{\text{ROMCS}}$ output from the ULA is connected via R33, and is therefore unable to pull the $\overline{\text{ROMCS}}$ signal low when the +5 volt connection is made. This might be useful for future add ons which would have their own ROM or RAM switched in instead. Different languages could then be run from the Spectrum in place of BASIC. Replacing the BASIC ROM in this way with a new chip requires a thorough understanding of the Spectrum hardware and software requirements. A totally new operating system for inclusion in the new chip would have to be written.

Chips called EPROMs (erasable programmable read only memories) are available with the same connections as the Sinclair ROM. The 27128 EPROM is such a device. It too contains 16K bytes of memory. The difference is that it can be programmed by the user. Once programmed, it retains all of the data just like a ROM, even when the power is switched off. EPROMS can be erased so that they can be reprogrammed, using ultraviolet light. This shines directly onto the silicon chip through a glass window in the top of the package. This facility is useful because it allows the same chip to be used again and again with different programs in it.

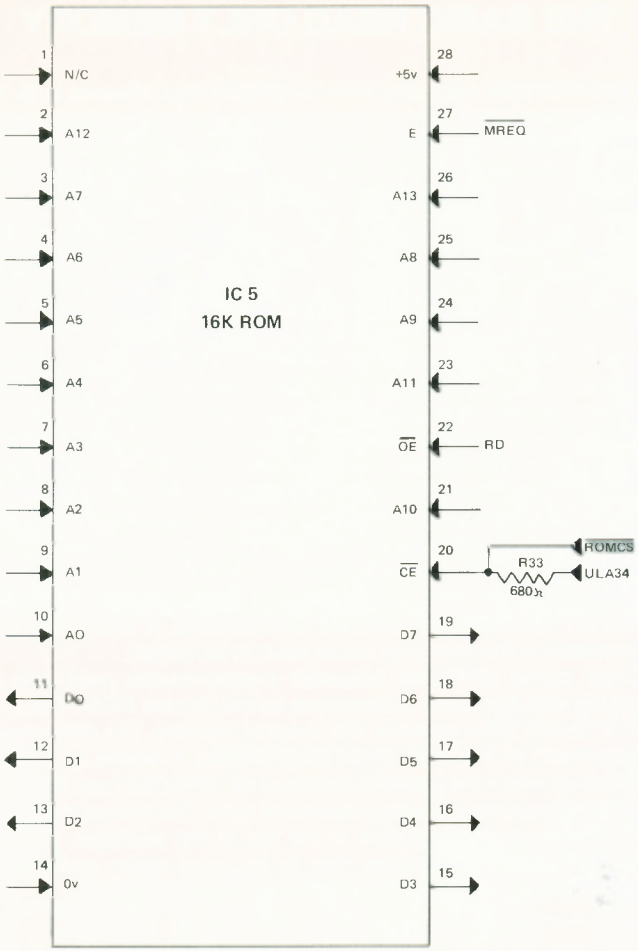


FIG 5 – BASIC READ ONLY MEMORY

7. THE KEYBOARD

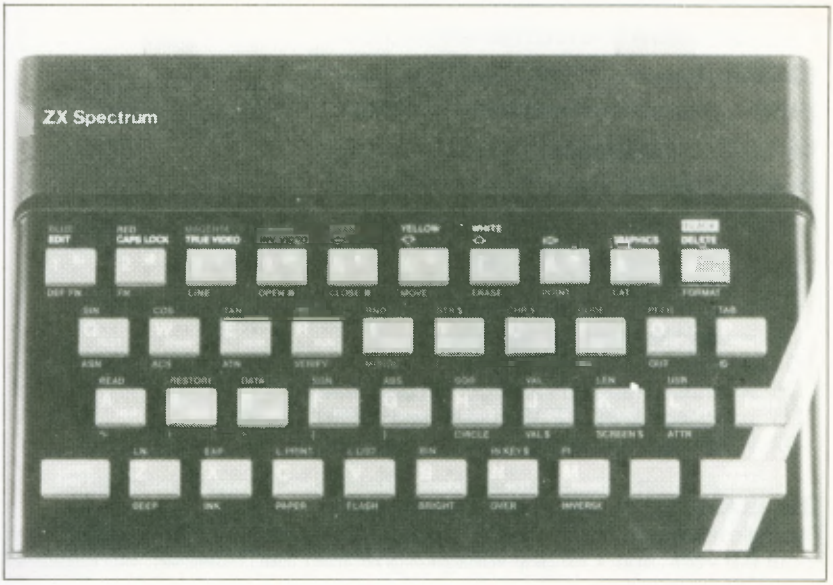


PLATE 6 –PHOTO OF KEYBOARD

The keyboard consists of a five by eight grid of wires, the crossing points of which can be connected by pressing the relevant key (see figure 6). Whenever the BASIC ROM program wishes to find out which key on the keyboard is pressed, it scans each of the eight rows in turn. Each row is selected by setting the relevant Z80 address line to logic 0, keeping the remainder at logic 1. Each of the five columns is usually held high by one of the resistors R65-R69. If any of the keys on a particular row are depressed, the associated column input to the ULA will be pulled down to logic 0 instead of its usual logic 1. The key can therefore be read.

Consider for example that key 'D' is pressed. By doing an IN from an address with all lines at logic 1 except for A9, bit D2 of the input byte would be 0, whilst D0, D1, D3 and D4 would all be at logic 1. The keyboard is scanned 50 times per second to see if any of the keys have been pressed, so that everything you type should be noticed by the Spectrum. A keyboard scan is initiated by the ULA interrupting the CPU at the end of displaying each video frame. The CPU then reads the keyboard.

If you wish to scan the keyboard yourself for some reason, the following addresses can be used. Bear in mind that each of these numbers is simply used to set all of these address lines except for the one being used to scan, to logic level 1. Using this method of input, the reading of keys is no longer restricted to 50 times per second. It can be done as often (within limits) or as infrequently as desired.

"IN 32766" uses A15 to read the half row SPACE to B

"IN 49150" uses A14 to read the half row ENTER to H

"IN 57342" uses A13 to read the half row P to Y

"IN 61438" uses A12 to read the half row 0 to 6

"IN 63486" uses A11 to read the half row 1 to 5

"IN 64510" uses A10 to read the half row Q to T

"IN 65022" uses A9 to read the half row A to G

"IN 65278" uses A8 to read the half row SHIFT to V

In the byte read in:

D0 = logic level at KBD 13 input
D1 = logic level at KBD 12 input
D2 = logic level at KBD 11 input
D3 = logic level at KBD 10 input
D4 = logic level at KBD 9 input
D5 = unused (appears as logic 1 in byte read in)
D6 = voltage level at EAR socket (see below)
D7 = unused (appears as logic 1 in byte read in)

THE LOGIC LEVEL AT THE EAR SOCKET

The logic level read in from the EAR socket will in general be 0 for voltages below about 0.6 volts, and 1 for any voltage higher than that. However, the threshold level between logic 0 and logic 1 is slightly different in the Issue 2 and Issue 3 models. The following table illustrates this difference. The voltages at the EAR input are set to four different values controlled by ULA control byte bits D4 and D3.

D4	D3	Voltage	Issue 3 IN 57342	Issue 2 IN 57342
0	0	0.4v	191	191
0	1	0.7v	191	255
1	0	3.5v	255	255
1	1	3.8v	255	255

The value read in using IN 57342 uses address line A13 to read the half row of keys P, O, I, U, Y, and the values shown are with none of these keys pressed. The read in values are the same for the two Spectrums, except when D4=0 and D3=1 in the ULA control byte. The Issue 3 then registers the value at the EAR port (D6 in input byte) as a 0. The Issue 2 recognises it as a 1. As it happens, D4 and D3 normally are in this state, so if the keyboard is scanned by a user program (rather than the ROM), bit 6 in the input byte should ALWAYS be masked. Several commercial programs looked to see if a key had been pressed by checking for IN 57342 NOT EQUAL TO 255. This worked on Issue 2 machines, because the value was 255 without a key pressed. However, as soon as Issue 3's came on the market, such software stopped working because it hadn't masked out bit 6!

Details for constructing your own additional keyboard interface which will plug into the rear edge connector are given in Chapter 16.

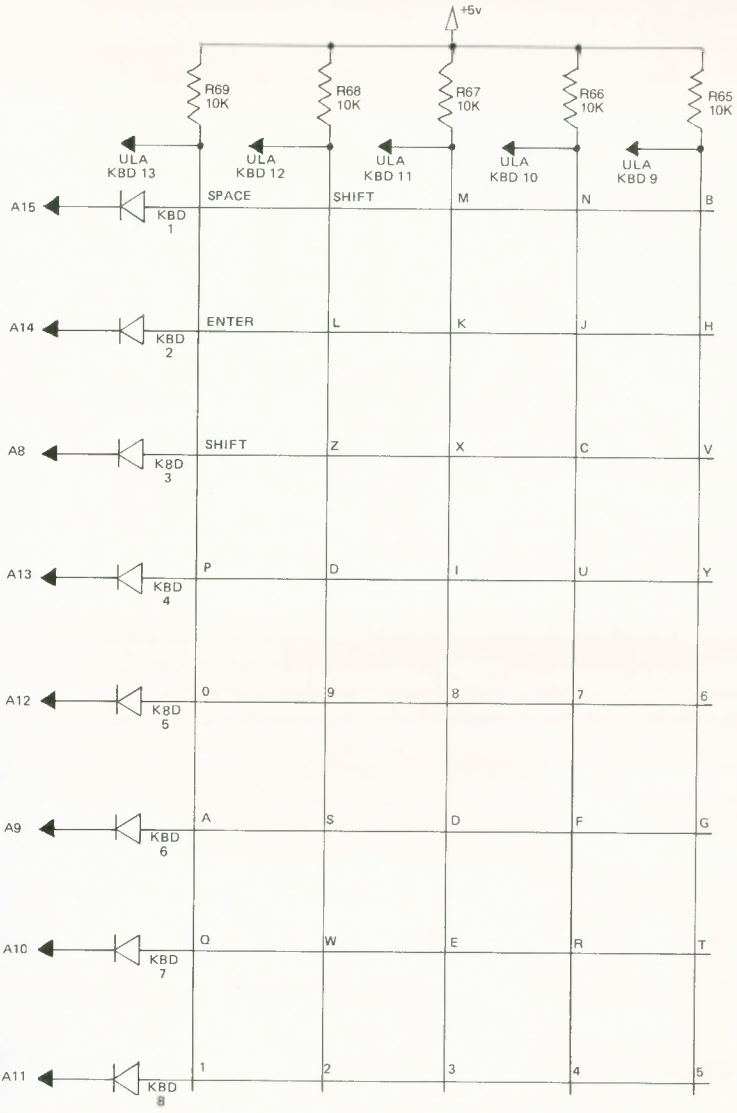
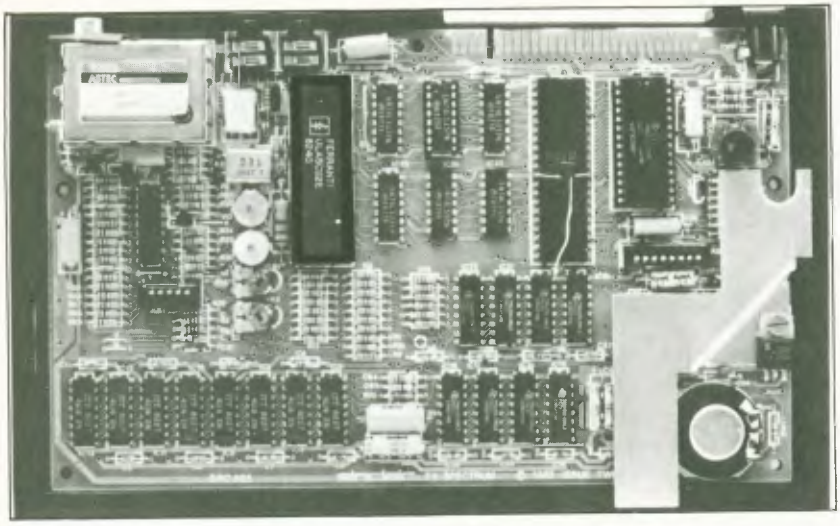


FIG 6 – SPECTRUM KEYBOARD

ISSUE 2 BOARD



ISSUE 3 BOARD

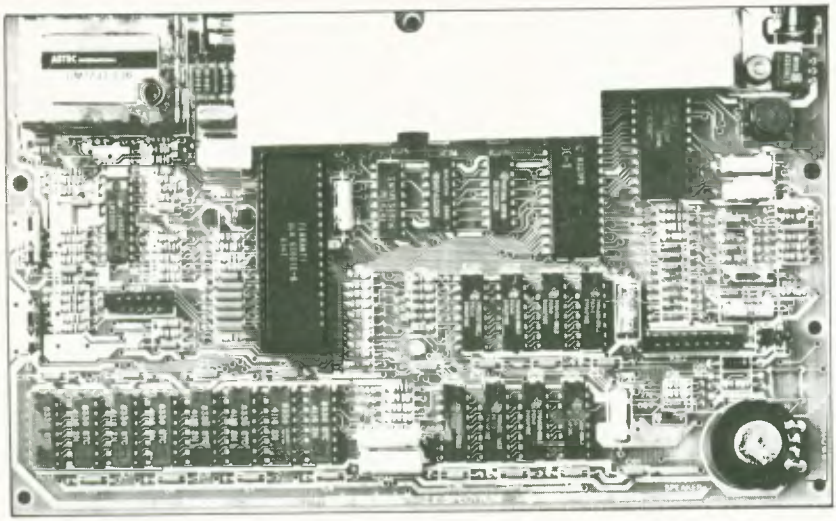


PLATE 7— PHOTO OF MAIN SPECTRUM BOARD
WITH ULA OUTLINED

8. THE UNCOMMITTED LOGIC ARRAY

The ULA is Sinclair's special chip. It has been designed to replace lots of smaller logic chips which were used in older computers. The way in which it operates is defined when the chip is manufactured, and can never be changed with software. Its function is to take the heavy burden of input and output from the CPU. It performs the tedious output of information to the television all of the time when power is applied to the Spectrum. Apart from this major task, the ULA also deals with output to the buzzer and cassette plus input from the keyboard and cassette.

ULA PIN DESCRIPTIONS

DRAM A0 — DRAM A6 from the memory address multiplexer chips IC3 and IC4. These enable the ULA to determine which address is being selected by the CPU. Also used by the ULA to select the address of video data from the video memory. When used by the ULA as outputs in this way, they are able to override the output from the address multiplexers because of the set of series 330 ohm resistors.

$\overline{\text{DRAM CAS}}$ — dynamic RAM column address strobe ($\overline{\text{CAS}}$) output. Used to latch in the column address for the dynamic RAM from the address multiplexer (see chapter 5 for more details).

$\overline{\text{ROMCS}}$ — ROM chip select output enables the 16K ROM chip IC5 whenever the CPU wishes to read from it. The ULA can monitor this with its A14 and A15 address inputs, so it can be outputting video information at the same time as the CPU is reading from the ROM.

$\overline{\text{IORQGE}}$ — input connected to the Z80A $\overline{\text{IORQ}}$ pin via R27. If this $\overline{\text{IORQGE}}$ connection is held high by connecting it to +5 volts, the Z80A $\overline{\text{IORQ}}$ signal no longer reaches the ULA. This can be useful for adding extra I/O devices. See chapter 15 for more details.

$\overline{\text{RAS}}$ — used as row address strobe on the dynamic RAM chips. (see chapter 5 for more details about refreshing dynamic memories). This pin is also connected to the Z80A refresh pin via R57 (330 ohms). The memories can then be refreshed by the CPU during the video field sync time, when regular accessing by the ULA stops for about 5 ms.

KBD9 — KBD13 — inputs from the Spectrum keyboard. See chapter 7 for further details.

U — blue — yellow colour difference output.

V — red — yellow colour difference output.

Y — luminance and sync outputs for the video.

D0 — D7 — 8 bit bidirectional databus. Connected directly to the video memory databus and via 470 ohm resistors to the main system databus. This enables asynchronous operation of the ULA accessing video RAM and the CPU accessing the rest of memory. The computer therefore runs faster than it would if the ULA stopped it every cycle.

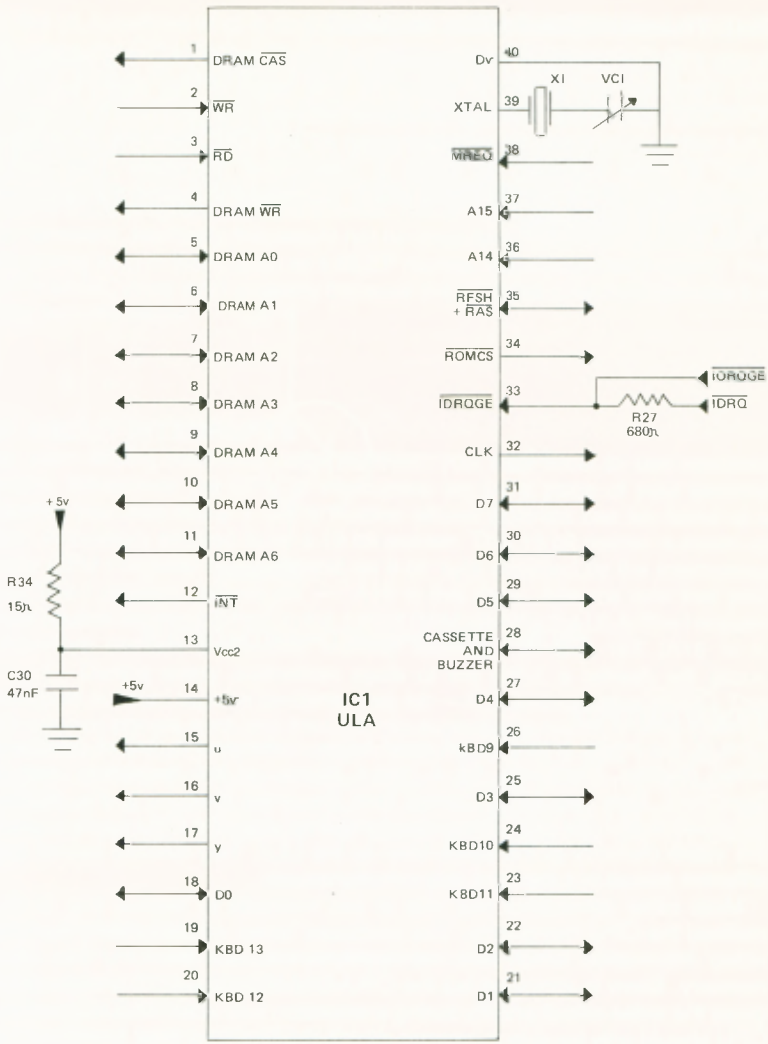
CLK — 3.5 MHz clock output to the Z80A CPU. This clock may occasionally be stopped by the ULA to prevent the CPU from accessing the video RAM when the ULA is using it.

$\overline{\text{WR}}$ — tells the ULA when the CPU is writing to some device. If that device happens to be the ULA then the ULA will use this signal to latch the incoming data.

$\overline{RD}$ — tells the ULA when the CPU is reading from a device. If the device is the ULA, data will be output onto the databus for the CPU.

$\overline{MREQ}$ — this input tells the ULA that the address bus now contains a valid address for a read or write operation. This signal is required to distinguish between a memory or I/O operation.

$\overline{INT}$ — interrupt to the CPU operates 50 times per second. Upon receiving this interrupt, the CPU increments a 2 byte counter in memory and scans the keyboard to see if any keys have been pressed.



NOTE — VC1 IN ISSUE 2 IS REPLACED BY C73 IN ISSUE 3

FIG 7a – THE UNCOMMITTED LOGIC ARRAY PIN CONNECTIONS

THE TRANSISTOR PATCH IN ISSUE 2

Issue 2 Spectrums have TR6 soldered across the Z80A chip. The connections to this transistor are shown in figure 7b. The effect of this patch is to pull the $\overline{\text{IORQGE}}$ input to the ULA high whenever address line zero (A0) is at logic 1. The ULA will therefore only be selected when A0 and $\overline{\text{IORQ}}$ from the Z80A are in the logic 0 state together. In Issue 3 Spectrums, transistor TR6 has been incorporated on the printed circuit board. It operates in exactly the same manner as in Issue 2 Spectrums.

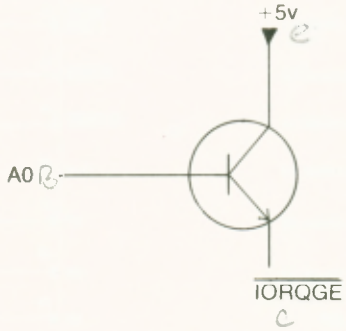


FIG 7b — THE TRANSISTOR PATCH CIRCUIT

VIDEO OUTPUT

One of the major problems on most home computers is that of producing the video display. Especially for a colour display of the resolution used in the Spectrum, data has to be copied from the video memory to the display at a continuous and fast rate. This poses problems when the CPU wants to read from the video memory at the same time as the ULA. Two devices cannot address different places in a memory chip simultaneously.

Most other computers use one of two methods to resolve this. In the first method the CPU has priority. This produces 'snow' on the screen, representing video information which was not displayed because the CPU was using the memory. Snow is annoying but the CPU runs at full speed. The second method gives the video circuit priority during a television field scan. This requires that the CPU should only be able to operate during the field sync time. Using this method does eliminate snow, but the computer operates very slowly. Neither of these methods is satisfactory.

Your Spectrum uses a very ingenious way to get over the problem. Let us assume that the ULA is accessing video memory. The CPU can simultaneously access the ROM or extra 32K of RAM without any bus contention occuring. The ULA and video memory have their address and data buses separated from the rest of the system by 330 ohm and 470 ohm series resistors respectively. Normally therefore, there are two separate systems operating independently of one other. The ULA outputting video, the Z80A operating BASIC. But then, the CPU may wish to access the 16K of RAM which the ULA is using, because this contains all of the BASIC system variables as well as the video memory. At this

point, the ULA realises what is about to happen (by monitoring A14 and A15), so it hastily stops the CPU clock. The Z80A doesn't notice this because its only way of measuring time is by assuming that its clock input is constant. The ULA can then let the CPU have access to the memory for a few hundred nanoseconds when there is a brief gap in video output.

How does this novel design feature affect any programs which you may wish to write? In BASIC, it will always appear totally transparent to the user, but if you run a machine code program from the affected 16K of RAM, the timing of routines will not be constant. Normally this would not be important, however, routines with a critical timing loop in them, such as a BEEP routine, will not operate properly. The BEEP in BASIC does work properly because the machine code that operates it is running from the ROM.

A BIT ABOUT INTERRUPTS

If you start writing machine code routines, you may wish to use vectored interrupts. Whenever the CPU is interrupted (eg by a piece of your external hardware), you can make it run a routine whose address can be found at a position in memory pointed to by a 16 bit pointer. This 16 bit pointer is made up from the CPU I register contents and an 8 bit byte supplied by the interrupting device. The I register defines A8 — A15 in this case. Assume now that your interrupt routine address is held in the 16K of RAM used by the ULA. The I register will therefore contain a decimal number between 64 and 127 (A15 = 0, A14 = 1). During every instruction cycle of the CPU, a refresh will occur. Refresh puts out the I register contents onto A8 — A15 and operates $\overline{MREQ}$. This combination of signals confuses the ULA into expecting a read to or write from the video memory by the CPU. This doesn't occur so the ULA gets confused. So confused in fact that it omits some video output, causing snow on the screen!

Try running this small BASIC program to set the I register so that you can see the snow for yourself. Remember that values of I between 64 and 127 create snow.

```
10  CLEAR 32499
20  INPUT "Enter the value for I register ";v
30  POKE 32500,62 :REM LD A,v
40  POKE 32501,v
50  POKE 32502,237 :REM LD I,A
60  POKE 32503,71
70  POKE 32504,201 :REM RET
80  LET a = USR 32500
90  GO TO 20
```

Line 10 stops BASIC using memory above address 32499. Lines 30 — 70 put a machine code program into memory. You will be prompted for the value required in the I register. The machine code program then sets the I register when it is called from BASIC at line 80. Return from the machine code jumps to line 90, causing the whole BASIC program to be repeated.

CLOCKS

The ULA generates its own master clock. This master clock frequency is held constant at 14 MHz by the crystal X1. The 14MHz master clock is divided by 2 to produce the correct video dot frequency of 7MHz. Division by two again reduces the frequency to 3.5MHz which is fed to the Z80A. This 3.5MHz clock is not constant and can be stopped for short periods by the ULA to override the CPU during video memory accesses.

KEYBOARD AND CASSETTE INPUTS

The keyboard is dealt with in chapter 7. In summary, if you read in a byte from I/O address 254, bits D0 — D4 will hold the logic level at the KBD13 — KBD9 inputs to the ULA. These bits are set to 0 if a key is pressed and to 1 if it isn't. D6 holds the input level at the EAR input from your casette recorder.

BUZZER, CASSETTE & BORDER COLOUR OUTPUTS

A control byte can be sent to the ULA by writing to output address 254. Of the eight bits in the control byte, only D0-D4 are used. Bits D0-D2 control the BORDER colour, bit 3 is the MIC output bit and bit 4 is the buzzer output bit.

BORDER COLOURS AND VALUES FOR BITS 0 — 2

D2	D1	D0	Colour
0	0	0	black
0	0	1	blue
0	1	0	red
0	1	1	magenta
1	0	0	green
1	0	1	cyan
1	1	0	yellow
1	1	1	white

In fact, it can be seen that D0 controls the BLUE output, D1 controls the RED output and D2 controls the GREEN output. All other colours are combinations of these basic primary colours.

BUZZER AND MIC OUPUT BITS 3-4

D4 (buzzer)	D3 (mic)	Voltage at ULA pin 28
0	0	0.4v
0	1	0.7v
1	0	3.5v
1	1	3.8v

Figure 7c and figure 7d illustrate the cassette interface and buzzer circuits for the two Spectrums. Looking at the above table, it will be seen that the MIC output bit only generates a voltage change of about 300mV when it is flipped between logic 0 and logic 1. This signal is used to save programs on cassette. However, the voltage level is insufficient to overcome the 0.7 volt drop across D9 (and D10 in Issue 2's). The buzzer therefore doesn't operate. When the buzzer output bit is flipped between logic 0 and logic 1, it generates a voltage change of about 3V. This large voltage change is sufficient to operate the buzzer. The buzzer in an Issue 3 Spectrum is driven via transistor TR7 from the +9V DC supply, so it doesn't present any additional load to the +5V regulated supply.

