A Hardware Guide For The BBC Microcomputer.

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Preface

The BBC Microcomputer, manufactured by Acorn Computers Limited, was commissioned by the BBC as part of its Computer Literacy Project. As such the machine is an educational tool, which is capable of being expanded into a very sophisticated computer with computational powers to rival those of present day mini-computers.

As with any complex machine it makes sense to understand something of how it works, what goes where and how to obtain the best from it. A computer is no different and a working knowledge of the internal functions and layout will boost your confidence in computing.

This Hardware Guide delves inside the computer to reveal some of the many modifications, upgrades and circuit changes that can be performed. Some modifications only require extra components to be inserted whilst others require careful work with a soldering iron on the main printed circuit board. For those who prefer only to peek inside the lid, photographs and circuit layouts have been provided to identify the various integrated circuits and work areas on the main board. Some handy tips, such as getting rid of that annoying buzz found on many computers, introduce the beginner to electronics stimulating his or her interest in both spheres of activity.

For the more advanced reader, system fault finding, further expansion and the inclusion of manufacturers data sheets and detailed descriptions of complex circuitry make this manual a necessary adjunct to the existing publications available.

SUPPLIERS ADDRESSES AND CODES.

Below are the names and addresses of suppliers, which are identified within the book by the following codes. These are given as examples to assist the reader, not as recommendations.

Code A:
Acorn Computers Ltd.
Fulbourn Road, Cherry Hinton, Cambridge. CB1 4JN.
Tel: 0223 245200

Code B:
W. Broady & Son Ltd.
English Street, Kingston-Upon-Hull. HU3 2DU.
Tel: 0482 29894

Code F: Farnell Electronic Components Ltd.
Canal Road, Leeds L512 2TU.
Tel: 0532 636311

Code RR:
The Radio Resistor Co. Ltd.
St. Martins Way Industrial. Estate, Cambridge Road, Bedford. MK42 0LF.
Te1: 0234 47188

Code RS:
RS Components Ltd. (TRADE ONLY)
P. O. Box 427,
13/17 Epworth Street, London.
EC2P 2HA.
Tel: 0l 253 3040
0l 250 3131

Code T:
Technomatic Ltd.
17 Burnley Road, London.
NW10 1ED.
Tel: 0l 452 l500
01 450 6597

Code W:
Watford Electronics.
34/35 Cardiff Road,
Watford. Herts.
Tel: 0923 40588

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CHAPTER 5 : MACHINE UPGRADING.

CHAPTER 6 : HINTS, TIPS AND MODIFICATIONS.

CHAPTER 1 :- INTRODUCTION.

It is the intention of the authors to provide the reader with detailed information on the hardware aspects of the BBC Microcomputer. Some of this information has appeared in magazines but these articles usually just give sufficient information to explain a particular project. This book goes further, giving both the enthusiast and advanced user a detailed understanding of the internal workings of the BBC Microcomputer, thus making it a very useful reference manual, whether undertaking projects of your own or elaborating on projects found in magazines. There is a comprehensive link survey and a large number of hints, tips and modifications which can be undertaken.

Servicing is a task that is best entrusted to an approved Acorn service centre. It should be pointed out that modifying the machine yourself could invalidate the manufacturers guarantee. Further, it is possible that you may discover a fault outside the scope of this book, or one you prefer not to tackle yourself. In either case it would be worth consulting your local Acorn dealer first who will probably have access to diagnostic test equipment. This should be either a Progressive Establishment Tester (PET), or Final Inspection Tester (FIT). Both of these diagnostic and test devices are produced by Acorn Computers Ltd. and are presently only available to official Acorn dealers.

Until late 1983 the machine was available in two options, model A and model B, both having the same main printed circuit board, case, and keyboard. The main differences being that the model A version had fewer IC's and connectors fitted. The BBC Microcomputer has a maximum available on-board Random Access Memory (RAM) of 32 Kilobytes, (one kilobyte = 1024 bytes). However only half of this RAM (16K) is fitted to the model A machine. The model B machine has the full 32K.

There is a requirement for a minimum of two Read Only Memories (ROMs) in the Machine (both A and B), one houses the Machine operating System, (MOS) the other houses the Basic Interpreter and 6502 Assembler. There are three additional internal sockets for other ROMs (e.g. Word Processors, Filing systems and other languages etc.). A number of hardware add-ons are available to allow a further 13 ROMs to be installed in the machine.

The Computer has a UHF output, to connect to the aerial socket of a standard television set tuned into channel 36. In addition to this there is a composite video output and a Red, Green and Blue, (RGB) output (model B only), to drive a black and white, or colour monitor respectively. These outputs give a much clearer and sharper display, since they eliminate the need to modulate and demodulate the signal on to a UHF carrier.

The Computer has eight different formats for the screen layout these are called screen modes and are numbered 0 to 7, each giving different resolutions and colour availability. The screen display is stored within the machines RAM, the amount required being dependant upon which particular screen mode is selected. The highest resolution modes require 20K of RAM. Mode 7 is unique, in that it uses a special teletext character generator IC. The advantages of using this method of character generation are that high quality text and easy to use graphics are available using only 1K of memory.

The two most common mass storage mediums used with the microcomputer are an audiocassette system, (models A and B), or a floppy disc system (with the relevant upgrade). The cassette interface is very tolerant with regard to the quality of the signal and the cassette storage system. Although the cassette interface used within the BBC Microcomputer is very reliable it still only represents a good compromise for a data storage and retrieval system. If you intend to use the machine for any serious work then you will probably find the cassette system rather inadequate. A floppy disc or "Econet" system will provide a much more suitable solution.

A single floppy disc can store between 100 and 300 Kilobytes of information with a 100-fold decrease in access time over a cassette based system.

The BBC Microcomputer has an on-board sound generator which provides four independent sound channels. Three of these channels can be used for music synthesis each one having full envelope control, attack, sustain, decay and release. The fourth channel is a white noise generator and uses the same envelope control features as the other three channels.

The machine also has the capability to interface to a great variety of other equipment, through its numerous Ports, the connectors for which are mainly situated on the underside of the case. These are as follows: -

Floppy Disc Interface (5 ¼ and 8 inch).

A Centronics type parallel printer interface.

1 MHz Bus Extension I/O.

The Acorn "Tube" second processor port.

An 8-bit parallel "User Port".

The Cartridge ROM system.

The Acorn "Econet" local area network system.

The analogue-to-digital converter.

RS423 (RS232C compatible) serial interface.

The parallel printer port can interface with a large number of different printers, including Epson, NEC, and Seikosha.

The 1MHz bus is used to interface the microcomputer to a whole range of slower peripheral devices such as EPROM programmers, input output rack systems, data acquisition systems etc.

The "User Port" provides the machine with an eight bit wide input/output connection which can be used to control external equipment such as robots and relays etc.

The Acorn "Tube" interface is used to allow the BBC Microcomputer to access a second high-speed microcomputer called a second processor. By adding a second processor to the standard machine the overall computing power can be greatly enhanced. The resulting improvement will depend upon the particular second processor. At the present time there are only two second-processor boards available these are the Z80 and a 3MHz version of the 6502. The Z80 processor will enable the BBC Microcomputer to use the C/PM operating system and thus enable the machine to run an extremely wide range of currently available software.

The Acorn "Econet" network feature enables up to 255 BBC Microcomputers to be connected together and each microcomputer can have access to a central information storage and retrieval device. This system enables a large number of users to share expensive peripheral devices and also provides each one with the facility to communicate with any other user in the network. The "Econet" system finds most use in schools and colleges.

The analogue port, which is located at the rear of the machine, (model B only) allows the user to connect up to four analogue signals into the computer. These signals could be derived from all manner of transducers thus enabling the machine to measure and record real physical quantities. This feature will enable the machine to be used for monitoring signals in experimental or perhaps industrial applications.

The RS423 port situated at the rear of the machine (model B only) enables the microcomputer to communicate with other pieces of equipment. This equipment could be peripheral devices such as serial printers or perhaps other computers. In most cases the RS423 port can interface with other equipment which uses the more common RS232C (V24) serial interface standard, although this is not always the case. The BBC Microcomputer does not provide all of the signals necessary for a full implementation of the RS423 standard but the main signal lines are provided. The machine’s operating system enables the port to be configured for a whole range of baud rates ranging from 75 to 19200 although the integrity of the data is not guaranteed at 19200 baud.

