

SPECTRUM



Melbourne
House

SPECTRUM *Hardware* MANUAL



ADRIAN DICKENS

**NEW & REVISED
FOR
SPECTRUM
ISSUE 3**

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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 occurred. All Spectrum circuits are the copyright of Sinclair Research Limited. Other designs and programs are the copyright of the author.

VIDEO MODULATOR

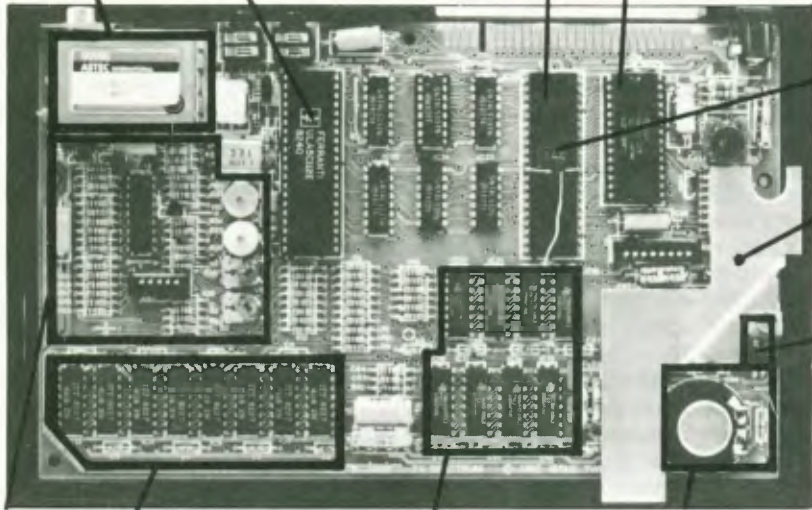
ULA

Z80A
CPU

ROM

ISSUE 2 BOARD

PATCH
HEATSINK
+5V REGULATOR



VIDEO
CIRCUIT

VIDEO AND PROGRAM
MEMORY

32K ADDITIONAL
MEMORY

BUZZER

VIDEO CIRCUIT

Z80 CPU

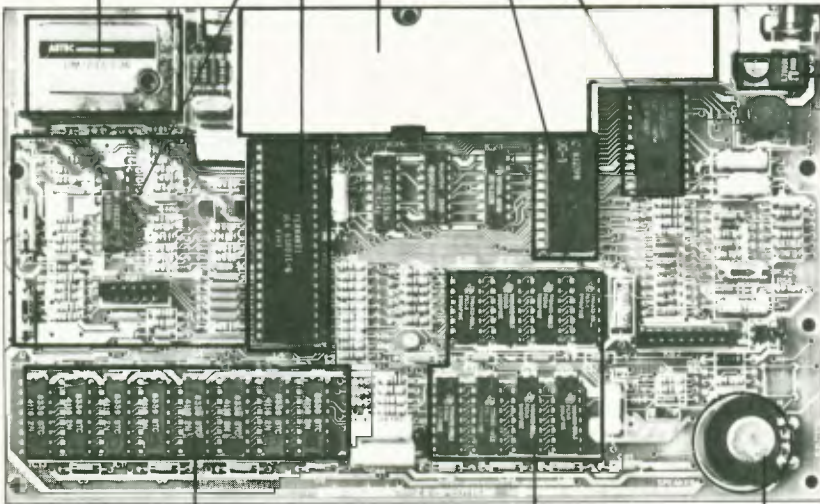
VIDEO MODULATOR

ULA HEATSINK

ROM

ISSUE 3 BOARD

+5V REGULATOR



VIDEO AND PROGRAM MEMORY

32K ADDITIONAL MEMORY

BUZZER

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