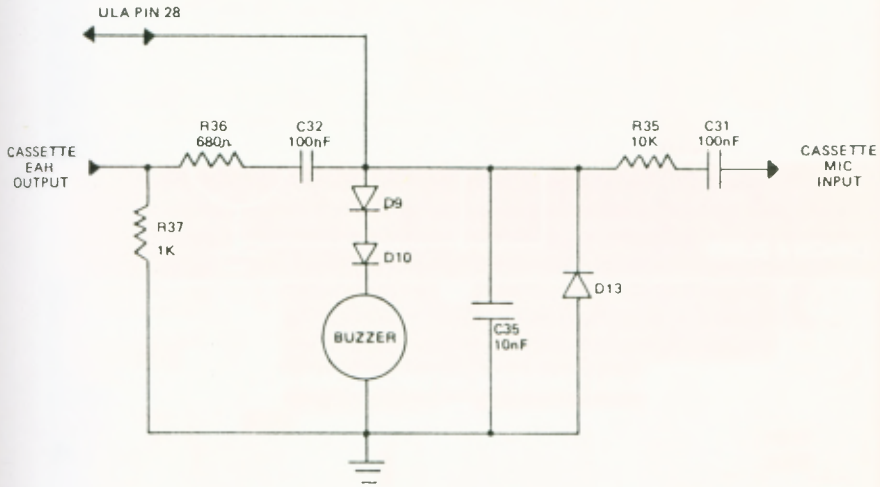


FIG. 7c — ISSUE 2 CASSETTE INTERFACE AND BUZZER CIRCUIT

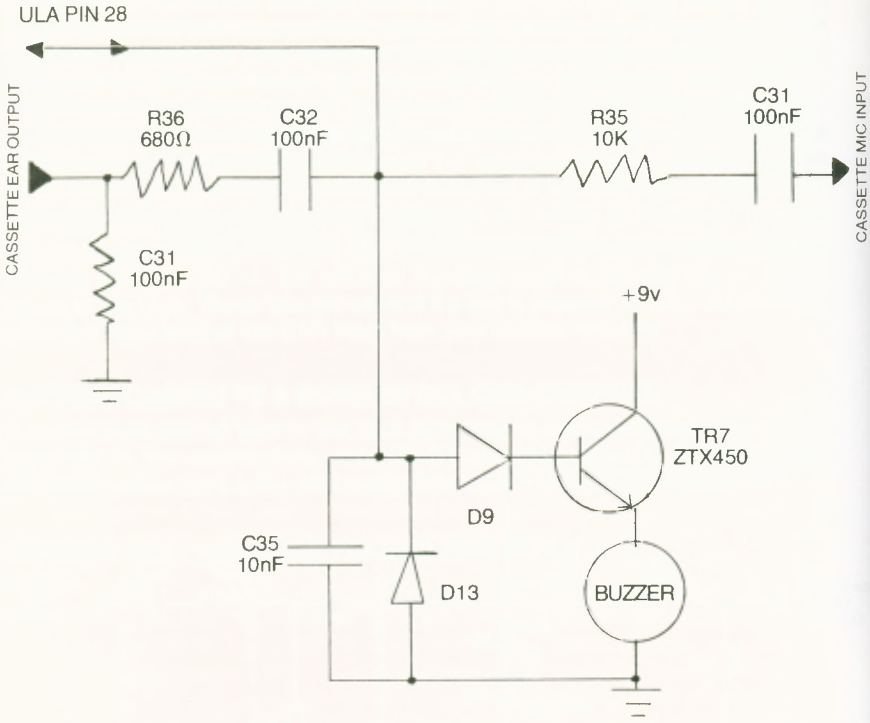


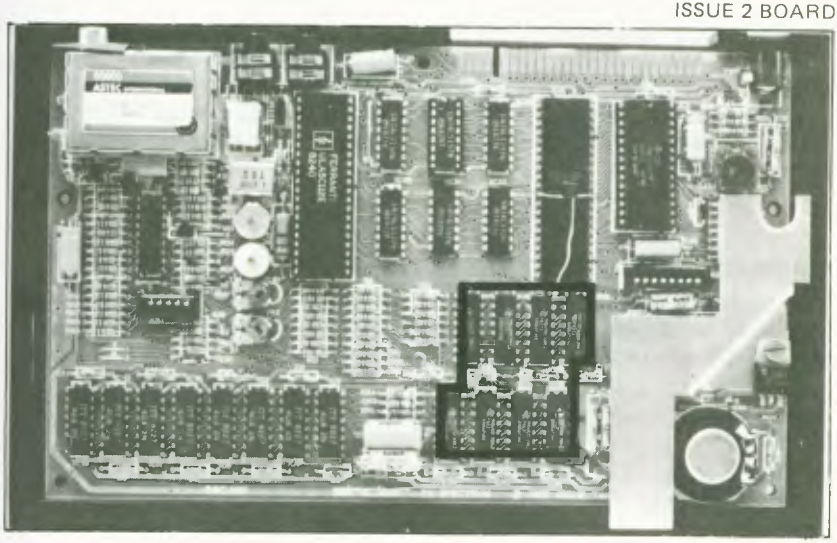
FIG. 7d — ISSUE 3 CASSETTE INTERFACE AND BUZZER CIRCUIT

AMPLIFYING THE BUZZER

The sound output from the Spectrum's internal buzzer is normally not very loud. For certain games or other applications, it may be advantageous to connect the Spectrum up to an amplifier. This is very easy, because the Spectrum sound signal is present on both the MIC and EAR sockets at the rear of the computer. All that is required is a standard 3.5mm jack plug, a length of two way audio cable and a suitable plug to the amplifier being used. Connect the two plugs to opposite ends of the cable. For an amplifier with a high impedance input, plug the 3.5mm jack into the Spectrum's MIC socket. For an amplifier with a low impedance input, plug the 3.5mm jack into the Spectrum's EAR socket.

CASSETTE MIC INPUT

ISSUE 2 BOARD



ISSUE 3 BOARD

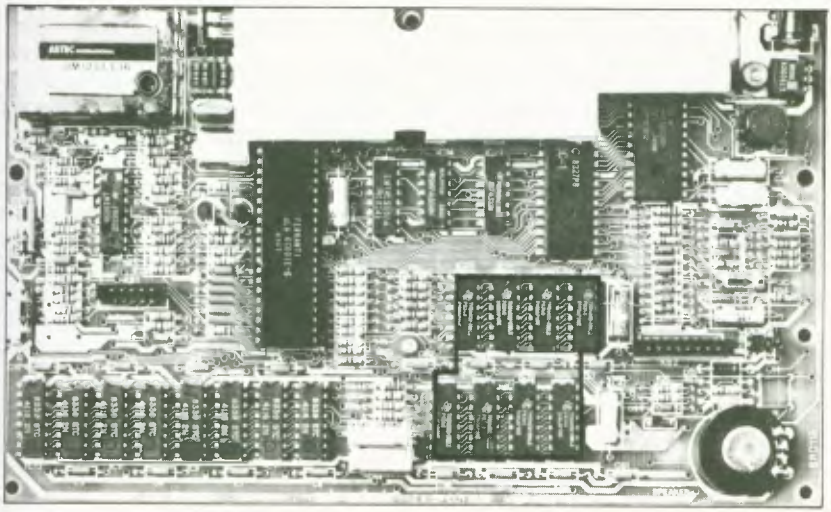


PLATE 8 — PHOTO OF MAIN SPECTRUM BOARD
WITH MEMORY EXPANSION SOCKETS OUTLINED

9. THE MEMORY EXPANSION SOCKETS

The Sinclair Spectrum can be purchased in two different versions. One of these contains 16K of user RAM, and the other contains 48K. This chapter explains first of all how a 16K Spectrum can be upgraded to a 48K Spectrum, and there then follows a detailed description of how the additional memory circuit operates.

Since upgrading an Issue 3 Spectrum enables the use of chips which cannot be used on a Issue 2 Spectrum, the type of Spectrum should be checked before purchasing any chips.

UPGRADING AN 'ISSUE 2' SPECTRUM

The upgrading procedure for Issue 2 Spectrums consists of plugging twelve integrated circuits into sockets on the printed circuit board and soldering one wire link. The following integrated circuits are required:

IC15-22	8 of 4532 32K×1 dynamic memory chips (see text)
IC23	1 of 74LS32
IC24	1 of 74LS00
IC25-IC26	2 of 74LS157

The 4532 memory IC's will probably be the most difficult to obtain. Luckily, several mail order companies can supply these, either individually, or as a complete 'Spectrum memory upgrade kit'. A current copy of any good computing magazine should contain advertisments by some such company.

The 4532 chips used in Issue 2 Spectrums are 64K RAMs from Texas Instruments which failed to operate to specifications. Usually, several bits in one half of the chips are permanently fixed to a logic 1 or 0. The bad half of the chip is not used. Two versions are therefore available corresponding to different operational halves. These are designated the 4532L in which the lower 32K bits function correctly, and the 4532H in which the upper 32K bits function correctly.

To select the particular type of 4532 which is used, a wire link is provided on the main circuit board. Note that only Texas Instruments chips should be used. This is because Texas 4532's are split in half using the ROW address A7. Most other manufacturers' chips use A15 (COLUMN address A7) to select the operational half of the chip, so they must NOT be used in the Issue 2 Spectrum. If any difficulty is experienced in obtaining 4532's, it is possible to use any manufacturers' 64K×1 chips instead. The 64K chips will probably be more expensive, but it will not be necessary to solder in the wire link.

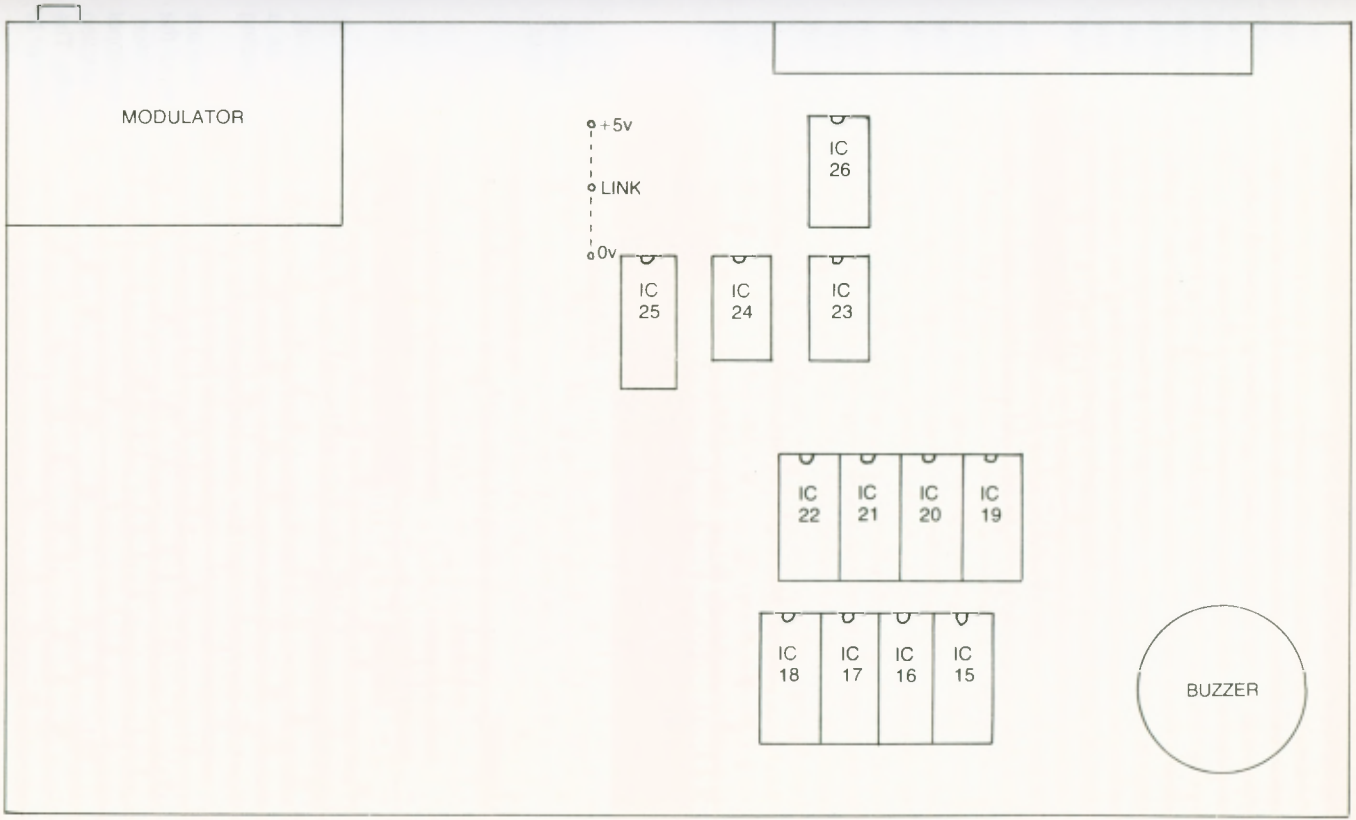


FIG. 8a — ISSUE 2 BOARD SHOWING POSITION OF MEMORY EXPANSION SOCKETS

You should now refer to the layout diagram in figure 8a. This illustrates the positions of the expansion sockets on an Issue 2 board. Carefully unscrew the five retaining screws on the underside of the Spectrum. The keyboard should then come away from the circuit board and base. Using the layout diagram as a guide, start by inserting the memory chips IC15 to IC22 into their sockets. Ensure that all of the pins on the integrated circuits are vertical and straight before attempting to insert them into sockets. The small indentations at the ends of the chips correspond to the indentations marked on the diagram. It is ESSENTIAL that ALL of the chips are inserted the correct way round. Now that all of the memories have been inserted, carefully plug in the 74LS32 (IC23), the 74LS00 (IC24) and the two 74LS157s (IC25 and IC26).

Using a fine tipped soldering iron and a piece of stripped single strand wire, the link can now be made. If 4532Ls have been installed then solder the wire between the central hole (marked "link" in figure 8a) and the hole marked 0V. If 4532Hs have been installed, then connect the wire between the central hole and the hole marked +5V. Take great care not to let the solder run onto any other connections, since that may damage the computer when power is applied.

The installation is now complete. Go back and check that all of the chips are in the correct sockets and pointing in the correct direction. Also check that none of the pins have been bent under the integrated circuits in case there is no contact with the socket.

Connect up the power supply and you should have an operational 48K Spectrum. Check this by typing PRINT PEEK 23733. The response should be 255. If it isn't then consult your local Spectrum expert.

UPGRADING AN 'ISSUE 3' SPECTRUM

The upgrading procedure for Issue 3 Spectrums consists of plugging twelve integrated circuits into sockets on the circuit board and soldering in two wire links. The following integrated circuits are required:

IC15-IC22	8 of 4532 32K×1 dynamic memory chips (see text)
IC23	1 of 74LS32
IC24	1 of 74LS00
IC25-IC26	2 of 74LS157

The 4532 memory IC's will probably be the most difficult to obtain. Luckily, several mail order companies can supply these, either individually or as a complete 'Spectrum memory upgrade kit'. A current copy of any good computing magazine should contain advertisements by some such company.

Most manufacturers' 4532's can be used in the Issue 3 Spectrum. These are 64K RAMs which failed to operate fully. Usually, several bits in one half of the chips are permanently set to a logic 0 or 1. The bad half of the chip is not used. Several versions are therefore available, corresponding to different operational halves. These are designated 4532L in which the lower 32K bits function correctly, and the 4532H in which the upper 32K bits function correctly. The definition of 'lower' and 'upper' operational halves varies from manufacturer to manufacturer.

To select the particular type of 4532 which is used, a block of contact pads which can be connected by wire links is provided on the main circuit board. The connections to this link block, together with various options for common types of memory chips are illustrated in figure 8c. Texas Instruments 4532's are split in half using the ROW address A7. Most other manufacturers' chips, such as those produced by OKI use A15 (COLUMN address A7) to select the operational half of the chip. If any difficulty is experienced in obtaining 4532's, it is possible to use any manufacturers' 64K×1 dynamic RAMs. The 64K chips will probably be more expensive, but either the 'L' or 'H' link pattern for that manufacturer's chip can be selected.

You should now refer to the layout diagram in Figure 8b. This illustrates the positions of the expansion sockets on an Issue 3 board. Carefully unscrew the five retaining screws on the underside of the Spectrum. The keyboard should then come away from the circuit board and base. Using the layout as a guide, start by inserting the memory chips IC15 to IC22 into their sockets. Ensure that all of the pins on the integrated circuits are vertical and straight before attempting to insert them into sockets. The small indentation at one end of the chip corresponds to the indentations marked on the diagram. It is ESSENTIAL that ALL chips are inserted the correct way round. Now that all of the memories have been inserted, carefully plug in the 74LS32 (IC23), the 74LS00 (IC24) and the two 74LS157's (IC25 and IC26).

Using a fine tipped soldering iron and two pieces of stripped single strand wire, the links can now be made. Various valid link patterns for different types of 4532's are illustrated in figure 8c. Choose the correct pattern for the type of chips being used. Take care not to let the solder run onto any other connections, since that may cause damage to the computer when the power is reconnected.

The installation is now complete. Go back and check that all of the chips are in the correct sockets and facing in the correct direction. Also check that none of the pins have been bent under the integrated circuits in case there is no contact with the socket.

Connect up the power supply and you should have an operational 48K Spectrum. Check this by typing PRINT PEEK 23733. The response should be 255. If it isn't, then consult your local Spectrum expert.

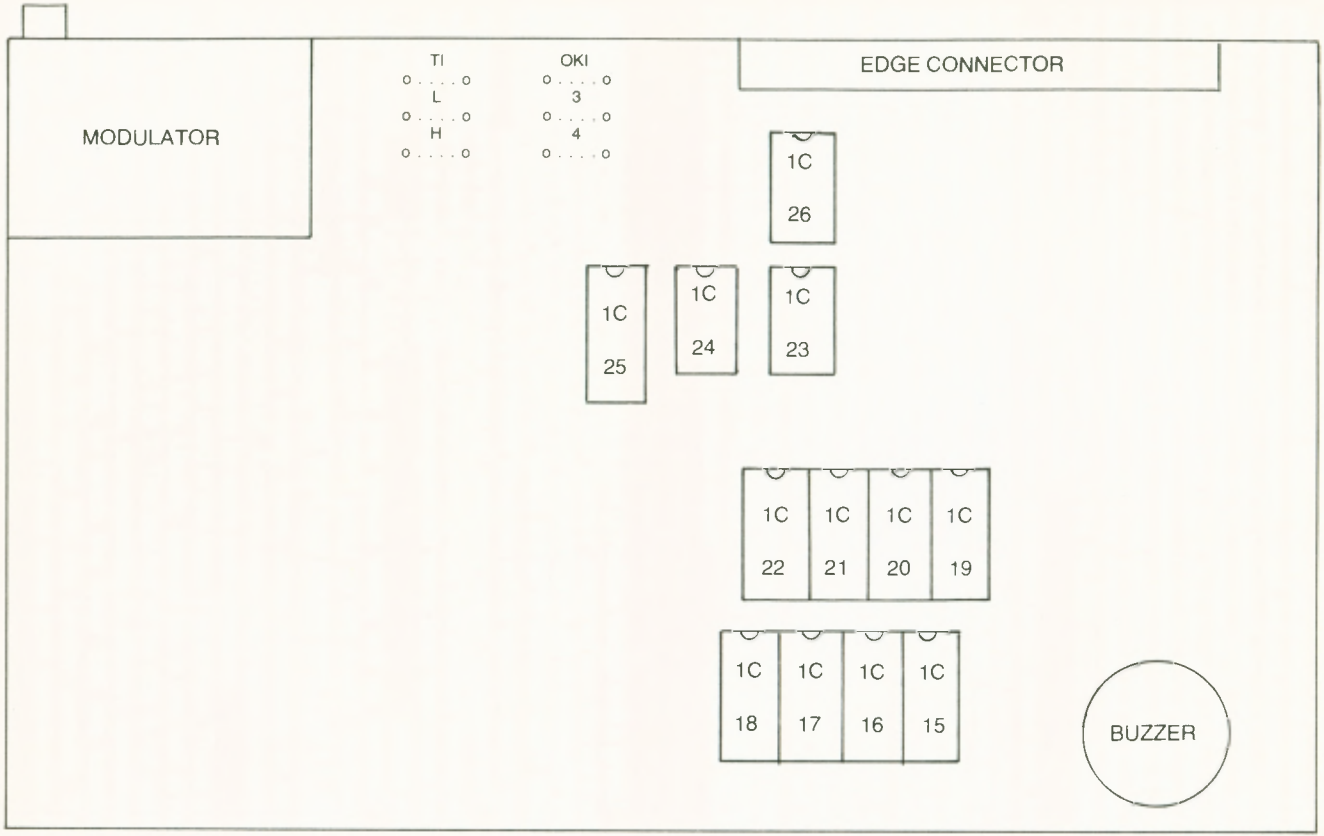
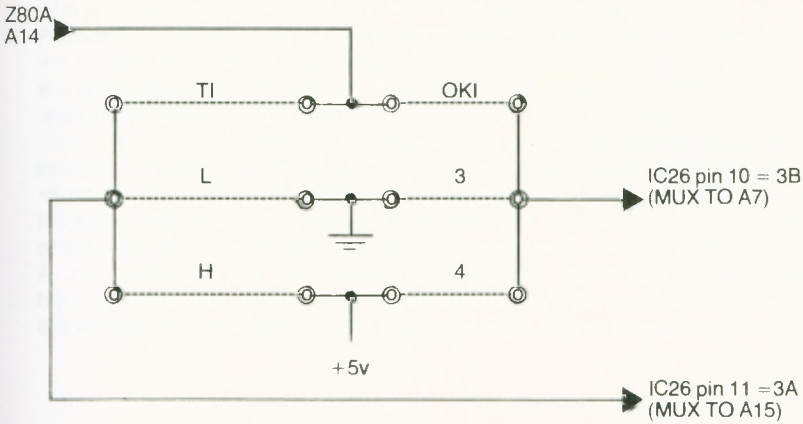


FIG. 8b — ISSUE 3 BOARD SHOWING POSITION OF MEMORY EXPANSION SOCKETS



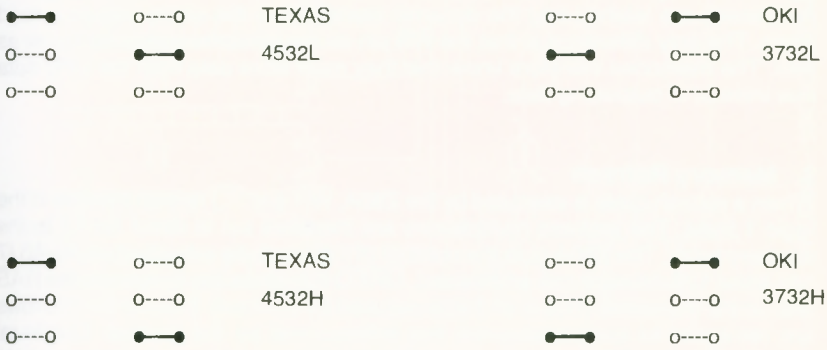


FIG. 8b — ISSUE 3 BOARD SHOWING POSITION OF MEMORY EXPANSION SOCKETS

FIG. 8c — ISSUE 3 MEMORY TYPE SELECTION LINKS

EXPANSION MEMORY CIRCUIT DESCRIPTION

1. MEMORY READ

Whenever the CPU wishes to read data from the 32K expansion memory, A15 will go to logic 1 to indicate an address in the range 32768 — 65535. As the Z80A read cycle is initiated both $\overline{RD}$ and $\overline{MREQ}$ signals will go low. The high to low transition of $\overline{MREQ}$ is buffered by IC23a to operate $\overline{RAS}$. The $\overline{RAS}$ line going low causes the addresses A0 — A7 to be latched into the eight dynamic RAM chips. $\overline{RAS}$ going low is delayed by the RC network comprising R71 and C63. Eventually, the $\overline{RAS}$ low signal filters through to IC23c which operates the address multiplexers "select" line. This changes the outputs from the address multiplexers to A8 — A14. Another RC network comprising R70 and C64 delays the low going signal yet again. This delay gives the address multiplexers a chance to stabilise before $\overline{CAS}$ finally latches their outputs into the memory chips. A complete 15 bit address will then be latched into the memory. After a further short delay the data appears on the Spectrum data bus so that it can be read by the CPU.

2. MEMORY WRITE

When the CPU wishes to store some data in this 32K block of memory, A15 is again set to logic 1. The write cycle commences with $\overline{WR}$ and $\overline{MREQ}$ going low. Addresses are latched into the dynamic memories in the same way as a read cycle. The only difference is that the $\overline{WR}$ pin on the dynamic memories is low as well. The memories therefore know that they must store data from the CPU data bus instead of outputting data.

3. Memory Refresh

When a refresh cycle is executed by the Z80A, $\overline{WR}$ and $\overline{RD}$ remain inactive in the logic 1 state. The address multiplexers are therefore set to direct A0-A7 to the memory array. The Z80A puts the number of the row to be refreshed on A0-A6 (7 bits allow 128 different row addresses). $\overline{MREQ}$ then goes low to operate the $\overline{RAS}$ line on the memories. This is all that is required for a refresh. Each of the 128 rows are refreshed at least once every two milliseconds by this method. Continual refreshing by the CPU was not required for the video memory except during field synchronisation pulses to the television. This is because the ULA is accessing the video memory sequentially at each of the 128 row addresses during video data output.