To complement the impressive graphics features of the BBC Microcomputer the model B machine is fitted with a primary colour drive RGB output. This can be used to connect the machine directly to primary colour drive monitors. The display produced on good quality RGB monitors is far superior to that produced by connecting the machine to a domestic television receiver.

Figure 1.1 is an overview of the BBC Microcomputer system showing the numerous expansions that can be added to the machine. It can clearly be seen from this diagram that the machine is capable of being considerably expanded.

The authors of this book have endeavoured to cover all of the hardware aspects of the machine in the hope of assisting people to understand the inner workings of what otherwise might be considered as a “magic black box" (cream box ?). It has been our aim throughout the book to simplify, wherever possible, the descriptions and explanations of the internal circuitry of the machine. In some instances it has been extremely difficult to describe in simple terms what is in fact a very complex process and the casual reader may, therefore, find certain sections difficult to understand. The manufacturers data sheets included in appendix 1 may be of help in such instances.

Wise Owl Publications have produced a further book on the hardware aspects of the BBC Microcomputer. This book contains a full set of manufacturers data sheets on all of the TTL 7400 and CMOS 4000 series devices used in the machine together with data sheets on all of the devices that are not given in appendix 1. In addition to this book Wise Owl also produce a range of hardware "add-ons" for the BBC Microcomputer including digital-to-analogue converters and an automatic stop/start scroller called the "Owl-Scroll". For details on any of the above items send an S.A.E. to:

Wise-Owl
Hull Innovation Centre,
Guildhall Road,
Queens Gardens,
Hull.
HUI 1HJ.

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CHAPTER 2 :- ATTITUDES TO WORK AND DISCIPLINES REQUIRED.

This chapter is intended to provide the less experienced reader with some of the information which he or she may require in order to carry out some of the more advanced upgrades and modifications described within this book. Those readers who already have some practical experience with a soldering iron may find some of what follows a little tedious, although they should still read the sections on anti-static precautions and perhaps de-fluxing.

2.1 Attitudes To Work And Working Environment.

Before going on to describe the precautions that should be taken when handling certain integrated circuits it is prudent to spend a little time considering the environment in which any work on the BBC Microcomputer should be carried out.

If you do intend to carry out any work on the circuitry within the microcomputer, whether to simply plug in additional chips or to perform soldering operations, you must first of all give some thought to the manner and place in which the work should be carried out.

You must have a solid work surface, which should ideally have a free area of no less than one metre square. It should be set at a comfortable height such that you can sit down whilst working. It is advisable to use a conductive cover placed over the surface of the workbench, the reasons for this are detailed in the section below on anti-static precautions.

There should be plenty of light, a desk top lamp fitted with the highest wattage bulb that it can safely hold is an ideal light source since it can be adjusted into position above the work. For some of the more delicate work a magnifying glass or eye glass may be required, these can be of great help when working on small or delicate parts. The best place to obtain a suitable magnifying glass would probably be your local philatelists or hobby shop.

Before commencing work on the machine, be sure that you fully understand exactly what it is you are doing. This is especially true if you have not tackled this type of work before. You should be totally familiar with the particular section in the book that deals with the work you are doing, if you are less experienced this will involve reading the section a number of times. All of the tools, integrated circuits, sockets and connectors etc, which you require for the work should be on hand ready. It is advisable to check that you do in fact have the correct devices before fitting them, this is especially true if the parts were purchased by mail order since more mistakes seem to occur when parts are bought in this way.

It is important to allow yourself plenty of time in which to carry out the work. Do not be tempted to rush because this usually results in poor quality workmanship. Also if you rush work of this type it is very likely that mistakes will be made and these could turn out to be costly.

A systematic and orderly approach should be adopted since this will minimise the likelihood of doing something incorrectly or omitting something. In practise this will mean planning ahead by mentally going through the procedure before you commence work. Try to keep the workbench tidy and do not clutter the space up with unnecessary objects, leave yourself plenty of room in which to work.

It is also important to seat yourself in a comfortable position at the workbench. If you are not comfortable whilst you are carrying out the work you will be tempted to rush the job and hence run a higher risk of making mistakes. If you do rush the work the end result will probably not be of a good standard.

Make sure that you have plenty of light on the work area, a strong light will make most of the work that you will be carrying out on the machine far easier.

Once you have completed the work on the printed circuit boards it is essential that you conduct a detailed visual inspection of both the work which you have carried out and the remaining areas of the PCB. It is quite likely that small pieces of wire etc., will have fallen onto the PCB whilst you were working on it. Under no circumstances should you reassemble and switch on the machine without having carried out this inspection, in fact it is advisable to inspect the board at least twice using a strong light and an eyeglass. As mentioned in chapter 5, be sure to check that the heat sink on IC6 (Video Uncommitted Logic Array) is firmly seated and that non of the resistors and capacitors have become bent over and shorted. The importance of this inspection cannot be over emphasised.

2.2 Anti-Static Precautions.

Many of the integrated circuits used within the BBC Microcomputer are either Negative Metal Oxide Semiconductor (NMOS) or Complementary Metal Oxide Semiconductor (CMOS) types. These types of IC's are susceptible to damage by static discharge and special precautions are, therefore, necessary when handling these devices.

Opinions on exactly what precautions should be observed when handling the devices seem to differ but the procedures outlined below, if observed, will ensure that the risk of damage to the IC's is very minimal. Although many people believe that with present day MOS devices the possibly of damage due to static discharge is hardly worth considering recent research has proved otherwise. Recent investigations have revealed that damage caused to MOS and CMOS integrated circuits may not be immediately apparent, that is to say that the device may function perfectly satisfactorily but will fail after only a relatively short time in service.

The number of MOS devices which you will be handling whilst upgrading or modifying your machine does not warrant the expense involved in purchasing any sophisticated anti-static handling equipment but a few simple precautions should be observed;

i) Avoid wearing any static generating materials such as Nylon.

ii) Do not have monitors or televisions switched on in close proximity to where you are working. There is a very high electrostatic field produced in the vicinity of the screen.

iii) Before commencing work touch some metal object that is known to be at Earth potential. The chrome portion of a central heating radiator valve or water tap are ideal.

iv) If possible, you should carry out the work on a conductive surface. This work surface should be connected to the mains EARTH via a 1 Megohm resistor. Do not on any account connect the work surface anything other than EARTH. Whilst handling the PCB's or integrated circuits keep them positioned on the conductive surface and try to keep part of your body in contact with the surface. The forearms are generally most easily kept in contact with the working surface.

v) Make sure that you use a low leakage soldering iron with an earthed bit. The ideal type is one which operates via a low voltage transformer (usually 24 volts) although these tend to be rather expensive. A mains operated iron with an earthed bit is generally suitable. The section below on soldering gives more details on soldering irons.

vi) If at all possible you should avoid carrying out the work in warm dry atmospheres since these usually produce high static charge levels.

2.3 Tools and Equipment Required.

In order to carry out many of the modifications described in subsequent chapters, certain basic tools are required. If possible, obtain good quality tools, as these should last a lifetime if treated with care.

The following list of tools will allow the reader to carry out all of the hardware upgrades and modifications that are described in this book:

- No.2 cross-point screwdriver.
- No.3 cross-point screwdriver.
- Flat bladed terminal screwdriver.
- Pair of thin nosed pliers.
- Pair of oblique cutters.
- Soldering iron, preferably temperature controlled (see section 2.4).
- Desolder pump (see section 2.5).
- Solder-22 S.W.G. rosin cored, 60/40 tin/lead alloy.
- Bench lamp (e.g. "Anglepoise" lamp).

2.4 Soldering.

Many newcomers to electronics and computing are under the misconception that the soldering of components to delicate printed circuit boards is a very difficult technique to master. Although good quality soldering does require practice and patience, it is a task that should be mastered fairly easily by the majority of readers. This is especially the case if the general guidelines that follow are carefully observed.

A good quality soldering iron is, of course, a necessary requirement. Poor quality soldering irons can easily cause damage to the main PCB of the BBC Microcomputer, since the board has fine copper tracks on both sides as well as through-hole plating. Ideally, a temperature controlled iron which is fitted with a fine pencil" tip, should be chosen. This type of iron may have a heating element power of up to 50 watts, the higher wattage types having a much faster temperature recovery than the lower wattage types. Temperature controlled soldering irons are, however, relatively expensive and if the price is considered to be excessive, then a good quality "thermally balanced" type is an inexpensive be alternative. This type of iron is designed such that the heating element and tip assembly combination is only capable of attaining a certain maximum tip temperature, in the steady be state condition. For work on the BBC Microcomputer, a thermally balanced soldering iron of power between 15 and 25 watts should be chosen.

