IBM PC Troubleshooting & Repair Guide

by

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CHAPTER 1

The IBM PC Described

Chapter 1 presents a basic overview of the IBM Personal Computer (PC) as a prelude to learning how to troubleshoot and repair this machine. The intent of this chapter is to familiarize novices with the computer and to provide a helpful review for more experienced users.

The introduction of the IBM PC on August 12, 1981 signified a major change in the corporate policy of the giant IBM company. And their entry into the small computer marketplace has had an impact on every microcomputer manufacturer in the world. When IBM introduced the PC, the Fortune 500 companies became aware of the professional capabilities of personal computers. Although microcomputers had been successfully meeting the needs of small businesses for several years, it was not until "Big Blue" (IBM) began actively marketing microcomputers that the personal computer leaped out of the hobby arena and became an accepted fact in modern business.

With the introduction of the PC, IBM adopted some major policy changes. Previously, the corporation had manufactured all the products it sold. IBM had had no interest in third-party components, modules, or equipment. However, early in the design phase of the PC, IBM recognized that third-party hardware would be vital in bringing the PC to market in the highly competitive microcomputer industry. A key ingredient to the success of the PC would be its ability to adapt to established industry standards and its compatibility with products already on the market.

The operating system software for the PC was developed outside IBM. Tim Patterson of Microsoft and Seattle Computer Company wrote PC-DOS between the spring of 1980 and the summer of 1981. He was also the originator of the 86-DOS that became Microsoft's MS-DOS. Other operating systems currently used on the IBM PC include CP/M-86 from Digital Research and UCSD p-System from Softech Microsystems.

IBM's list of high-level language and applications software sources includes Digital Research, Microsoft, Peachtree Software, Personal Software, Softech Microsystems, and Information Unlimited Software. The decision to use established outside software suppliers was a major break in IBM tradition.

The disk drives used in the PC were built by companies such as Tandon Magnetics. The dot-matrix printer sporting that IBM logo was manufactured by Epson. Even the display monitors were manufactured by other companies.

To get the PC quickly into the hands of a vast market of users, IBM opened up its technical knowledge base. It provided full technical specifications, including the source code for the operating system, to encourage peripheral hardware and software developments by entrepreneurial computer enthusiasts all over the United States. Just as Apple had, IBM found this strategy very successful. In less than two years, over 600 outside vendors were marketing more than 2,000 different products for the IBM PC.

The PC's modular construction with five expansion slots for add-on peripherals provides flexibility. The IBM PC XT has eight built-in expansion slots. IBM PC users can choose from a wide selection of enhancements, including color and monochrome (single-color) displays, additional floppy disk drives, hard disks, communications adapters for modem (modulator-demodulator) use, game and joystick adapters, expanded memory boards, plotters, and a wide range of printers.

THE STRUCTURE OF THE PC SYSTEM

A typical PC system includes the system unit that houses the main electronics of the computer, two disk drives, the full-size keyboard, a video display device, and a printer. Fig. 1-1 shows this system (without the printer).

The System Unit

The system unit is 5.5 inches high, 19.6 inches wide, and 16.1 inches deep. It weighs 28 pounds with two disk drives. Two standard-height, double-density disk drives are mounted in the system unit, providing 320 kilobytes (K) of mass-storage disk capacity for programs and data. Earlier models of the PC came with 160K single-density drives.

Fig. 1-1. The IBM Personal Computer (PC).

Inside the system unit are the primary components that make the PC function—the switching power supply, the main logic board (called the system board, or motherboard) with its memory chips, and five input/output expansion slots.

The Keyboard

The 20-by-8-by-2.5-inch detachable typewriter keyboard shown in Fig. 1-2 has 83 keys that can generate all 128 characters in ASCII (the American Standard Code for Information Interchange), as well as special symbols and graphic shapes. The keyboard can provide a total of 256 characters, shapes, and symbols.

Fig. 1-2. The IBM PC detachable keyboard.

On the right side of the keyboard is a numeric keypad; some of its keys double as cursor-control keys. On the left side of the board are 10 programmable function keys that can be used to execute selected programs or to initiate special routines (subprograms). The functions of these keys can be programmed by the software designer. In IBM BASIC the function keys allow commands such as LIST and RUN to be entered with a single keystroke.

In addition to Shift and Up, Down, Right, and Left arrow keys, the keyboard has a number of special keys such as Caps Lock, Number Lock, Scroll Lock, Backspace, Enter, Home, Page Down, Page Up, End, Delete, Insert, Print Screen, Tab, Control, and Alternate. The function of each key is described in the *IBM Guide to Operations* manual. Several of these keys can be used together to perform special functions. For example, holding down the Ctrl and Alt keys and then pressing the Del key will cause a system reset, or warm boot, to occur. Other combinations of key actions stop the program that is being executed in the machine, move the cursor to the next or previous word, or clear the screen.

Holding any key down for more than a half second causes its character to repeat automatically. All 83 keys have this automatic repeat feature. In addition, a storage space is built into the keyboard to let you type ahead. It will remember up to 10 characters, letting you type at rapid speed without getting ahead of the computer.

The IBM PC keyboard was structured after a profile developed in 1980 by West Germany's Deutsche Industrie Normenausschuss (DIN). The DIN specification sets keyboard height (profile) for angles between 0 and 10 degrees from horizontal and also determines how far the keys can be depressed (key travel distance). It requires the use of sculptured keytops and tactile key action. The placement of the backslash key between the left Shift and Z keys is also a result of the DIN specification. This layout has become quite natural to Europeans, and most users become accustomed to it after just a few hours of typing operation.

The keys are "dished" slightly (they have concave top surfaces). This sculpted shape gives each key a comfortable feel. The keys also provide a tactile feedback, or snap-over sensation, when depressed to the operating point. An audible contact click also provides positive feedback that key action has been completed.

Unlike many other microcomputer keyboards, the IBM PC keyboard contains electronic circuits that enhance key operation and permit keys to be redefined. This redefinition potential provides increased programming flexibility.

Two plastic feet built into the keyboard housing allow it to be tilted in two positions for comfortable use. A horizontal plastic ridge located just above the top row of keys can be used to prop up a book or report between the keyboard and the display screen. It also was designed to hold templates for special applications software across the top of the keyboard. The keyboard connects to the rear of the system unit by means of a 6-foot coiled cable.

On the right side of the system unit, toward the back, is the ON/OFF power switch.

Display Unit and Printer

Two other units make the computer a complete system—a display unit and a printer. Both of these devices are considered options by IBM. IBM sells both a monochrome monitor and a color monitor. In addition, when an interface called a radio frequency (RF) modulator is connected to the video adapter card inserted into one of the input/output slots, a standard television can be connected to the computer. Monitors connect through the rear of the system unit to the appropriate adapter cards. Although this guide doesn't cover internal repair of monitors, it does address a number of display problems that are easy to correct.

A number of printers can interface with the IBM PC. IBM sells a dot-matrix printer manufactured by Epson as an IBM-recommended option.

Connections

Fig. 1-3 shows the connections at the back of your IBM PC computer. From left to right, notice the female connector to provide power to the IBM monochrome display; the male connector to which you connect the power cord that plugs into a wall socket or power strip; a round, slotted opening for the fan air exhaust; a 5-pin circular connector for the keyboard cable; a 5-pin circular connector for the cassette input/output port; and five slots for connecting displays, disk drives, printers, plotters, and other peripherals to the system unit.

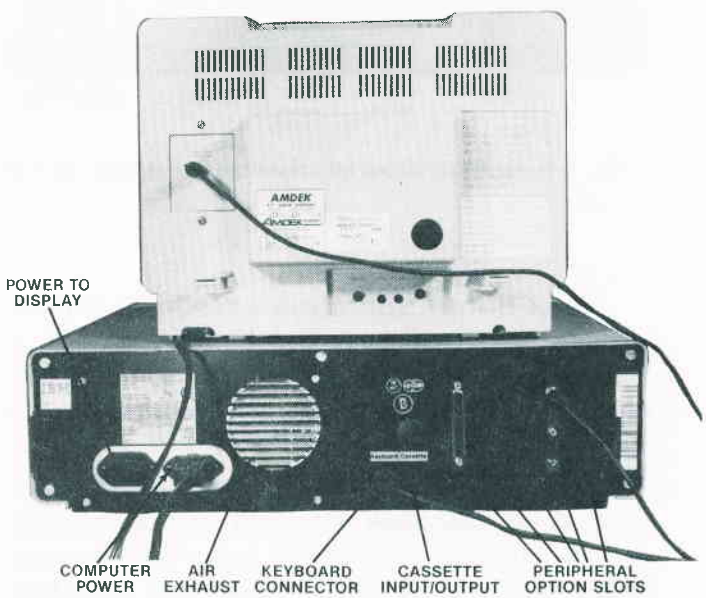


Fig. 1-3. The connections found on the back of the PC system unit.

INSIDE THE SYSTEM UNIT

Facing the rear of the IBM PC's system unit, you'll see either three or five screws holding the cover housing on the system unit electronics chassis. Make sure the power to your IBM PC is turned off. Then use a nutdriver or a flat-head screwdriver to remove the five screws (three on earlier machines) from the back of the computer (see the Appendix). Turn the unit around so the disk drive doors face you, and carefully slide the housing forward, tilting it as it is removed. Look inside and compare what you see with the components identified in Fig. 1-4.

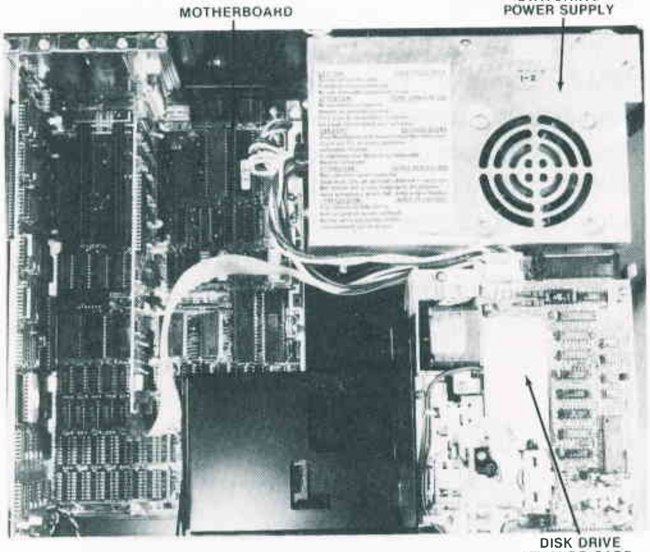


Fig. 1-4. Looking down into the system unit from the top.

Notice that the system unit is composed of three subunits—a printed-circuit board on the left side, a power supply in a metal shield at the right rear, and one or two disk drives in their metal housings.

The Motherboard

That big, flat, black thing with the copper traces and all those tiny components is the printed-circuit board, *main system board*, or *motherboard*, of the IBM PC. Mounted on this board are tiny, black integrated circuits (ICs, or *chips*) that make up the most important part of the machine—the 8088 *central processing unit* (CPU), *microprocessor*, or simply *processor*, with its input/output (I/O) unit, memory, and a host of other chips that help the CPU move information around, into, and out of the motherboard.

The IBM PC has 99 chips on its motherboard. Half again as many chips can be found on the adapter boards required to provide display and disk drive capability.

Expansion Slots

Looking toward the rear of the chassis, you'll see five 62-pin *connector slots*. These slots are used to connect peripheral devices to the motherboard. Each slot provides access to the most important signals in the computer. The PC was designed with an open architecture. It's sold unbundled (in parts), so the user must buy each unit separately and then connect these units to form a completed system. Nothing but the system unit and keyboard is included in the basic PC configuration. Everything else must be added on, including the display, the disk drives, and the printer. Each peripheral connects to the computer by means of an *adapter card*. The PC's design provides for integration flexibility, but the expansion slots fill up quickly. The slots are numbered J1 (slot 1) to J5 (slot 5) from left to right.

Any slot can be used for any type of adapter card, but IBM has recommended that slot 2 be used for the display adapter, because it is the longest card that can fit into a slot, and slot 2 (on early PCs) has a special plastic guide to prevent the long card from wobbling in the socket. A typical configuration with a monochrome display unit is connected as shown in Table 1-1.

Table 1-1. Typical slot configuration

Slot	Interface Installed
1	Disk controller interface board
2	Monochrome adapter and parallel printer port
3	Asynchronous/synchronous communications card

The expansion slots can be used to connect many other devices, including modems, which allow you to send and receive information through your phone lines; voice-recognition and voice-generation boards; elaborate displays; and even additional printers. It is possible to connect both a dot-matrix and a daisy-wheel printer to the IBM PC concurrently.