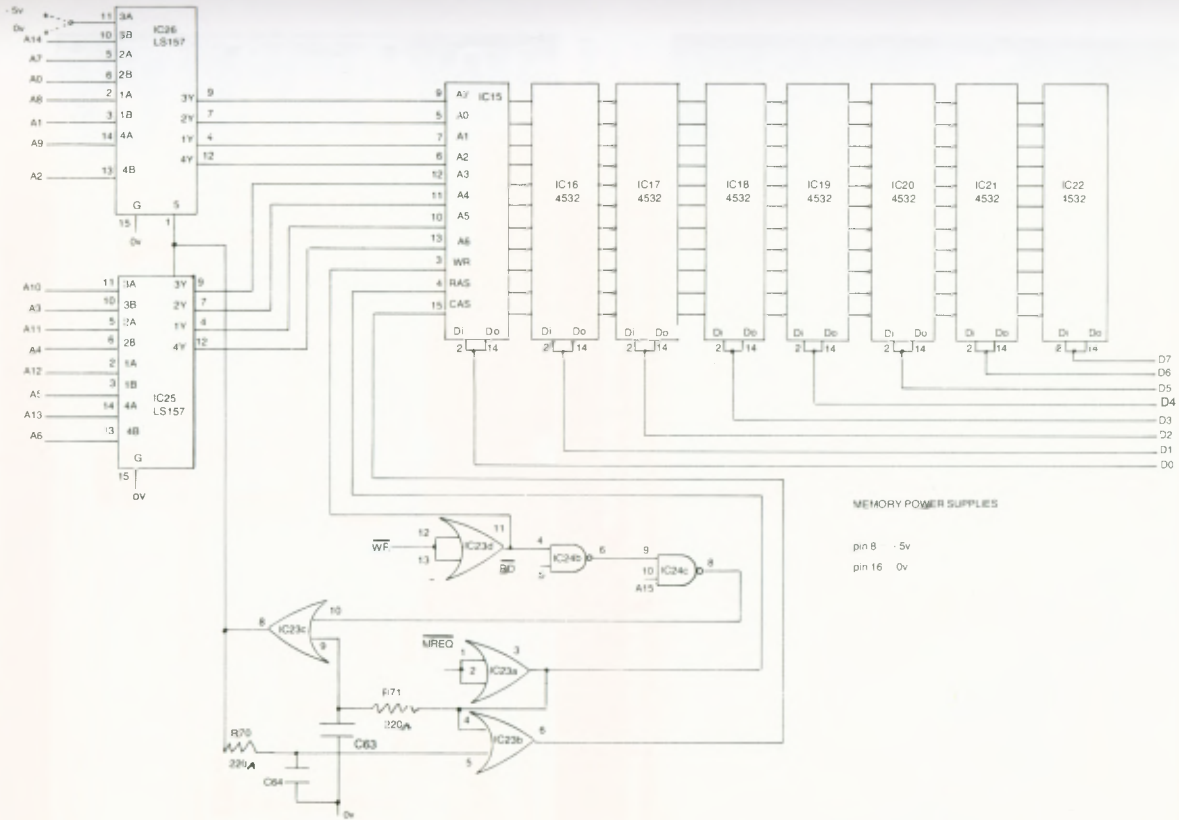
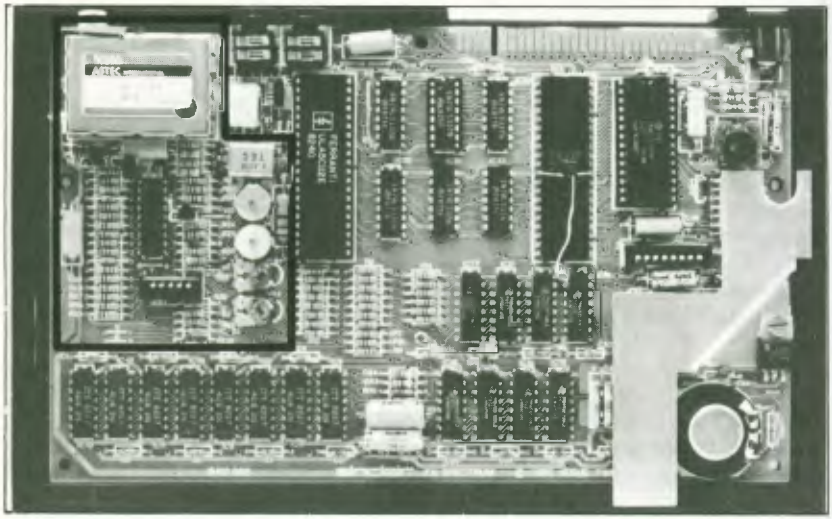


FIG. 8d — 32K ADDITIONAL RAM EXPANSION

ISSUE 2 BOARD



ISSUE 3 BOARD

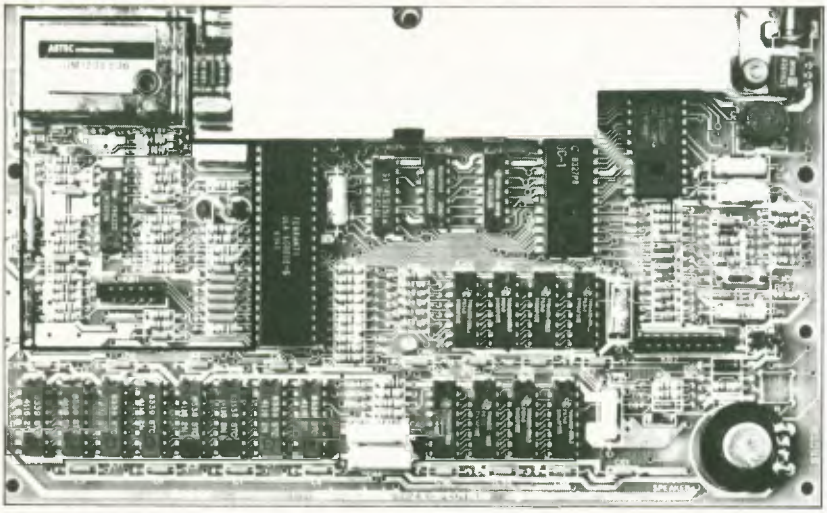


PLATE 9 – PHOTO OF MAIN SPECTRUM BOARD
OUTLINED VIDEO CIRCUIT

10. THE VIDEO CIRCUIT

The Spectrum video circuitry is based around the LM1889N integrated circuit produced by National Semiconductor. The video circuit diagrams for Issue 2 and Issue 3 Spectrums are shown in Figure 9a and Figure 9b respectively. The LM1889N accepts two colour difference signals (U = blue-yellow, and V = red-yellow) from the ULA. These are combined to produce a single colour output signal. It is more economic to use colour difference signals rather than separate RED, GREEN and BLUE signals. Only two sets of circuitry are required instead of three associated with RGB signals. The colour is mixed with the incoming composite video sync. and luminance (Y from the ULA) to produce the composite colour video signal. After being buffered by the emitter follower circuit using TR2, the video signal is fed into the video modulator. This enables the video information to be displayed on an ordinary colour television.

It is unfortunate that RGB video was not used, because some colour monitors require these signals. However, it is still possible to improve the rather poor quality display obtained on a television. For this, a monitor with a composite video input is required. Chapter 20 explains how such a monitor can be connected to your Spectrum.

Looking at figures 9a and 9b, it will be seen that several adjustments are available on Issue 2 Spectrums. The two adjustment resistors VR1 and VR2 alter the relative amplification of the red-yellow and the blue-yellow signals. By varying these adjustments, you can vary the output colour quality or the grey scales. See the next chapter for details on how to accomplish this. Note that NO adjustable components are provided in Issue 3 Spectrums.

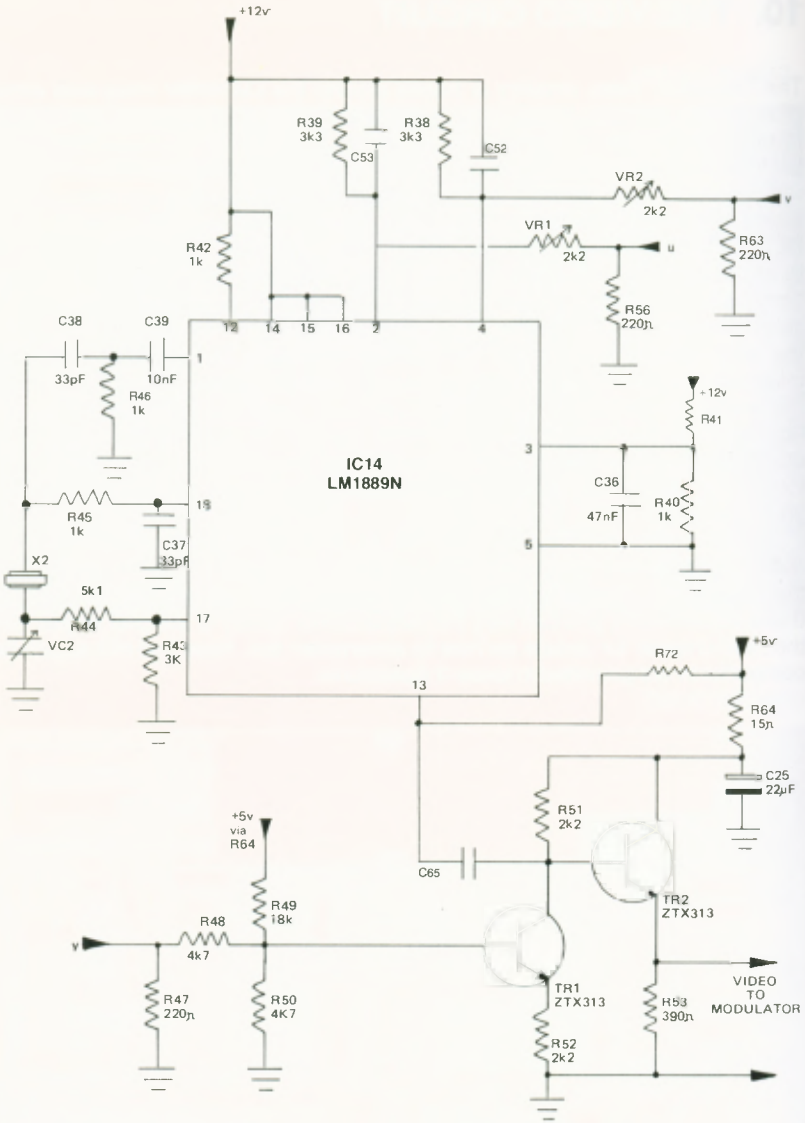


FIG. 9a — ISSUE 2 VIDEO CIRCUIT DIAGRAM

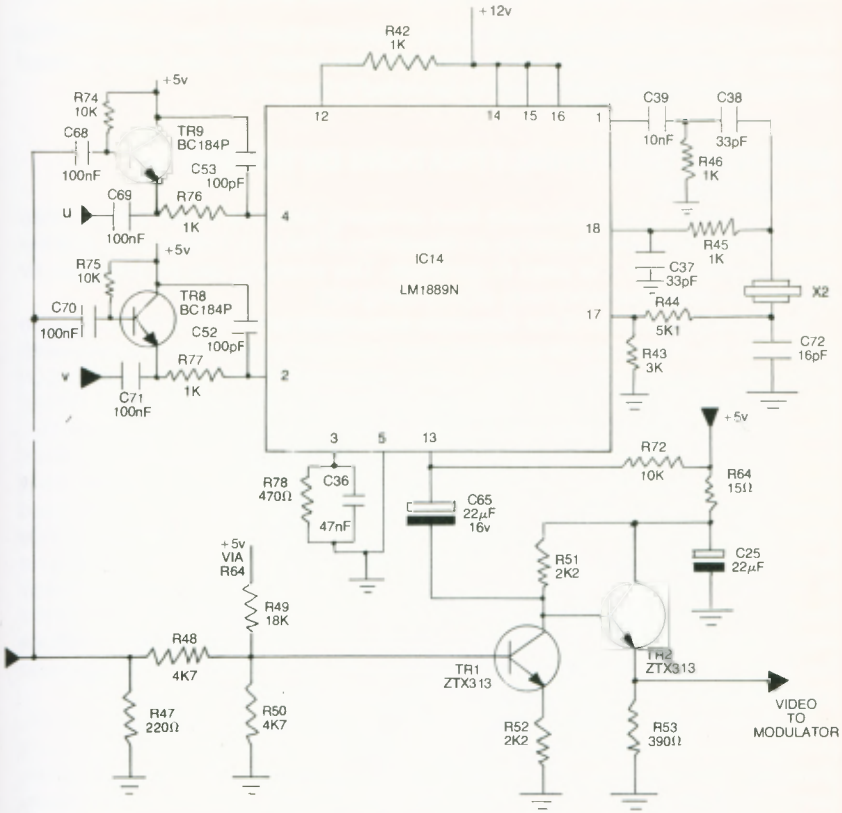


FIG. 9b — ISSUE 3 VIDEO CIRCUIT DIAGRAM

11. TUNING THE ISSUE 2 VIDEO CIRCUIT FOR A BETTER QUALITY DISPLAY

It should be noted that this chapter is only relevant to Issue 2 Spectrums. The four variable components which were present inside Issue 2's have been replaced with fixed components which cannot be varied in Issue 3's.

IMPROVING THE MOVING STRIATIONS ON THE SIDE OF CHARACTERS

Many Spectrum computers suffer from annoying striations on the side of video characters. These are caused by an interaction of the ULA 14MHz clock with the video display which it is used to generate. The striations can be improved by altering the clock frequency very slightly using VC1.

To do this, you should fill the Spectrum screen with some text. Any old program listing will do. Then turn the computer over so that it is resting on the keyboard. If you have an early version of the Spectrum, a small hole should be present on the right hand side. A small screw head should be visible inside the hole. If your Spectrum has not got a hole then it will be necessary to open the case. To do this, remove the 5 retaining screws that are visible on the underside of the Spectrum and lift off the keyboard as far as you can. Locate and remove the small retaining screw on the component side of the board near the middle. The circuit board should now be free from the bottom of the case. Turn the circuit board upside down. You should see a small hole with a screw head inside on the right hand side of the board. Using a small screwdriver carefully turn this screw a little way clockwise then back a little way anticlockwise. This should give you a feel for the effect of the adjustment. You should then be able to adjust the setting to produce the most pleasing display possible. Note that turning the screw through one complete revolution will set the adjustment back to its original value.

Sometimes it will help to readjust the channel setting on your television. Unfortunately, as the computer warms up, the crystal expands and its frequency changes. Bad striations may therefore reoccur whenever the temperature of the computer changes a lot. You should therefore let it warm up a bit before trying any adjustments. If the striations do become bad again, the only solution is to readjust the frequency as before using VC1.

The easiest way to vary the colour is with the colour control on your television. Similarly for grey scales, adjust the brightness and contrast on your TV. The following paragraph explains how to vary the colour settings inside the Spectrum. This ONLY applies to a colour (or grey scale) CHANGE. If there is no colour at all then refer to chapter 13.

To adjust the colour setting (or grey scale), you will need to open up your Spectrum by removing the 5 retaining screws which are accessible from the underside of your computer. Having unscrewed the case you should put a display showing all of the colours and shades onto the screen. The program at the start of Chapter 16 of your BASIC manual is suitable for this. Now you can carefully adjust VR1 and VR2 using a screwdriver. The positions of these two adjustment presets are shown in Appendix D and in Fig. 9c. Watch the colours on the screen

as you vary the settings. This will give you a feeling for the effect of each control. VR1 varies the red-yellow amplitude and VR2 varies the blue-yellow amplitude. VR1 has to be varied in conjunction with VR2 to vary the green level. How you eventually set the colour (or grey scale) is purely a matter of personal preference.

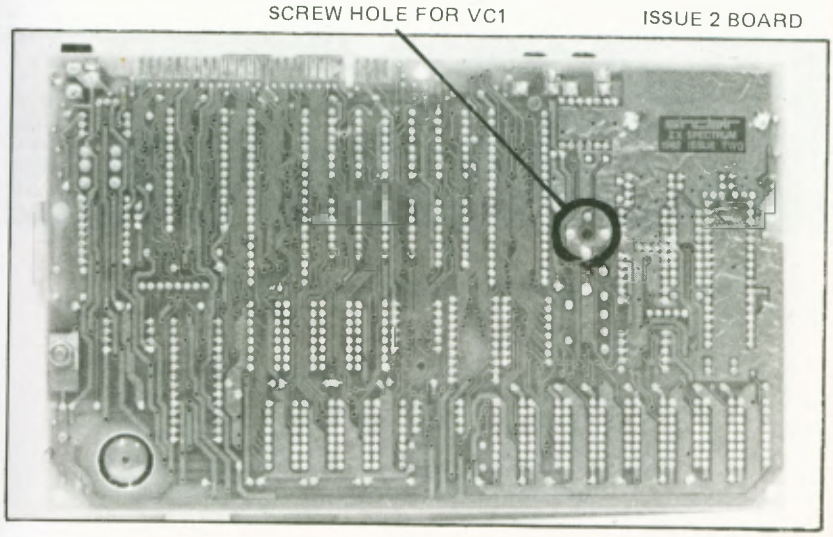


PLATE 10 — PHOTO OF SCREW HEAD FOR VC1

CHANGING THE COLOUR OR GREY SCALE

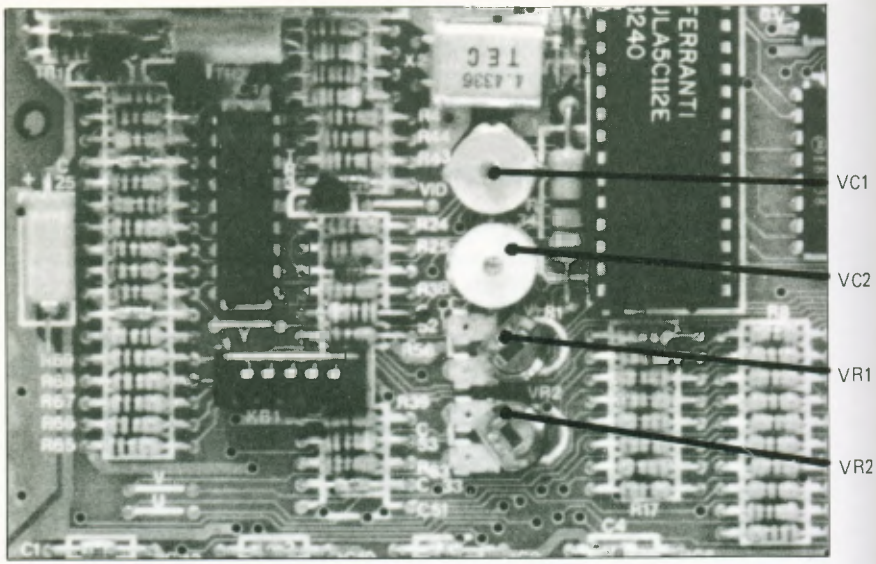


FIG. 9c — ISSUE 2 VIDEO CIRCUIT ADJUSTMENT CONTROLS

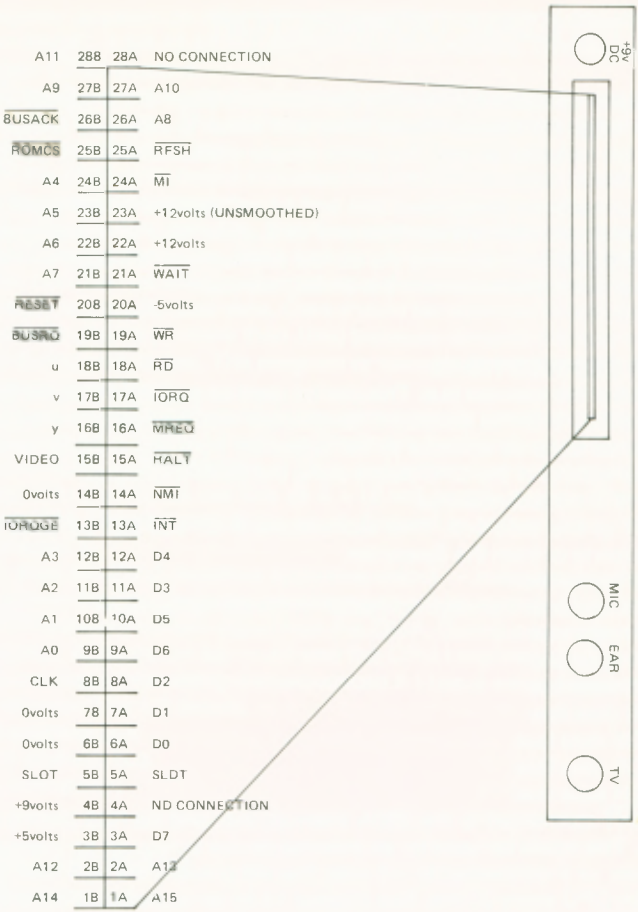


FIG 10a – THE EDGE CONNECTOR

12. THE EDGE CONNECTOR

This chapter contains a contact by contact description of the signals available on the rear edge connector. Some hints and ideas to help you design your own circuits are included as well. For some simple experiments which you can do see chapter 14.

The connections designated 28A and 1A are marked on the upper side of the Spectrum board. 28B is under 28A and 1B is under 1A. Fig 10a illustrates the rear view of the Spectrum showing the correct orientation of the edge connector. Note that it is shown upside down in the BASIC manual!

SIDE A CONNECTIONS

1A A15 of the address bus. This can be used as an output from the Spectrum to select various external devices in conjunction with the rest of the address bus. It can also be used as an input to the Spectrum from any external devices which take over control of the CPU buses using the $\overline{\text{BUSREQ}}$ signal.

2A A13 of the address bus

3A D7 of the data bus. This bidirectional 8 bit bus can be used to transfer information to or from the Spectrum.

4A no connection

5A slot to locate the edge connector in the correct position.

6A D0 data bus

7A D1 data bus

8A D2 data bus

9A D6 data bus

10A D5 data bus

11A D3 data bus

12A D4 data bus

13A $\overline{\text{INT}}$ connected to the Z80A interrupt line, and via R26 (680R) to the ULA $\overline{\text{INT}}$ pin. This could be used by an external device to request an interrupt from the Spectrum, or if connected to +5 volts this will prevent the ULA from interrupting the Z80A CPU every 20 ms. See chapter 14 for an experiment using $\overline{\text{INT}}$.

14A $\overline{\text{NMI}}$ to the Z80A non-maskable interrupt input. Normally held at logic 1 by R28(10K) connected to +5 volts. If taken low by an external device the Z80A will be forced to jump to address 102 decimal (66Hex) and start executing the machine code from there. See chapter 14 for an experiment using an $\overline{\text{NMI}}$.

15A $\overline{\text{HALT}}$ from the CPU $\overline{\text{HALT}}$ output — indicates that the CPU has executed a software HALT instruction. The CPU waits for an interrupt from an external device before continuing to execute the program. See chapter 14 for a simple experiment using a HALT.

16A $\overline{\text{MREQ}}$ from the CPU memory request output — indicates that the address bus now holds a valid address for a memory read or write operation. This signal is also operated during a memory refresh.

17A $\overline{\text{IORQ}}$ connected directly to the Z80A input/ouput request output. Indicates that the lower half of the address bus holds a valid I/O address for an I/O operation. The upper half of the address bus holds the contents of the CPU A register if IN A,n or OUT n,A are used in a machine language program. n appears on the lower half of the address bus. If a register indirect I/O operation occurs, the

CPU C register appears on A0 — A7 and the CPU B register appears on A8 — A15. From BASIC, a full 16 bit I/O address can be specified. This appears on A0 — A15 when $\overline{IORQ}$ is active.

18A $\overline{RD}$ the Z80A read output indicates that the CPU wishes to read data from memory or an I/O device. The addressed device should use this signal to put the relevant data onto the data bus.

19A $\overline{WR}$ the Z80A write output indicates that the CPU data bus holds data to be stored at the addressed location.

20A −5 volts power supply line. See the power supply circuit for details.

21A $\overline{WAIT}$ connected to the Z80A wait input, held high via R29 (1K5) to + 5 volts — this input can be used by slow external devices to make the CPU wait until they are ready to transfer their data. Care should be taken not to operate this line for long periods of time (ie more than 1ms) because dynamic memory will not be refreshed during wait states. The program or data could be corrupted and lost if $\overline{WAIT}$ is used for too long.

22A +12 volt power supply output (see power supply circuit for more details).

23A +12 volts NOT minus 12 volts as labelled in the Spectrum manual! This pin is in fact connected to the collector of TR 4 and is therefore an unsmoothed +12 volt supply. You should not use this as a +12 volt supply directly. The +12 volt supply from 22A should normally be used. A circuit to convert it to −12 volts is given in chapter 3.

24A $\overline{M1}$ from the Z80A machine cycle one output — indicates that the CPU is currently getting the opcode for the next instruction to be executed from memory.

25A $\overline{RFSH}$ memory refresh signal from the Z80A. During a memory refresh the CPU R register appears on A0 — A7 and the CPU I register appears on A8 — A15. This can have interesting consequences if I has a value between 64 and 127. See chapter 8 for full details.

26A A8 address bus

27A A10 address bus

28A no connection

SIDE B CONNECTIONS

1B A14 address bus

2B A12 address bus

3B +5 volts logic chip supply

4B +9 volts unregulated DC supply from the mains adaptor.

5B slot for locating the edge connector in the correct position.

6B 0 volts connection for the power supplies. Two connections are supplied because this line carries the sum of the other

7B 0 volts power supply currents. You should connect both to your external circuit to prevent either connection being overloaded.

8B CLK the 3.5 MHz clock signal from the ULA. Can be used to synchronise the operation of several Z80A support chips with the Z80A CPU. Note that the ULA may stop this clock for an odd cycle now and again if the CPU is accessing the first 16K of RAM. See chapter 8 for more details.

9B A0 address bus

10B A1 address bus

11B A2 address bus

12B A3 address bus

13B IORQGE connects to the IORQ input of the ULA chip. It is also connected to the IORQ output from the Z80A via R27 (680R). If IORQGE is connected to +5 volts the ULA chip will not receive its IORQ signal from the Z80A. This could be useful for expanding the number of devices available for user I/O, A7 could be used to disable the IORQGE signal when it is low. You would then be able to use A0 — A6 in any combination to address any one of 128 I/O devices. A circuit to do this together with an experiment using IORQGE is given in chapter 14.

14B 0v another zero volts connection intended for use in conjunction with the video signals.

15B VIDEO
16B Y
17B V
18B U

Video signals from the Spectrum. These are not always connected to their designated signals on Issue 2 Spectrums. Chapter 20 explains how to connect up a video monitor to these signals.

19B BUSRQ connected to the Z80A bus request input and held high by R30 (1K) to +5 volts. This can be used by external devices to request the use of all the CPU buses. Control is handed over after the current machine cycle is completed. The Z80A signals to the external device when its buses are available by taking BUSACK low.

20B RESET connected to the Z80A reset pin. This line is provided with a simple RC delay, at power on, to allow the whole computer to reach an operational state before the CPU tries to do anything. A simple RESET button can be connected between this pin and 0 volts (see fig 10b). When this switch is operated the CPU will reset in the same way as at power on. The difference is that you do not have to disconnect the power supply and then reconnect it. A RESET switch would be extremely useful to anyone who replaces the BASIC ROM with a machine code monitor, because memory would not then be erased whenever a reset had to be performed.