Before the soldering iron is used to make a joint, the heated tip should be thoroughly cleaned on a damp sponge and then "tinned" using rosin cored solder. For soldering delicate PCB assemblies, such as the main PCB of the BBC Microcomputer, a good quality, rosin flux cored, 60% tin, 40% lead solder of 22 SWG should be used for both tinning the bit and soldering the components. To solder a joint, place the fully heated tip of the soldering iron into position and allow the area to heat up for approximately two seconds, before "feeding" in the cored solder. When the solder has flowed uniformly around the joint, stop feeding in the solder and then remove the soldering iron. After the soldered joint has cooled, inspect it to see that the solder has formed a good quality joint, which has a bright, shiny appearance. Dry-joints, which are usually caused by insufficient heating of the joint or contaminants on the component leads, can quite often be identified by their dull, matt appearance.

When soldering multi-leaded components such as integrated circuit sockets and some types of connector, it is recommended that soldering is alternated between diagonally opposite pins, so that localised overheating of the component and PCB is avoided.

2.5 Desoldering.

Occasionally, it will be necessary to desolder components or clear PCB holes which are blocked with solder. This task can be successfully performed using a desolder pump, which should be available from most electronic component stockists. Most desolder pumps consist of a spring loaded plunger inside a cylindrical barrel. The spring is held compressed by a catch, which when released causes the plunger to travel rapidly along the barrel, thus sucking the molten solder through the fine, heat resistant plastic nozzle.

To remove excess solder using a desolder pump, firstly "arm" the pump by depressing and locking the spring loaded plunger. Position the nozzle of the pump close to the solder to be removed and whilst keeping your thumb positioned over the trigger button, melt the solder using a soldering iron. When the solder is fully molten, depress the trigger button such that solder is sucked up into the barrel of the desolder pump. The molten solder forms a pellet inside the barrel, which should be discarded by re-arming the pump. This operation should not be carried out whilst the desolder pump is positioned over the PCB, since the solder pellet or any solder flakes which have been formed can easily fall onto the board, thus bridging tracks.

2.6 Defluxing.

After soldering, flux deposits will be left on the printed circuit board, which look unsightly as well as possibly causing high impedance tracks between soldered joints. These deposits can be easily removed, using a proprietary defluxing solvent (e.g. RS stock number 555-134), which should be applied using a stiff brush. It is recommended that the manufacturers instructions supplied with the defluxing fluid are carefully read and understood, since the solvents used can be harmful, are particularly if defluxing is not carried out in a well ventilated area. It is also important to ensure that the point solvent does not come into contact with the bodies of the components on the PCB, since the solvent may dissolve certain types of component marking and some thermoplastic.

CHAPTER 3 :- COMPLETE CIRCUIT DESCRIPTION.

3.1 The Power Supply Unit.

The power supply unit fitted to the BBC Microcomputer is a switch mode type. This unit produces +5 volts at 3.75 amps and -5 volts at 0.l amps, which are supplied to the main printed circuit board (main PCB) via seven flying leads. These leads are connected to the main PCB using 0.ll" blade type push-on receptacles. The three red leads carry +5 volts to various points on the board, which are all connected together electrically by copper tracks on the underside. The reason for this is to overcome the need for large, high current carrying, copper tracks on the printed circuit board. The mauve coloured lead carries the -5 volt supply and the three black leads connect the zero volt line to the board. Note on the early, linear type, supply the -5V lead is coloured brown.

A six pin connector, which is mounted on the case of the power supply unit on the underside of the microcomputer (see photograph chapter 5), provides auxiliary power for accessories such as a floppy disc drive unit. This socket provides a +12 volt supply in addition to the supplies carried to the main PCB. Details of the connections to this socket are given in chapter 5 (fig 5.2).

Early BBC Microcomputers, mainly issues 1 and 2, were fitted with a linear type power supply unit which employed a conventional mains transformer and bridge rectifier, the regulation of the voltage being performed by several 7800 series voltage regulators. These power units tend to get rather hot, even in an unexpanded model A machine and do not provide any auxiliary power. The linear supply can be distinguished from the later switch mode type by its black painted case and the absence of an auxiliary power socket.

Both types of supply contain no user-serviceable components and should therefore be exchanged if they are found to be faulty. The early linear supply should be exchanged for a switch mode type if it overheats or is faulty.

3.2 The Microprocessor (MPU)

The Microprocessor Unit (MPU) used in the BBC Microcomputer is the 6502A, which is a 2 MHz version of the popular 8 bit 6502, introduced by MOS Technology in 1975. Although a 2 MHz device is used, and indeed many devices such as the Random Access Memory (RAM) are accessed at this speed, the MPU does in fact run at 1MHz when addressing slow devices within the computer. Examples of these 1MHz devices are the Versatile Interface Adapters (VIA's) and the Analogue-to-Digital (A to D) converter.

3.3 The Clock Circuitry.

The microcomputer uses a master clock frequency of 16MHz, which is generated by a crystal controlled oscillator. The oscillator circuitry is designed around a high speed TTL hex inverter type 74S04 (IC43). Two of the inverters within IC43 form an RC oscillator which is forced to run at 16 MHz by a 16MHz crystal (X1). The output of this oscillator is buffered by one of the remaining inverters within IC43 before being conditioned by a high-speed NAND gate, part of IC40. This provides the 16 MHz clock signal for both the video ULA, the floppy disc circuitry and the serial ULA.

One section of the video ULA is used to subdivide the 16MHz clock into four in-phase signals of 1,2,4 and 8 MHz, thus providing the required clock signals for the remaining circuitry within the microcomputer.

A 6MHz clock is required by the SAA5050 Teletext character generator (IC5) and also the "Econet" circuitry on early versions of the machine. This is produced in a rather unique way using the 4MHz and 8MHz clock signals. A set-reset (SR) bistable is formed using two cross coupled NAND gates (part of IC40) and two inverters (part of ICs 37 and 43) The 8MHz signal is inverted by part of IC37 (74LS04) and fed to one input of the cross-coupled NAND gates. Similarly, the 4MHz signal having been inverted by part of IC43 is coupled via a capacitor/resistor network (C41 and R94) to the other input of the cross-coupled NAND gates. This CR network delays the reset action of the bistable thus producing a modified 4MHz waveform (see figure 3.1).

The phase-modified 4MHz waveform produced by the bistable is exclusively ORed (using part of IC38) with the 2MHz clock to produce a 6MHz clock which is "phase-locked" to the master clock. This 6MHz signal contains erroneous pulses which are removed by a CR network coupled to the input of an inverter (IC37, 74LS04)

Figure 3.1 Generation of 6MHz Clock signal:

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3.4 Memory Devices.

The 8-bit 6502A microprocessor can directly address 64 kilobytes of memory. In the BBC Microcomputer, 32 kilobytes of this memory is contained within Read Only Memories (ROM's). ROM is non-volatile; that is, it retains data when the power to it is removed. The Machine Operating System (MOS) of the microcomputer is contained within 15 kilobytes of this read-only memory on a 16-kilobyte device, (normally IC 51). The machines address decoding circuitry "maps-out" the remaining 1 kilobyte, since this area is devoted to JIM, FRED and SHEILA. The BASIC interpreter is contained within another mask-programmed, 16 kilobyte ROM (normally IC52).

In early versions of the BBC Microcomputer the 0.1 operating system was contained within four 2732 type, 4 kilobyte ultra violet light Erasable programmable Read Only Memory devices (EPROMs). These were located in IC positions 52,88,l00, l0l, the BASIC interpreter ROM being in IC position 51. In this case the devices were accessed at 1MHZ. The Machine Operating System (MOS) was in EPROM due to delays in producing the mask programmed ROM version. The reason for using four 4K devices was probably due to the high cost of 8K and 16K EPROMs at the time.

Early versions of the series 1 (l.0) operating system, supplied with machines fitted with a disc interface, were contained within two 8-kilobyte EPROMs on a small "carrier board". When replacing this with a Series 1 Operating System ROM it should be noted that the carrier board has rather large diameter pins, which sometimes damage the IC socket into which the board was fitted. Chapter 6 gives details on a remedy for this.