Since the IBM PC can address up to 1 megabyte of memory, additional memory cards can be installed in the expansion slots to increase the available memory to over 600K.

Up to four disk drives (two internal and two external) can be connected to the IBM PC using a disk controller card interface. With third-party hardware, the PC's disk drive capability can be expanded to six double-sided, double-density drives.

You'll find eight sizes of chips on your IBM PC motherboard—8-pin, 14-pin, 16-pin, 18-pin, 20-pin, 24-pin, 28-pin, and 40-pin.

Chips

That big, long chip sitting just below the cassette I/O port is the brain of your IBM PC—the Intel 8088 processor, or central processing unit. Everything that happens inside your computer is controlled by this chip. The 8088 moves data and instructions on an 8-bit data bus. It operates as a 16-bit machine internally, using the same 16-bit instruction set as the Intel 8086 microprocessor.

Next to the 8088 processor is an empty slot for connecting an 8087 numeric data processor chip. The 8087 is a high-speed, two-channel I/O controller and coprocessor that extends the 8088 instruction set to include arithmetic and logical operations. The 8087 doesn't change the way the system operates, yet it can perform some mathematical functions many times faster than the 8088 CPU. With the addition of an 8087, the PC becomes an impressive engineering and scientific tool.

There are some other special chips on your IBM's main board. Just to the left of the 8088 CPU is the 8259 *interrupt controller*. The IBM PC is called an "interrupt-driven machine," because all I/O devices, including the keyboard, the display, and the printer, communicate with the CPU by causing an interrupt signal to occur. This interrupt signal makes the CPU stop, look, and listen to whatever is trying to send or get information. The 8259 is the device that hears the request to communicate from the peripherals and generates the interrupt signal that is sent to the CPU.

At the far right on the second row of chips is the 8284 *clock generator*. This socketed chip connects directly to the 14.31818 MHz crystal and develops the various clock signals used within the computer. When power is first turned on, this chip receives a special signal from the power supply indicating that power levels are normal. The 8284 uses this signal to develop a RESET pulse to start the CPU operating.

ROM

On the fourth row of chips, and below the expansion slots, is an empty socket and then a row of five large chips. These five devices make up the *read-only memory* (ROM) of the computer. The five ROM chips have special programs permanently stored in them. This software that is stored in hardware is called *firmware*. ROM can only be read from. You can't store any of your programs in a ROM chip. Its purpose is to hold programs placed there by the manufacturer. These programs are available as soon as you turn power on.

One ROM chip holds the ROM *basic input/output system* (BIOS), a set of programs that control information transfer between the CPU and the input/output devices. The BIOS provides control for all devices except the disk drives. Included in this ROM is a self-test program that checks out the PC when power is first turned on.

The other four ROM chips hold the version of the high-level language BASIC that IBM calls *Cassette BASIC*. Cassette BASIC is a large program, but it was included in the PC design because BASIC is a popular language for writing your own programs.

The empty socket was originally planned to hold another ROM BASIC chip. But in the final design, Cassette BASIC fit into four chips.

To the right of the last ROM chip is the 8253 *programmable interval timer* (PIT). This device develops a special time-interrupt signal. It also develops a pulse to operate the speaker.

Next to the 8253 PIT is the 8237 *direct memory access* (DMA) *controller*. This chip controls the movement of large blocks of information into and out of the computer. It is used primarily to move data between the mass storage memory (disk drives) and the internal memory.

To the right of the 8237 DMA controller is the 8255 *programmable peripheral interface* (PPI) chip. This device has several ports through which external devices can communicate with the CPU. The ports can be configured by sending software commands to the programmable chip.

RAM

Sitting in four neat rows of nine chips each at the lower right of the system board is the IBM PC's *random-access memory* (RAM). This is the scratch pad or blackboard of your PC's memory. These chips can be read from or written to. Each of these chips is a 16K-by-1-bit or 64K-by-1-bit RAM, depending on the type of motherboard installed (16K to 64K in four rows, or 64K to 256K in four rows). Eight of these chips make up the 8-bit data word memory. The ninth chip in the row is used to confirm the accuracy of the data stored in the other eight. The eight data word chips temporarily store programs that you write or load from your disks. Remember to save your work before you turn your IBM PC off, because once power is turned off, any information in RAM is lost.

On the version of the system board that uses 16K-by-1-bit chips, all four rows of RAM sockets can be filled, bringing the total of on-board RAM to 64K. The newer version of the system board uses 64K-by-1-bit chips. This board is fully populated, to achieve a total of 256K of on-board RAM.

Additional RAM can be added by inserting memory cards into the expansion sockets. With system board and expansion sockets, the PC has a RAM capacity of 640K.

The Power Supply

Inside the chassis, to the right of the system board, is a *switching power supply*, housed in a big, shiny metal box. This subunit faithfully takes in electrical power from the cord you plug into the wall socket and converts it to the voltages necessary to make your computer system function properly. The switching power supply is very reliable. This guide doesn't discuss repairing the power supply, because extensive training is required to conduct repairs in high-voltage circuits. The electrical cord plugs into the back of this power supply just to the left of the ON/OFF rocker switch. A special jack at the rear of the power supply accepts the power plug for the IBM display unit.

VIDEO AND SOUND

The video of the IBM PC also has certain advantages over those of other microcomputer systems on the market. Two display adapters are available; a monochrome display adapter that supports text, and a color/graphics adapter that supports color graphics or text.

Using the *monochrome adapter*, the machine can generate 25 rows of 80 characters each. Characters can be displayed in white on a black background (green on black with the IBM monochrome monitor), black on a white background (or black on green), blinking, in high intensity, or underlined. The monochrome adapter card includes an interface connection for the IBM 80-character-per-second dot-matrix printer.

The *color/graphics adapter* card provides the capability to display two types of text and three types of graphics. This adapter also supports a light pen.

The color/graphics card's first text format displays 25 rows of 40 characters each. This format is suitable for standard monitors and televisions. But you'll need another type of adapter (RF modulator) connected to the video output of the color/graphics adapter in order to use your television set.

The second text format provides 25 rows of 80 characters each. The characters can be displayed on an RGB (red-green-blue) monitor for sharp, high-quality presentation.

Three types of color graphics are possible: only two are supported by the ROM.

Low-resolution graphics lets you display 100 rows of 160 pixels (picture elements), or dots, in any of the 16 standard colors described in Table 1-2.

Table 1-2. Colors available in low-resolution graphics mode

Black	Blue	Green	Cyan
Red	Magenta	Brown	Light Gray
Dark Gray	Light Blue	Light Green	Light Cyan
Light Red	Light Magenta	Yellow	White

Low-resolution graphics mode can be used only with special programs that directly address the 6845 CRT controller device on the adapter card.

Medium-resolution graphics mode allows display of 200 rows of 320 pixels, in any of four possible colors. Additional colors can be generated by juxtaposing dots of different colors.

In *high-resolution graphics* the display, 200 rows of 640 pixels, is limited to black and white. Text can be placed within the graphics.

Inside the chassis at the left side of the system board is a small (2-inch) 8-ohm speaker that can produce all sorts of sounds, including the familiar beep, arcade sounds, music, and even crude speech.

MASS STORAGE

At the back of the computer is a connection for a cassette interface. When the first microcomputer was built, disk drives were very expensive, so the first microcomputer users were given the option of using standard audio cassette recorders as mass storage devices.

Cassette Storage

Using cassette tapes is an inexpensive way to provide mass storage for your programs, but saving or loading these programs with a cassette tape recorder is slow and frustrating because of the rewinding and the close attention to the tape counter required to locate the beginnings and endings of files. Most IBM PC users who start out with these recorders soon shift to a floppy disk drive storage device for its speed, reliability, and simplicity of operation, and because many more programs are available on disk than on tape.

One reason you might want to consider using cassettes as a mass storage medium is for archive, or backup, storage. Many more files or pages of information can be stored on a good audio cassette tape than can be stored on a floppy disk. In fact, one type of archive storage for hard disks is a cassette video tape. Corvus, a hard disk manufacturer, uses a system called the Mirror to back up hard disk files on video tape.

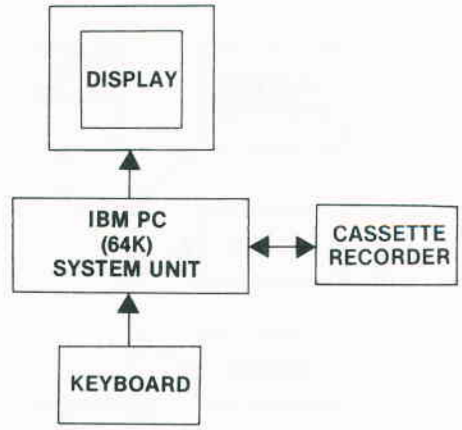


Fig. 1-5. The basic IBM PC system.

Disk Drives

Disk drives connect to the PC via a special adapter card (usually plugged into expansion slot 5 at J5). Your disk drive lets you store and retrieve information on flexible magnetic disks called minidiskettes, or floppy disks. Disk drives are an important part of your IBM PC system. Chapter 4, "IBM PC–Specific Troubleshooting and Repair," and Chapter 5, "Routine Preventive Maintenance," contain extensive information on disk drives.

SYSTEM CONFIGURATION

A "basic" IBM PC system is shown in Fig. 1-5. With the built-in speaker, this is a minimal system configuration for the IBM PC. Without the display, keyboard, or cassette recorder/player, your computer would be so limited that it couldn't really be called a system.

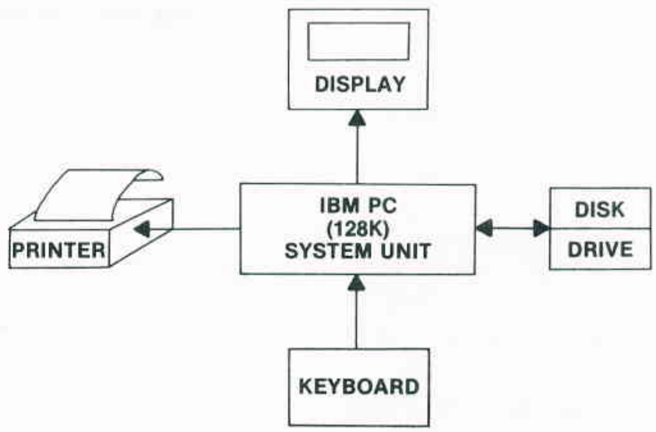


Fig. 1-6. The standard IBM PC configuration.

In Fig. 1-6, you see the "standard" IBM PC configuration. The cassette recorder/player has been replaced with a floppy disk drive, and a printer has been added to provide hard copy, or printed output. The memory has been expanded to 128K, the standard memory size for current software packages.

Small business users generally configure a system as shown in Fig. 1-7. Connecting an optional memory expansion card brings the total RAM to 640K. The addition of a CP/M card allows you to use programs written for the popular CP/M operating system. The two disk drives let you use larger software programs that actually need more than one disk drive to run.

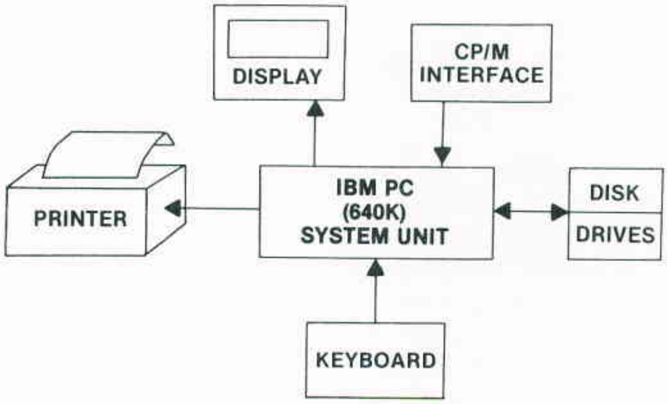


Fig. 1-7. The typical small business IBM PC system.

The IBM PC's flexibility is illustrated in Fig. 1-8. You can connect almost any electrically controlled equipment to your computer.