21B A7 address bus
22B A6 address bus
23B A5 address bus
24B A4 address bus

25B ROMCS connects directly to the ROM chip select pin and via R33 (680R) to the ULA. If you connect ROMCS to +5 volts the 16K BASIC ROM will disappear from the Spectrum memory. Obviously you must replace this with another program in some external memory at switch over, otherwise the computer will crash!

26B BUSACK the Z80A bus acknowledge signal tells an external device that it now has full control of the Z80A buses. It is used in conjunction with the BUSRQ signal.

27B A9 address bus
28B A11 address bus

13. FAULT DIAGNOSIS

The Spectrum is a complicated device and there are several faults which could occur. Most faults tend to be of a simple nature such as a loose connection, bad tuning or a blown fuse. It is these simple type of faults which this chapter aims to isolate. For more complex repairs, the computer should be returned to Sinclair or a qualified repair company.

SYMPTOM: No display at all

Follow these instructions in sequence:

a. Connect the video lead from the Spectrum to the television.
b. Switch on the TV.
c. Connect the Spectrum power supply unit to the mains.
d. Connect the supply lead to the Spectrum.
e. Press the 'ENTER' key on your Spectrum and keep it pressed. Can you hear a faint clicking coming from the buzzer? If you cannot then go to 'g'.
f. If you get here then most of your Spectrum is working. Try tuning your television to match the channel output from the Spectrum. If you still do not get a display on the TV then go to 'j'.
g. Check that your mains power pack lead is correctly inserted into the Spectrum.
h. Check the fuse in the mains plug to the ZX power supply.
i. If you have access to a multimeter check that there is a +9 volts between the 0v and +9 connections on the rear edge connector. If there is not any voltage then thoroughly check all power supply connections. There is almost certainly a break in connection somewhere.
j. If your Spectrum still isn't working then seek professional aid.

SYMPTOM: No colour on the display

Follow these instructions in sequence:

a. Make sure that you are actually meant to be displaying colour. The program at the start of Chapter 16 in the BASIC manual will put all available colours on the screen.

b. Check that the colour control on your television set is adjusted to give colour. At one end of the scale you will only get black and white pictures.

c. Check that the TV channel you are using is exactly tuned to your Spectrum. If it is not you will get a poor quality display with little or no colour.

d. If you get as far as this, it is quite probable that the colour crystal in your Spectrum is not tuned to the colour crystal in your television. On Issue 3 Spectrums, it is not possible to tune this, so the computer will have to be repaired professionally. On Issue 2 Spectrums however, you may try to retune the Spectrum. First unscrew the five retaining screws under your Spectrum so that you can move the keyboard. The adjustment to be varied is VC2. Look at the component layout diagram in Appendix D to find it. Now rotate VC2 slowly using a small screwdriver (clockwise or anticlockwise). You should find a point at which colour returns to your display. If after a complete turn of VC2 the colour hasn't returned, you will have to get the Spectrum repaired professionally.

SYMPTOM: Random graphics on the screen

When power is connected to the Spectrum a display of random graphics in assorted colours appears. There is no copyright message present. If this occurs with no external circuits connected to the Spectrum, your Spectrum will have to be repaired professionally. The fault is normally caused by bad power supply regulation or a fault in one of the chips. The reduction in regulation of the power supplies caused by extra circuits being added can sometimes cause this problem as well. You should therefore disconnect any external circuits and try providing them with an external power supply.

Long leads to external circuits can also cause problems. There are two solutions to long leads. You can either shorten the leads, or if this is impossible, incorporate some buffer integrated circuits.

If this problem occurs even with no peripherals attached, the fault is most probably with the power supply. You can verify this by listening to the Spectrum when it is switched on. A small buzzing sound can be heard if the power supply is functioning properly.

It is advised that you return your Spectrum to Sinclair Research if this is the fault with your Spectrum. If you are feeling adventurous, however, you may take your Spectrum's life in your own hands and try replacing TR4 with a small NPN transistor. If this does not rectify the fault, then try replacing TR5 with a small PNP transistor.

14. EXPERIMENTING WITH THE EDGE CONNECTOR

This chapter provides lots of practical information which will be required by those who want to connect their own circuits up to the Spectrum. It should be read in conjunction with chapter 12 which explains each of the edge connector signals on a pin by pin basis. To illustrate how some of the signals can be used there are some small circuits and associated test programs.

WHAT YOU WILL NEED

The first piece of hardware which you must have is a suitable connector to plug into the back of your Spectrum. A connector will allow you to solder wires onto the various contacts very easily.

The type of connector required is a 28 way double sided 0.1" pitch edge connector with a key in position 5. The key is there to locate the connector in the correct position. You should be able to purchase a connector like this from your local computer/electronics store or by mail order. If you have any difficulty getting one it is possible to use a standard 43 way 0.1" double sided connector with a key in any position from 5 — 20. The extra contacts can then be carefully cut off with a hacksaw to produce the correct size of connector.

Now that you have got your connector you will want to start connecting some circuits to it. Two simple options are available:

1. Breadboard system

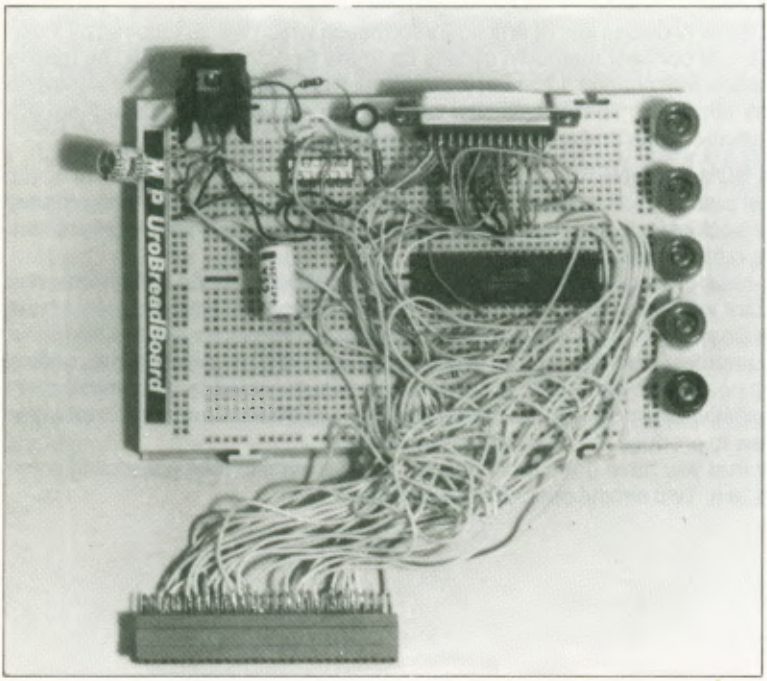


FIG 10h – BREADBOARD SYSTEM

Many different types of breadboards are available. Most modern ones have metal contact strips with about 5 contacts per strip. These strips are moulded into a plastic baseboard. The leads to components such as integrated circuits, resistors, capacitors etc can be pushed through holes in the plastic to make contact with the metal strips underneath. Connections between components can then be made with lengths of single core insulated wire. These pieces of wire have about 5mm of insulation stripped from each end. The wires then push into the relevant holes on the breadboard.

This type of construction for circuits is very quick and easy. Once you have finished with a circuit it can be unplugged and a new one can be constructed. A breadboarding system is illustrated in fig 10h. This shows the prototype PIO addition and an extra +5 volt power supply. Single strand wires were soldered onto the Spectrum edge connector at one end. The other end is left free to connect to anywhere on the breadboard.

2. Vero strip board system

A veroboard is a ready made circuit board with horizontal copper connection strips on one side. Holes are drilled through the board spaced 0.1" apart on a square grid pattern. This type of board is useful for experimental work where a more permanent circuit than breadboarding can offer is required. Component leads are inserted through the holes and soldered onto the copper strips. So that useful circuits can be made, the copper strips will often have to be broken. These breaks remove unwanted connections between component leads. A special 'vero spot face cutter' can be used to make breaks in the tracks. A more readily available alternative is to use a 1/6" drill. To make a break, place the drill into a hole on the copper side of the board. Revolve it in the cutting direction whilst pressing it into the board. Stop when a break in the copper strip has been made.

If you use veroboard it is highly advisable to use integrated circuit sockets. This will make the chips easy to remove in the event of failure and will eliminate the possibility of them overheating when they are being soldered. The big advantage of veroboard is that you have a permanent circuit. The disadvantage is that it cannot be modified as easily as a breadboard, and used veroboards may have to be thrown away. A circuit constructed on a veroboard is shown in fig 12b.

Whichever of the above two types of prototyping board you use, you should always try to keep the connection wires as short as possible. If leads attached to edge connector contacts are too long, then the extra capacitive load may prevent the Spectrum from working at all. Long leads sometimes make the computer crash fairly frequently until it has warmed up.

Adding a few chips onto the Spectrum, such as the designs in this book, presents no problems. The Z80A can provide sufficient line driving capability itself. If you decide to design lots of additional circuits then some form of buffering will have to be added. If you are designing circuits of this complexity then it shouldn't prove too difficult to design this buffering yourself using the information given in the rest of this book. Refer to some of the books in appendix B for help.

We now come to some simple circuits which you can build. Many only consist of a simple switch and resistor.

RESET SWITCH

The circuit is illustrated in fig 10b. You simply connect a push button between $\overline{\text{RESET}}$ and 0v on the edge connector. When you press the button the RESET line is pulled down to 0v to reset the Z80A. Upon releasing the button, C27 charges via R31 until the voltage reaches logic 1 level. The Z80A then starts to run the machine code program starting from address 0 (usually in the Sinclair ROM). Using this button simulates a "power on reset" and consequently programs which were in the memory are deleted.

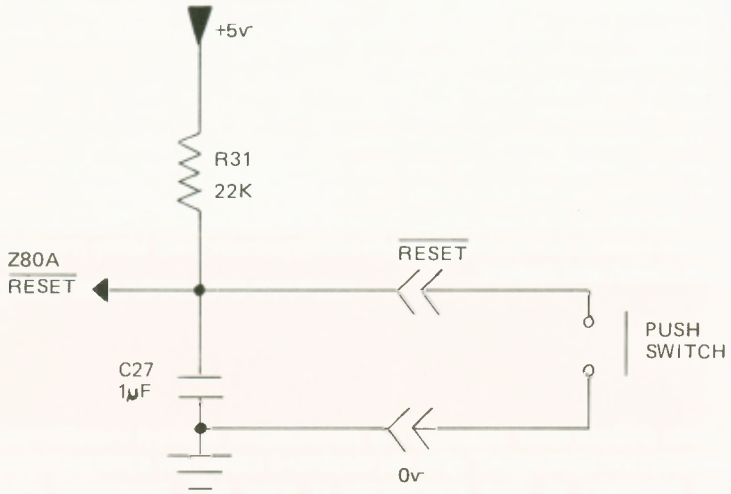


FIG 10b – RESET SWITCH ADDITION

HALT EXPERIMENT

The $\overline{\text{HALT}}$ line is an output from the Z80A chip. When active (output = logic 0) it indicates that the CPU has executed a software HALT instruction and is awaiting an interrupt from an external device. Whilst the CPU is halted it executes NOP's (NO operations which do nothing). These ensure that the memory refresh mechanism continues to operate irrespective of the duration of the HALT.

The circuit for this experiment is shown in fig 10c. Any small LED (light emitting diode) will do. Now try running this little program.

```
10  CLEAR 32499
20  POKE 32500,118 :REM HALT
30  POKE 32501,201 :REM RET
40  LET a = USR 32500
50  GO TO 40
```

Line 10 stops BASIC using memory above 32499. Lines 20 and 30 set up a machine code program to execute a HALT then return control to BASIC (after an interrupt has been received from the ULA). Line 40 jumps to the small machine code program. You should notice that the LED lights when you run the program. In fact it is switched on when the program first gets to line 40. Then the ULA sends an interrupt to the CPU which turns off the HALT line. The program goes back to line 40 and turns the HALT on again, until the next interrupt is received from the ULA. You can't actually see the LED flashing on and off because it is flashing at 50 Hz (the ULA interrupts the CPU 50 times every second).

NMI TEST

The circuit for this test is shown in fig 10d. It simply requires a push switch between the $\overline{\text{NMI}}$ input on the edge connector and the 0 volt line. If you press the button to generate an $\overline{\text{NMI}}$ (non maskable interrupt) then, no matter what the CPU was doing previously, it will now start to run the interrupt service routine at address 66Hex (102 decimal). This in fact will reinitialise BASIC and so it has the same effect as pressing the RESET button.

INT AND IORQGE TESTS

In these tests we are going to use the circuits in fig 10e and fig 10f. These effectively connect the appropriate lines on the edge connector directly to +5v. The 100 ohm resistor is there to reduce the current taken from the power supply and can be omitted.

Now enter the following short program. Leave both switches for $\overline{\text{INT}}$ and $\overline{\text{IORQGE}}$ open whilst doing this.

```
10  CLS
20  PRINT AT 0,0; PEEK 23672 + 256*PEEK 23673
30  GO TO 20
```

When you run the program you will see an incrementing number at the top of your screen. This shows how many times the CPU has been interrupted since it was switched on. Now operate the INT switch. The clock stops. Try to BREAK your BASIC program. Nothing happens! All is not lost however. Switch the INT switch off again and the counter restarts where it left off. You can also use the keyboard again.

Why did this happen? Well, the way in which the counter and keyboard operate relies upon interrupts. Once every 50th of a second the ULA activates the $\overline{\text{INT}}$ line. This causes the CPU to jump to a little bit of machine code in the BASIC

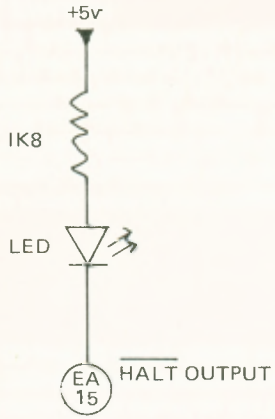


FIG 10c – $\overline{\text{HALT}}$ TEST

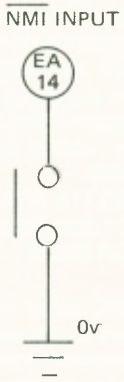


FIG 10d – $\overline{\text{NMI}}$ TEST

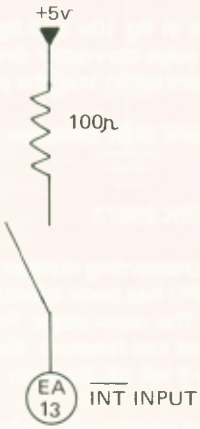


FIG 10e – $\overline{\text{INT}}$ TEST

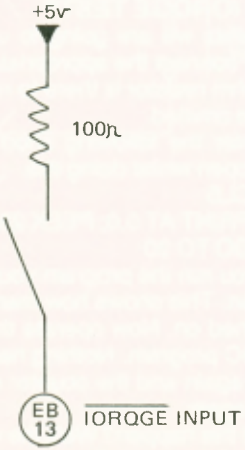


FIG 10f – $\overline{\text{IORQGE}}$ TEST

ROM. The purpose of this routine is to scan the keyboard to see if a key has been pressed and to increment a 3 byte counter in memory. By connecting $\overline{INT}$ to +5 volts, you stop the ULA interrupt signal reaching the CPU. The CPU doesn't ever scan the keyboard or increment its counter unless it receives an interrupt. Therefore none of the keys on the keyboard operate and the counter stops.

Now enter this one line program.

```
10  FOR t = 1 TO 30: BEEP 0.01,t: NEXT t: GO TO 10
```

If you run it you will hear a BEEP of rising pitch from the buzzer. Try operating the INT switch. It has no effect and the tone continues. INT doesn't affect output from the CPU to the ULA. It only affects inputs from the ULA to the CPU. Switch INT off again. Now try operating the IORQGE switch. The BEEP suddenly stops. Yet again the keyboard has become totally unuseable, but for a totally different reason. Can you see why?

All I/O which is done by the ULA relies upon the ULA being able to detect whenever the CPU wants to send it information or get information from it. The ULA uses the address lines, $\overline{RD}$, $\overline{WR}$ and $\overline{IORQGE}$ to test if the CPU is trying to communicate. By connecting IORQGE to +5 volts, you are preventing the Z80A $\overline{IORQ}$ signal from reaching the ULA. No communication between the two devices can therefore occur. The 3 byte ON time clock does continue to run because the ULA is still generating interrupts for the CPU 50 times per second.

15. ADDING A Z80A PIO CHIP

This parallel input/output chip enables the Z80A CPU to communicate with the outside world. In this chapter a brief explanation of how the PIO works, how to program it, and how to connect it up to the rear edge connector will be given. It is not intended to give a complete and fully detailed description of the PIO chip. This information can be readily obtained from specialised books on Z80 interfacing. Chapter 18 contains details of an 8 channel analogue voltage to digital output converter as a practical example of a useful device which can be run from the PIO. One of its many uses is for reading the X and Y coordinates from a joystick input.

The Z80A PIO chip has been designed specifically for use with the Z80A CPU chip. If you look at the pin connections in fig. 11a you will notice lots of familiar signals. There is the databus for fully bidirectional communication with the CPU, the clock, $\overline{M1}$, $\overline{IORQ}$, $\overline{RD}$ and $\overline{INT}$ signals all being connected directly to their equivalent pins on the edge connector. There are also two pins for the "interrupt enable input" and "interrupt enable output" signals. These are only of relevance when interrupts are being used. The basic use of interrupts are to force the CPU to run a specified piece of machine code program. For example, the Spectrum might be running BASIC and also be under use as a central heating controller. The CPU doesn't want to waste time keeping a check on the house temperature (from a signal from a thermostat) because this would slow down the BASIC. We would therefore use interrupts. If the temperature gets too high or too low anywhere in the house the thermostat circuit would interrupt the CPU which is then forced to run the central heating program. When this is completed it can go back to BASIC and forget about the heating until it is interrupted again.

Looking at the other connections you will see that there are two I/O ports. These are designated port A and port B to distinguish between them. Each port has 8 I/O lines (PA0 — PA7 and PB0 — PB7) and two handshake lines (ARDY, $\overline{ASTB}$ and BRDY, $\overline{BSTB}$). In this book only the eight I/O lines will be used. The other signals are used in BYTE data transfer modes between input/output devices (usually of different computers).

In order to illustrate the PIO chip programming there follows a practical example with explanation. The object is to define PA0 to PA1 as inputs and PA2 to PA7 as outputs. It will then be seen how these can be used by the CPU to operate the switches and lamps circuit. This example uses port A, however port B can be used in exactly the same way by sending control words and data words to port B instead. The circuit shown in fig 11b should be built on the same board as the PIO chip. The 74LS05 integrated circuit is used to operate the light emitting diodes (LED's) because the PIO chip outputs cannot supply enough current. Virtually any type of LED can be used in this circuit.

If you have a 16K Spectrum then the Spectrum's own +5 volt power supply should be sufficient to operate all of the circuits in this book. 48K Spectrum owners may find that their +5 volt power supply just cannot provide sufficient current for their extra 32K of memory plus the additional circuits given here. If you find this to be the case with your Spectrum, an additional +5 volt power supply will be required. A suitable design is discussed in chapter 3.

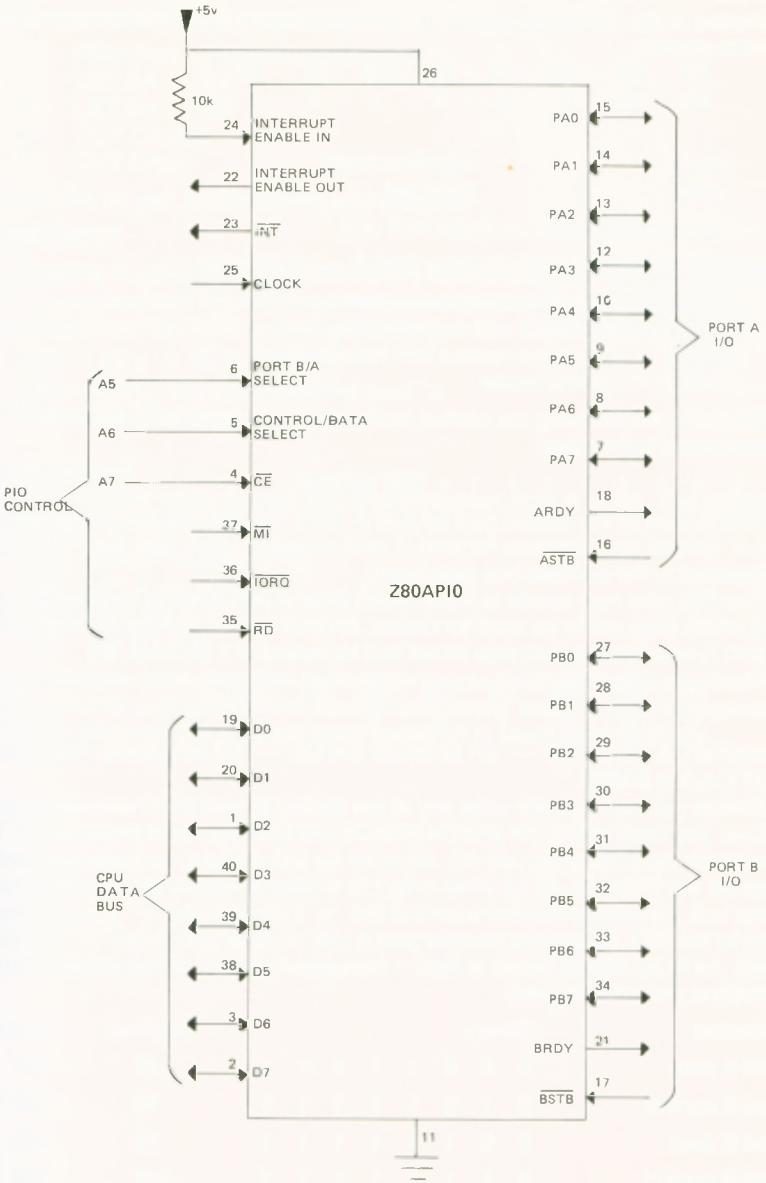


FIG 11a – Z80A PARALLEL INPUT/OUTPUT CHIP

Before the PIO chip can begin to operate as we desire, it must be told what it is expected to do. This is carried out by writing a control word to it. The format of a control word is:

D7	D6	D5	D4	D3	D2	D1	D0
M1	M0	x	x	1	1	1	1

mode word — signifies mode to be set.

x = not used by the PIO so it can be 0 or 1.

The mode word can be any number from 0 — 3 inclusive.

mode 0 = byte output with handshaking
mode 1 = byte input with handshaking
mode 2 = byte input/output with handshaking
mode 3 = control mode

Since we will be using the control mode, the mode word must be set to 3. The control word is therefore:

1 1 1 1 1 1 1 1 = 255 decimal

This is sent to the control port for port A. OUT CA,255 can be used in BASIC. CA = control port address for port A and depends upon how the PIO chip is connected to the address bus (see later).

The PIO chip now needs to know which lines of port A are to be used for input and which lines are to be used for output. Another control word is therfore written to port A with the relevant data bit set to 0 for output or 1 for input. So

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	0	0	0	1	1

written to CA will set D0 — D1 as inputs and D2 — D7 as outputs. You can use OUT CA,3 in BASIC.

Before you can actually write any of the BASIC IN and OUT commands given above, you must define CA and DA plus CB and DB if you want to use port B. The Spectrum itself does not use A7, A6 or A5 for I/O devices, so these are used to operate the PIO chip. A7 as wired in fig 11a is used to enable the PIO chip when it is set to 0. A6 selects whether a control (A6 = 1) or data (A6 = 0) word is being sent to the PIO. A5 selects whether port A (A5 = 0) or port B (A5 = 1) is being used. A4 to A0 should be left at logic 1 throughout, so that ordinary Spectrum I/O functions are not disrupted.

Selected	Binary								Decimal	Token
Port A data	0	0	0	1	1	1	1	1	31	DA
Port A control	0	1	0	1	1	1	1	1	93	CA
Port B data	0	0	1	1	1	1	1	1	63	DB
Port B control	0	1	1	1	1	1	1	1	127	CB

EXPERIMENTS WITH THE LED's and SWITCHES

Always start your BASIC programs with:

```
10  REM Port A initialisation program
20  LET DA = 31
30  LET CA = 93
40  OUT CA,255
50  OUT CA,3
```

This will set up port A correctly for your program.

SOME INPUT

It is possible to generate each of the binary numbers 00, 01, 10, 11 equivalent to 0 — 3 in decimal with the switches in different positions. Try the following program loop to see how the number displayed changes with different switch positions.

```
100  LET x = IN DA
120  PRINT "My input switches read ";x
130  GO TO 100
```

Some output

The LED's allow us to display any binary number from 0 —63. The following program will do this for you:

```
100  INPUT "Number? ";A
110  LET A = A * 4
120  OUT DA,A
130  GO TO 100
```

Now that you have seen how to do some simple input and output with the PIO, you could write a program which counts up in binary automatically. By operating one of the switches the program could then start to count down in binary.