There are positions for five read-only memories on the main PCB, the operating system and BASIC normally occupying two of these, as previously mentioned. The remaining three positions are for fitting utility or additional language ROMs and are often referred to as the "paged" or "sideways" ROM positions. In order to select between these, IC 76, which is a 74L5163, must be fitted and two circuit board links removed (see chapter 4). This modification is only required on issues 1,2 and 3 of the main PCB. In order to be able to make use of the paged ROM facility it is also necessary to have a Series 1 Machine Operating System fitted.

If the sideways ROM to be selected is an 8 or 16 kilobyte device, then it can be switched into the ROM memory space by writing to a 74L5163 4-bit synchronous binary counter (IC76), which is referred to as the ROM select latch. In cases where four, 4 kilobyte ROMs are fitted in the paged ROM sockets, a 74L5139 two-to-four line decoder (part of IC 20) selects which of the four devices is being selected by lines A12 and A13 of the address bus.

3.5 Random Access Memory.

The Model A BBC Microcomputer is fitted with eight 16k by 1 bit random-access memory devices in IC positions 53 to 60 providing a total of 16 kilobytes. A further 16 kilobytes of RAM is fitted to the Model B machine in IC positions 61-68 inclusive, thus providing the full 32 kilobytes of RAM.

The RAM devices used are dynamic types. In dynamic RAMS each bit of information is stored as an electrical charge on the gate capacitance of a field effect transistor. The charge on the gate capacitance leaks away with time (typically 2ms) and must therefore be replenished or "refreshed" periodically, in order to retain the data stored in the memory. This is accomplished by activating the Row Address Select (RAS) signal whilst a valid row address is on the address lines. In this way, 256 bytes of RAM are refreshed after each high to low transition of the RAS line.

The 6502A microprocessor, unlike the Z80, does not provide a facility for directly refreshing dynamic RAM and therefore additional circuitry is required. In the BBC Microcomputer the RAS inputs of the dynamic RAMs are continuously activated by the output of a D-type bistable (half of IC44). The 4 and 8MHz clock signals provide the input to this bistable.

The 6845 cathode ray tube controller (CRTC, IC2) or the microprocessor may have control of the RAM address lines. Six octal three-state buffers (IC8 to IC13) are used to select which of these two devices has access to the RAM address lines. The outputs of the dynamic RAMs are enabled when the Column Address Select (CAS) lines are activated.

Control of the RAM address lines is alternately switched between the microprocessor and the CRTC every 250ns. One of the primary functions of the 6845 CRTC is to generate RAM refresh addresses, which it must do in order to refresh the screen. The RAM refresh addresses are generated sequentially and since the CRTC has access to the RAM address lines twice in every microsecond, 512 bytes are refreshed in this period. This method of RAM refreshing is often referred to as "transparent" RAM refresh since it is performed whilst the microprocessor is engaged in internal activity and hence the operation is transparent to it.

3.6 The Video Generating Circuitry.

The video circuitry of the BBC Microcomputer is designed around three integrated circuits. These are

i) IC2 a 6845 cathode ray tube controller (CRTC).
ii) IC6 a custom designed video processor (VULA).
iii) IC5 an SAA5050 Teletext character generator.

The 6845 CRTC is used to generate the raster scanned video display and also to refresh the dynamic RAM (see previous section). The horizontal and vertical synchronisation signals required for the video display are generated by this device. These two signals are fed to the SAA5050 Teletext character generator (ICS) and are also combined by a NOR gate (part of IC41) to provide the composite synchronisation (CSYNC) signal.

In screen modes 1 to 6, the bit patterns for the character fonts are contained within the operating system ROM of the machine. These bit patterns are transferred into screen RAM as required and are latched in to the video ULA at the end of each CRTC access cycle. According to which screen mode is in operation, the video ULA serialises each byte of information read from the screen memory (2 bytes per microsecond) into a 2,4 or 8 bit wide train of pulses. This enables the screen to display modes varying from 640 horizontal pixels in 2 colours (high-resolution mode 0) to 160 pixels in 8 colours, which may be flashing (mode 2).

The bit patterns required to produce the graphics images are generated by routines within the operating system and are then stored in the relevant locations in the screen memory. These bit patterns are interpreted by the video ULA in a similar way to the character font information.

Within the video ULA, the serialised bit patterns are presented to a high speed (16MHz) 16 by 4-bit matrix of bipolar memory. This is referred to as the "palette memory". The palette memory is used to relate the logical colour held in the screen memory to the physical colour produced by the RGB output signal.

The technique of storing software generated character and graphics fonts in RAM demands a relatively large amount of user memory (20 kilobytes in the highest resolution modes). For this reason screen mode 7 is provided which displays high quality text and also limited graphics whilst only using 1 kilobyte of RAM. This is achieved using a Mullard SAA5050 Teletext character generator (IC5). Each character to be displayed is stored as a single byte in the screen memory as an ASCII code, which is interpreted by the SAA5050. This device then produces the video information, in the form of an RGB signal, to display the corresponding ASCII character on the screen. The RGB signals produced are then fed into the video ULA for the cursor control to be added. Solid state switches within the video ULA are used to route either the Teletext or the internally generated RGB signals to the video driving circuitry.

<Figure 3.2 to go here>

PALETTE

64 BJT RAM

(4x16)

RGB FROM SAA5050

MULTIPLEXER

CURSOR CONTROL
RGB out

FIGURE 3.2 RGB SYNTHESIS IN VIDEO ULA

A feature of the BBC Microcomputer is its ability to perform a "hardware scroll". The start-address-register within the 6845 CRTC is used to refer to the start address of screen memory. By altering the contents of this register it is possible to scroll the "active" screen display area. In the BBC Microcomputer, the hardware scroll is implemented in a more sophisticated fashion.

Not only is this start address register used, but also an offset can be added to the high order refresh address lines of the CRTC. This offset is specified by the system VIA (IC3), under the control of the operating system, and a two-bit code produced via an addressable latch IC32 (74LS259). This two bit code (C0 and C1) controls a combination of four NAND gates (parts of IC36, 40 and 27) and a full adder IC39 (74LS283) such that the required offset is added to the refresh address lines of the CRTC. The offset to be added is calculated such that by incrementing the CRTC refresh address lines by this amount, the active display area is shifted by one line to reveal the next line where the new data is to be written. Using this technique, the microcomputer can scroll the screen very rapidly.

In screen modes 0, 1 and 2, 20 kilobytes of RAM is required and since sufficient address lines are provided to access 32 kilobytes, this leaves an excess of 12 kilobytes. This poses a problem in that if the start of screen memory were at &3000, (as would be the case in these screen modes) then as the active display area is scrolled upwards, the 20 kilobytes required by the screen would normally enter the area of the memory map which is set aside for ROM. This is prevented by the machine operating system adding 12 kilobytes to the CRTC refresh address lines and thus the active screen display area is wrapped around" within the machine's screen memory. Similarly, in other screen modes the required offsets are added according to table 3.1.

TABLE 3.1

3.7 The Video Driving Circuitry.

The video uncommitted logic array (IC6) produces red, green and blue signals which after buffering by transistors Q4, 6 and 5, are fed to the 6-pin RGB DIN socket (SK3) via current limiting resistors R112,113 and 111 respectively. A composite of synchronisation signal, which can be selected to be positive or negative going by a circuit board link (S31), is also fed to this socket along with ground and +5V connections.

The horizontal and vertical components of the composite synchronisation signal are generated by the 6845 cathode ray tube controller chip (IC2). Monitors equipped with red, green and blue (RGB) drive inputs can be connected to this socket. Since the R.G.B output generated by the computer, is fed to the drivers of the primary colour guns of the picture tube directly, a high quality display is achieved.

In order to drive monochrome monitors equipped with a 1V peak-to-peak composite video input (RSI70 standard), the RGB and composite synchronisation signals are summed by resistors R117, R118 and R116 and fed to the base of transistor Q7. The 1-volt peak-to-peak drive required is thus produced at the emitter of this transistor. The phase alternating line (PAL) colour information may be added to the composite video output by the addition of a capacitor or by the bridging of a PCB link (S39), if present (see chapter 4). Connection to the composite video output of the computer is by a standard BNC type connector (SK2).