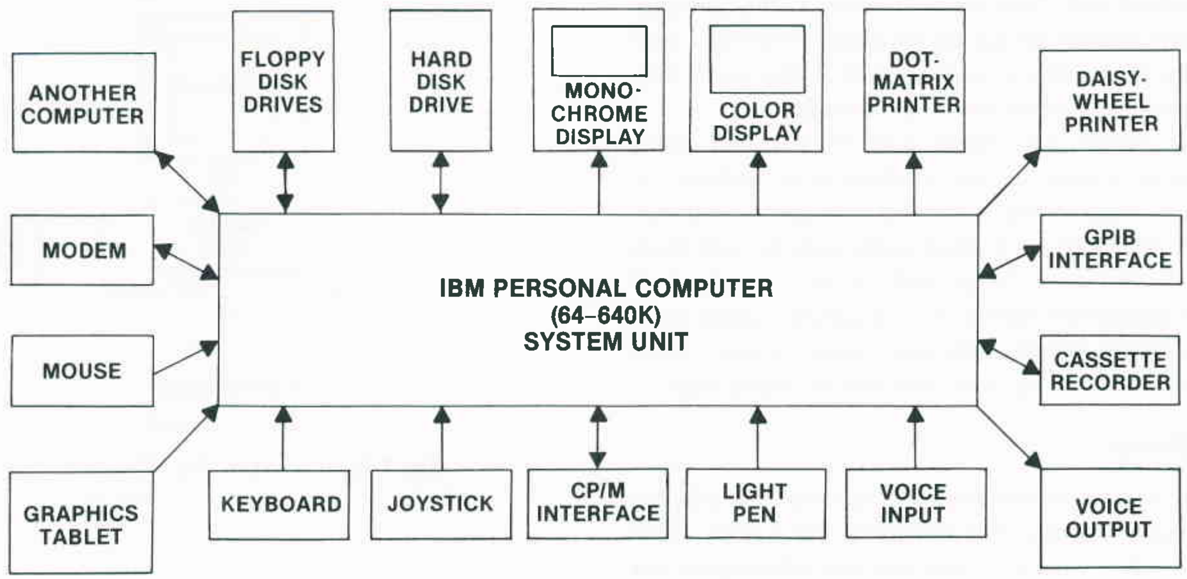


Fig. 1-8. The flexibility of the IBM PC.

CHAPTER 2

IBM PC Operations

In Chapter 1, you read a descriptive overview of the IBM PC. This chapter explores how the IBM PC works. Some of the material in this chapter is quite technical. You won't need to know the technical details of how PC components work in order to troubleshoot and repair your system. However, this information is included for those readers with a more technical interest.

THE BASIC PARTS OF THE IBM PC

Whether it's a tiny single-chip micro, an IBM PC, or a room-size mainframe, every computer has five basic parts:

- An arithmetic logic unit
- A memory unit
- An input unit
- An output unit
- A control unit

These parts are associated as shown in Fig. 2-1.

Math and number crunching occur in the **arithmetic logic unit** (ALU). All the adding, subtracting, multiplying, dividing, comparing, and other manipulations are done by the ALU.

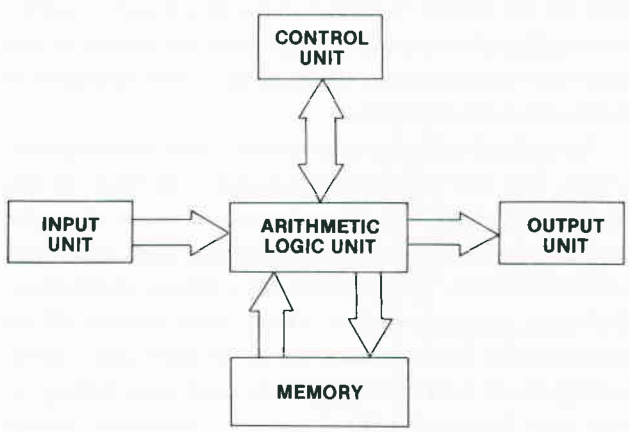


Fig. 2-1. The five basic parts of the IBM PC.

The **memory unit** is used to store programs, calculations, and results. As shown in Fig. 2-2, this unit includes two types of memory—*RAM* (random-access memory), which can be read from and written to, and *ROM* (read-only memory), which can be read from but not written to. RAM is sometimes called *main memory*.

When you turn off power to your IBM PC, whatever you had stored in RAM is lost unless you have first saved it on a disk. The program in ROM is placed there by IBM during manufacturing, and it remains even

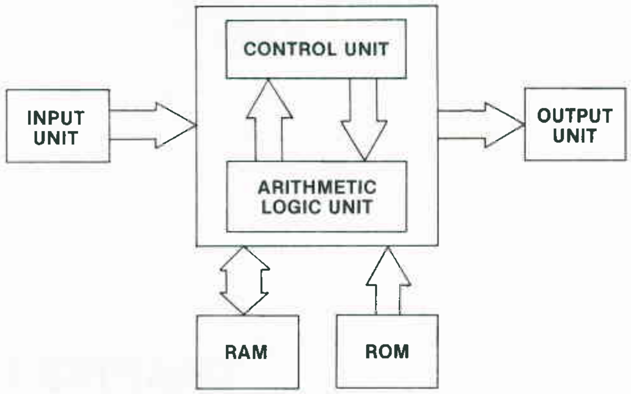


Fig. 2-2. The memory is composed of RAM and ROM.

when the power is off. Since the ROM program (software) is in a device (hardware), we call it *firmware*.

The **input unit** lets you enter information into the computer. It is a way for you to "talk" to your PC. This communication is called the "man-to-machine" interface. You can communicate with your computer through your keyboard, a light pen that reacts as you touch a place on the screen, a special pen and a graphics tablet, a mouse that moves your cursor about the screen as you move the mouse on your desktop, or a voice-recognition board and a microphone.

An **output unit** gets information from the computer to you. We call this machine-to-man interface. It lets the IBM PC "talk" to you. A monochrome or color monitor screen is the most commonly used machine-to-man interface. You can also use a printer to produce hard copy, or paper output. Other ways for your PC to communicate include turning on motors and lights, making music and arcade sounds, and even talking in your own language with a speech synthesizer board and a speaker.

Some computer devices are for both input and output. One input/output (I/O) device includes a form of memory external to the computer—*mass storage*. You save your programs to mass storage and retrieve them as needed. Mass storage includes floppy disks, cassette tapes, hard disks, and the recently developed optical disks. Another I/O device is the modem (modulator-demodulator), which you use to send or receive information through your telephone line. Modems can connect your computer to any other computer in the country (if not the world) using either dedicated telephone lines or the standard four-wire telephone lines of your home or office.

Input/output devices are called peripherals. Some can be built into your computer—for instance, your speaker. Others are connected to your IBM PC through printed-circuit cards called interfaces, or adapters, that plug into slots, those long sockets on your PC system board, or motherboard. A large number and variety of interface cards are available for the PC. Some cards provide interface to the devices needed to make your system function—the display monitor, the disk drives, and the printer. Only five expansion slots are available in the PC. This limits the configuration that can be developed. The number of expansion slots can be increased by adding an expansion chassis to the computer. This will use only one slot in the main system unit, but will add eight slots of expansion capability.

Everything your PC does is directed by the **control unit**. This unit interprets computer instructions and initiates the signals that cause the computer's circuits to do certain tasks.

The control unit and the arithmetic logic unit are combined into a single chip called the *central processing unit*, or CPU. As shown in Fig. 2-3, the CPU on your IBM PC motherboard is an 8088 microprocessor. This microprocessor uses the same instruction set as the Intel 8086, and handles instructions in 16-bit sets, although the data output word is 8 bits wide. The 8088 is therefore, a 16-bit instruction, 8-bit data microprocessor. Its address word width distinguishes it from other 8- or 16-bit microprocessors. The 8088 uses 20-bit address words to access memory. This means that it can directly address over 1 million memory locations (1,048,576 to be exact).

Your PC's 8088 CPU looks into memory, fetches an instruction from that location, interprets the instruction, performs the actions the instruction requires (e.g., adding two numbers), and then moves on to process the next instruction. Unless the next instruction directs

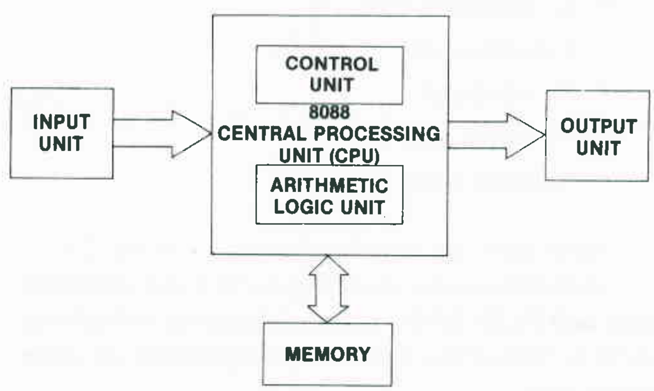


Fig. 2-3. The control unit and arithmetic unit together form the central processing unit (CPU).

the 8088 to a particular memory location to carry out the instruction stored there, the CPU will move from one instruction to the next instruction in sequential memory locations (one step after the other). Perhaps the most important difference between your stepping through a program (sequence of instructions) and your PC's doing the stepping is that the IBM can handle about a million of these steps each second.

CHIP LOCATION SCHEME

When IBM designed the new PC motherboard, they took a number of steps to make the board easy to install and easy to troubleshoot. The motherboard was divided into five functional areas—the processor subsystem and its supporting chips, the ROM subsystem, the RAM subsystem, the integrated I/O adapters, and the I/O channel, which includes the expansion slots. As shown in Fig. 2-4, IBM PC designers laid out the board with most of the chips mounted vertically with pin 1 of each chip at the top left corner. They also marked each component's identification code on the printed-circuit board (system board) and numbered the chip locations in increasing order from left to right, top to bottom. This allows you to quickly locate any IC or chip on the board. Fig. 2-4 shows the original (16K–64K) PC system board. In Chapter 3 (Fig. 3-2) you'll find a photograph of the newer (64K–256K) PC system board.

In the pages that follow, all system board chips being discussed will be identified by the chip type (e.g., 74LS125), name (e.g., quad tri-state buffer) and board designation or chip location (e.g., U80). The chip types and location numbers are shown in Fig. 2-5. In addition, a list of all chips used in your IBM PC can be found in the Appendix.

CENTRAL PROCESSING UNIT

Look at the motherboard. Reopen the machine if necessary (see the Appendix for disassembly instructions).

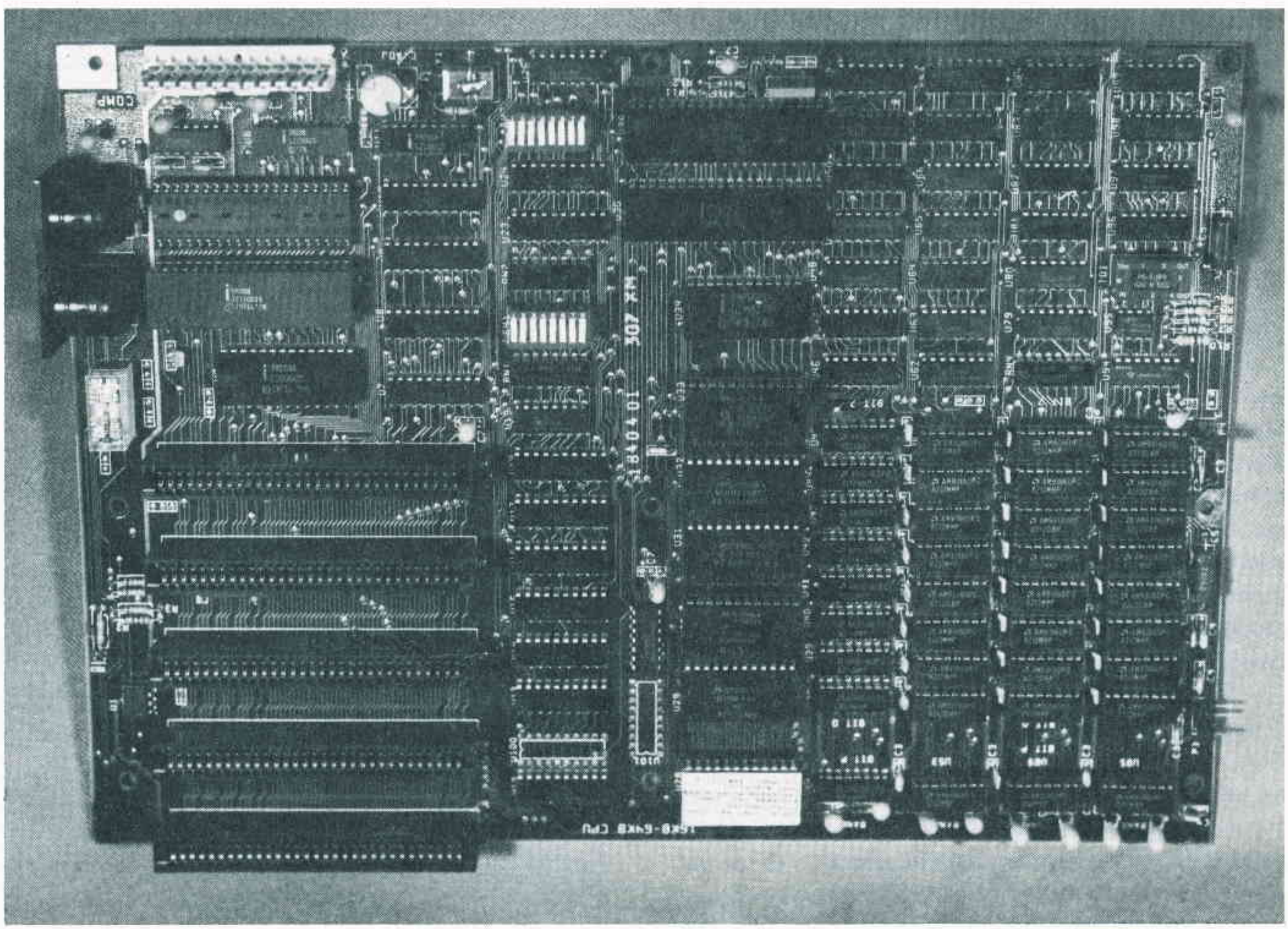


Fig. 2-4. The IBM PC system board (motherboard).