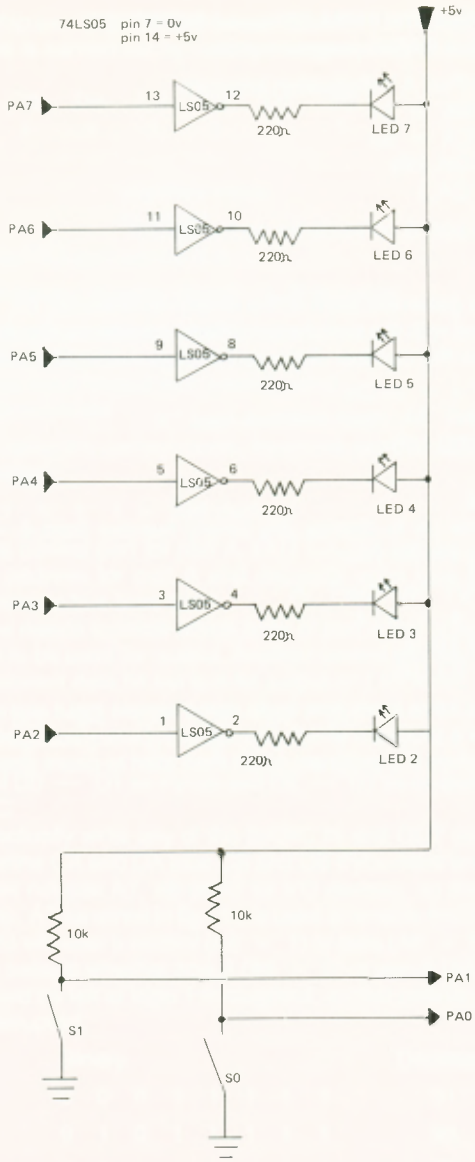


FIG 11b – LAMPS AND SWITCHES EXPERIMENT

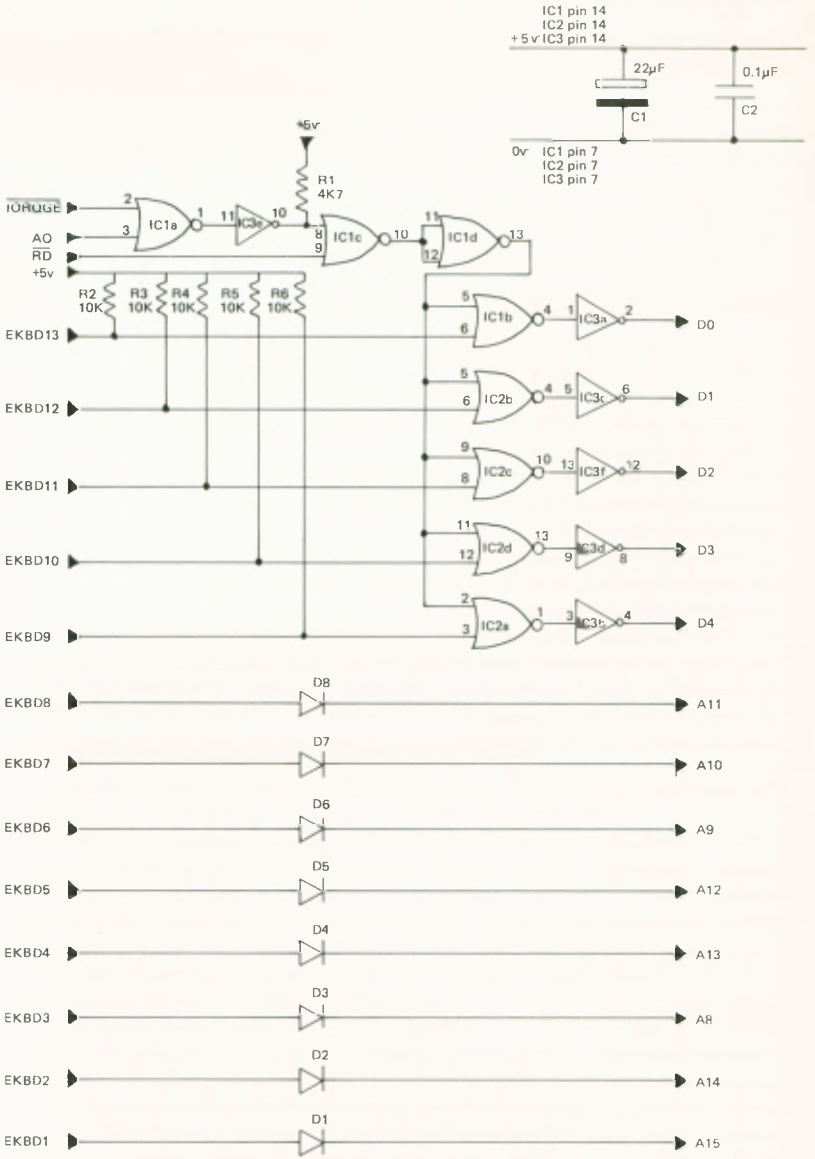


FIG 12a – ADDITIONAL KEYBOARD CIRCUIT DIAGRAM

16. ADDING YOUR OWN KEYBOARD

INTRODUCTION

This chapter explains in detail how you can build a keyboard interface which will plug directly into the rear edge connector. It will operate in parallel with the original Spectrum keyboard so that two keyboards can be used simultaneously. Chapter 17 explains how you can use this keyboard interface for Sinclair compatible joysticks. The possibilities are enormous. You could add a numeric keypad (an old calculator keypad for example), a hexadecimal keypad for machine code programming, or a complete full size keyboard.

CIRCUIT DESCRIPTION

You should refer to the circuit diagram illustrated in fig 12a. The keyboard connections EKBD1 — EKBD13 shown on this circuit diagram are equivalent connections to KBD1 — KBD13 shown in fig 6. The signals $\overline{IORQGE}$, A0, and $\overline{RD}$ are all combined so that the common inputs to NOR gates IC1b, and IC2a — IC2d are only low when these signals are all low. This extra keyboard interface is therefore selected whenever the ULA (port 254) is addressed to be read from. If none of the keys are pressed then the inputs to the NOR gates are pulled high by resistors R2 — R6. Outputs to the NOR gates are low and are inverted by IC3 to give a high on the data bus lines D0 — D4. Since IC3 hex buffers have 'open collector' outputs, the ULA can easily set any of D0 — D4 at logic 0 if any of the Spectrum keyboard keys are pressed. Now imagine that EKBD10 is connected to EKBD6. If you look at fig 6 you will see that this indicates that the 'F' key has been operated. When a read occurs with A9 low the input to IC2d is pulled low. The output to IC2d goes high and D3 is pulled low by IC3d. The CPU can then read D0 — D4 directly from its data bus and register that the 'F' key has been pressed.

PARTS LIST

Resistors

R1	4K7
R2 — R6	10K

all 5% ¼ watt

Capacitors

C1	22uF 6 volt electrolytic
C2	0.1 uF disc ceramic

Semiconductors

IC1	74LS02
IC2	74LS02
IC3	74LS05

D1 — D8 IN4148 diodes

Miscellaneous

3 off 14 pin DIL IC sockets
28 way Spectrum edge connector
2.3" x 2.6" (or larger) piece of 0.1" pitch copper strip veroboard
wire and solder

CONSTRUCTION DETAILS

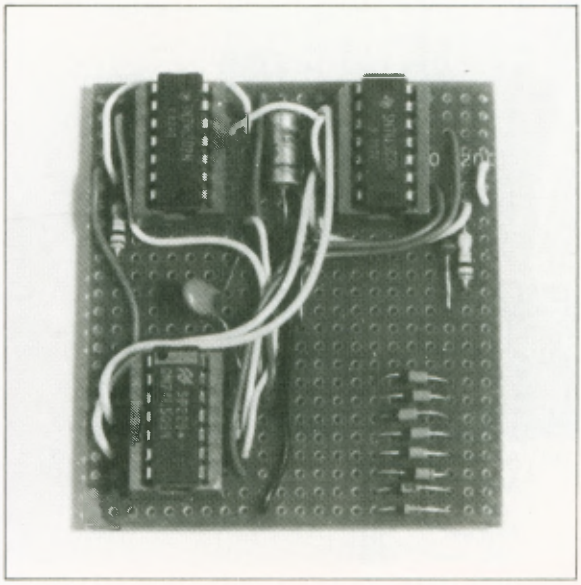


FIG 12b – KEYBOARD INTERFACE BOARD

This circuit can be built on breadboard or veroboard. The component arrangements for the veroboard design are illustrated in fig 12b. Sockets should be used for the three integrated circuits so that they are not damaged by overheating during soldering. Make sure that you break all of the copper strips as shown in the diagram. A 1/6" drill is suitable for this (see chapter 14 for some hints on construction). The circuit must be carefully wired up as in the full circuit diagram in fig 12a. The completed circuit board showing all of the components soldered into position, together with the interconnection wires is shown in fig 12b. The tips of the arrows on diodes D1 — D8 in the circuit diagram are normally represented by a band on the correct end of the components.

You will now want to connect some form of keyboard up to the circuit. The next chapter explains in detail how to connect up some joystick game controls. Alternatively, there are lots of full size keyboards available which could be connected up. The major problem here is that all of the keyboards tend to be wired in a different way. It is not therefore possible to give exact details for converting different keyboards in a book of this nature. The basic requirement is that the keyboard is rewired to conform to the Sinclair keyboard shown in fig 6. For example, the '1' key must be connected between EKBD4 and EKBD11. The '7' key must be connected between EKBD5 and EKBD10 and so on. If this rewiring of a keyboard does not appeal to you, several large mail order companies will supply individual keyboard switches. It is fairly easy to mount these on a large piece of veroboard on a 5 × 8 key grid.

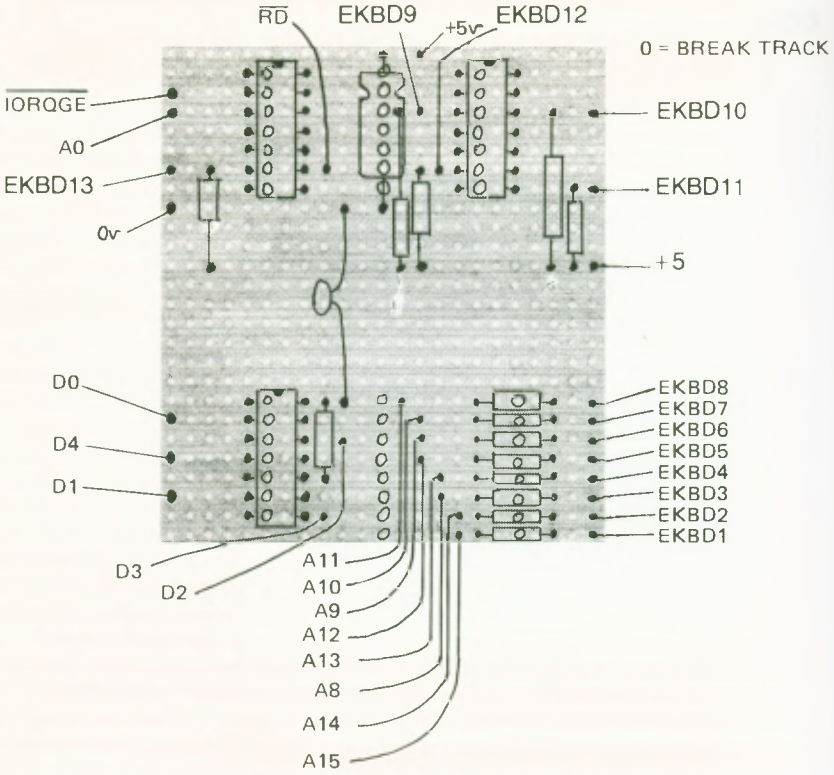
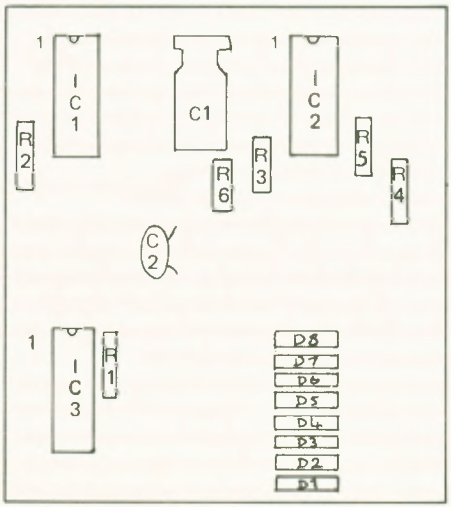


FIG 12b – ADDITIONAL KEYBOARD/JOYSTICKS COMPONENT LAYOUT DIAGRAM



NOTE — Connections between components must be made as in the circuit diagram

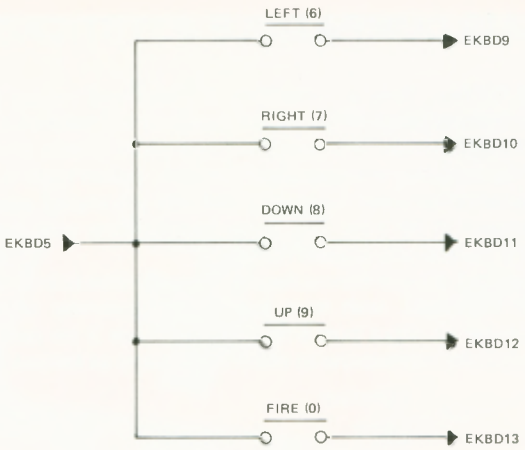


FIG 12c – JOYSTICK 1 CONNECTIONS

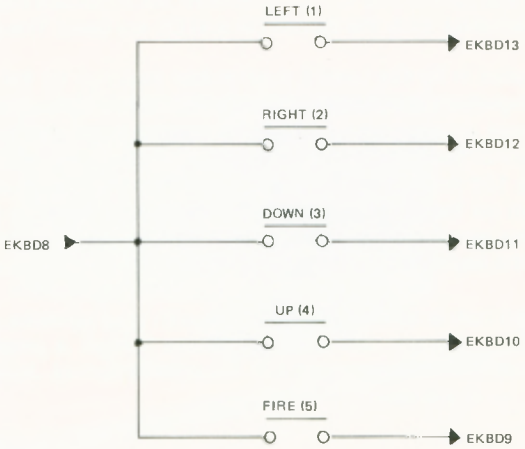


FIG 12d – JOYSTICK 2 CONNECTIONS

17. SINCLAIR COMPATIBLE JOYSTICKS

A joystick, in this context, means some form of hand held device used to give movement instructions to programs. Sinclair joysticks will have a LEFT, RIGHT, UP, DOWN and FIRE function. The hand held unit could consist of a lever which operates one of four switches when pushed forwards, pulled back or moved from side to side. An alternative small hand held unit with a compact arrangement of pushbuttons is shown in fig 12e. The outer four buttons give the movement commands and the central one is a fire button.

The Sinclair joysticks appear from software to be identical to the top row of keys on the Spectrum keyboard, both from BASIC and machine code programs. Joystick 1 will appear on input port 61438 and joystick 2 on port 63486. The functions of the joysticks correspond to the number keys as follows:

Key	Function	
1	LEFT	
2	RIGHT	
3	DOWN	JOYSTICK 2
4	UP	
5	FIRE	
6	LEFT	
7	RIGHT	
8	DOWN	JOYSTICK 1
9	UP	
0	FIRE	

In order to add this control box to your Spectrum, the keyboard interface circuit of chapter 16 is required. Only the diodes D8 and D5 are used. The other diodes can be omitted.

The unit illustrated in fig 12e uses 5 push button switches for the control box. The internal arrangement of buttons soldered onto a piece of veroboard is shown in fig 12f. The exact arrangement and type of buttons is left to the constructor. Internally the control box (es) must be wired in accordance with fig 12c (for joystick 1) and fig 12d (for joystick 2). The connections to the keyboard interface are clearly shown on these diagrams. If you are able to obtain a ready made joystick control box which makes contacts as in fig 12c and fig 12d then this can be connected to the keyboard interface circuit instead of a completely homebrew circuit.

All that you need now is some software to use with your joysticks. Any Sinclair joystick compatible software can be used. There follows a program named 'APOLLO' to enable you to experiment with the joystick control. Joystick 2 or the keyboard keys 1 — 5 are used.

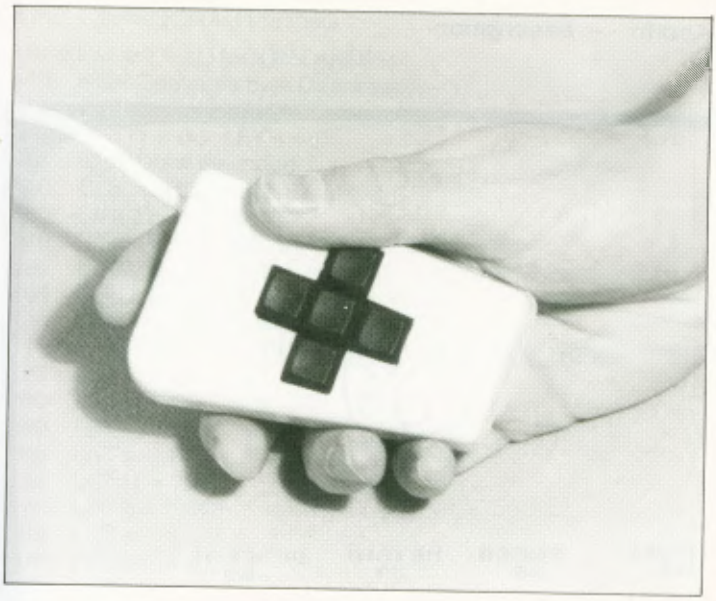


FIG 12e – JOYSTICK CONTROL IN HAND

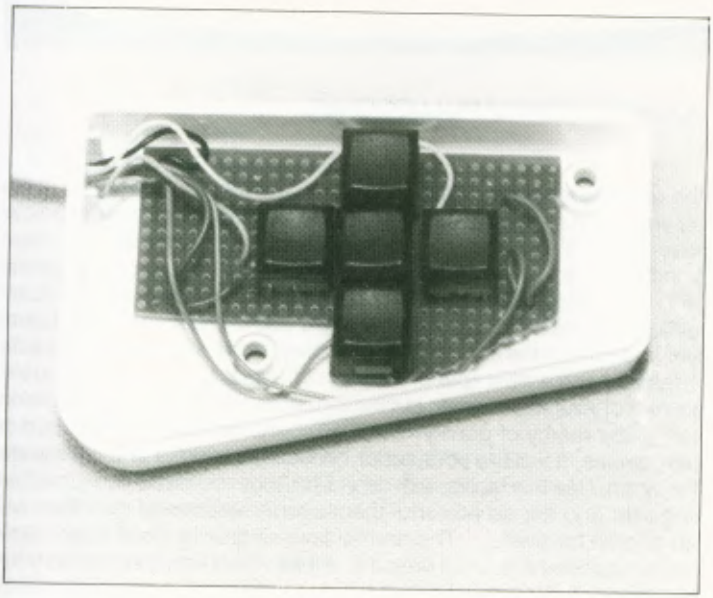


FIG 12f – INTERNAL LAYOUT OF HAND HELD JOYSTICK

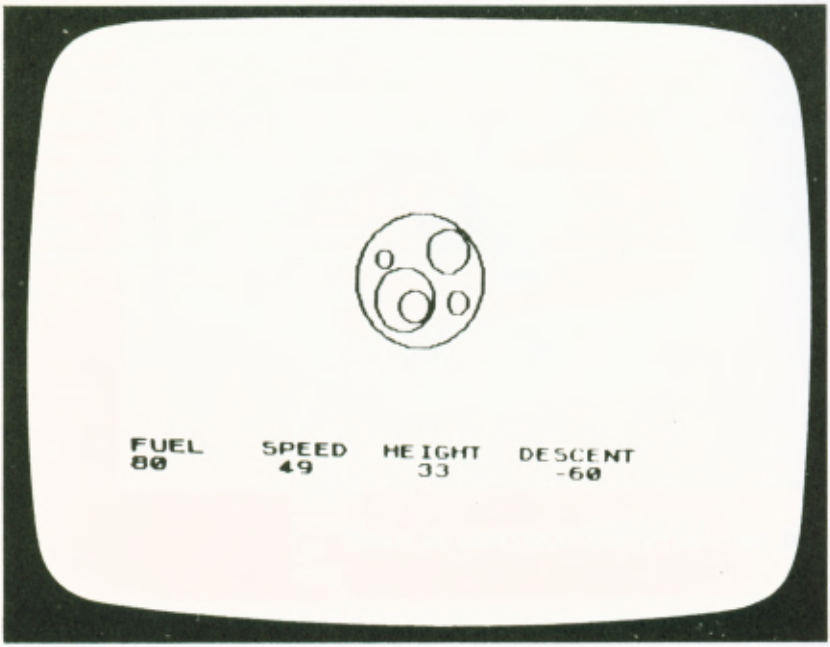


FIG 12d — DISPLAY FOR "APOLLO" GAME

The aim of the game is to successfully land a lunar module on the surface of the moon. Initially you are in a steady circular orbit. The joystick controls your thruster rockets. These apply thrust away from the moon (UP), towards the moon (DOWN), to increase tangential velocity (RIGHT) and to decrease tangential velocity (LEFT). You only use fuel when operating a thruster. A continuously updating readout of remaining fuel, speed, height above the lunar surface, and rate of descent appears on the screen. The objective is to land on the surface with a low rate of descent and a slow speed. If either of these is too large then you will crash. In the event of your fuel running out the thrusters will no longer operate and you will be left to the mercy of gravity! The FIRE button should only be used in absolute emergencies. It will fire your super boost retro rockets and accelerate away from the moon. Use this facility with care. The super boosters consume fuel at an alarming rate and are so powerful that several seconds of operation will boost you out of orbit for ever . . . The normal laws of gravity are obeyed. Slow down your orbital speed and you will drop into a lower orbit which increases your speed again. Applying full thrust towards the lunar surface will push you closer to the moon, but your orbital speed increases rapidly so that centrifugal acceleration throws you out further into space. Happy landings.

APOLLO PROGRAM LISTING

```
100 REM APOLLO MOON LANDER
110   REM Copyright by A C Dickens
120   REM December 1982
130   LET r1 = 30 : LET s = 0
140   REM Draw the moon
150   CLS : CIRCLE 127, 87, r1
160   CIRCLE 110, 96, 4
170   CIRCLE 140, 100, 10
180   CIRCLE 125, 75, 7
190   CIRCLE 145, 77, 5
200   CIRCLE 120, 78, 14
210   PRINT AT 20, 0; "FUEL □□□ SPEED □□ HEIGHT □□ DESCENT"
220   LET x = 127
230   LET y = 157
240   LET r = 70
250   LET v = 1
260   LET kt = 70
270   LET p = 0.095
280   LET w = 1/70
290   LET am = 70
300   LET p1 = p/3
310   LET u = 0
320   LET k = 0
330   LET fu = 100
340   LET fl = 0.2
350   REM Get joystick input
360   IF fu = 0 THEN LET e = 31 : GO TO 380
370   LET e = IN 63486 - 224
380   LET f = INT (e/16) : REM FIRE key
390   LET e = e-f*16
400   LET f1 = INT (e/8) :REM LEFT key
410   LET e = e-f1*8
420   LET f3 = INT (e/4): REM DOWN key
430   LET e = e-f3*4
440   LET f2 = INT (e/2): REM RIGHT key
450   LET e = e-f2*2
460   LET f4 = INT e: REM UP key
470   LET f1 = (1-f1) *p
480   LET f2 = (1-f2) *p1
490   LET f3 = (1-f3) *p
500   LET f4 = (1-f4) *p1
510   IF f = 0 THEN LET fu = fu-10 : LET f1 = 5*p
520   IF f1+f2+f3+f4> 0 THEN LET fu = fu-fl
530   REM Calculate next position
540   LET f = (kt/r-v*v)/r
550   LET am = am+(f2-f4)*r
560   LET u = u+(f1-f3-f)
570   LET r = r+u
580   LET v = am/r
```

```
590  LET j = v/r
600  LET k = k+j
610  REM Clear previous spaceship
620  PLOT INVERSE 1; x,y
630  PLOT INVERSE 1; x, y+1
640  PLOT INVERSE 1; x-1,y
650  LET x = 127+r* SIN k
660  LET y = 87+r* COS k
670  IF x < 225 AND x >= 1 AND y >= 0 AND y <= 174 THEN GO TO 710
680  LET x = 0
690  LET y = 0
700  GO TO 750
710  REM Draw new spaceship
720  PLOT x, y
730  PLOT x-1,y
740  PLOT x,y+1
750  IF fu < 0 THEN GOSUB 950
760  LET h = r-r1
770  PRINT AT 21, 0; INT (fu*10)/10: "□□";
780  PRINT AT 21, 8; INT (v*100); "□□";
790  PRINT AT 21, 16; INT h; "□□";
800  PRINT AT 21, 24; INT (u*100); "□□";
810  IF h <= 0 THEN GO TO 830
820  GO TO 350
830  REM At lunar surface
840  IF ABS v > 0.04 THEN GO TO 900
850  IF ABS u > 0.15 THEN GO TO 900
860  CLS
870  PRINT AT 20, 0; "SAFE LANDING - WELL DONE!"
880  FOR x = 0 TO 300: NEXT x
890  GO TO 100
900  REM Impact with the moon
910  CLS
920  PRINT; FLASH 1; "TOO FAST >>> YOU CRASHED!"
930  PAUSE 200
940  GO TO 100
950  REM Out of fuel
960  PRINT AT 20, 0; FLASH 1; "EMPTY";
970  LET fu = 0
980  RETURN
```

Note: □ indicates a space.

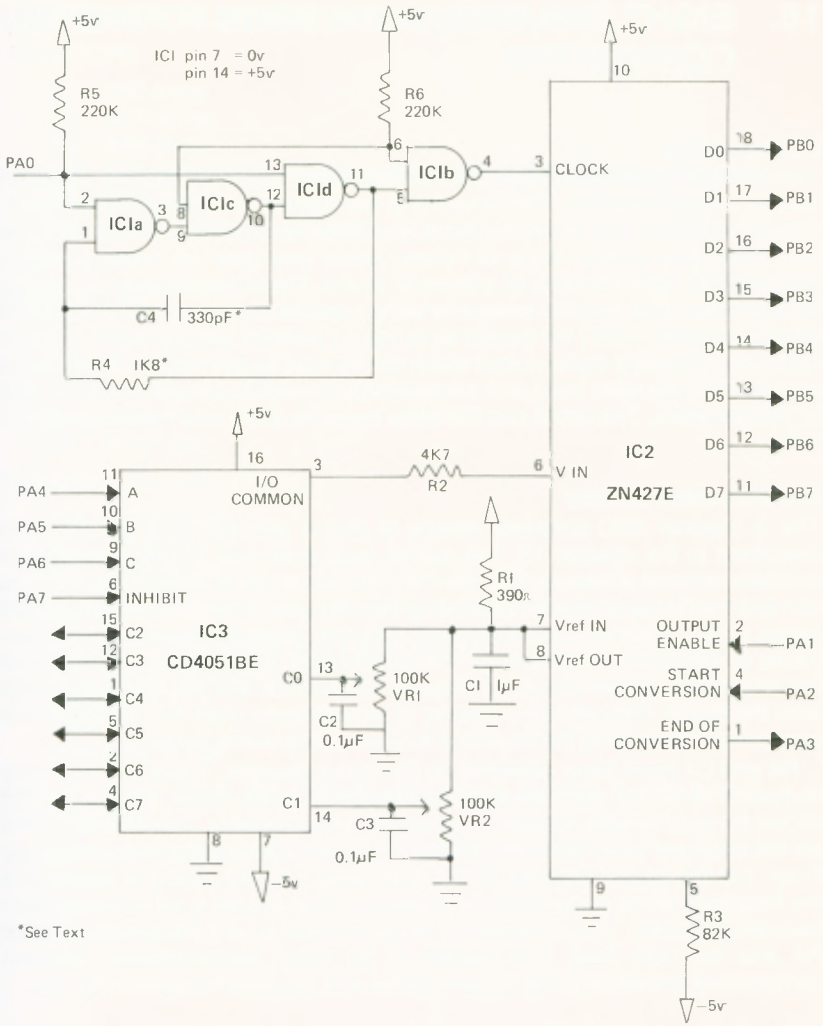


FIG 13a – 8 CHANNEL ANALOGUE TO DIGITAL CONVERTER CIRCUIT

18. EIGHT CHANNEL ANALOGUE TO DIGITAL CONVERTER

Introduction

You will appreciate from reading earlier chapters in this book that the computer deals in digital quantities. This leaves only two options for each bit of information. It must be either 1 or 0. In the real world, quantities which we may wish to measure can often take a wide range of values. Some examples are blood pressure, temperature, light intensity, or volume of sound. These parameters can usually be expressed as a variable voltage by using a special transducer. An analogue to digital converter (ADC) will accept as its input a variable voltage (say 0 — 2.55 volts) and provide a digital output which can be read by a computer. In this circuit an 8 bit ADC has been used, and consequently its output can vary from 0 — 255 in integral steps. The circuit can therefore measure down to an accuracy of 0.01 volts.