It must be stressed that any monitor connected to either the R.G.B. or video B.N.C. sockets must be electrically isolated from the mains supply. The easiest way to check this is to consult the manufactures of the monitor in question.

Colour television receivers usually require a UHF modulated PAL encoded signal. Such a signal is provided by the BBC Microcomputer from the socket marked "UHF out". An Astec UM1233 modulator, which has a video bandwidth of 8MHz, is used to convert the composite video signal to the required UHF signal.

The PAL encoding is performed using discrete circuitry. A 17.73 MHz signal is generated by a crystal controlled oscillator consisting of a transistor (Q10) and a 17.73 MHz crystal (X2). The signal produced is then inverted using a NAND gate (part of IC50) and divided by four using a 74574 bistable (IC46) to provide the 4.4325 MHz colour subcarrier frequency. The quadrature colour-difference signals "U" and "V" are produced on pin 9 of IC46 and pin 11 of IC48 respectively. The horizontal synchronisation pulses produced by the CRTC (IC2) use an exclusive OR gate (part of IC48) to gate the "V" colour difference signal. This produces the required alternating phase signal for each horizontal line scan. Exclusive OR gates (IC47 and IC48) are then used to generate the yellow, cyan, green, magenta, red and blue colours according to the phase relationships of the "U" and "V" signals. These signals are then "mixed" using six NAND gates (IC49 and part of IC50). The colour burst gate signal is generated using an inverter (part of IC37) and a NOR gate (part of IC4). This arrangement is timed by a CR network (C45 and R189) thus producing a burst gate pulse in the back porch period of the line scan. The burst gate signal is also mixed using the NAND gate mixer

3.8 Cycle stretching.

Certain devices within the BBC microcomputer need to be serviced at 1MHz instead of the normal 2MHz. These devices are:

i) Analogue-to-digital converter (IC73)
ii) System and user VIAs (IC3 and IC69).
iii) Sideways ROMs (optional) (ICs 52,88,100 and 101).
iv) MC6850 ACIA (IC4)
v) 6845 CRT controller (IC2).
vi) 1MHz extension bus (PL11)

The circuitry used to perform this function is designed around IC's 23,29,30,3l,33 and 34. Whenever a 1MHz device requires servicing, the relevant input of an 8 input NAND gate IC23 (74LS30 please note this gate is drawn as a NOR gate with inverted inputs on the Acorn circuit diagram), is taken low. This results in the output from the NAND gate going to logic '1', which is used to inform the cycle stretch circuitry that a slow access device requires service. The logic '1' is first inverted by part of IC33 (74LS04) before being fed to the set input of a bistable (half of IC31) and also one input of a NOR gate (part of IC~9). This bistable remains set, thus it effectively "remembers" that a slow access has been requested.

The output of the bistable is fed via the NOR gate to the input of another bistable, part of IC34. This second bistable is used to reset the "memory" bistable after a time governed by the phase relationship between the 1MHZ and 2MHz clock signals. Meanwhile, one of the 2MHz clock cycles will have been masked off by this second bistable. Depending on the phase relationship between the two clocks at the time of the request, the 2MHz clock to the microprocessor will be held at logic '1' for either 3 or 5 half cycles.

3.9 The "Econet" Circuitry.

The heart of the "Econet" circuitry is IC89, a Motorola MC6854 Advanced Data Link Controller (ADLC)

Connection to the "Econet" network is by a 5-pin l80 degree DIN socket (SK7) on the rear of the machine. The network clock I] connects to pins 3 and 5 of this socket, whilst pins 1 and 4 carry the data. Pin 2 is connected to 0 volts. The data line is bi-directional, thus both transmitted and received data is carried along the same pair of wires in half-duplex mode. Unlike the RS423 serial data transmission port, the "Econet" system uses a differential mode of operation to provide high common mode noise immunity and achieve high transfer rates.

Pin 6 (TXD) of the ADLC feeds the TTL data to be transmitted to one half of a differential line driver (IC93). provided that this line driver is enabled by the output of IC91, one quarter of which is used as an inverting buffer, data will then be transmitted. The input signal to this inverter comes directly from pin 2 (RTS) of the ADLC.

Any "incoming" data on the data lines is converted to a TTL signal by an analogue comparator (one half of IC94). The TTL signal is then fed into the received data input (RXD) of the ADLC. In a similar way, the network clock is also detected by the other half of IC94. The output of this comparator feeds both the receive clock and transmit clock inputs of the ADLC. Thus it is not possible to use different receive and transmit baud rates.

The network clock must always be present in order for the ADLC to synchronise correctly, a monostable (half of IC87) is used to achieve this. The time constant of this monostable is such that as long as the clock signal is present it remains permanently triggered. One output of the monostable provides the data carrier detect signal (DCD) into the ADLC, the other output activates the clear to send signal (CTS) via a dual input NAND Schmitt gate. By using this technique, network activity is suspended if the clock signal is interrupted.

Because of the democratic nature of the Econet system it is possible for two or more devices to attempt simultaneously to transmit data on the network. This condition is known as a "collision". A collision on the network will cause the nominal signal level on the data lines to drop because of the increased he loading, this condition is detected by a dual comparator (IC95). The dual comparator arrangement sends a TTL output signal into one quarter of IC91, which is acting as an inverter. The output of this inverter activates the clear to send input of the ADL.C via another quarter of IC91, thus transmission is suspended in the event of a collision. Each of the microcomputers involved in the collision will then retry. The condition is detected by both machines and an arbitration algorithm within the "Econet" system software ensures that no two computers will retry simultaneously.

The individual station address is set by the group of links S11, in conjunction with IC96. This is detailed in the chapter 4 which deals with link functions. The "Econet" network must be terminated at each end with its characteristic impedance to prevent signal reflections. On early issue printed circuit boards resistors R26,42,53,54,56, capacitors C19,22 and diode D3 provide this optional termination.

The network clock is usually derived from an external "clock box", however, on some early issue main PCB's, circuitry was provided to enable the network clock to be generated on board. This circuitry consisted of IC90 (40I8), IC97 (74LS74) and the normally unused half of IC93. The 6MHz clock signal derived from the output of IC37 is divided by two, using half of IC97 (74LS74). This 3MHz signal is then further subdivided in to a range of frequencies by IC90, link S3 is then used to select the required base clock frequency. Clock base frequencies usually lie in the region 75KHz to 625KHz. The required frequency is dependent on the line length of the network. The base clock frequency is then fed directly in to the input the normally unused half of the line driver IC93. The of this line driver is then connected to the clock output the DIN "Econet" connector and provides the network clock source.

The link S5 is used to enable the clock line driver and link S6 may be used to further subdivide the clock base frequency by 2 or 4.

3.10 The Keyboard Circuitry.

The keyboard consists of a ten by eight matrix of normally open contact switches, which are mounted on a metal plate. Connections to the contacts of these switches are made by a glass-fibre printed circuit board. This board also carries ICs 1, 2, 3 and 4, the loudspeaker, three LED's, the keyboard connector (to PL13) and the ROM cartridge socket (if fitted)

The keyboard circuitry is based on the "walking zero' 0 technique. IC1 is a synchronous binary counter (74L5163), which is clocked by the 1MHz system clock. The outputs from this IC are decoded by IC3, which is a BCD to decimal decoder (7445). The ten outputs of this decoder are connected to the column lines of the keyboard matrix. In this way, each column in turn is pulsed low then high thus producing the "walking zero' 5" pattern. Depression of any key results in the output of IC4, an 8 input NAND gate (74LS30), pulsing high as the walking zero passes the column to which that key is connected. The output from IC4 interrupts the microprocessor using the CA2 line of the system VIA (IC3). On recognition of this interrupt, the computer executes the keyboard reading routine to discover which key was depressed. This is achieved by latching the BCD address of each column in turn directly into IC1 using outputs PA0 to PA3 of IC3, the system VIA, thus interrogating each column in turn. At the same time outputs PA4, 5 and 6 of the system VIA are used to load data into IC2, which is a data selector (74LS251). Each row is selected in turn by the three bit code present on PA4, 5 and 6. The logic level on a particular row appears at the output of the data selector when selected. In this way, the keyboard matrix is scanned for the coincidence created when a key has been depressed.