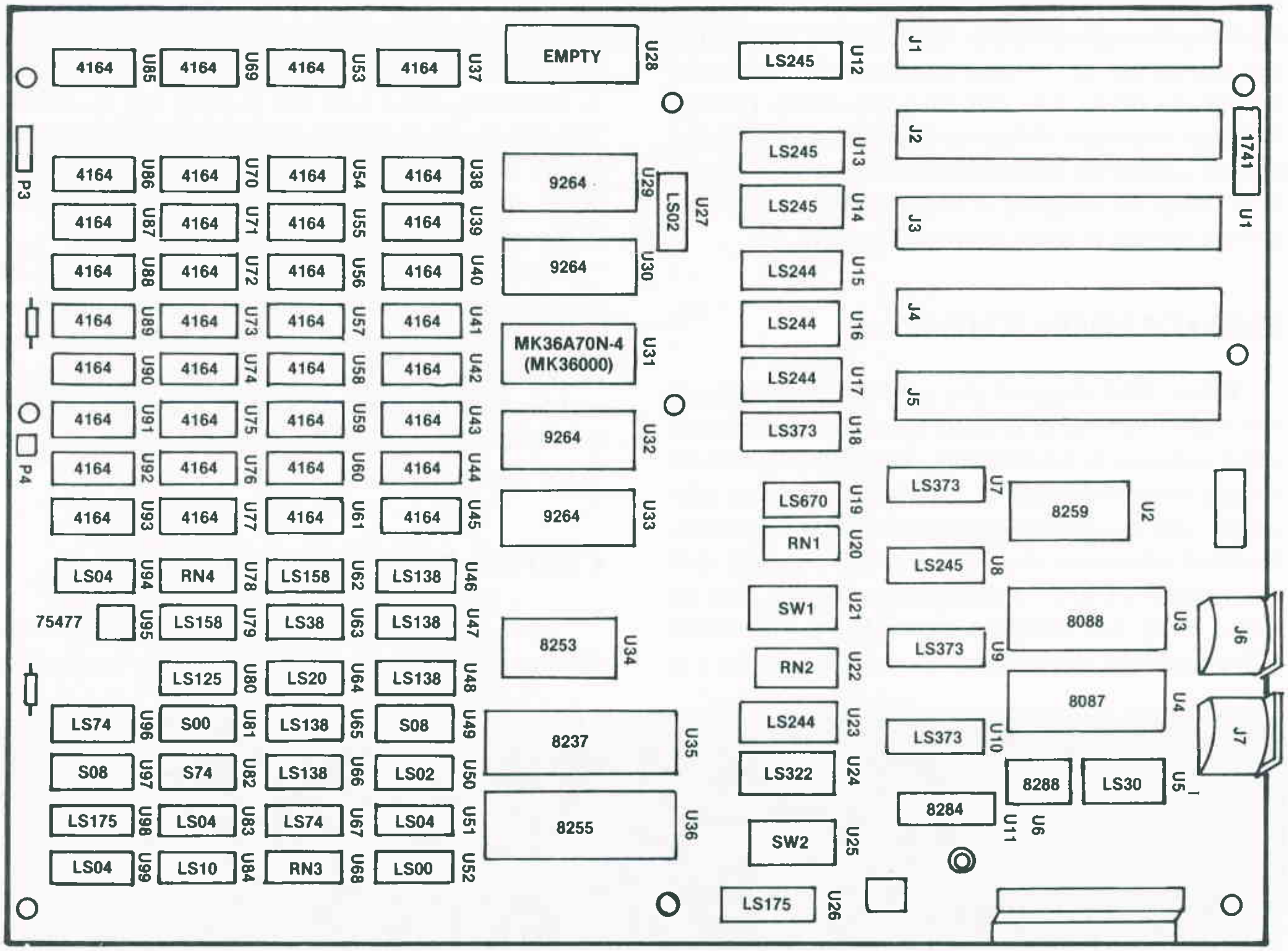


Fig. 2-5. The system board chip layout.

As indicated earlier, the 8088 CPU (shown in Fig. 2-6) is an 8-bit version of Intel's 16-bit 8086 processor. The size is determined by the number of bits in the data word. The 8088 uses the same instruction set as the 8086, so it supports 16-bit operations, including multiply and divide. With 20 address lines (20 bits in the address word), the 8088 can address over a million memory locations. It can also operate in maximum mode with a coprocessor, the 8087 numeric data processor, which greatly increases computational speed.

The 8088 operates at a 4.77 MHz. Since, internally, it handles words up to 16 bits long only, the CPU expands its internal address word to 20 bits at its output by using a segmentation scheme. Memory addresses are logically subdivided into special segments of 64K bytes each. These segments can be allocated to special segment registers within the 8088. Bytes within a segment are addressed using a 16-bit offset address. The 20-bit physical address is constructed inside the 8088

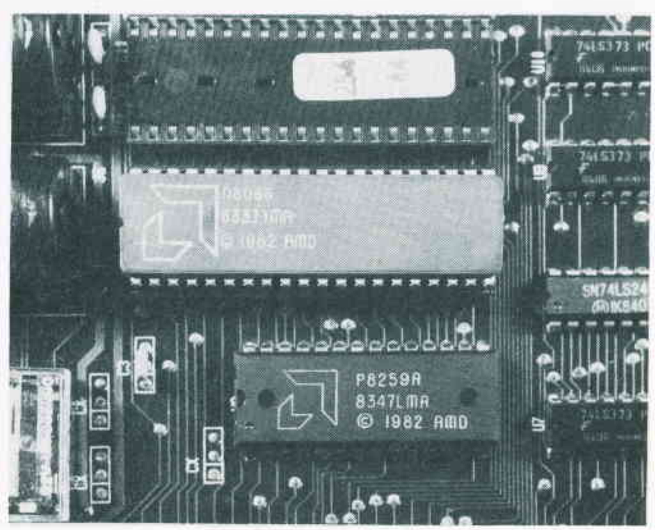


Fig. 2-6. The 8088 CPU.

by adding the 16-bit offset address to the 16-bit segment address with the segment address shifted left by one hexadecimal value as shown in Fig. 2-7. Once the offset and segment addresses are summed, the physical address is available on the 20 address pins of the chip.

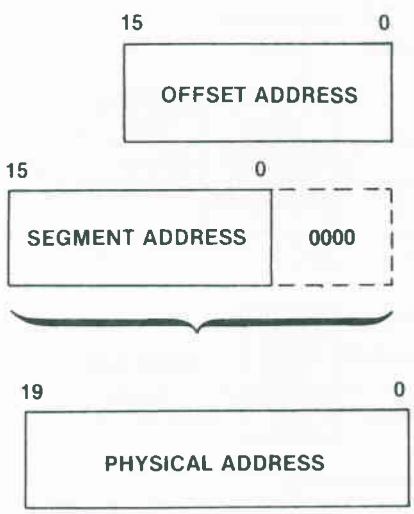


Fig. 2-7. The 20-bit address word consists of a segment address and an offset address, combined to form a physical address.

Some programs can be loaded or manipulated within a single segment and do not use the segment registers. These programs are said to be *dynamically relocatable*. The high-level language BASIC can address up to 64K only. Therefore, most programs written in BASIC are dynamically relocatable.

The 8088 uses 20 address lines to specify a location in its 1,048,576-byte (1 megabyte) range. These signal lines are designated AD0–AD7 and A8–A19. The first eight lines (AD0–AD7) are dual purpose. They are used for both address and data transfer. As shown in Fig. 2-8, the address latch enable (ALE) signal from the 8288 bus controller (U6) to the three 74LS373 address latches (U7, U9, and U10) controls the multiplexing of address information out of the CPU. When the information on AD0–AD7 is part of an address, the 8088 generates a special code on the S0–S2 lines to U6, causing the 8088 to let the ALE latch the 8 address bits into U7. After the address is latched, lines AD0–AD7 are available for two-way data transfer. Data transfer is controlled by the data enable (DEN) signal from U6. The data transmit/receive (DT/R) signal from U6 is used to let the 74LS245 data line buffer (U8) write (transmit) or read (receive) on the data bus.

CPU signals S0–S2 are also used to tell the bus controller (U6) what devices the CPU wants to communicate with. The bus controller then generates the appropriate memory read (MEMR/), memory write (MEMW/), I/O read (IOR/), or I/O write (IOW/) signals. For I/O read and write functions, only address lines AD0–AD7 and A8–A15 are used. Therefore, with 16 address lines, a total of 65,536 (64K) addresses are available for I/O.

Special System Support Chips

The 8088 CPU on the system board is configured with special support chips as shown in Fig. 2-8. These chips work hand in hand with the 8088 CPU to make the computer function as a complete unit. These chips include the 8284 clock generator (U11), the 8259 programmable interrupt controller (U2), an 8255 programmable peripheral interface (U36) (not shown), and the 8253 programmable interval timer (U34) (Fig. 2-9). Each of these chips will be addressed in the next several paragraphs.

The 8284 Clock Generator

Information processing is possible in those tiny chips on the system board because the clock generator (U11) continuously sends out several clock signals that pulse throughout your IBM PC. As shown in Fig. 2-9, a crystal oscillator (Y1) connects to the 8284 clock generator. When the power is turned on, or when you press the Ctrl-Alt-Del key combination, the POWER GOOD signal reaches U11 from the power supply and a RESET signal is produced. This signal initializes storage registers within the 8088 and causes it to start operation at address 0FFFFH (H means hexadecimal). This address is in ROM. The clock generator (U11) also produces a READY signal to let the CPU know that the rest of the circuitry is clear to receive or send information. If the memory or an I/O device cannot keep up with the CPU, the READY line goes to a logic LOW, causing the 8088 to stop processing until the rest of the system is ready to proceed. The 8284 clock generator then brings the READY line to a logic HIGH again.

When the power is turned on, the oscillator starts pulsing at a 14.31818 MHz rate. This master oscillator signal is used to develop all other clock signals on the motherboard, as shown in Fig. 2-9.

The clock pulses are divided by 3 in the 8284 clock generator (U11) to produce a 4.772727 MHz system clock timing signal, CLK88. CLK88 is buffered through a 74LS244 tri-state octal buffer (U15) (not shown) to become the CLK signal applied to the expansion slots. The 8284 clock generator also produces a 2.386363

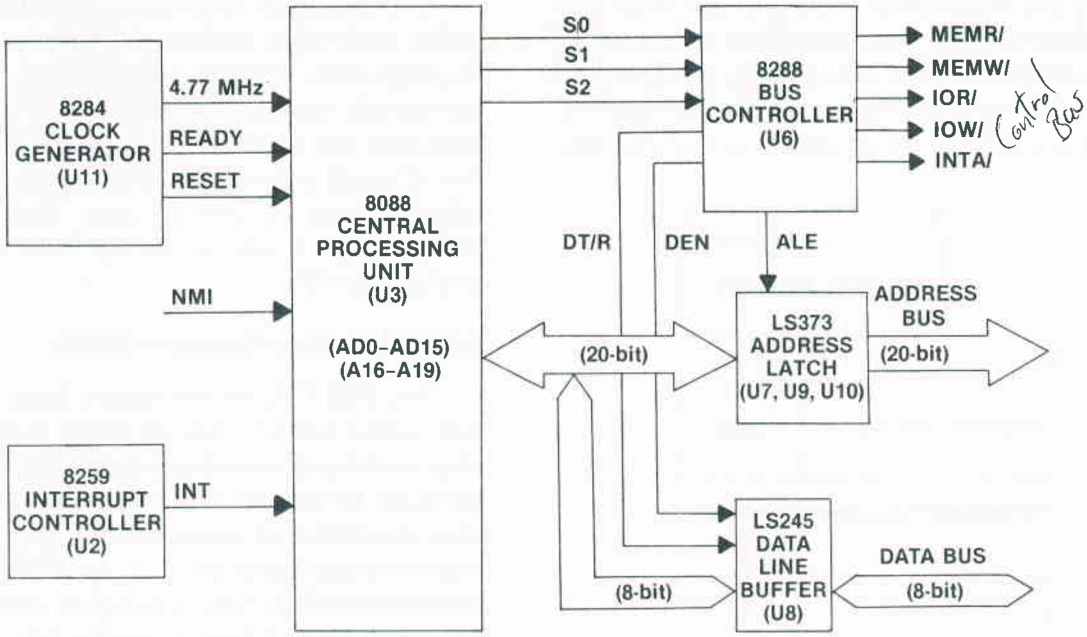


Fig. 2-8. The 8088 CPU and its support circuitry.