Construction details

The 8 channel ADC connects directly to port A and port B of the PIO chip described in the chapter 15. The author used a 25 way D type connector to facilitate removal of devices from the PIO. The unit in use is shown in fig 13c. You can see the D type connector protruding from the side of the box. The component layout on 0.1" pitch veroboard is shown in fig 13b. Make the breaks in the copper tracks as shown before soldering in the components. It is recommended that all of the integrated circuits should be plugged into sockets and not soldered directly onto the board. This will make it easier to replace faulty chips and eliminates the possibility of damaging the chips due to overheating during soldering.

R4 and C4 have been asterixed on the layout diagram. These are the timing components for the clock circuit. The photograph of the circuit board in fig 13d shows R4 as a variable resistor in series with a fixed resistor. This enables you to set the oscillator to its maximum of 600KHz, however it is not normally necessary to run it at this speed because BASIC is so slow. It is also difficult to ensure that the frequency is not above 600KHz unless you have access to an oscilloscope or frequency counter. You are therefore recommended to omit the variable resistor R4 and use one fixed 1K8 resistor in its place. Interconnection between components should be made in accordance with the circuit diagram in fig 13a.

COMPONENTS LIST FOR THE 8 CHANNEL ADC

RESISTORS

R1 390 ohms
R2 4K7 ohms
R3 82K ohms
R4* 1K8 ohms (or 330 ohms in series with a 2K2 preset — see text)
R5 220K ohms
R6 220K ohms

all ¼ watt 5%

CAPACITORS

C1 1 uF
C2 0.1 uF
C3 0.1 uF
C4 330 pF
C5 22 uF 6v

INTEGRATED CIRCUITS

IC1 CD4011BE
IC2 ZN427E
IC3 CD4051BE

MISCELLANEOUS

VR1,VR2 100K ohm X and Y axes joystick
0.1" copper strip board
sockets for IC's
case
connector to PIO

Note — if you have any difficulty obtaining a suitable 2 axis joystick, it is available from:

Maplin Electronic Supplies,
P.O. Box 3,
Rayleigh,
ESSEX SS6 2BR

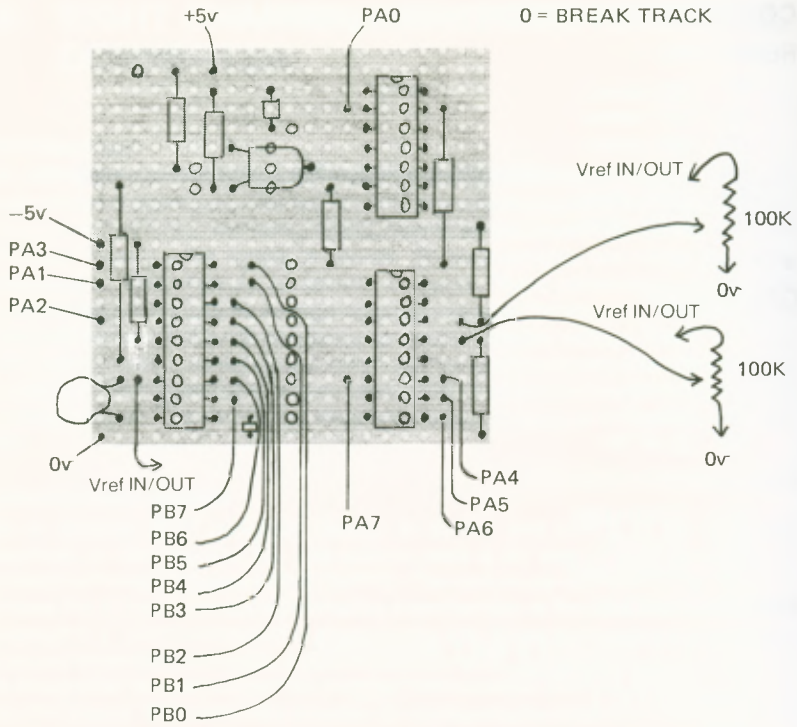
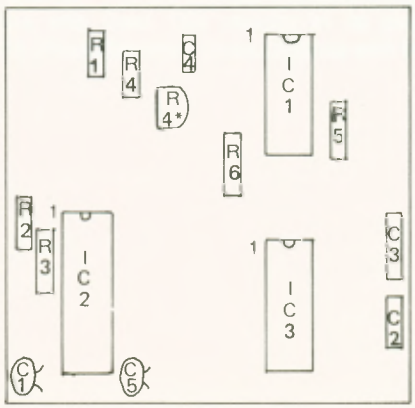


FIG 13b – 8 CHANNEL ADC COMPONENT LAYOUT DIAGRAM



NOTE — Connections between components must be made as in the circuit diagram

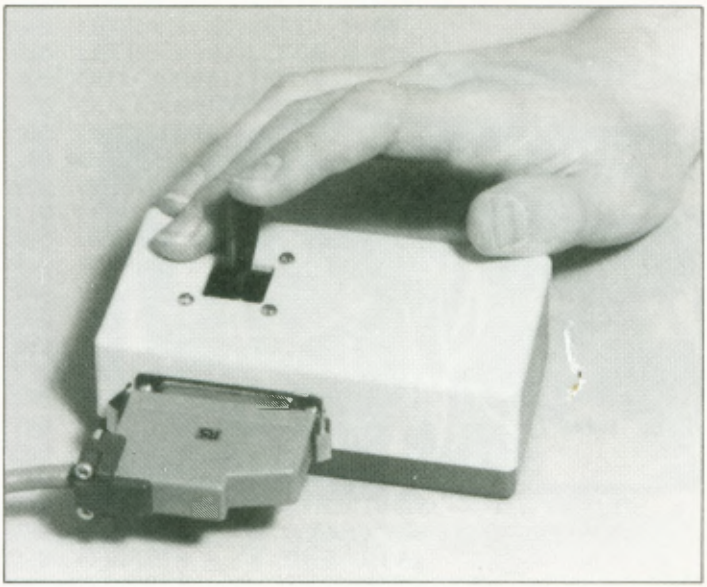


FIG 13c – 8 CHANNEL ADC IN USE WITH A JOYSTICK

HOW IT WORKS

The heart of the circuit is the analogue to digital converter chip (IC2). Its objective is to accept a voltage at its Vin input and convert it to an 8 bit digital output. To do this it requires several signals from the PIO chip plus a clock. The clock is similar to the Z80A clock in your Spectrum, but operates at a lower frequency. On each clock pulse the chip performs the next bit of the conversion. The frequency of the clock is about 500 kHz, and it is turned on and off by PA0. Each analogue to digital conversion therefore takes about 20 uS. The conversion is initiated by PA2 operating the start of conversion pin and PA0 switching on the clock. IC1 together with its associated resistors and capacitor forms the clock circuit. When the conversion is complete, IC2 sends an end of conversion signal to PA3. This indicates that the output data byte can then be read. PA1 operates the output enable pin. Port B of the PIO can then be used to read in the 8 bit data byte from the ADC.

In the sample BASIC drawing program, PA0, PA1, and PA2 are all operated simultaneously. The end of conversion signal will be finished in the time it takes BASIC to complete the coordinate read routine. If machine code were to be used then it would be necessary to use the end of conversion signal. This is because machine code operates so much faster than BASIC. The ADC may not have completed the conversion, and therefore it must be checked.

The ADC chip is fairly expensive, so if we wish to measure analogue voltages from more than one source, it is better if we can arrange this with only one ADC

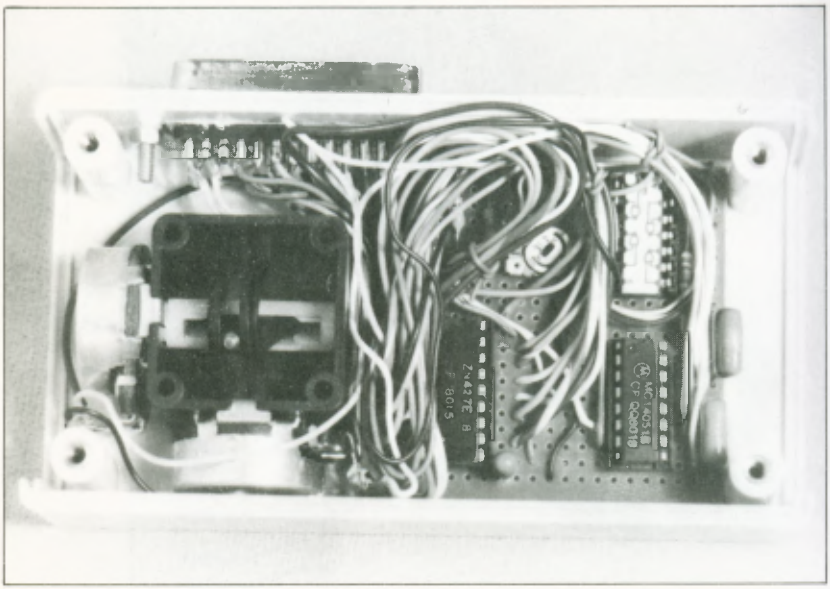


FIG 13d – 8 CHANNEL ADC INTERNAL LAYOUT

chip. This is where IC3 comes in useful. This is a 1 to 8 line analogue multiplexer chip. An address from 0 to 7 can be applied to it via PA4, PA5 and PA6. This enables any one of the 8 inputs to be connected via the multiplexer to the common output. If we select address 0 for example, the input voltage applied at C0 will appear at the I/O common pin. The chip is conceptually similar to an 8 way 1 pole switch. Changing the address to the chip is like changing the position of the switch.

The BASIC drawing program will operate with the X and Y axes of the joystick connected channel to 0 and channel 1 respectively. Lines 10 to 90 set up the PIO port so that port B is all input and port A is all output except for PA3. Consider lines 140 to 170, which read in the X coordinate. First of all, port A outputs are set to zero. This stops the clock, selects multiplexer channel 0, and disables the ADC chip. Then in line 160, the clock is started simultaneously with the start of conversion signal to the ADC chip. By the time that line 170 reads in the X coordinate from port B, the conversion is complete.

The BASIC drawing program itself is very easy to use. There are two modes, 'D' and 'S', each entered by pressing the appropriate key on the Spectrum keyboard. In 'S' mode a small flashing dot can be moved around the screen with the joystick, but it doesn't leave any mark. If 'D' is pressed then the moving dot leaves a line behind it. You can draw pictures in this way. Typing 'S' again stops the drawing until you press 'D'. To start a new drawing press 'N'.

DRAWING PROGRAM LISTING

```
 10  REM JOYSTICK DRAWING PROGRAM
 20  REM
 30  REM SET UP THE PIO PORTS
 40  LET DA = 31: LET CA = 95
 50  LET DB = 63: LET CB = 127
 60  OUT CA,BIN 11111111
 70  OUT CA,BIN 00001000
 80  OUT CB,BIN 11111111
 90  OUT CB,BIN 11111111
100  LET A$ = "S"
110  LET X1 = 0: LET Y1 =0
120  REM SET UPTHE SCREEN FOR PLOTTING
130  BORDER 7: PAPER 7: INK 0: CLS
140  REM READ X COORDINATE
150  OUT DA,BIN 00000000
160  OUT DA,BIN 00000111
170  LET X = IN DB
180  REM READ Y COORDINATE
190  OUT DA,BIN 00000000
200  OUT DA,BIN 00010111
210  LET Y = IN DB*175/255
220  REM D=DRAW, S=STOP DRAW, N=NEW PICTURE
230  IF INKEY$ = "D" THEN LET A$ = "D"
240  IF INKEY$ = "S" THEN LET A$ = "S"
250  IF INKEY$ = "N" THEN GO TO 100
260  IF A$ = "D" THEN GO TO 350
270  REM FLASH DRAWING POINT
280  PLOT OVER 1; X,Y
290  REM GENERATE DELAY
300  PAUSE 10
310  PLOT OVER 1; X,Y
320  LET X1 = X
330  LET Y1 = Y
340  GO TO 140
350  REM DRAW
360  PLOT X1, Y1
370  DRAW X-X1, Y-Y1
380  GO TO 320
```

19. A CENTRONICS PARALLEL PRINTER INTERFACE

INTRODUCTION

The Spectrum has been designed to operate with a variety of Sinclair peripherals. Two of these can be used to obtain printed output on paper. The first is the ZX Printer, which produces output on narrow strips of aluminised paper. Such output is normally sufficient for program listings, but unsuitable for most professional applications such as word processing. High quality printers for such applications do exist. They are generally provided with one of two standard printer interfaces — centronics parallel or RS232 serial. The Zx Interface 1 peripheral allows RS232 printers to be connected directly to the Spectrum. However, most modern printers are equipped with Centronics parallel interfaces as standard, and no Sinclair interfaces are yet available to allow such printers to be connected directly to the Spectrum. This chapter explains how to make a suitable Centronics parallel printer interface using just one Z80A PIO chip. A comprehensive interface program is also provided, for use with a 16K or 48K Spectrum.

CIRCUIT DESCRIPTION

In order to construct the parallel printer interface, the Z80A PIO chip must be connected to the Spectrum rear edge connector. This is explained in Chapter 15. Having wired up the Z80A PIO chip to the Spectrum, it is then necessary to connect it up to the printer. The connections should be made as illustrated in figure 14a. Some form of multicore cable will be required to connect between the PIO and printer plug. The type used will be dependent upon the Centronics plug employed to connect to the printer. Two common types exist: an insulation displacement type and an individual wire type. Either type will plug into the mating socket on the printer. The former is designed for use with ribbon cable (strands of wire moulded side by side in the form of a ribbon). This type is very easy to use, because no soldering is required at the printer end of the interface cable. The second type is designed to have individual wires soldered onto the terminals inside the connector. The type used will be determined by availability and/or personal preference.

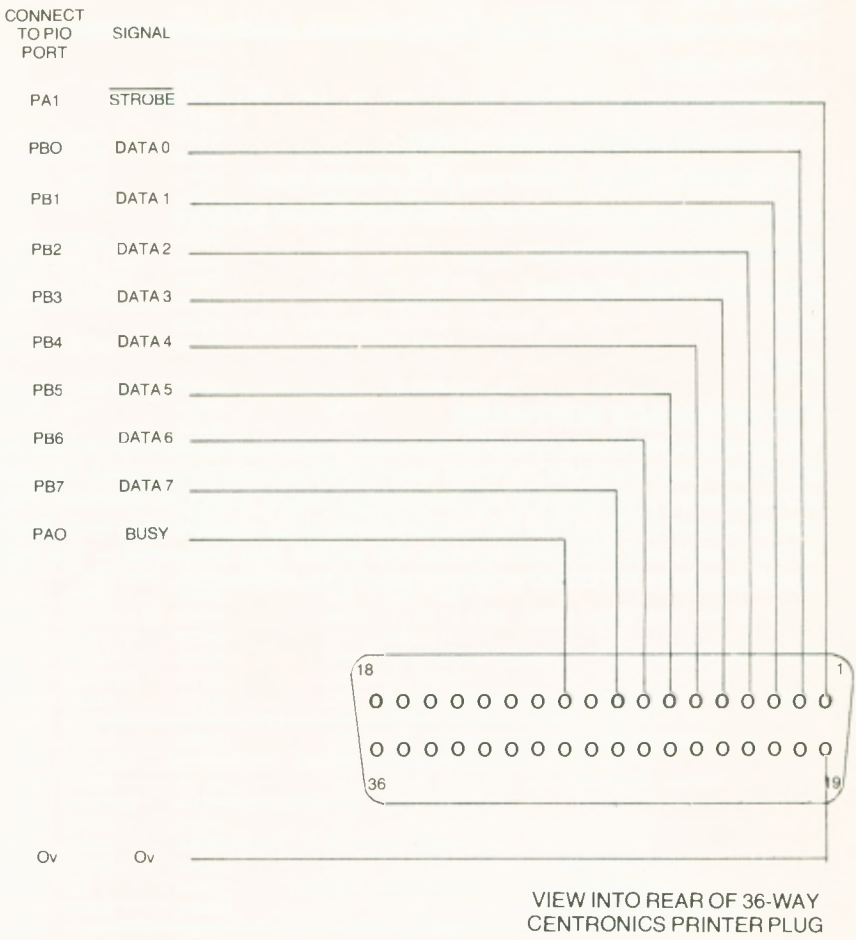


FIG. 14a — CONNECTIONS BETWEEN Z80A PIO AND PRINTER

PARTS LIST

The following parts are required for the Centronics parallel printer interface:

1 of 10K resistor

1 of Z80A PIO chip

1 of 40 pin DIL socket for Z80A PIO chip

1 of Centronics 36-way printer plug (IDC or solder type)

Length of suitable interconnection cable (with at least 12 cores)

28-way card edge connector

piece of 0.1" pitch veroboard

wire

solder

THE INTERFACE SOFTWARE

The job of the interface software is to send the correct characters to be printed on the printer when the BASIC 'LPRINT' and 'LLIST' commands are used. The use of this software is explained in the next section entitled 'Using the interface'. This current section explains how the program works at the machine code level. If you do not understand Z80 machine code, this section may be ignored — it is only necessary to use the BASIC programs listed in the next section.

```
ZEAP Z80 Assembler - Source Listing

7E4E            0100          ORG  £7E4E
                0110 ;**************************************
                0120 ;
                0130 ;     CENTRONICS PARALLEL INTERFACE
                0140 ;
                0150 ;         for a 16K ZX SPECTRUM
                0160 ;
                0170 ;       (c) Copyright A C DICKENS
                0180 ;
                0190 ;              January 1984
                0200 ;
                0210 ;**************************************
                0220 ;
7E4E 005F       0230 CA       EQU  95 ;CONTROL PORT A
7E4E 007F       0240 CB       EQU  127 ;CONTROL PORT B
7E4E 001F       0250 DA       EQU  31 ;DATA PORT A
7E4E 003F       0260 DB       EQU  63 ;DATA PORT B
                0270 ;Line length storage byte
7E4E 5C81       0280 LENGTH EQU  £5C81 ;Decimal 23681
                0290 ;RESERVED WORD TABLE start address
7E4E 0095       0300 TABLE    EQU  £0095
                0310 ;PRINTER ROUTINE ADDRESS VECTOR
7E4E 5CC5       0320 ECHO     EQU  £5CC5
                0330 ;
                0340 ;INIT sets up the PIO ports and the
                0350 ;printer routine vector.
                0360 ;
7E4E 3EFF       0370 INIT     LD   A,255
7E50 D35F       0380          OUT  (CA),A
7E52 3EFD       0390          LD   A,253
```

```
7E54 D35F      0400          OUT   (CA),A
               0410 ;A1 = printer STROBE (output from PIO)
               0420 ;A0 = printer BUSY line (input to PIO)
               0430 ;
               0440 ;
               0450 ;SET ALL of port B as outputs
               0460 ;
7E56 3EFF      0470          LD    A,255
7E58 D37F      0480          OUT   (CB),A
7E5A 3E00      0490          LD    A,0
7E5C D37F      0500          OUT   (CB),A
               0510 ;SET a default of NO LF after a CR
7E5E 3E00      0520          LD    A,0
7E60 FD7776    0530          LD    (IY+118),A
7E63 01707E    0540          LD    BC,MAIN
7E66 ED43C55C  0550          LD    (ECHO),BC
               0560 ;SET default line length to 70
7E6A 3E46      0570          LD    A,70

7E6C 32815C    0580          LD    (LENGTH),A
7E6F C9        0590          RET
               0600 ;
               0610 ;MAIN output routine is entered with the
               0620 ;character to be printed in the A reg.
               0630 ;Reserved words, TAB, AT, commas in a
               0640 ;PRINT statemnet and standard ASCII
               0650 ;characters are all dealt with.
               0660 ;
7E70 FDCB7646  0670 MAIN    BIT   0,(IY+118) ;Was last char a TAB?
7E74 205C      0680          JR    NZ,TAB
7E76 FDCB764E  0690          BIT   1,(IY+118) ;Was last chr an AT?
7E7A C2007F    0700          JP    NZ,AT
7E7D FE06      0710          CP    6 ;PRINT comma?
7E7F CA097F    0720          JP    Z,PCOM
7E82 FE16      0730          CP    22 ;AT control character?
7E84 CA197F    0740          JP    Z,PAT
7E87 FE17      0750          CP    23 ;TAB control character?
7E89 CA1E7F    0760          JP    Z,PTAB
7E8C FEA5      0770          CP    165 ;Is it a reserved word?
7E8E D2277F    0780          JP    NC,RESWRD
7E91 FE0D      0790          CP    13 ;ENTER code?
7E93 282C      0800          JR    Z,ENTER
7E95 FE20      0810          CP    32 ;Control code?
7E97 D8        0820          RET   C ;Ignore control codes
7E98 FE80      0830          CP    128 ;Standard ASCII character?
7E9A 3802      0840          JR    C,PROUT
               0850 ;
               0860 ;It must be a user defined graphic if
               0870 ;here, so output a SPACE
               0880 ;
7E9C 3E20      0890 SPCOUT LD    A,32
7E9E FD3477    0900 PROUT  INC   (IY+119) ;Increment CHR counter
7EA1 47        0910          LD    B,A
7EA2 3A815C    0920          LD    A,(LENGTH)
7EA5 FDBE77    0930          CP    (IY+119)
7EA8 3014      0940          JR    NC,PRINT
               0950 ;
               0960 ;Maximum allowed line length has been
               0970 ;reached, so go to new line
               0980 ;
7EAA 3E0D      0990          LD    A,13 ;ENTER code
7EAC CD457F    1000          CALL  OUTPUT
7EAF FD367701  1010          LD    (IY+119),1
7EB3 FDCB7656  1020          BIT   2,(IY+118) ;Should an LF be supplied?
```

```
7EB7 2805      1030         JR   Z,PRINT
               1040 ;Output an LF
7EB9 3E0A      1050         LD   A,10 ;LF code
7EBB CD457F    1060         CALL OUTPUT
7EBE 78        1070 PRINT   LD   A,B ;Restore value in the A reg.
7EBF 180F      1080         JR   LINK

               1090 ;
               1100 ;Deal with an ENTER code
               1110 ;
7EC1 FD367700  1120 ENTER   LD   (IY+119),0
7EC5 FDCB7656  1130         BIT  2,(IY+118)
7EC9 287A      1140         JR   Z,OUTPUT
7ECB CD457F    1150         CALL OUTPUT
               1160 ;Supply a LF
7ECE 3E0A      1170         LD   A,10
7ED0 1873      1180 LINK    JR   OUTPUT
               1190 ;
               1200 ;Deal with TABs
               1210 ;
7ED2 FDCB7686  1220 TAB     RES  0,(IY+118)
7ED6 FDBE77    1230         CP   (IY+119)
7ED9 3807      1240         JR   C,TAB1 ;Past print head?
7EDB FD9677    1250         SUB  (IY+119)
7EDE 47        1260         LD   B,A
7EDF 04        1270         INC  B
7EE0 1819      1280         JR   TAB2
7EE2 47        1290 TAB1    LD   B,A
7EE3 04        1300         INC  B
7EE4 FD3677FF  1310         LD   (IY+119),255
7EE8 3E0D      1320         LD   A,13 ;ENTER
7EEA CD457F    1330         CALL OUTPUT
7EED FDCB7656  1340         BIT  2,(IY+118) ;LF after ENTER?
7EF1 2805      1350         JR   Z,TAB3
7EF3 3E0A      1360         LD   A,10
7EF5 CD457F    1370 TAB4    CALL OUTPUT
7EF8 FD3477    1380 TAB3    INC  (IY+119)
7EFB 3E20      1390 TAB2    LD   A,32 ;SPACE character
7EFD 10F6      1400         DJNZ TAB4
7EFF C9        1410         RET
               1420 ;
               1430 ;Deal with AT code
               1440 ;
7F00 FDCB76C6  1450 AT      SET  0,(IY+118)
7F04 FDCB768E  1460         RES  1,(IY+118);Take 2nd value after AT
7F08 C9        1470         RET
               1480 ;
               1490 ;Deal with PRINT comma code
               1500 ;
7F09 FD7E77    1510 PCOM    LD   A,(IY+119)
7F0C E60F      1520         AND  15 ;Columns are 15 spaces apart
7F0E C8        1530         RET  Z
7F0F 3E20      1540         LD   A,32 ;SPACE
7F11 CD457F    1550         CALL OUTPUT
7F14 FD3477    1560         INC  (IY+119)
7F17 18F0      1570         JR   PCOM
               1580 ;
               1590 ;Skip first parameter after an AT
               1600 ;
7F19 FDCB76CE  1610 PAT     SET  1,(IY+118)
```

```
7F1D C9          1620          RET
                 1630 ;
                 1640 ;Record that last code was a TAB so that
                 1650 ;a TAB parameter is expected next time
                 1660 ;this routine is called.
                 1670 ;
7F1E FDCB76C6    1680 PTAB     SET  0,(IY+118)
7F22 FDCB768E    1690          RES  1,(IY+118)
7F26 C9          1700          RET
                 1710 ;
                 1720 ;Print out a reserved word
                 1730 ;
7F27 219500      1740 RESWRD LD    HL,TABLE ;Reserved words in ROM
7F2A D6A4        1750          SUB  164
                 1760 ;Scan the reserved word table until A
                 1770 ;equals 0. Each reserved word is stored
                 1780 ;as its ASCII codes with the last letter
                 1790 ;having BIT 7 set to a 1.
                 1800 ;
7F2C CB7E        1810 RESW1    BIT  7,(HL)
7F2E 23          1820          INC  HL
7F2F 28FB        1830          JR   Z,RESW1
7F31 3D          1840          DEC  A
7F32 FE00        1850          CP   0
7F34 20F6        1860          JR   NZ,RESW1
                 1870 ;
                 1880 ;HL now points to the start of the
                 1890 ;correct word. Output a SPACE first.
                 1900 ;
7F36 CD9C7E      1910          CALL SPCOUT
7F39 7E          1920 RESWOT LD   A,(HL)
7F3A 23          1930          INC  HL
                 1940 ;
                 1950 ;Output a character of the reserved
                 1960 ;word taking care of line length.
                 1970 ;
7F3B CD9E7E      1980          CALL PROUT
7F3E CB7F        1990          BIT  7,A ;End of word?
7F40 28F7        2000          JR   Z,RESWOT
                 2010 ;
                 2020 ;Output a SPACE to terminate word
                 2030 ;
7F42 C39C7E      2040          JP   SPCOUT
                 2050 ;
                 2060 ;OUTPUT routine sends the character in
                 2070 ;the A reg. to the printer. If the printer
                 2080 ;is BUSY then the routine waits for it
                 2090 ;to become READY.
                 2100 ;
7F45 F5          2110 OUTPUT PUSH AF
7F46 D33F        2120          OUT  (DB),A
                 2130 ;WAIT for BUSY to go low
7F48 DB1F        2140 LOOP     IN   A,(DA)
7F4A CB47        2150          BIT  0,A
7F4C 20FA        2160          JR   NZ,LOOP
                 2170 ;
                 2180 ;STROBE data into the printer
                 2190 ;
7F4E 3EFD        2200          LD   A,£FD
7F50 D31F        2210          OUT  (DA),A
7F52 3EFF        2220          LD   A,£FF
7F54 D31F        2230          OUT  (DA),A
7F56 F1          2240          POP  AF
7F57 C9          2250          RET
```

The following paragraphs describe the operation of the above Assembler program.