3.11 The Cassette and RS423 Serial Interfaces.

The cassette interface has two software selectable baud rates, 0 and I200 baud. The majority of the circuitry for this interface is contained within a custom designed Uncommitted Logic Array (serial ULA-IC7)

The output signal from the cassette recorder enters the microcomputer on pin 3 of the 7-pin DIN socket SKS. Three of the operational amplifiers contained within IC35 (LM324) are used to condition this signal before it is fed into the cassette input (pin 12) of the serial ULA. Once inside the ULA this signal is presented to both a data /clock separator and a run-in header detector.

Solid state switches within the ULA, under the control of the microprocessor, are used to route the logic signal from the run-in detector to the data carrier detect output of the ULA (see fig 3.3). Similarly, the clock and data logic outputs are routed to the receive clock (RXC) and receive data (RXD) outputs respectively. The RXD, DCD and RXC outputs of the serial ULA are fed into the RXD, DCD and RXC inputs of IC4, an Asynchronous Communication Interface Adapter (ACIA) type MC6850. The ACIA converts the data to a parallel form, which is then presented to the data bus of the microprocessor, on demand.

The cassette clock signals are derived from the 16MHz master clock. The 16MHz signal is firstly divided by 13 using a 74LS163 synchronous binary counter (IC42) and then further subdivided within the serial ULA.

The data to be saved on to the cassette recorder is taken from the data bus and converted into serial form by the ACIA. This serial information is then fed into the TXD input of the ULA. Within the ULA, the serial data is converted to a synthesised sine wave signal, suitable for feeding to a standard cassette recorder. The synthesised sine wave signal is buffered using an operational amplifier (part of IC35) and then fed to pins 1 and 4 of the DIN cassette connector via a DC blocking capacitor (C34)

The CASMO (cassette motor) output of the serial ULA drives a transistor (Q3), which in turn operates the cassette motor relay and also the keyboard "cassette" lamp (LED). The normally open contacts of this relay are used for automatic motor control switching of the cassette recorder. The connections from these contacts are available on pins 1 and 7 of the cassette DIN socket (SK5)

The solid state switches within the serial ULA are used to route either the cassette signals or the R5423 signals to the ACIA. This switching is determined by the control register of the ULA which is controlled from the data bus. The serial ULA also contains the programmable baud rate generator, which is required by the R5423 interface.

The Data Out (D OUT) and Request to Send (RTS) signals from the ULA are converted from a TTL level to R5423 compatible form by a DS3691N line driver (IC75). This device requires both a +5 and -5 volt supply. The data-in (DIN) and clear-to-send (CTS) input signals from the R5423 interface are converted from R5423 to TTL levels by a line receiver IC type DS88LSl20N (IC74).

Connection to the R5423 interface is by a 5-pin DIN "domino" socket (SK4)

3.12 The Floppy Disc Interface.

The BBC Microcomputer was designed for use with either one or two 5 1/4 inch or 8 inch floppy disc drive units. These drives may be single or double sided.

In order to use floppy disc drives with the BBC Microcomputer, the disc interface circuitry must be fitted to the main PCB of the machine (see chapter 6). The heart of the floppy disc interface is an Intel P8271 Floppy Disc Controller (FDC) chip (IC78). This device controls data exchange between the floppy disc drive unit and the data bus of the microcomputer. An interrupt generated by the FDC acts on the non-maskable interrupt (NMI) line of the microprocessor (IC1). Note that apart from the FDC, there are two other devices within the microcomputer which generate NMI signals. These are the "Econet" interface and some 1MHz bus peripherals.

The TTL output signals from the FDC are fed into open collector NAND buffers, type 7438 (IC79 and IC8~). The outputs from these buffers connect to the disc drive unit via the disc interface plug (PL8). The data input (Read Data) and index pulse (Index) signals from the floppy disc drive enter the microcomputer on pin 30 and pin 4 (5 ¼ inch drive) respectively. In the case of an 8-inch drive, the index pulses enter on pin 8 of this connector. The option of whether the index pulse input to the P8271 FDC is taken from pin 4 (5 1/4-inch drive) or pin 8 (8 inch drive) of the connector is selected by a PCB link (S10)

The unseparated data signal from the floppy disc drive is fed into one half of a 74LS123 monostable (IC87), which "stretches" the incoming pulses to a length determined by the time constant of R33 and C13. The outputs of this monostable then feed into a data separation circuit consisting of a dual four-bit binary counter (IC81) and a triple 3-input NAND gate (IC82). This arrangement produces the "data window" signal which is fed to pin 26 of the FDC. The negated output of IC87 also supplies the read data input to the FDC.

Link S27 is used to route either the 8MHz (5 ¼ inch drive) or the 16MHz clock signal (8 inch drive) from the video ULA into one input of a 74LS393 dual 4-bit binary counter (IC86). The divide by four (QB) output of this counter provides the clock input to the FDC. Thus either a 2MHz or 4MHz FDC clock is provided, depending on which drive size is to be used. The remaining half of IC86 further sub-divides the FDC clock to produce either a 31.25KHz or 62.5KHz signal. This signal is then used in conjunction with IC83, IC84 and IC85 to detect the drive index pulses and to determine when the drive is ready for a read or write operation.

3.13 The User and Printer Ports.

IC69 is a 6522 Versatile Interface Adapter (VIA) which is used to provide both a standard Centronics parallel printer interface and the user port on the BBC Microcomputer. The printer port uses lines PA~ to PA7 of this VIA, which are buffered by an octal 3-state driver (IC70). Thus, because this driver is fitted, the printer port may only be configured as an output device. When this port is not being used to drive a printer, it may well be used for driving other user output devices (e.g. a digital-to-analogue converter)

The remaining eight lines (PB0 to PB7) of the user VIA allow the user to interface devices which produce digital signals to the computer. This port can be configured to be an output port or an input port, the option being software selectable.

For further details on the 6522 VIA consult the comprehensive data sheet given at the end of this book.

3.14 The Reset Circuitry.

When the BBC Microcomputer is switched on, a capacitor (C10) is charged up by a resistor (R20) which is connected to the +5V power supply rail. The signal at the junction of the CR network provides a reset signal (RSTA), which is low at switch-on and rises to +5V when the capacitor is fully charged. Whenever the break key is pressed and also on power up, a timer integrated circuit, type LM555 (IC16), produces another reset signal (RST).

The RSTA reset signal is only used to reset the system VIA (IC3) whilst the RST signal is a general reset signal which is used throughout the remaining circuitry. In this way the operating system can interrogate the system VIA to determine whether the reset signal was produced at power-up (RSTA) or simply by the break key (RST)

3.15 The Analogue Port.

A four channel, dual-slope integrating, 12-bit Analogue-to-Digital Converter (ADC), type PD7002 (IC73), is used to convert analogue signals to the digital form required by computer's data bus. The digital outputs of this device are connected directly to the system data bus. The end-of-conversion (EOC) signal from the ADC is fed to the CB1 input (pin 18) of the system VIA (IC3), which then requests an interrupt (IRQ).

The ADC derives its reference voltage (V_{ref}) from the forward voltage drop across three silicon diodes connected in series (D6, D7 and D8). A resistor (R71) limits the current through these diodes.

Connection to the inputs of the ADC is by a printed circuit board mounted, fifteen way, "D-type" connector socket (SK6). This socket also carries the connections to the light pen strobe input of the 6845 cathode ray tube controller (IC2) and the joystick "fire" buttons.

3.16 The Voice Synthesiser.

The voice synthesiser used in the BBC Microcomputer is a Texas Instrument two chip set, comprising of a microprocessor-bus compatible Voice Synthesis Processor (VSP) type TMS522~ (IC99) and a Voice Synthesis read-only Memory (VSM) containing speech data, type TMS6l~~ (IC98). Speech data for the VSP can be taken either from the VSM or from a slow (1MHz) data bus which is provided by port A of the system VIA (IC3). Interrupt (INT) and ready (RDY) output signals from the VSP are fed to lines PB6 and PB7 of the system VIA, respectively. Thus the VSP is under software control.

The speech data inside the VSM is a digitised form of the originally recorded human speech. In order to keep memory requirements to a minimum, this data is a compressed form of the original digitised speech data. The compression technique used is pitch excited Linear Predictive Coding (LPC). The data from the VSM is decoded within the VSP to reconstruct the digital speech information. An 8-bit digital-to-analogue converter inside the VSP provides the analogue speech signal, which is then filtered using an operational amplifier based filter (part of IC17). The filtered signal is then mixed with the analogue signals from the 1MHz bus and sound generator before amplification by the LM386 power amplifier (IC19) details of which are given in the following section.