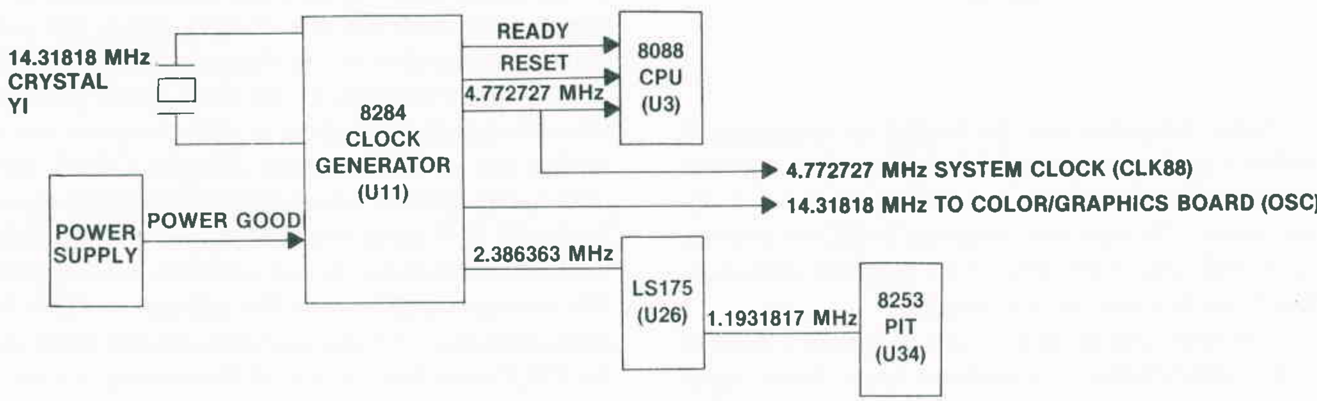


Fig. 2-9. The IBM PC clock circuitry.

MHz intermediate clock frequency, which is divided by 2 in the 74LS175 quad-D flip-flop (U26) to provide a 1.1931817 MHz clock signal to the 8253 programmable interrupt timer (U34).

The basic clock signal, OSC, is provided to the color graphics board where OSC is used to develop the synchronization and horizontal scan signals. The system clock signal is also available on the I/O connectors (expansion slots).

Should your machine behave erratically, a sick clock may be your problem. (Another could be the 8088 CPU itself.) We'll learn more about this in Chapter 4.

The 8259 Programmable Interrupt Controller

The IBM PC is an interrupt-driven machine. This means that all the input and output functions are controlled by or control other devices by means of interrupt signals. Each time one of the peripherals needs to communicate with the CPU, it requests to interrupt the CPU by sending a signal to the 8259 interrupt controller (U2). This controller chip places an interrupt signal, INT, on the input to the 8088, causing the CPU to stop processing and look at a special address for a subroutine to handle, or service, the interrupt. The CPU also places a special code on the S0–S2 lines to the 8288 bus controller (U6), causing the generation of an interrupt-acknowledge signal, INTA/.

Interrupts can be initiated by hardware (the chips themselves) or by a program that you are running in the machine. The key to hardware-interrupt generation is the 8259 programmable interrupt controller (U2), as shown in Fig. 2-10.

The programmable interrupt controller at U2 has eight interrupt-request-line inputs (IRQ0–IRQ7). These inputs are acted upon by U2 in a specific priority order. IRQ0 has the highest priority. If two interrupt requests arrive at U2 at the same time, the interrupt request with the number closest to 0 will take priority and be acted upon first. For example, if IRQ5 and IRQ3 interrupt request lines both go high at the same time, IRQ3 will be serviced first. Then IRQ5 will receive attention.

When the interrupt request is sensed by U2, the device generates an interrupt signal, INT, which is sent to the 8088 CPU. If interrupts are being accepted (you can turn them off with a software command), the 8088 sends a code to the 8288 bus controller (U6) causing an interrupt acknowledge (INTA/) signal to be returned to U2. Upon sensing INTA/, U2 places an 8-bit interrupt vector on the data bus.

This causes U2 to send a SP/EN signal to the 74LS10 triple 3-input NAND gate (U84), disabling the system data bus buffer 74LS245 tri-state octal transceiver (U8) so U2 can control the data bus for that moment.

The 8088 CPU stores its internal condition (the address it is going to access next, etc.) and looks at the data placed on the data bus by the interrupt controller (U2). It interprets this data as specifying a memory location that equals four times the value of the interrupt vector from U2.

The CPU accepts the data stored at this location as the starting address of a subroutine to service the interrupt. It jumps to the subroutine and executes the instructions there. When the interrupt has been serviced, the subroutine will return the CPU to the initial program it was running. The initial conditions will be restored, and the CPU will go on about its business once more.

8255 Programmable Peripheral Interface

The 8255 *programmable peripheral interface* (PPI) at U36 is a smart peripheral device with an addressable data bus interface controlled by handshaking lines (special communications signals). On the input/output side, U36 has three programmable 8-bit ports. Each port can be configured as either input or output. The third port, port C, can be divided so it provides both input and output. The chip is configured by a control word sent to it on the data bus. U36 is configured as shown in Fig. 2-11.

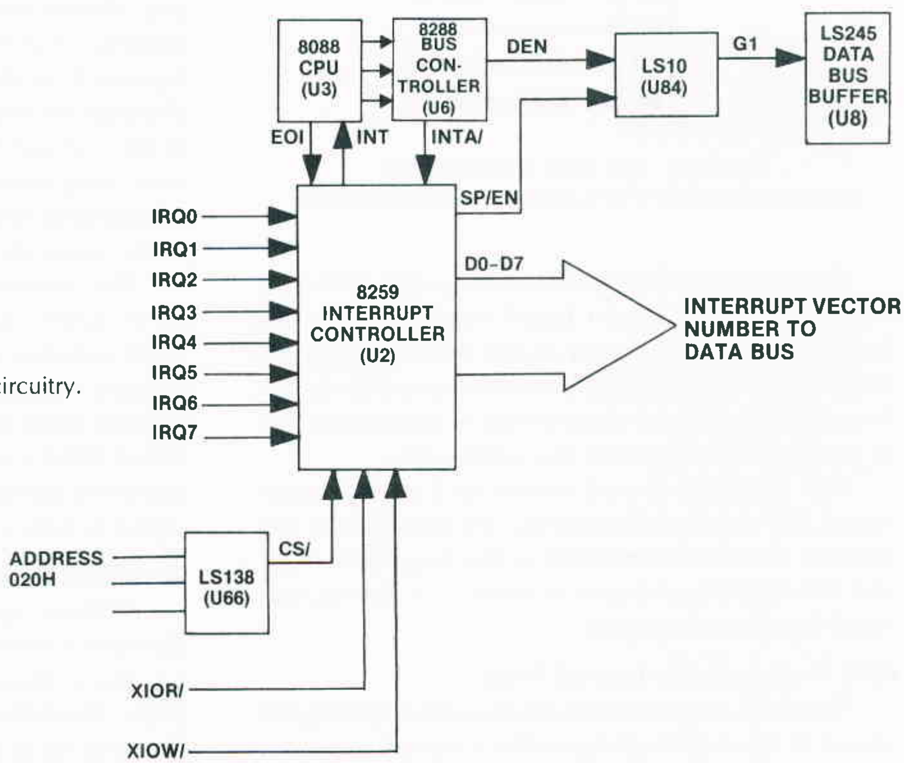


Fig. 2-10. The 8259 interrupt controller circuitry.

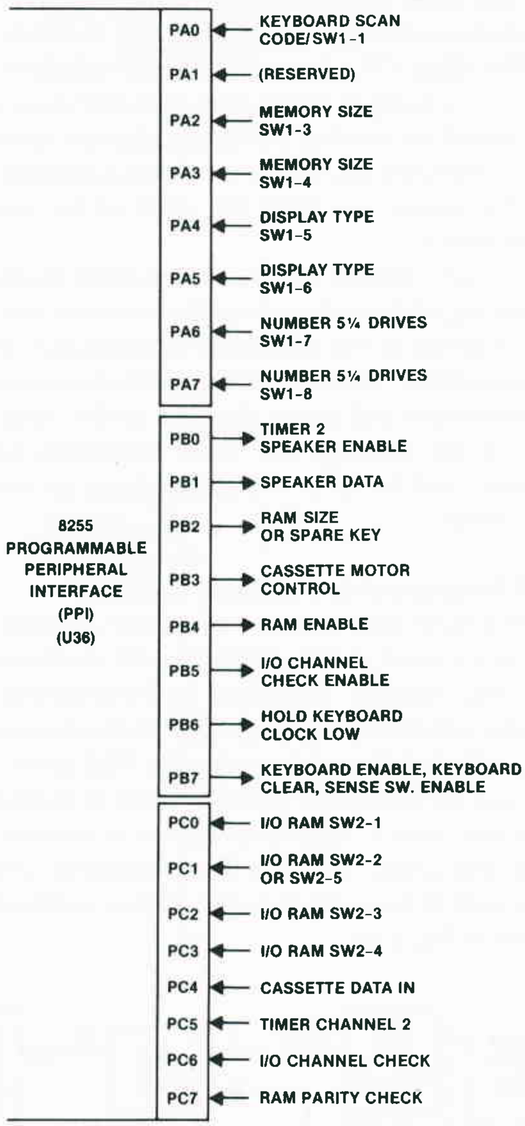


Fig. 2-11. The 8255 programmable peripheral interface (PPI) configuration in the IBM PC.

Depending on the status of bit 7 in port B (PB7), port A reads either the system board switch (SW1) or the keyboard. Port B is used to enable the 8253 programmable interval timer (U34), to turn on the speaker signal, to control the cassette motor (if one is connected), and to enable a RAM accuracy test called *parity*.

Port C is used to read switch SW2 on the system board, the status of RAM parity, the status of the I/O channel (the lines connected to the expansion slots), and the 8253 timer output channel 2. It also accepts input data from a cassette.

8253 Programmable Interval Timer

The 8253 *programmable interval timer* (PIT) (U34) shown in Fig. 2-12 is configured by a control word sent to it over the data bus. The PIT at U34 receives a 1.1931817 MHz clock pulse from 74LS175 quad-D flip-flop (U26) and produces three important outputs. OUT0 is an 18.2 kHz interrupt signal (IRQ0) used to cause a time-of-day clock tick. OUT1 is a 15-microsecond clock pulse used to cause the dynamic RAM chips to be addressed (refreshed). OUT2 is a square-wave signal sent to the speaker. This output frequency can be varied under software control.

MEMORY DESIGN

Your IBM PC comes with capability for 64K or 256K of onboard RAM. Since the 8088 CPU can address 1,048,576 locations, memory expansion capabilities have been designed to increase the onboard RAM to as much as 640K of available memory. The design requires that the onboard RAM sockets be fully populated (filled) before expansion boards are plugged into the slots. All the RAM, ROM, and additional memory cards are allocated within the 1-megabyte address space.

Address space is separated into areas for RAM, ROM, and input and output. Input and output ports have unique memory addresses—that is, the I/O is memory-mapped. For example, to send data to the speaker via 8255 PPI port B, line 1 (causing it to click), you address location 00061H (97 in decimal), and then you address the 8253 PIT at location 00043H (67 in decimal) to set the speaker output frequency. Addressing port C of the 8255 PPI at location 00062H (98 in decimal) will enable the system to read cassette data into bit 4 of port C. The map of memory allocation for your computer is shown in Table 2-1. For convenience, a decimal-to-hexadecimal conversion table is included in the Appendix.