The BASIC 'LLIST' and 'LPRINT' commands have been designed so that the character output routine address is stored in RAM at £5CC5 (23749 decimal). Normally, this would be set to point to the character output routine contained within the BASIC ROM. However, by POKEing a new output routine address into £5CC5, characters to be output can be routed via a new, user defined routine. This is the basis of the new output routine listed here.

The first part of the program labelled as routine INIT is the initialisation routine. The PIO chip is initialised so that all port B lines are defined as outputs (for the 8 data lines). Only A0 and A1 of port A are used. A0 is used as an input from the printer BUSY line, and A1 is used as a STROBE output to the printer. The defaults for linefeeds and carriage returns are also set up.

At this stage, it is worth noting the use of the Z80 IY register. In the Spectrum it is always set to £5C3A (23610 decimal). Therefore, location IY+118 is 23728 and IY+119 is location 23729. If you look at the list of the Spectrum System Variables chapter in the BASIC programming manual, you will see that locations 23728 and 23729 are not used. This program therefore makes good use of them. Location IY+118 (23728) records if a linefeed should be generated after carriage return and also whether or not the previous print instruction was an AT or a TAB. Location IY+119 (23729) stores the number of characters which have been printed out on the current line. The only other variable used by this program is labelled LENGTH. This is in location 23681, again an unused byte in the System Variables area. It contains the number of characters per line of the printer, and may take any value between 1 and 255.

Finally, at the end of the INIT routine, the output routine vector (labelled ECHO) is set to point to the start of the output program, MAIN. Routine INIT is called once to initialise the parallel printer. The parallel printer will then remain in use until the BASIC command 'NEW' is performed, or until a different address is POKEd into location ECHO.

Routine MAIN expects to be entered with the character to be printer contained in the Z80's A register. It will perform in the following ways, dependent upon the character in the A register:

A=0–31

These are the Control Codes, as listed in Appendix A of the *Spectrum BASIC Programming* manual. Of all of the control codes available, only four are directly relevant to the printer output format. These are code 6 (PRINT comma), code 13 (ENTER), code 22 (AT control) and code 23 (TAB control). Upon receiving a 'PRINT comma' code, subroutine PCOM is entered. This routine outputs SPACEs so that all characters separated by commas are printed in columns 16 characters wide. TAB and AT codes cause flags to be set in location IY+118. The code received after a TAB is then used to move the printer head to the correct column position. AT codes are followed by two parameters (the line and column positions). The first parameter after an AT is therefore ignored. The second parameter moves the print head to the correct column position, as with TAB. The ENTER code sends a carriage return character to the printer, followed by a linefeed (if selected). Carriage return characters will also be sent to the printer if the number of characters already printed out exceed the programmed line length.

A=32–127
All of these codes represent standard ASCII characters, so they are all sent directly to the printer for printing.

A=128–164
These codes represent the User Defined and Block graphics characters in the Spectrum. Since none of the available Centronics printers support this part of the Spectrum character set, a blank SPACE is output to the printer.

A=165–255
These codes all represent BASIC keywords. There is a table containing BASIC keywords in the ROM. Keywords are stored in ASCII format, the last letter of each keyword having bit 7 set to 1. Subroutine RESWRD scans this table up to the relevant keyword. It then outputs the keyword to the printer character by character until the last character with bit 7=1 is reached.

You should now have a general idea about the operation of this software. Individual routines and their operational description can be seen in the Assembler listing. The Assembler program printout and the BASIC program listings were all produced on an EPSON MX80F/T dot matrix printer using the Centronics parallel interface described in these pages.

USING THE INTERFACE

Once the hardware for the interface has been constructed and connected to the printer, the new printer program will have to be typed in. Two BASIC program listings are provided for this. One is for 16K Spectrums, the other is for 48K Spectrums. They are written so that the interface machine code is POKEd into the uppermost bytes of available RAM. Once the relevant program has been RUN, the LLIST and LPRINT commands can be used. Other BASIC programs should be LOADed on top of the BASIC interface routine. Do not type NEW, because this will delete the machine code which has been POKEd into the top of memory.

```
100 REM ****************************************
110 REM
120 REM Centronics Parallel Interface Routine
130 REM
140 REM (c)by Adrian Dickens January 1984
150 REM
160 REM ****************************************
170 REM
180 REM This is for a 16K Spectrum
190 REM
200 CLEAR 32333
210 LET a=32334
220 READ x
230 IF x=256 THEN  RANDOMIZE  USR 32334: STOP
240 POKE a,x
250 LET a=a+1
260 GO TO 220
270 DATA 62,255,211,95,62,253,211,95,62,255,211,127
280 DATA 62,0,211,127,62,4,253,119,118,1,112,126,237
290 DATA 67,197,92,62,70,50,129,92,201
300 DATA 253,203,118,70,32,92,253
310 DATA 203,118,78,194,0,127,254,6,202,9,127
320 DATA 254,22,202,25,127,254,23
```

```
330 DATA 202,30,127,254,165,210,39,127,254,13,40
340 DATA 44,254,32,216,254,128,56,2,62,32
350 DATA 253,52,119,71,58,129,92,253,190,119,48,20
360 DATA 62,13,205,69,127,253,54,119,1,253,203,118
370 DATA 86,40,5,62,10,205,69,127,120,24,15
380 DATA 253,54,119,0,253,203,118,86,40,122,205,69
390 DATA 127,62,10,24,115
400 DATA 253,203,118,134,253,190,119,56,7,253,150,119
410 DATA 71,4,24,25,71,4,253,54,119,255,62,13,205,69
420 DATA 127,253,203,118,86,40,3,62,10,205,69,127,253
430 DATA 52,119,62,32,16,246,201
440 DATA 253,203,118,198,253,203,118,142,201
450 DATA 253,126,119,230,15,200,62,32,205,69,127,253
460 DATA 52,119,24,240
470 DATA 253,203,118,206,201,253,203,118,198,253,203
480 DATA 118,142,201,33,149,0,214,164
490 DATA 203,126,35,40,251,61,254,0,32,246,205,156,126
500 DATA 126,35,205,158,126,203,127,40,247,195,156,126
510 DATA 245,211,63,219,31,203,71,32,250
520 DATA 62,253,211,31,62,255,211,31,241,201,256

100 REM ****************************************
110 REM
120 REM Centronics Parallel Interface Routine
130 REM
140 REM (c)by Adrian Dickens January 1984
150 REM
160 REM ****************************************
170 REM
180 REM This is for a 48K Spectrum
190 REM
200 CLEAR 65101
210 LET a=65102
220 READ x
230 IF x=256 THEN  RANDOMIZE  USR 65102: STOP
240 POKE a,x
250 LET a=a+1
260 GO TO 220
270 DATA 62,255,211,95,62,253,211,95,62,255,211,127
280 DATA 62,0,211,127,62,4,253,119,118,1,112,254,237
290 DATA 67,197,92,62,70,50,129,92,201
300 DATA 253,203,118,70,32,92,253
310 DATA 203,118,78,194,0,255,254,6,202,9,255
320 DATA 254,22,202,25,255,254,23
330 DATA 202,30,255,254,165,210,39,255,254,13,40
340 DATA 44,254,32,216,254,128,56,2,62,32
350 DATA 253,52,119,71,58,129,92,253,190,119,48,20
360 DATA 62,13,205,69,255,253,54,119,1,253,203,118
370 DATA 86,40,5,62,10,205,69,255,120,24,15
380 DATA 253,54,119,0,253,203,118,86,40,122,205,69
390 DATA 255,62,10,24,115
400 DATA 253,203,118,134,253,190,119,56,7,253,150,119
410 DATA 71,4,24,25,71,4,253,54,119,255,62,13,205,69
420 DATA 255,253,203,118,86,40,3,62,10,205,69,255,253
430 DATA 52,119,62,32,16,246,201
440 DATA 253,203,118,198,253,203,118,142,201
450 DATA 253,126,119,230,15,200,62,32,205,69,255,253
460 DATA 52,119,24,240
470 DATA 253,203,118,206,201,253,203,118,198,253,203
480 DATA 118,142,201,33,149,0,214,164
490 DATA 203,126,35,40,251,61,254,0,32,246,205,156,254
500 DATA 126,35,205,158,254,203,127,40,247,195,156,254
510 DATA 245,211,63,219,31,203,71,32,250
520 DATA 62,253,211,31,62,255,211,31,241,201,256
```

SOME BASIC NOTES ON USING THE PROGRAM

The number of characters printed per line on the printer can be changed by POKEing the desired number into location 23681. For example, suppose that a line length of 64 characters per line is required. Simply **POKE 23681,64.**

Some printers turn the paper on by one line when they receive a carriage return (CR) character, but others only move the paper onto the next line when they receive a linefeed character (LF). In order to support both types of printers, bit 2 of location IY+118 (decimal 23728) determines whether or not linefeeds are provided.

To generate linefeeds, **POKE 23728,4**
To suppress linefeeds, **POKE 23728,0**

Since a printer is likely to be used in lots of applications, the interface program could be stored in an EPROM chip. Such a chip could be connected to the edge connector of the Spectrum. The programs provided in this section will operate from an EPROM, because all variables are stored in the System Variables area in RAM.

20. CONNECTING A VIDEO MONITOR TO YOUR SPECTRUM

Most people use a standard colour or monochrome television set with their Spectrum. Good pictures can be obtained on televisions, but coloured characters on coloured backgrounds can sometimes be difficult to see. This is a compromise which must be accepted if a television is used as the computer display device. However, it is possible to obtain a marked improvement in picture quality by connecting a specialised computer display device in place of the television. Such a device is called a Video Monitor.

A Video Monitor looks very similar to a television. It will have a screen, together with some controls to adjust contrast, brightness and the horizontal and vertical position of the display. Notable absences are the speaker and channel tuning controls usually associated with a television. These controls are not necessary on a monitor. The video signal connected to its input is displayed on the screen — there is no possibility of tuning into another signal. Effectively, the video modulator circuit on the Spectrum and the video demodulator circuit on the television have been bypassed by a direct link. A good analogy exists between video and audio signals.

Normally, when a television is being used with the Spectrum, the signal from the Spectrum is just like that transmitted by the television networks. It must be received at the television end, sorted out from all of the other television channels, then displayed. Radios operate in a similar manner. With audio signals, it is much better to connect the signal source (record or tape deck) directly to the amplifier. Transmitting the signal, then receiving it on a radio tends to reduce the sound quality dramatically. Exactly the same happens with video signals.

If you decide to add a video monitor to your Spectrum, there are two basic types — colour or monochrone. Provided that the particular monitor which you choose has a COMPOSITE VIDEO input, it should be suitable.

Connection to the Spectrum is made via the rear edge connector. The composite video output is connected to 15B on the edge connector. A suitable earth connection is pin 14B on the edge connector. Figure 15a shows how to connect the video plug to the rear edge connector. A suitable length of COAXIAL single core cable should be used.

If the Spectrum is an Issue 3, simply plug the video plug into the socket on the monitor, and start to use the Spectrum as if a television were being used. If an Issue 2 Spectrum is being used, a link may have to be made inside the Spectrum. The position of this link on the circuit board is shown in figure 15b. Any short length of interconnection wire can be used to make the link. Once the link has been made, the monitor can be used as with the Issue 3 Spectrum.

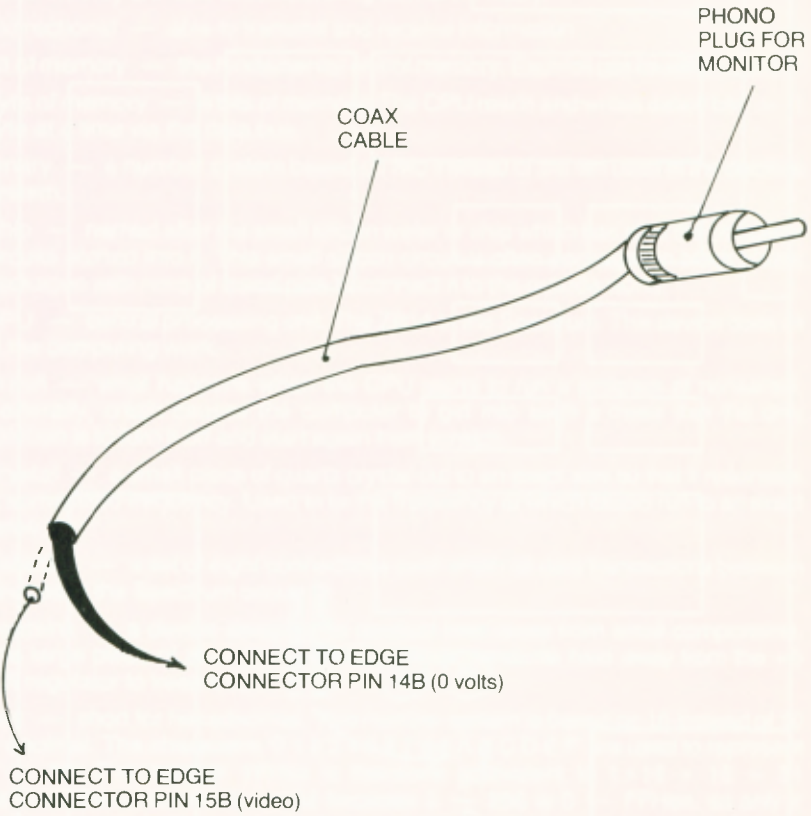


FIG. 15a — CONNECTING A VIDEO PLUG TO THE REAR EDGE CONNECTOR

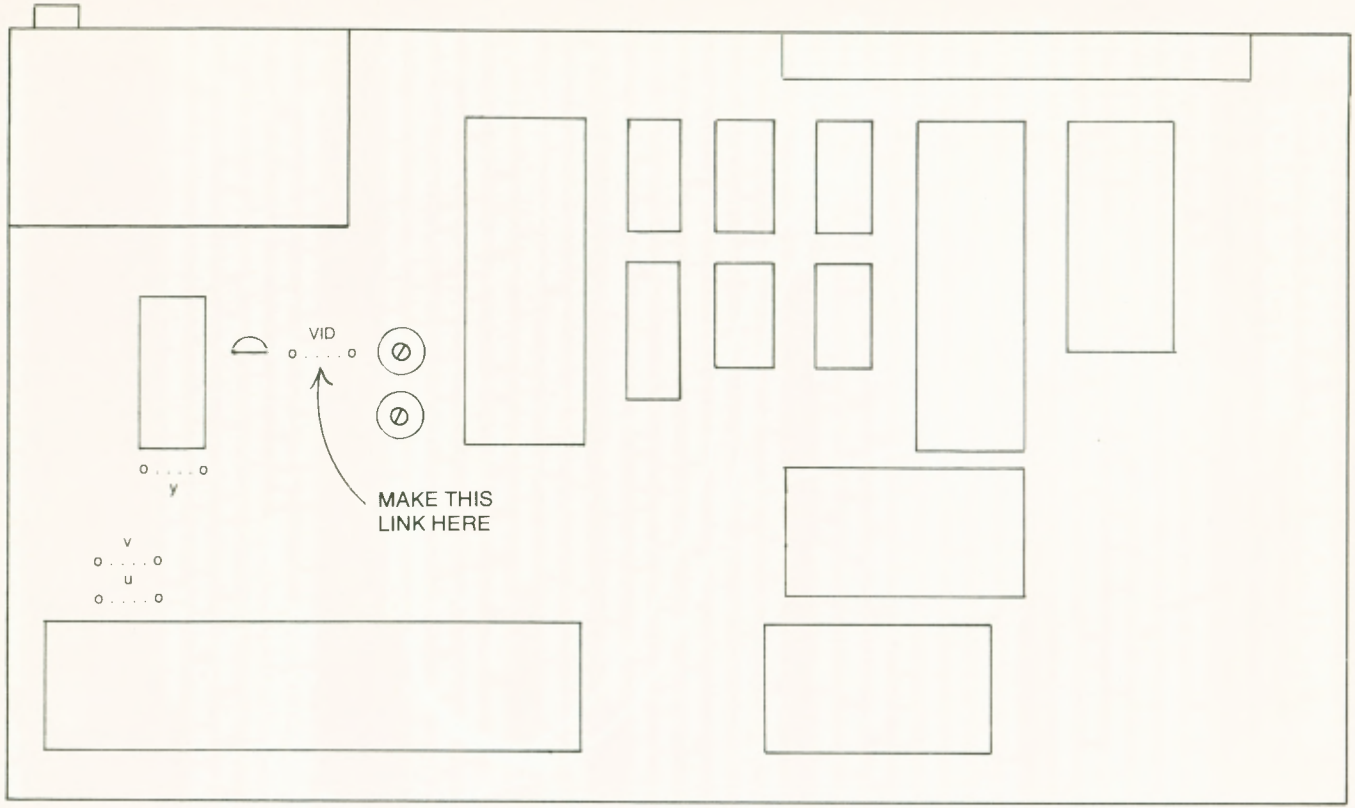


FIG. 15b — VIDEO LINK POSITION ON ISSUE 2 SPECTRUMS ONLY

APPENDIX A — GLOSSARY

Address bus — a set of 16 connections which allow the CPU to select the location at which it wishes to perform a particular operation.

Active low — signals which are 'active low' are deemed to be operational when they are at logic 0.

Analogue to digital converter (ADC) — a circuit to convert an analogue voltage into digital number which can be read by a computer.

Asynchronous — when two devices are operating independently of one another, they are said to be operating asynchronously.

Bidirectional — able to transmit and receive information.

Bit of memory — the fundamental unit of memory. Each bit can be either 0 or 1.

Byte of memory — 8 bits of memory. The CPU reads and writes data 8 bits = 1 byte at a time via the data bus.

Binary — a number system based on two instead of the ten used in the decimal system.

Chip — named after the small silicon wafer or chip which has all of the computer circuits etched into it. This small silicon circuit is often packaged in black plastic packages with rows of metal pins to connect it to the outside world.

CPU — central processing unit. The Z80A in the Spectrum. This device does all of the computing work.

Crash — what happens when the CPU starts to run a program of nonsense. Generally, crash causes the computer to get into such a mess that the only solution is to turn it off and start again from scratch.

Crystal — a small piece of quartz crystal cut to an exact size so that it resonates at some fixed frequency. Used to fix the frequency at which clocks run to an exact value.

Data bus — a set of eight connections over which all data transactions between devices in the Spectrum occur.

Heatsink — a device designed to conduct heat away from small components. The large piece of aluminum in the Spectrum conducts heat away from the +5 volt regulator to keep it cool.

Hex — short for hexadecimal. This number system is based on 16 instead of 10 in decimal. The characters '0 1 2 3 4 5 6 7 8 9 A B C D E F' are used to represent 0 — 15. The number 1FHex is therefore equivalent to $1 \times 16 + 15 = 31$ decimal. Hexadecimal is useful because 0 — 255 is 0 — FFHex, so only 2 digits are required to represent any of the possible numbers which can be transferred on the data bus.

High — sometimes used to indicate logic level 1

Interrupt — a signal produced by external devices to interrupt whatever the CPU is doing and make it do something else.

Light emitting diode — a device which will only pass current in one direction. Light is emitted when the device is conducting.

Low — sometimes used to signify logic level 0.

Machine code — a program in binary which the CPU can understand directly.

Memory — the devices in which all of the information about BASIC and programs is stored.

1MHz — a frequency of 1 million oscillations per second.

Peripheral device — some device connected to the CPU. The keyboard and cassette recorder are both peripheral devices.

Refresh — an operation which must be performed regularly on certain types of memory if they are to retain their stored data.

RAM — random access memory can be read from or written to at any address by the CPU. Two types are commonly used, static which does not need refreshing and dynamic (as used in the Spectrum) which does.

ROM — read only memory, as the name implies can only be read from but not written to. The BASIC operating system in the Spectrum is stored in this type of memory.

State — an input or output can normally only be in one of two states, 0 or 1 (* but see tristate).

Transducer — a device which converts some physical quantity such as speed, air pressure or temperature into an electrical signal suitable for processing by a computer.

Tristate — sometimes several outputs from different chips can be connected together. So that their data cannot conflict by having a logic 0 and logic 1 state connected together (shorting the power supply through the chips!), all but one of the outputs would be placed in a tristate condition. The tristate outputs can then be either a 1 or 0 and it doesn't matter.

ULA — uncommitted logic array. Mass produced device which can be committed to perform a particular function in the final stages of manufacture.

Zener diode — used to stabilise the voltage across it at some level defined by the diode characteristics.

APPENDIX B — REFERENCES

1. Sinclair ZX Spectrum BASIC programming manual, Sinclair Research, 1982.
2. Sinclair ZX Spectrum Introduction booklet, Sinclair Research, 1982.
3. Oxford Illustrated Dictionary, Oxford Univ. Press 1962.
4. Mostek Z80 and PIO databooks.
5. Mostek 1980 memory databook and designers guide.
6. Texas Instruments, TTL Databook, 1980.
7. Ferranti Semiconductors, Quick Reference Guide 1981.
8. Zilog Microcomputer Components Data Book, 1980.
9. National Semiconductor, Linear Databook, 1980.
10. National Semiconductor, CMOS Databook, 1981.
11. Ferranti Electronics Ltd., Data Converter Handbook, 1980.
12. J.C. Nichols, E.A. Nichols and P.R. Rony, Z80 Microprocessor Programming & Interfacing Book 2, 1981.