3.17 The Sound Generator and Audio Amplifier.

The four-channel sound effects facility on the BBC Microcomputer is provided by a microprocessor-bus compatible sound generator integrated circuit type SN76489AN (IC18). This device is accessed at 1MHz by the system VIA (IC3). The pitch and attenuation of each channel is therefore under the control of the microprocessor. The 4MHz clock from the video ULA provides the clock input to the sound generator.

The audio output signal from the sound generator is mixed with the other audio signals generated by the microcomputer, thus providing a composite sound signal. This signal is then amplified and filtered using analogue circuitry based on operational amplifiers within an LM324 integrated circuit

(IC19). The resulting analogue signal is fed to PL16, which is the low-level (DIN) audio output connector. The same signal is also fed to a pre-set potentiometer (VR1), which acts as a volume control for the internal power amplifier of the computer. This power amplifier is a low supply voltage device, type LM386 (IC19).

3.18 The 1MHz Bus Interface.

In addition to the high speed **"Tube"** interface the BBC Microcomputer also has a 1MHz extension bus. Connection to this interface is through PL11 on the underside of the machine. The 1MHZ extension bus provides buffered address lines A0 to A7 (IC71), buffered bi-directional data bus lines D0 to D7 (IC72) and numerous control lines. The interface also has an analogue input line which is fed to the machines internal audio amplifier (IC's 17 and 19) and loudspeaker. The input impedance of this analogue input is 9 kilohms. If the speech and internal sound generator systems are not in use then a signal of + 3 volts RMS will produce full volume output at the loudspeaker. This input level will need to be reduced in order to avoid excessive distortion if the speech and sound generator systems are in use at the same time. There are two other lines on the 1MHz bus connector which will require further explanation, these are the lines NPGFC (Not PaGe &FC) and NPGFD (Not PaGe &FD) which are often referred to as FRED and JIM respectively.

3.19 FRED.

This signal is decoded from the machines address bus such that when the address bus holds a valid address in the range &FC00 to &FCFF this line will go low. The microcomputer address decoding circuitry around IC20 (74LS139) is used to accomplish this. FRED is intended for use by peripheral devices with small memory requirements.

There are various links within the machine that can be used to enable/disable FRED (S17) or alter its access times (S16) Further information on these links is given in chapter 4.

Acorn Computers Ltd. have standardised on particular addresses in the range &FC00 to &FCFF (FRED) to be used for specific functions, at the present time these are as

&FC00 - &FC0F	Test hardware use.
&FC18 - &FC13	Teletext use.
&FC14 - &FC1F	Prestel use.
&FC20 - &FC27	IEEE 488 interface (Control Universal Ltd.).
&FC28 - &FC2F	Future Acorn expansion.
&FC30 - &FC3F	Cambridge Ring interface.
&FC40 - &FC47	Winchester disc interface.
&FC48 - &FC7F	Future Acorn expansion.
&FC80 - &FC8F	Test hardware devices.
&FC90 - &FCBF	Future Acorn expansion.
&FCC8 - &FCFE	User applications.
&FCFF	JIM paging register (see JIM)

TABLE 3.2

Normally devices attached to the 1MHz bus should decode the address lines A~ to A7 and also the NPGFC line (FRED). In most cases the signal on the NPGFC line will need to be "cleaned up" by one of the circuits shown in figure 3.5 below.

The reason that the NPGFC and NPGFD signals need to be cleaned up is because of the difference in the speed that the 1MHz bus is running at, compared to the speed at which the machines internal 65~2A processor is running. The machines internal processor runs at a clock speed of 2 MHz unless a slow speed device, such as the 1 MHz bus, is being accessed. Circuitry within the BBC Microcomputer is used to effectively "stretch" the 2 MHz normal 6502A clock cycle into the 1 MHz clock (1 MHz E) cycle, required by 1 MHz peripheral devices attached to the 1MHz bus. This circuitry is described in some detail above.

The NPGFC signal (FRED) produced by the microcomputer's internal circuitry suffers from two distinct problems, these are "glitches" and "double accessing

Refer to diagram 3.4 below.

<u>3.20</u> <u>Glitches</u>.

The machines internal address bus will normally only change state when the 2MHz clock (2MHz E) is low. It can be seen from figure 3.4, however, that when the address bus changes state the 1MHz E clock is alternately high then low. This results in low-going "glitches" being produced in the NPGFC signal. These glitches are marked X and Y in figure 3.4. The glitches which occur when the 1MHz E clock is low (marked Y in figure 3.4) are normally of no consequence but the glitches occurring when 1MHz E is high (marked X in the diagram) may cause the chip select inputs of the various IC's on the 1MHz peripheral device to be spuriously activated. One of the circuits shown in figure 3.5, below, can be used to eliminate this problem.

FIGURE 3.5A CLEANING UP PAGE SELECT LINES

The circuit shown in figure 3.5 (a) is basically a gated S-R flip flop which will only allow the clean NPCFC/D signal to be low when 1MHz E is low. This same circuit can be used to clean up the NPGFD (JIM) signal which is also subject to a similar "glitch" problem.

There are also other circuits shown below in figure 3.5 (b) and (c). Figure 3.5 (b) uses a single integrated circuit and allows both FRED and JIM to be cleaned up. Figure 3.5 (c) is an alternative to 3.5 (a).

3.21 Double Accessing.

It is possible for a peripheral device, which is attached to the 1MHz bus, to be accessed twice by the CPU. This happens as a result of the way in which the pulse stretching circuitry within the microcomputer works. Basically, it occurs because the CPU clock is in fact held high until the falling edges of the 1MHz clock and the 2 MHz clock are coincident. If a 1MHz peripheral is accessed when the 1MHz clock is high then this peripheral will be given almost immediate access to the CPU. However, because of the fact that the CPU clock is held high, waiting for the coincident edge, the peripheral device will be accessed for a second time when the 1MHz clock next goes high. This characteristic will not normally be a problem unless the peripheral is reading or writing to a device in order to change the state of an interrupt flag, for instance. This could result in an interrupt going unrecognised.

3.22 NPGFD (JIM).

The NPGFD signal is very similar to the NPGFC line the only difference being that this line is active when the address bus holds a valid address in the range &FD00 to &FDFF. As with FRED this signal also suffers from glitches and must, therefore, be cleaned up using a similar clean up circuit to one of those shown in figure 3.5.

The NPGFD line is intended to be used in conjunction with the paging register in FRED (address &FCFF) to allow the machine to address up to 64k of additional memory. This memory would normally be accessed one page (256 bytes) at a time, the paging register in FRED (at address &FCFF) would contain the page number i.e. up to 256 pages each with 256 bytes. The value contained in the paging register is referred to as the "Extended Page Number" (EPN)

Acorn Computers Ltd. have adopted a convention for use of the extended pages which presently is as follows;

EPN' 5.	Allocation.
0 to &7F	Reserved for use by Acorn.
&80 to &FF	General user applications.

TABLE 3.3

On power up or hard break the contents of the paging register are set to 0.

<p41: fig 3.5B and 3.5C>

3.23 General Guidelines For Use Of The 1MHZ Bus.

Acorn Computers Ltd. have issued certain guidelines which should be adhered to when designing devices to attach to the 1MHz bus, these are summarised as follows;

i) The maximum permissible loading on any one line of the 1MHz bus is 1 low power Schottky TTL load. In practise this will mean that all lines will have to be buffered by the peripheral device. It may be possible when using an expansion box that the expansion box back-plane will provide the necessary buffering requirements. The Control Universal expansion box is to be recommended in this respect.

ii) Each of the logic lines on the 1MHz bus except NIRQ, NRST and NNMI should have the facility to be terminated by a potential divider composed of two 2k2 resistors placed between 0 volts and +5 volts. Each logic line is then connected to the junction of its potential divider. In this way, bus reflections etc. will be minimised.

Chapter 4 LINK SETTINGS AND FUNCTIONS

The BBC Microcomputer has a number of "selectable" links. There are 33 of these links on main printed circuit boards (main PCB's) up to issue 31 subsequent issues having 39 links. It may be that future issues will have more than these 39 links available. This section explains the functions of the various links within the machine.