The computer determines how much memory is in the PC system by the setting of two *dual in-line package* (DIP) *switches* mounted on the motherboard. When memory is added, the switch settings are changed to reflect the larger memory space available. The lower portion of RAM is used to store interrupt information and part of the operating system. This memory is allocated as shown in Table 2-2

Read-Only Memory (ROM)

Memory spaces from C0000H to FFFFFH are allocated to ROM. These are allocated as shown in Table 2-3. These addresses can be translated to specific ROM chips. The ROM chip position U28 is an empty socket that was once planned for holding part of Cassette

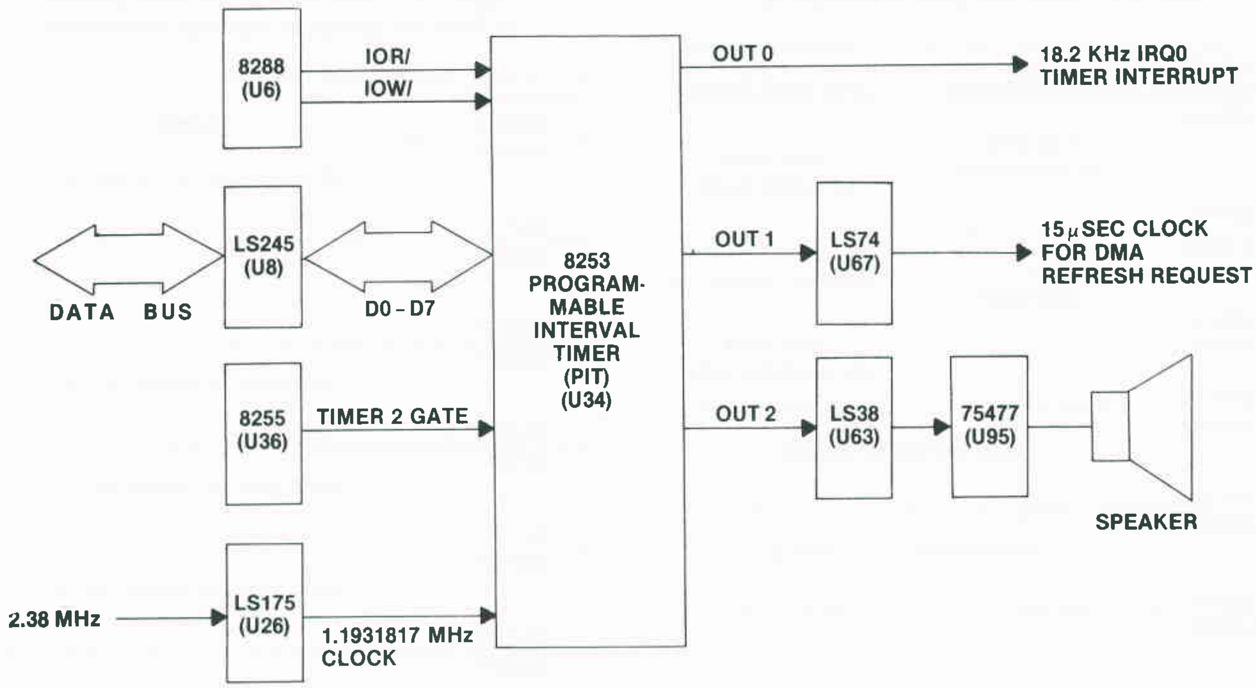


Fig. 2-12. The 8253 programmable interval timer (PIT) circuitry.

BASIC. Its allocated address space is F4000H to F5FFFH. The next four ROM chips, U29-U32, hold the 32K Cassette BASIC. Cassette BASIC resides in memory between F6000H and FDFFFH. ROM U33 holds the PC's basic input/output system (BIOS) routines. Its address allocation covers FE000H to FFFFFH.

The address space between C0000H and F3FFFH is reserved for future ROM application. If a hard disk is connected to the PC, addresses C8000H-CBFFFH are allocated for its control. All the memory below C0000H is allocated for RAM.

Stored permanently within the 8K ROM BIOS chip are software routines to handle video display graphics, printer and asynchronous communications, a time-of-day clock, printing the screen display, cassette operations, a minifloppy disk bootstrap loader, and a power-up self test.

The self-test (actually a series of tests) occupies 2K of the 8K ROM. This series of 14 tests is initiated when power is turned on. The tests check the 8088 CPU, the ROM, the RAM, the keyboard, the video display adapter card, the cassette recorder, and the floppy disk system. The RAM test includes five different read/write tests. The entire memory area available to the user is checked. Each of the five memory tests writes and then reads a different bit pattern into the memory locations. Depending on how much RAM is in your system, the tests can take as long as 1.5 minutes. A 128K system takes about 30 seconds to conduct the tests and complete the system initialization process.

When the computer is restarted with the power already on, the system tests are bypassed, thus reducing the time to initialize by almost 40 percent.

The ROM circuitry is shown in Fig. 2-13.

Addresses A0-A7 are buffered through 74LS244 (U16) and combined with addresses A8-A12 buffered through 74LS244 (U15) to become XA0-XA12. These 13 address bits are applied to the address inputs to ROM chips U29 through U33. The addressed ROM is enabled by the chip-select signal decoded by the 74LS138 1/8 decoder/demultiplexer (U46). Its inputs include the seven highest address bits (A13-A19) and the extended memory read signal (XMEMR/). Address bits A16-A19 are used to develop the ROM address select signal (ROM ADDR SEL/). This same signal is combined with I/O read (IOR) and extended address bit 9 (XA9) in the 74LS02 quad 2-input NOR gate to determine the direction of data flow passing through the 74LS245 tri-state octal transceiver (U13) at the output of the ROM array.

Data read out of the ROM passes through U13 onto the data bus, where it can be accessed by the CPU.

Table 2-1. RAM allocation in the IBM PC

Hexadecimal Address	16K–64K System	64K–256K System
00000H	64K RAM on motherboard	256K RAM on system board
0BFFFFH		
0C000H	576K RAM	
3FFFFH		
40000H		384K RAM on expansion cards
9FFFFH		
A0000H – AFFFFH	128K reserved for displays	
B0000H – B3FFFH	Monochrome video memory	
B4000H – B7FFFH		
B8000H – BBFFFH	Color/graphics video memory	
BC000H – BFFFFH		
C0000H – FFFFFH	ROM	

Table 2-2. Allocation of the lower portion of RAM for storage of interrupt information

Hexadecimal Address	Content
00000H – 0001FH	BIOS interrupt vectors (00–1F)
00020H – 0007FH	
00080H – 0009FH	DOS interrupt vectors (20–3F)
00100H – 001FFH	USER interrupt vectors (40–7F)
00200H – 003FFH	BASIC interrupt vectors (80–FF)
00400H – 004FFH	BIOS data area
00500H – 005FFH	BASIC and DOS data area
00600H – 0BFFFH	62.5K user RAM area

Random-Access Memory (RAM)

As pointed out earlier, there are two types of PC system boards. The first PCs to reach the public have system boards designed for 4116-type 16K-by-1-bit chips. Up to 64K bytes of RAM can be mounted on these boards. Newer PCs use the 4164-type 64K-by-1-bit chips. Up to 256K bytes of RAM can be mounted on the newer boards. Another 384K bytes of RAM can be added by using the expansion slots, providing a total of 640K bytes of available RAM space.

RAM can be described as a read/write type of memory. These chips can have programs written into them, and they can have programs or data read from them. The RAM is like the scratch pad or blackboard for the computer, whereas the ROM could be considered a book that the computer reads.

Unlike ROM, anything stored in RAM disappears when the computer's operating voltages are removed. Hence, the statement earlier about saving the information on a disk or cassette before turning the machine off.

As you saw in Table 2-1, your system board can hold either up to 64K of 4116 RAM chips, or up to 256K of 4164 RAM chips. Each board has four rows of nine chips. The ninth chip in each row is used for parity. Parity will be explained in detail shortly.

Bank Addressing Scheme

Since there are four banks of RAM on the system board, a bank addressing scheme is used to write or read information into each part of memory (see Fig. 2-14). Address bits A14 and A15 are combined with RAM address select (RAM ADDR SEL/) and chip address select (CAS/) in a 74LS138 1/8 decoder demultiplexer (U47) to form the four bank chip address select signals, CAS0/, CAS1/, CAS2/, and CAS3/. The same two address bits (A14 and A15) are also combined with data acknowledge signal DACK0/ and RAM ADDR SEL/ in 74LS138 (U65) and then ANDed with the REFRESH

Table 2-3. ROM allocation in the IBM PC

Hexadecimal Address	16K-64K System	64K-256K System
C0000H C7FFFH		192K ROM expansion and control
C8000H CBFFFH	Hard disk control	
CC000H EFFFFH F0000H F3FFFH	Reserved for future use	
F4000H F5FFFH	(Open ROM socket) (8K)	
F6000H FDFFFH	ROM Cassette BASIC (32K)	
FE000H FFFFFH	ROM BIOS (8K)	

GATE/ signal in 74S08 AND gate U49 to generate four bank RAM address select signals RAS0/, RAS1/, RAS2/, and RAS3/.

As shown in Fig. 2-14, CAS0/ and RAS0/ enable the data passing through a 74LS245 tri-state octal transceiver at U12 (MD0-MD7) to be written to or read from Bank 0 RAM (U38-U45).

Parity Checking

The lone RAM chip at U37 is used for parity checking. Parity is a self-test to ensure that the data being read is accurate and that no bits have changed logic value (indicating a bad RAM chip). To understand how parity works, refer to Fig. 2-15. When the data is written (stored) into a memory location, all the logic 1's are added, and the parity bit is set or not set, depending on the outcome of the addition. The parity bit is used to ensure that the addition result is an even number.

The 8-bit data word (MD0-MD7) that is being stored in RAM (U38-U45) is passed to the 74S280 9-bit odd/even parity generator/checker at U94. This chip senses the number of logic 1's in the data word and places a logic 1 output from either an odd-parity output pin or an even-parity output pin. If the result is odd parity, the 74S280 places a logic 1 on its odd-parity output. This signal is passed through a 74LS125 quad tri-state buffer at U80 and into the parity RAM chip for that row of memory chips (U37 in this case). When the data

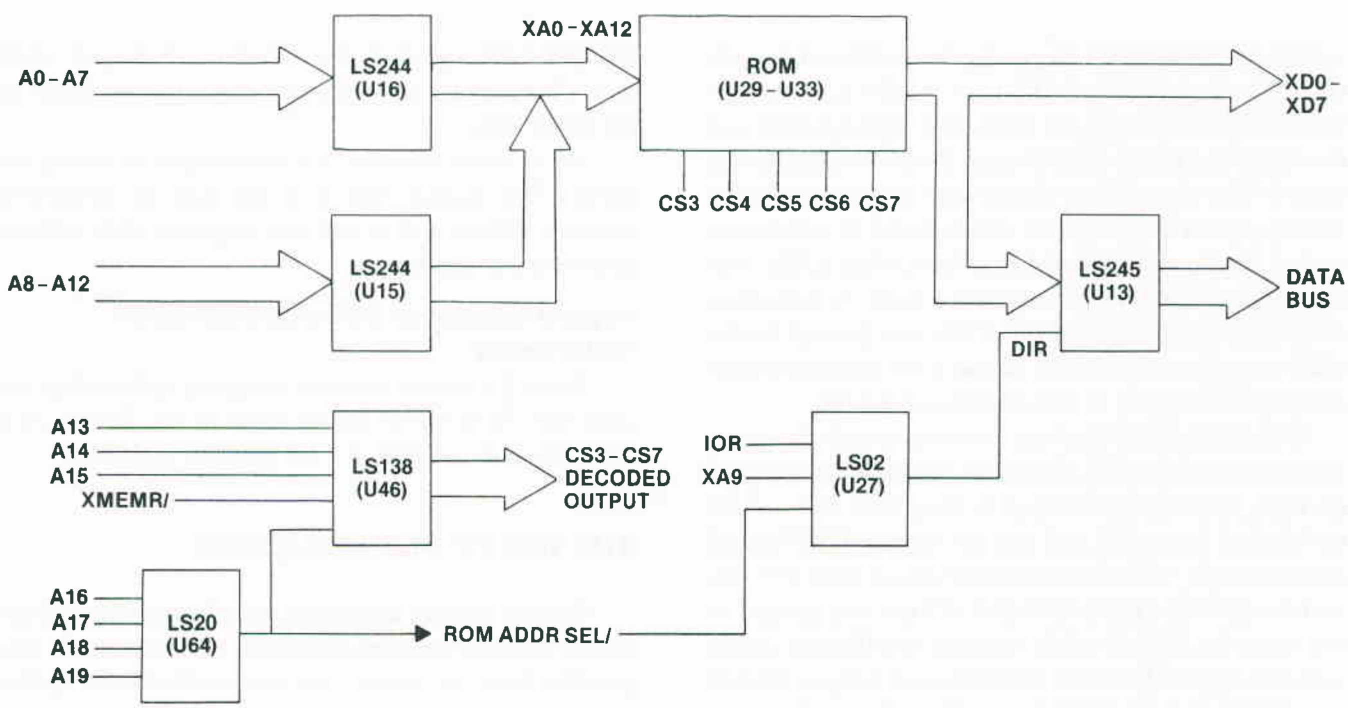


Fig. 2-13. The ROM circuitry.