APPENDIX C — SPECTRUM PARTS LIST

Resistors

R1 470R
R2 470R
R3 470R
R4 470R
R5 470R
R6 570R
R7 470R
R8 470R
R9 8K2
R10 8K2
R11 8K2
R12 8K2
R13 8K2
R14 8K2
R15 8K2
R16 8K2
R17 330R
R18 330R
R19 330R
R20 330R
R21 330R
R22 330R
R23 330R
R24 3K3 (or 1K)
R25 180R
R26 680R
R27 680R
R28 10K
R29 1K5
R30 1K
R31 220K
R32 100R
R33 680R
R34 15R
R35 10K
R36 680R
R37 1K
R38 3K3
R39 3K3
R40 1K
R41 1K5
R42 1K
R43 3K
R44 5K1
R45 1K
R46 1K
R47 220R
R48 4K7 (or 2K2)
R49 18K (or 8K2)
R50 4K7
R51 2K2
R52 2K2
R53 390R
R54 100K
R55 56R
R56 220R
R57 330R
R58 1K
R59 1K8
R60 100R
R61 15R
R62 15R
R63 22OR
R64 15R
R65 10K
R66 10K
R67 10K
R68 10K
R69 10K
R70 220R
R71 220R
R72 10K
R73 1K
R74 10K
R75 10K
R76 1K
R77 1K
R78 470R

Capacitors

C1 47nF
C2 47nF
C3 47nF
C4 47nF
C5 47nF
C6 47nF
C7 47nF
C8 47nF
C9 — C24 Decoupling Capacitors
C25 22uF 16v
C26 47 nF
C27 1uF 63v
C28 22uF 16v

C29 47nF
C30 47nF
C31 100nF
C32 100nF
C33 47nF
C34 22uF 16v
C35 10nF
C36 47nF
C37 33pF
C38 33pF
C39 10nF
C40 47nF
C41 47nF
C42 47nF
C43 100nF
C44 100uF 16v
C45 100uF 16v
C46 1uF 50v
C47 22uF 16v
C48 47nF
C49 47nF
C50 22uF 16v
C51 NOT USED
C52 100pF (or 150pF)
C53 100pF (or 150pF)
C54 470pF
C55 — C62 Decoupling Capacitors
C63 47pF
C64 100pF
C65 22uF 16v
C66 47nF
C67 100pF
C68 100nF
C69 100nF
C70 100nF
C71 100nF
C72 16pF
C73 16pF
C74 4.7uF 63v
C75 100nF

Transistors

TR1 ZTX 313
TR2 ZTX 313
TR3 ZTX 313
TR4 ZTX 651
TR5 ZTX 213
TR6 ZTX313
TR7 ZTX450
TR8 BC184P
TR9 BC184P

Miscellaneous

7805 1 amp 5 volt regulator
X1 14 MHz crystal
X2 4.4336 MHz colour crystal
VR1 2K2 horizontal preset
VR2 2K2 horizontal preset

Diodes

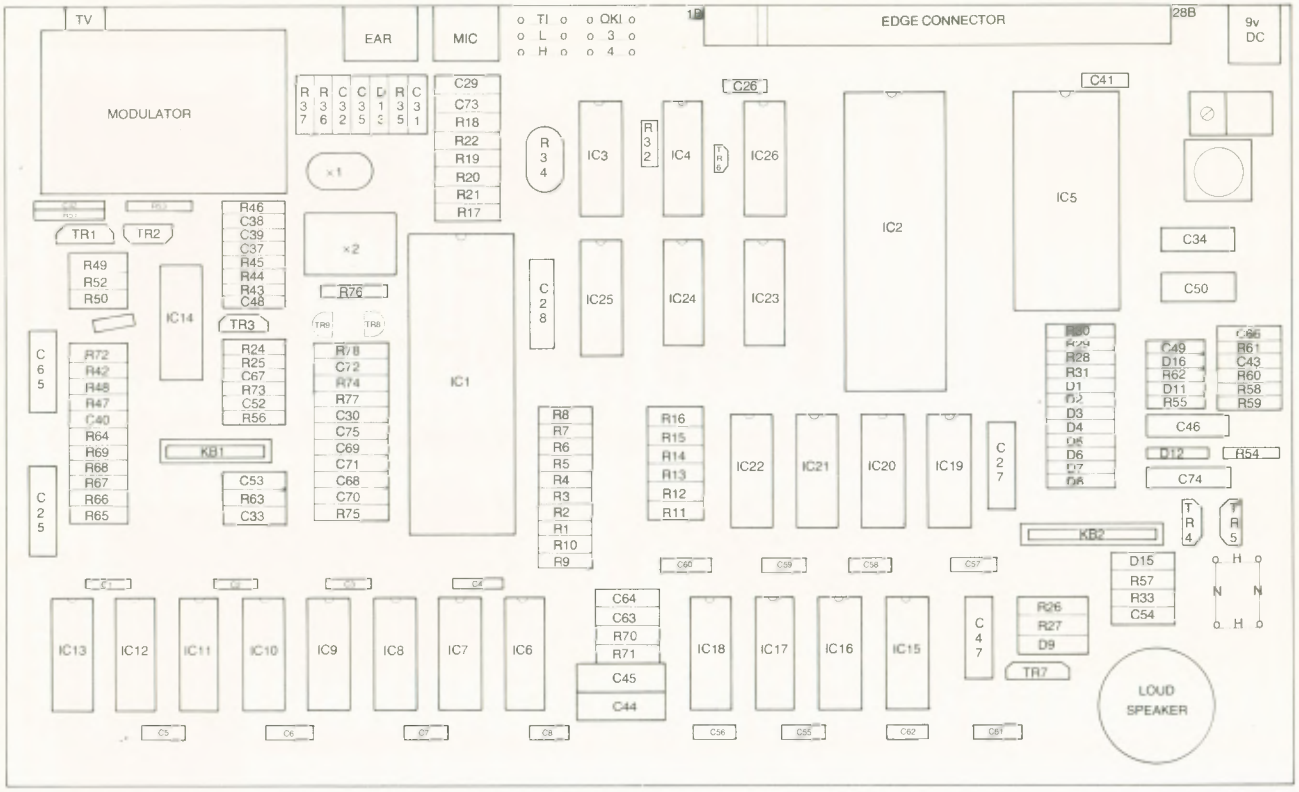
D1 — D14 IN4148
D15 high power silicon diode
D16 Zener diode

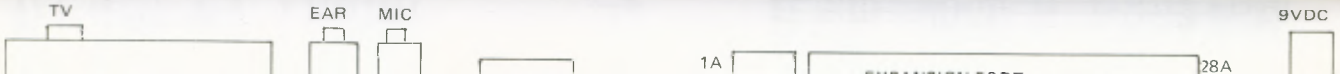
Integrated circuits

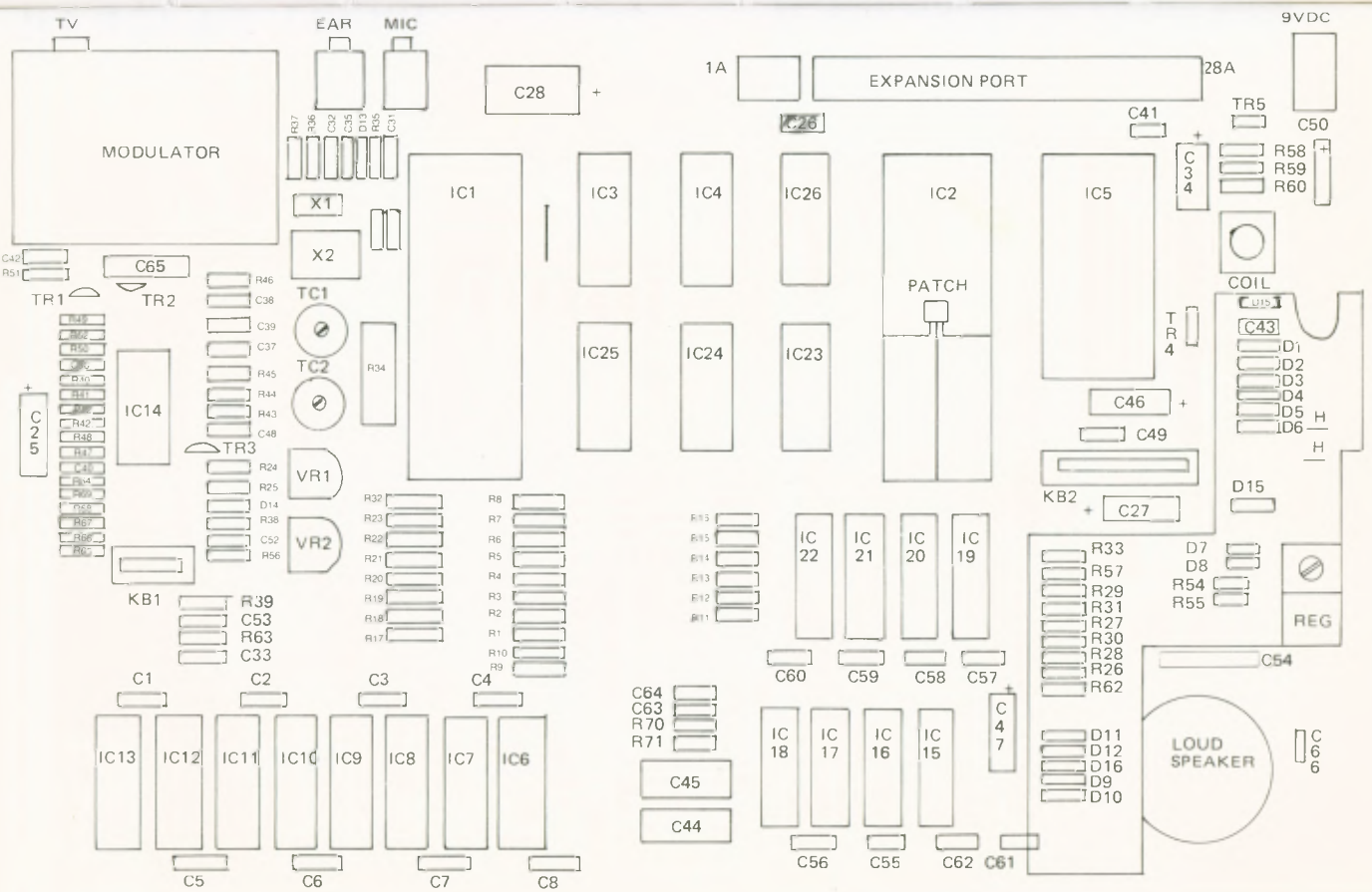
IC1 Sinclair ULA
IC2 Z80A CPU
IC3 74LS157
IC4 74LS157
IC5 16K ROM
IC6 — IC13 16K×1 4116 Dynamic RAMS
IC14 LM1889N
IC15 — IC22 32K×1 4532 Dynamic RAMS
IC23 74LS32N
IC24 74LS00N
IC25 74LS157N
IC26 74LS157N

NOTE: This is a complete list of parts, as used in Issue 1, Issue 2 and Issue 3 Spectrum computers. Whilst many components are common to all three versions, some components will only be found in one or two of the Issues.

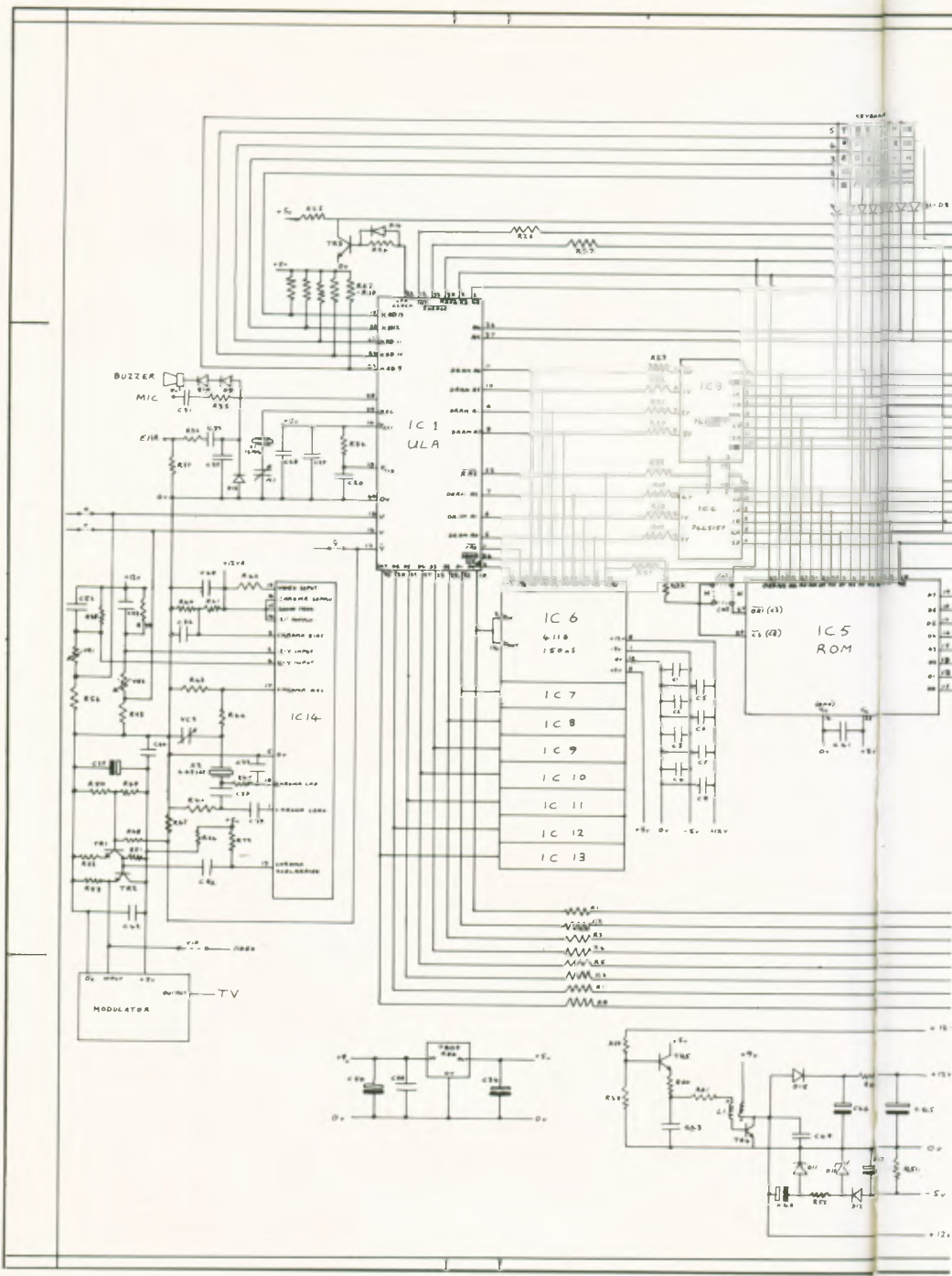
APPENDIX D — COMPONENT LAYOUT DIAGRAM ISSUE 3 BOARD

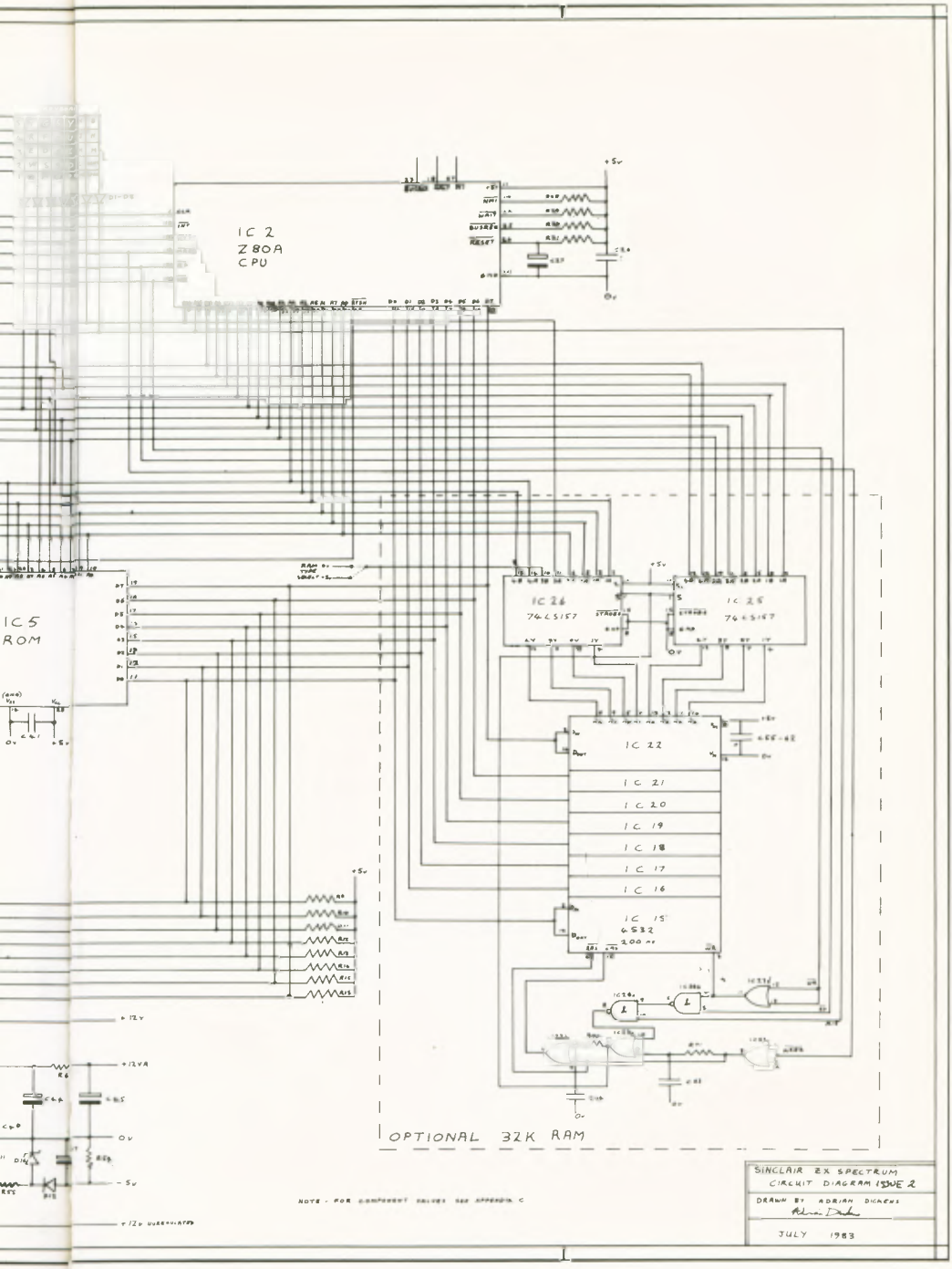




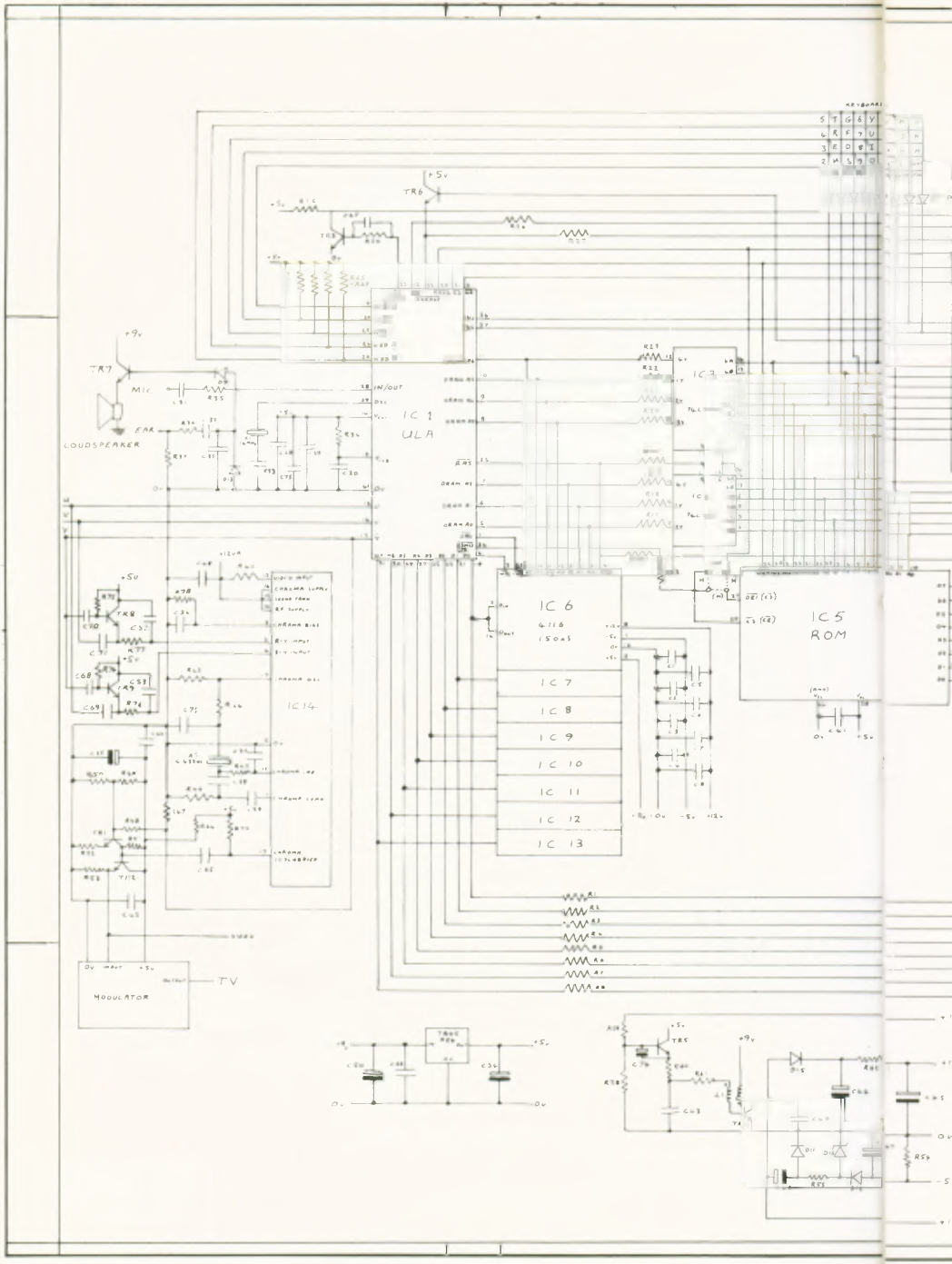


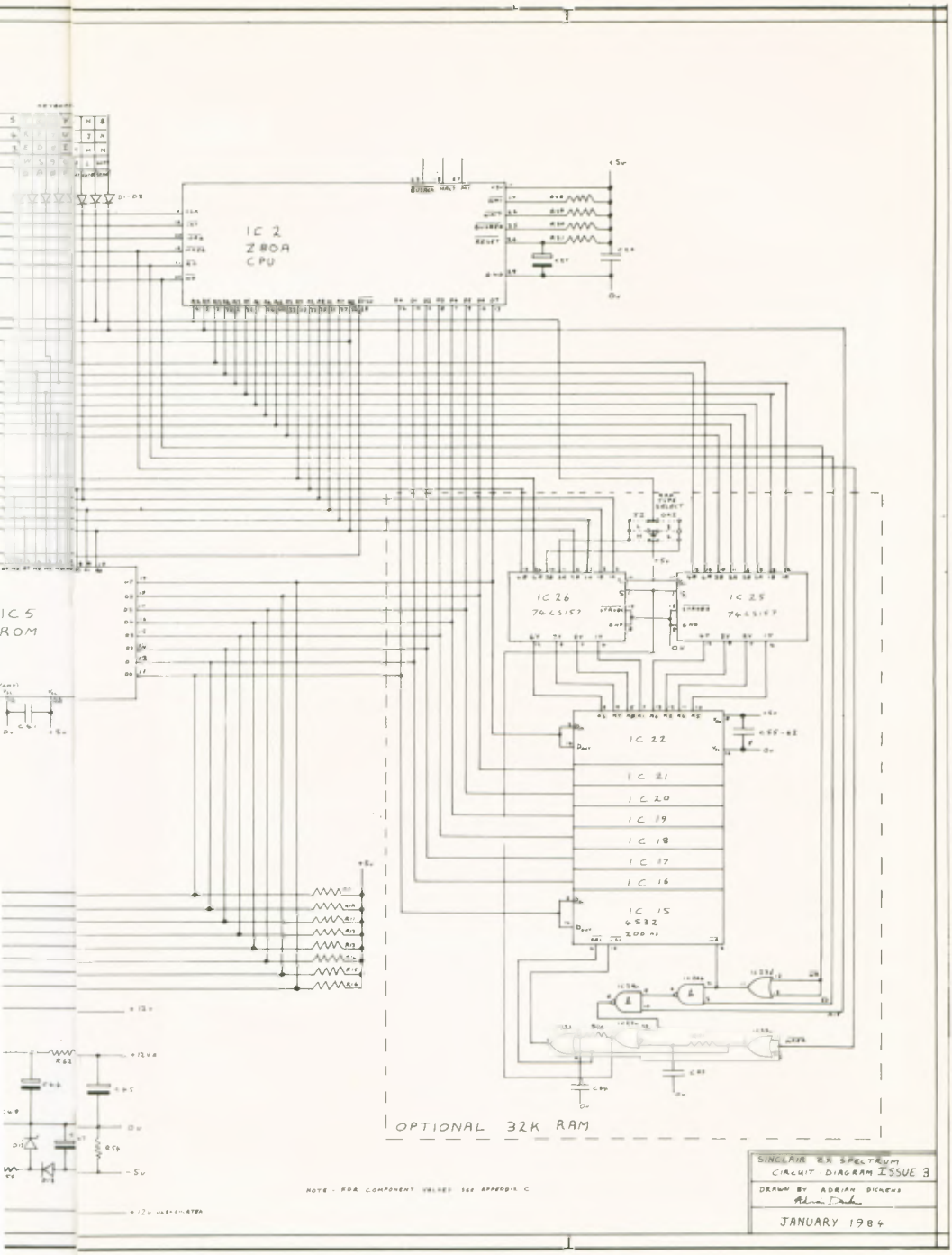
COMPONENT LAYOUT FOR ISSUE 2 BOARD


BUZZER
MIC
IC 1
ULA
IC 3
IC 4
IC 5
ROM
IC 6
6116
150nS
IC 7
IC 8
IC 9
IC 10
IC 11
IC 12
IC 13
IC14
MODULATOR
TV



APPENDIX E — ISSUE 2 ZX SPECTRUM CIRCUIT DIAGRAM


+5v
TR6
+9v
TR7
MIC
EAR
LOUDSPEAKER
IC 1
ULA
IC 6
4116
150nS
IC 7
IC 8
IC 9
IC 10
IC 11
IC 12
IC 13
IC 14
IC 2
IC 3
IC 4
IC 5
ROM
+12V
TR8
TR9
TR10
TR11
TR12
MODULATOR
TV
TR5



APPENDIX E — ISSUE 3 ZX SPECTRUM CIRCUIT DIAGRAM

INDEX

P.C.W. April 12th 19 - '89

Spectrum +3 to Silver Reed

Henry Burek of Barnsley, South Yorkshire, writes:

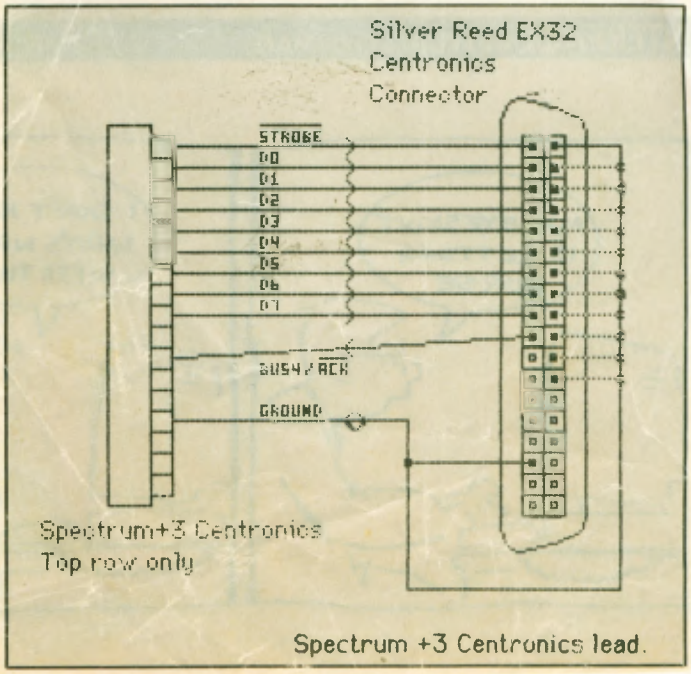
Q I have a Sinclair ZX Spectrum +3 and a Silver Reed EX32 typewriter/printer. Both are equipped with interfaces which are Centronics-compatible parallel. When the two are connected together nothing happens.

I know the Spectrum +3 and the connecting lead are satisfactory as they drive another Centronics printer – a Seikoshja GP100A – successfully. I know the Silver Reed EX32 is satisfactory, as it can be driven by a 48K Spectrum via a Kempston interface.

What can I do to make the Silver Reed and the Spectrum +3 work together? They are both supposed to have the same interface standard.

A As far as I can see, it should work. The only possibilities I can think of are that either the ground lines are connected incorrectly or that the BUSY/ Acknowledge lines are connected wrongly. The latter seems the most likely and you should make sure that the BUSY(11) input of the Spectrum +3 is connected to the ACK(10) pin of the Centronics connector. Apart from that I do not know what to suggest. It should work.

If you wish, you will be able to use the RF (UHF) output to connect to a TV while watching the monochrome picture on the Amstrad monitor.



Spectrum +3 Centronics lead.

NOTES

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