The links are situated at various positions on the main PCB, taking the form of soldered wire, printed track or shorting jumpers. Table 4.1 at the end of this section lists each of the links and provides grid reference information as to their approximate position on the main PCB. This table also identifies the type of link together with the upgrade or expansion with which it deals. Figure 4.1, at the end of this chapter, is a shadow diagram of the main PCB which shows the positions of the various links.

In addition to the links on the main PCB there are 8 more links that can be fitted to the machine, these are situated in the bottom right hand corner of the printed circuit board on which -the keyboard is mounted. The keyboard links are shown on the photographs at the end of chapter 5. These keyboard links are not normally fitted on models A or B but some may have to be installed if the floppy disc expansion is to be fitted. For further details see chapter 5.

In order to simplify matters and minimise any ambiguities, the orientation of the various links will be described in terms of the cardinal points of the compass (see shadow diagram fig 4.1).

With the machine placed in front of you in the normal position (with the keyboard facing towards you) the rear of the machine will be referred to as NORTH and the front of the machine as SOUTH. The left and right hand sides will be referred to as WEST and EAST respectively. This is shown diagrammatically in fig 4.1 and on the photographs at the end of chapter 5.

As with all modifications that are to be made to the machine the microcomputer should be completely disconnected from the mains supply before the top cover is removed.

It must be stressed that by making modifications to the links on the main PCB you are likely to invalidate the manufacturers guarantee. If you are in any doubt you should consult your local Acorn dealer.
The top cover can be released by removing the four large fixing screws (which may be marked "FIX") using a No.2 cross-point screwdriver. The positions of these screws can be seen from the photographs at the end of chapter 5. Two are situated at the rear of the machine and the remaining two are on the underside of the machine beneath the keyboard.

Depending on the particular links that are to be modified it may be necessary to remove the keyboard in order to gain access. Links S4, 58, S10, S14, S17, S18, and S30 are those in question on boards up to issue 3. Boards from issue 4 onwards also have links S35, S36, S37 and S38 beneath the keyboard.

At this stage one must consider the particular links that are to be modified. Table 4.1 at the end of this section specifies whether a particular link is soldered wire, copper track or a jumper.

If any of the soldered wire links are to be modified then the main PCB may have to be removed from the base to allow access to the underside of the PCB.

4.1 Keyboard PCB Removal.

The keyboard assembly can be detached by removing the two nuts and bolts situated on either side of the keyboard PCB (please note that some main PCB's prior to issue 4 have two keyboard securing bolts on the left hand side of the keyboard PCB). The location of these bolts can be seen from the photographs in chapter 5. The next step in removing the keyboard assembly is to carefully unplug the interconnecting ribbon cable from the main PCB (PL13) and also the loudspeaker connector from PL15.

The keyboard can now be safely set aside to reveal the main PCB beneath.

4.2 Removing the Main PCB.

Before the main PCB can be removed the two wires from the BNC "video out" socket on the rear of the case must be disconnected. On early issue boards these two wires were soldered but some later issues use push fit connectors. It is important to note which of the two wires is the signal wire and which is the ground wire, so that they can be replaced correctly. It is suggested that the ground wire be marked by placing a piece of coloured insulating sleeving over the wire. On some late issue boards black (0V) and red (signal) wires are fitted as standard.

The next step is to remove each of the seven power supply cables from the main PCB. It is important to take care when removing these cables as a reasonable amount of force may be required. It is particularly important not to bend the flat PCB pins backwards and forwards because they can easily fracture.

All that remains now is to remove the four screws that secure the main PCB to the base with a No.2 cross-point screwdriver. The positions of these screws are shown in the photographs at the end of chapter 5. The PCB can now be removed from the base and carefully placed on a work surface which should be clean and free from static charge. The ideal working surface would be an electrically conductive sheet (perhaps aluminium foil) connected via a 1 Megohm resistor to earth. Chapter 2, gives more details on static precautions and working environment. As some of the following description involves handling of MOS devices it is strongly recommended that the reader should be familiar with the section on static hazards as detailed in that chapter.

Before describing the function of each individual link on the main PCB, the procedure for re-assembling the microcomputer will be described.

4.3 Re-Assembling the Machine.

Re assembly is essentially the reverse of the dismantling procedure with the main PCB being replaced before the keyboard PCB. There are, however, a number of points to note

i) Do not forget to replace the two wires on the BNC "video out" connector correctly i.e. the ground wire to the tab and the signal wire to the centre pin.

ii) When reconnecting the seven power supply wires back to the main PCB be sure to connect the positives and negatives correctly, the red positive wires connect to the pins marked "V_{CC}" and the black negative to the pins marked "0V". The mauve wire connects to the -5v tab.

Also make sure that the flat PCB pins fit securely into the socket and are not simply tucked down the side of the plastic cover which shrouds the receptacle. This happens surprisingly regularly the usual symptoms being that the microcomputer becomes microphonic: i.e. when the microcomputer is mechanically shocked the video display "flickers".

iii) Be sure not to over-tighten the self-tapping screws, which are used to fasten the main PCB to the case. If over tightened either the plastic case or the PCB may be damaged or distorted. Also check that when tightened the heads of the screws do not touch any of the copper tracks on the PCB. In latter issue boards this may become a problem. It is a good idea to fit nylon or fibre washers under the heads of the screws. This is done on later issue machines.

iv) Conduct a detailed visual inspection of the PCB's paying particular attention to those areas which have a high population of discrete components such as resistors and capacitors. These areas are mainly around the UM1233 video modulator in the NORTH EAST corner of the main PCB, the DIN sockets at the rear of the machine and the "Econet" circuitry, if fitted.

It is very common when working on the PCB for some of these resistors and capacitors to become bent over and consequently the wires on adjacent components may short together. Take great care to ensure that this does not happen.

It is likely that on later issue PCB's the number of discrete components will be considerably reduced.
v) It is a good idea to remove the flux residues that will be left behind after soldering. This is best accomplished by using a proprietary flux removing agent such as RS Components stock number 555-134 together with a fairly stiff bristle brush. A cut down artists paint brush is quite suitable.

Chapter 1 gives information on de-fluxing procedures.
vi) Check that the heat sink on IC6 (video ULA) is still correctly positioned.
It is likely to have been disturbed whilst the work was being carried out on the board.
vii) Visually check the entire PCB for traces of solder or fine pieces of wire etc. which may have dropped onto it whilst it was being worked on. Use a bright light and take your time.
viii) Conduct the above visual check again.

4.4 Link Functions.

Link No.	Position.	Function.
1		Printer strobe select; Only present on issue 4 boards onwards. Selects the type of printer strobe output to pin 1 of PL9 (printer port);
	SOUTH	Printer strobe output taken directly from CA2 output of IC69 (VIA) i.e. Centronics standard.
	NORTH	Printer strobe output with "current sink" capability.
2		Econet Non Maskable Interrupt (NMI) This link must not be fitted with IC91 (74LS132) in place. Note this link must fitted in order for the floppy disk interface to be able to produce a NMI;
	FITTED	Disables the Econet NMI function.
	REMOVED	Enables the Econet NMI function.
3		Econet clock base frequency selection;

Only used on issues prior to 4, consult circuit diagram and "Econet" manual.

If the microcomputer is to be used as the network clock source then the clock frequency is set using this group of 9 links together with link S6. The frequency can be set in the range 75 to 625 kHz. In practice the frequency setting will depend upon the length of the network. See chapter 3 for a more detailed explanation.
Link S3 actually sets the base clock frequency which can then be further subdivided by either 4 or 2 using link 47.

ii) All peripheral devices should have their own power supply source and should not draw power from the BBC Microcomputer (via the 1MHz bus)

iii) The timing relationship of the logic signals on the 1MHz bus may alter when fully loaded. This will happen as a result of the increased rise and fall times which occur as the lines become more capacitively and inductively loaded. The set up times for the address bus and for FRED and JIM will have a minimum value of 300 ns and a maximum value of 0. Any attached peripheral device should, therefore, be able to cope with this.

iv) The recommended method of connecting the peripheral device to the 1MHz bus is via a 600 mm length of 34 way ribbon cable terminated at each end with a 34 way IDC header socket i.e. RS part no. 467-302. The peripheral device should allow all of the signal lines to "pass through" and fed to an on-board 34 way header plug i.e. RS part no. 467-368 or 467-992. This arrangement allows additional peripheral devices to be "daisy chained".