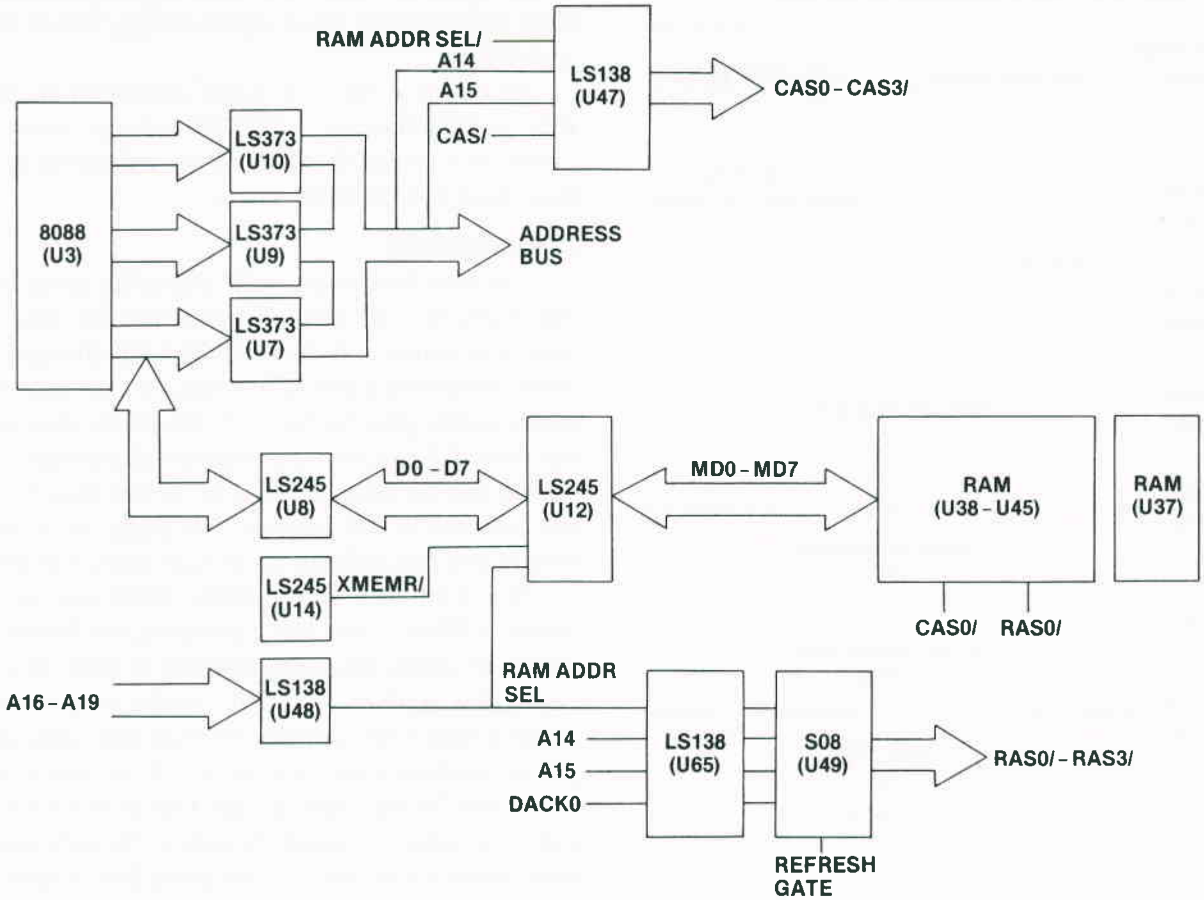


Fig. 2-14. RAM Bank 0 addressing scheme.

is read out of the RAM, the parity bit (MDP) is read with the data word (MD0-MD7) into 74S280 (U94). Since the result should now be even, the signal passed out the ODD line to the 74LS02 quad 2-input NOR gate is a logic 0. This signal is combined with the inverted RAM address select (RAM ADDR SEL/I) signal to produce a logic 1 set signal to 74LS74 dual-D flip-flop (U96). The Q output of U96 (PCK) becomes a logic 1, indicating that parity is good. The status of PCK can be read by the 8088 by addressing port C of the 8255 programmable peripheral interface at U36 (address 00062H).

If the data word read out of memory with the parity bit was sensed as odd, the ODD output of U94 would go high, causing U27 output to drop low. This would be latched into U96 and the Q/ output PCK/ would become high. When I/O channel check (I/O CH CK) and enable I/O check (ENABLE I/O CK) are sensed at the input to 74LS10 triple 3-input NAND gate (U84) with the signals from the 74LS00 quad 2-input NAND gate (U81) and the PCK/ from U96, U84 produces an output that is high. This logic high is ANDed with the ALLOW NMI signal in the 74S08 quad 2-input AND gate U97, producing a nonmaskable interrupt (NMI) to the 8088 CPU.

All of RAM memory is continuously checked for parity. This built-in test is a fast way to determine memory failure and to prevent improper data utilization or transmission.

Physical Location of RAM Addresses on the Motherboard

Table 2-4 relates memory locations to the chips on your IBM PC's motherboard. Refer to Fig. 2-5 for chip locations and to Table 2-1 for memory content.

THE IBM PC BUS STRUCTURE

Control signals, addresses, and data are shared between the CPU and the rest of the PC system over tiny parallel lines, or traces, on the motherboard called *buses* (see Fig. 2-16).

A bus is like a roadway over which the 8088 CPU

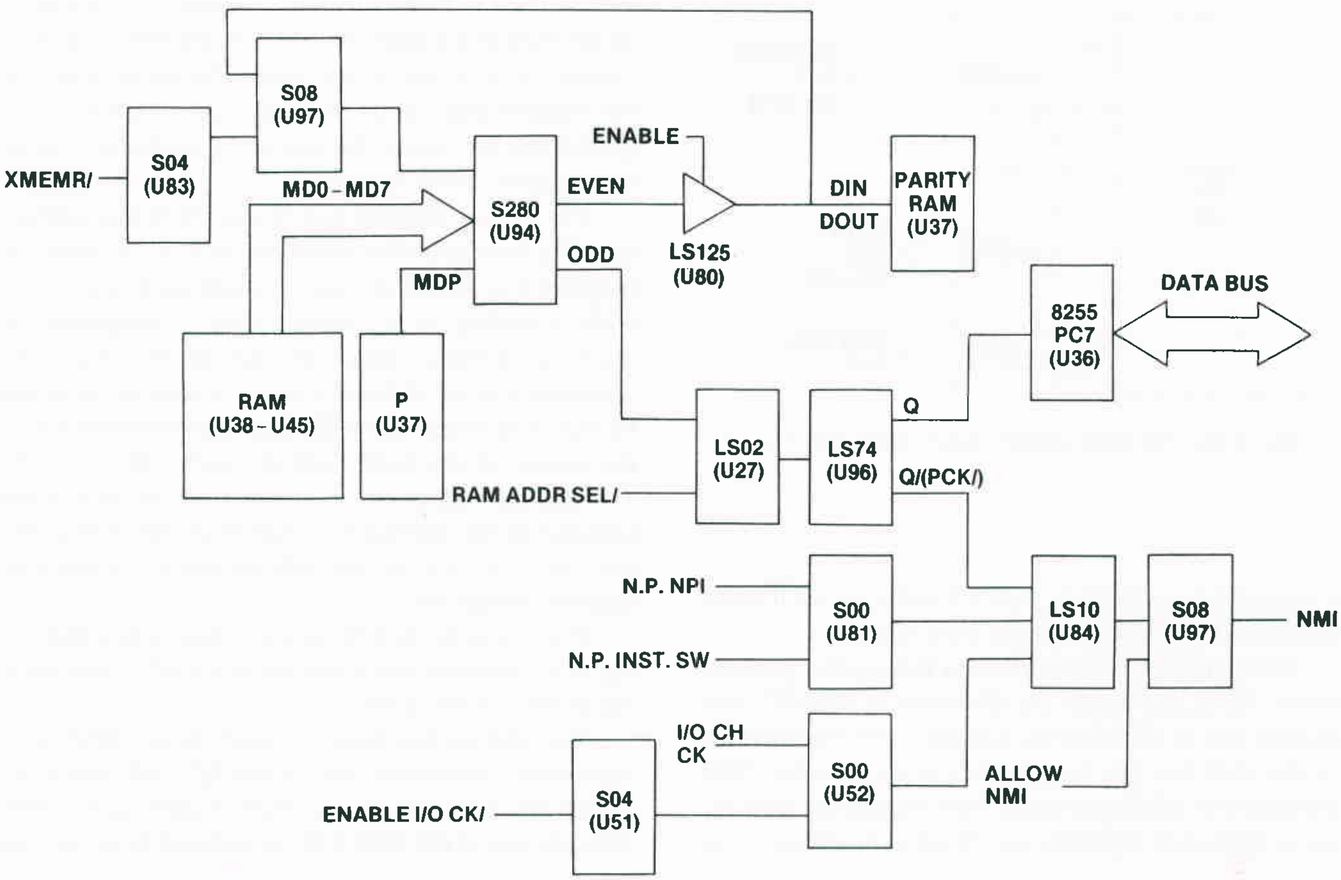


Fig. 2-15. The parity circuitry in the IBM PC.

Table 2-4. Memory location in relation to chip location

Function	Parity	D0	D1	D2	D3	D4	D5	D6	D7
Memory Location (16K-64K)									
			Bank 0 (16K)						
00000H through 03FFFH	U37	U38	U39	U40	U41	U42	U43	U44	U45
			Bank 1 (32K)						
04000H through 07FFFH	U53	U54	U55	U56	U57	U58	U59	U60	U61
			Bank 2 (48K)						
08000H through 0BFFFH	U69	U70	U71	U72	U73	U74	U75	U76	U77
			Bank 3 (64K)						
0C000H through 0FFFFH	U85	U86	U87	U88	U89	U90	U91	U92	U93

Function	Parity	D0	D1	D2	D3	D4	D5	D6	D7
Memory Location (16K-256K)									
			Bank 0 (64K)						
00000H through 0FFFFH	U37	U38	U39	U40	U41	U42	U43	U44	U45
			Bank 1 (128K)						
10000H through 1FFFFH	U53	U54	U55	U56	U57	U58	U59	U60	U61
			Bank 2 (192K)						
20000H through 2FFFFH	U69	U70	U71	U72	U73	U74	U75	U76	U77
			Bank 3 (256K)						
30000H through 3FFFFH	U85	U86	U87	U88	U89	U90	U91	U92	U93

communicates with other components (peripherals such as disk drives) and the outside world (motors, lights, sensors, etc.). Your IBM PC has an advanced bus design with all data and address output lines fully buffered for protection. The IBM PC buses include:

- A data bus
- An address bus
- A control bus

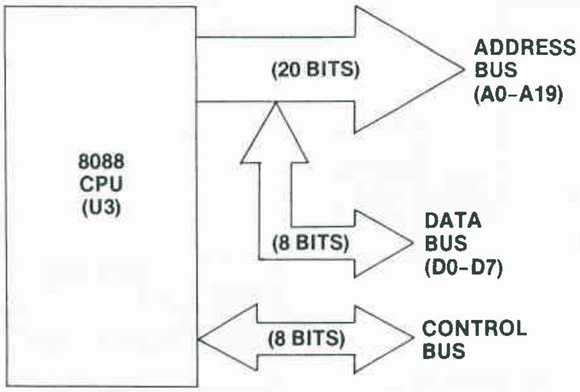


Fig. 2-16. The three primary buses in the IBM PC.

A voltage (approximately 0 or +5 volts) on each trace of each bus represents a logic level (0 or 1).

The **data bus** and the **address bus** are the primary buses. Data bus words are identified as D0-D7. The address bus is identified by bits A0-A19. Information on the data bus can travel either to or from the CPU (the data bus is bidirectional). Even though the IBM PC has a CPU that operates on 16-bit instructions, it is technically an "8-bit machine" because the data word on the data bus is eight bits wide. It requires a signal to control the direction of data flow. This signal is part of the **control bus**—a set of traces, or lines, on which special voltage signals are placed to enable or disable certain parts of the circuitry.