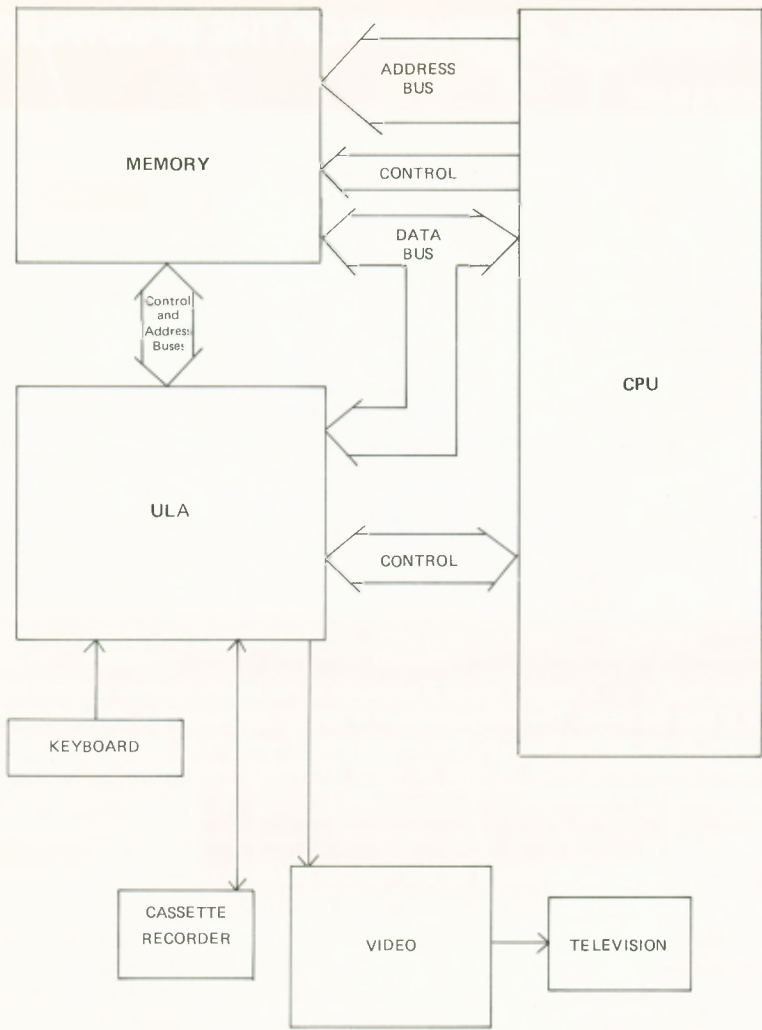


FIG 1 – SPECTRUM BLOCK DIAGRAM

(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.

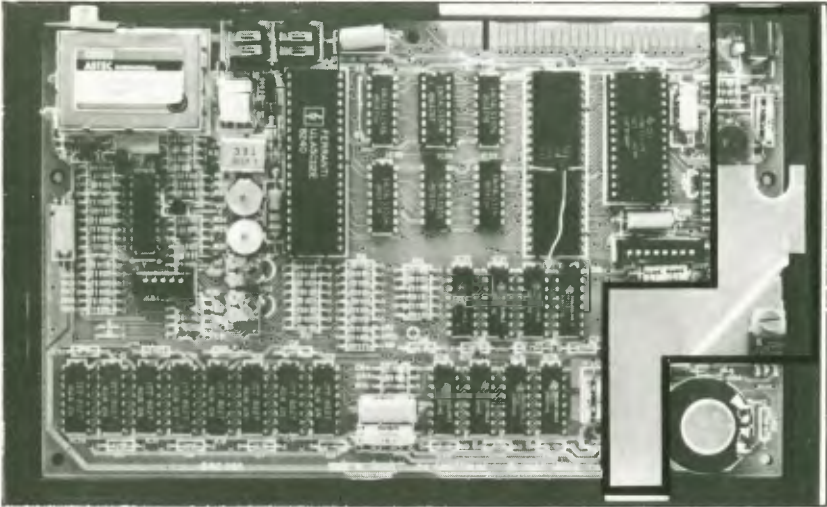
Having found what to do from the program in ROM, the CPU must get inputs from the keyboard or cassette and send outputs to the video display or cassette. The uncommitted logic array (ULA) helps the CPU to interface with the outside world. The ULA gets information directly from the keyboard and cassette 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

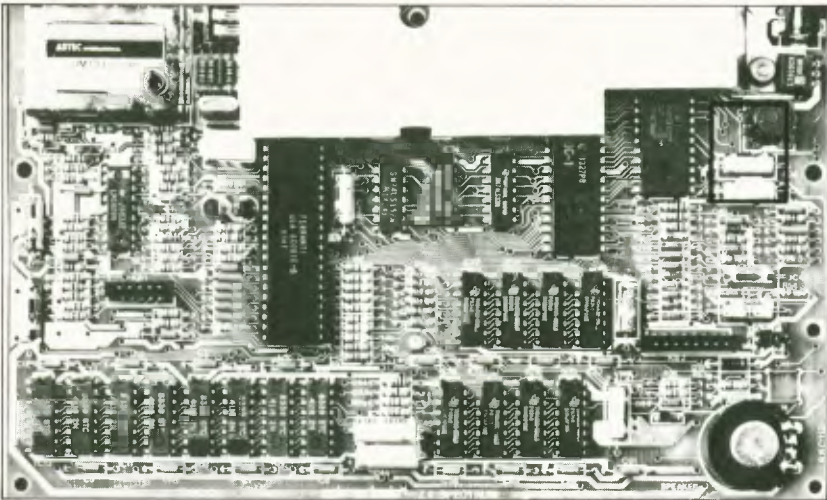


PLATE 2 – PHOTO OF MAIN SPECTRUM BOARD
WITH POWER SUPPLY OUTLINED

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 circuit 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