The largest (widest) bus in the PC is the address bus. This bus carries the addresses the CPU accesses for program instructions or data. The address bus is 20 bits wide, enabling it to address over 1 megabyte of memory locations. These 20 logic levels collectively represent unique address locations in memory or in the PC I/O. Addresses AD0-AD7 become unidirectional at the output of the buffer address latch 74LS373 (U7). The address output of U7 is called A0-A7 and is the low part of the address bus. Addresses A8-A19 come out from the CPU on the address bus on a one-way (unidirectional) path.

The complete IBM PC bus structure is described in Fig. 2-17. Notice that the address bus is fully buffered to the ROM and the RAM.

The address bus passes through three 74LS373 tri-state octal transparent latch chips (U7, U9, and U10) before being applied to any other circuitry as A0-A19. The data out of the 8088 CPU is buffered by a 74LS245

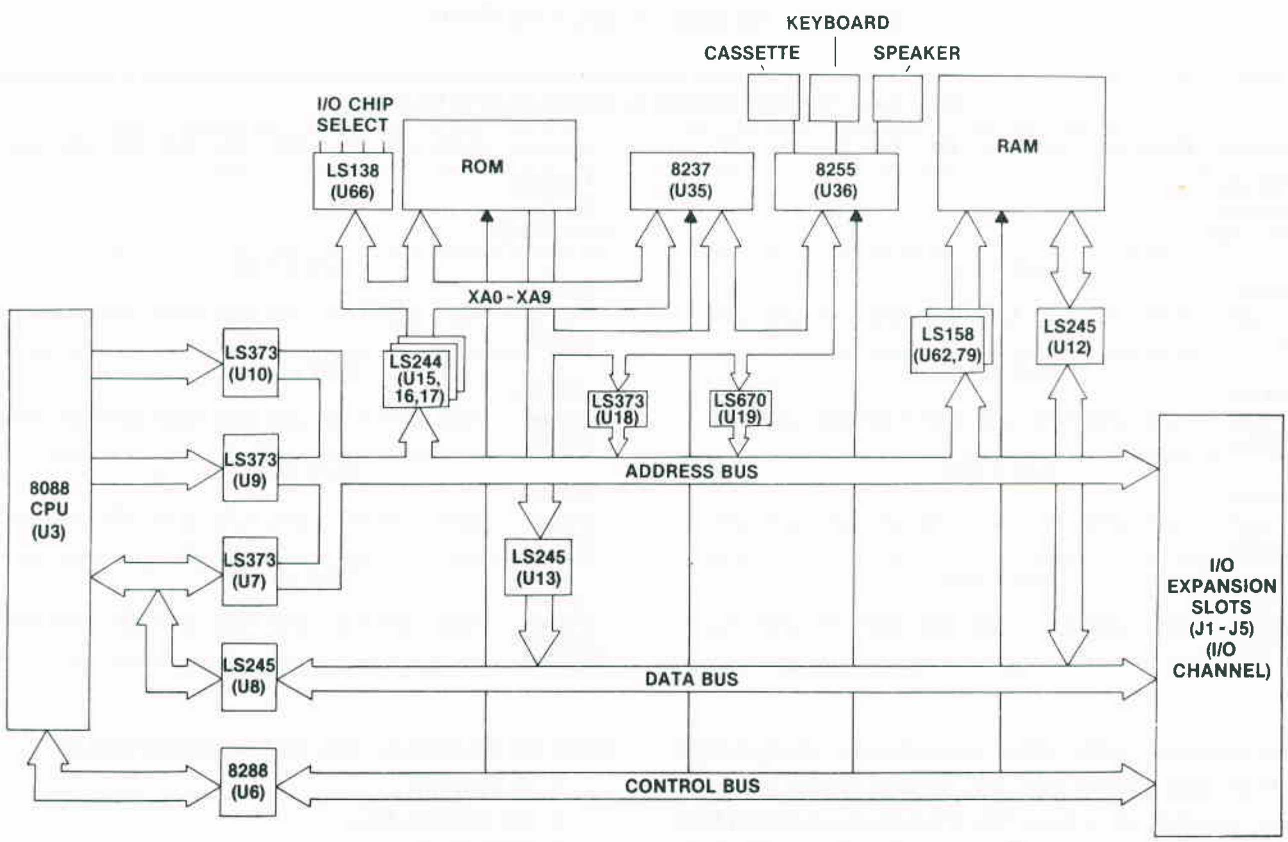


Fig. 2-17. The complete IBM PC bus structure.

tri-state octal transceiver (U8) before becoming the data bus D0–D7.

Several smaller bus structures are formed from the address and data buses. Part of the address bus is coupled through three 74LS244 tri-state octal buffer chips (U15, U16, and U17) to become the extended address bus XA0–XA9. Likewise, the data bus is passed through a second 74LS245 tri-state octal transceiver (U13) to become the extended data bus XD0–XD7. This extended bus connects directly to the ROM chips, the 8237 DMA controller, a 74LS373 tri-state octal transparent latch (U18) and a 74LS670 tri-state 4 × 4 register file (U19).

Under the direction of the CPU, special control signals are placed on the control bus and unique addresses are placed on the address bus. The control signals open the address locations, letting the information stored in these locations appear on the data bus, which is acted on by the CPU or I/O.

Together, the address bus, the data bus, and the control bus are called the *system bus*. The system bus lies beneath those five expansion slots on your IBM PC motherboard.

In addition to the address bus, the data bus, and the control bus, the 62-pin system bus includes timing and power signals. It is accessible on five 62-pin I/O sockets mounted at the rear of the system board. Another name for this 62-pin arrangement is the *PC bus*.

Except for disk drive access signals, all data moves through the CPU and all addresses are generated and placed on the address bus by the CPU.

INPUT AND OUTPUT

Each of the I/O ports, or windows through which information passes, has its own address. This is called memory-mapped I/O. Other CPU chips such as the 8080 and the Z80 use special instructions or commands to access the I/O ports. In the PC, you simply address a certain memory location in your computer to access the computer's ports.

Many peripherals have been developed for the IBM PC; and you have quite a bit of choice in connecting devices to your IBM PC to increase its capabilities.

Video Display

IBM chose to produce all of its video signals external to the system board. Monochrome and color video displays are produced using one of two IBM display adapters that plug into the expansion slots on the system board.

Only one video adapter board is required, although you can use two adapters should you wish to drive both color and black-and-white displays.

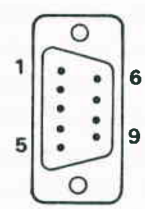
Caution: Do not connect the monochrome display to the color adapter. You could burn out the display unit.

An excellent description of video operation can be found in *The IBM Personal Computer from the Inside Out*, by Murray Sargent and Richard Shoemaker.

Both video adapters use a Motorola 6845 CRT controller. Because monochrome and color video are produced in different ways, each adapter will be discussed separately.

Monochrome Video Adapter

The monochrome adapter card has two functions. The first is to enable the system to display text via a 9-pin D-connector to a black-and-white display. A second connector is a 25-pin parallel-printer interface for the IBM 80-character-per-second printer. The connectors and signals are shown in Fig. 2-18.



PIN	SIGNAL
1	GROUND
2	GROUND
3	–
4	–
5	–
6	INTENSITY
7	VIDEO
8	HORIZONTAL SYNC
9	VERTICAL SYNC

Fig. 2-18. The signals present on the pins of the connector of the monochrome adapter card.

Each character is produced as a 7-dot-wide by 9-dot-high matrix within a larger, 9-dot-wide by 14-dot-high array. The extra dots on the top and bottom of the matrix are used for descenders (such as the letters "g" and "j," which have parts that extend below an invisible baseline) and for spacing between lines. Extra dots also provide spacing between characters on a single line.

IBM designed a custom adapter for its monochrome display. The adapter card generates nonstandard horizontal and vertical frequencies, so that few non-IBM monitors can be used with this adapter. In addition, the video output from the adapter card is not a composite video with the horizontal and vertical synchronization

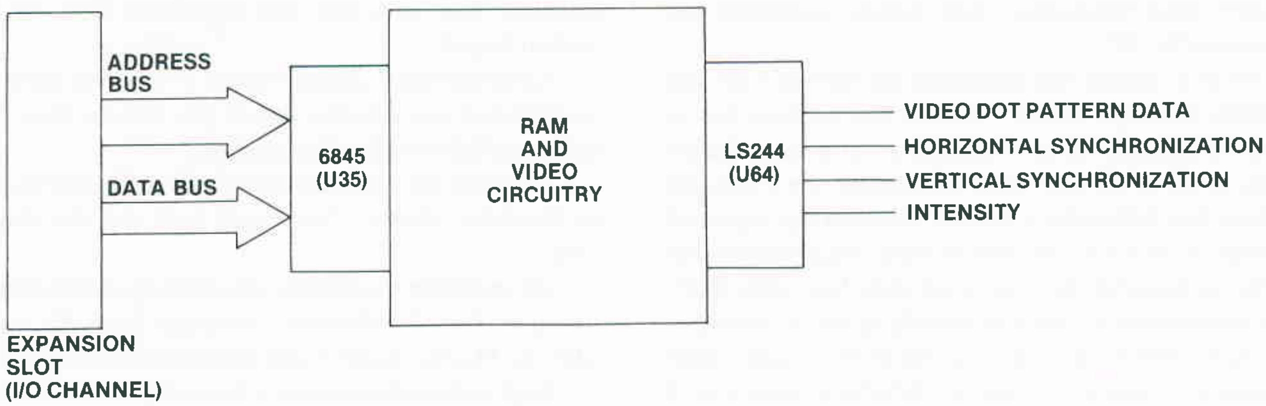


Fig. 2-19. The input and output signals for the monochrome video circuitry.

signals combined with the video dot pattern data. Instead, as shown in Fig. 2-19, the two synchronization signals and the video data are provided to the display unit separately. The video data is in two parts: the video data itself and a brightness attribute.

The key device on the input to the adapter card is the 6845 CRT controller. This chip accepts the address and data buses and the clock inputs from the system board and converts these inputs to signals suitable for the video RAM and video circuitry. The 6845 produces the horizontal and vertical synchronization pulses. In between generating the sync pulses, the 6845 reads out the contents of the RAM into a character generator that translates the RAM data into video dot information.

At the output of the monochrome video circuitry, a 74LS244 tri-state octal buffer (U64) provides three separate video component signals to a 9-pin connector (labelled J3 on the adapter card). The IBM monochrome monitor can be connected to the PC via J3.

The monochrome adapter accepts ASCII character code from the system board data bus. An MK-36000 character generator converts the ASCII code into the appropriate dot pattern for display on the screen. The MK-36000 is an 8K ROM. It contains three character fonts, although only the font in the first 4K of its memory is used on the monochrome card.

Two bytes of data are sent to the adapter card for each alphanumeric character. One contains the ASCII code for that character; the second contains attribute information such as blinking, high intensity, normal, or reverse video.

The data from the 8088 CPU on the system board is stored in a fast static 4K RAM on the adapter card as shown in Fig. 2-20. The starting address of this video buffer is B0000H. This address corresponds to the upper left corner of the screen. With 2 bytes per character, the full 4K of memory is required to store 25 lines of 80-character display (25 lines × 80 characters per line × 2 bytes per character = 4,000 bytes). The lower right corner of the screen corresponds to the top of the 4K memory (address B0F9FH).

When the 6845 controller determines that display data is required, it causes the ASCII code and attribute data stored in RAM to be read out and temporarily latched in two octal flip-flops. The 8-bit character data word is then sent into the MK-36000 character generator ROM. The other input to the MK-36000 is a 4-bit address code defining which row of dots for the ASCII character will be passed out to the 74LS166 8-bit shift register (U32). U32 receives the video dot pattern as a parallel word. After one dot-pattern word has been loaded into U32, it begins to shift the word serially out (one character at a time).

The attribute data is combined with the dot stream to produce a modified dot pattern that reflects the attribute data received. This signal is then clocked to the output of the video circuitry, where it enters the video cable attached to the 9-pin connector on the adapter card. The signal passes out of the adapter card, through the video cable, and into the display monitor, where it is converted into high-voltage electron beams that illuminate the P39 phosphor on a certain row of the screen.

The two signals that control where on the screen the dot character shape appears are the horizontal and vertical synchronization signals (syncs). These two signals are produced by the circuitry shown in Fig. 2-21.

Both sync signals originate in the 6845 CRT controller (U35). The 15.75 MHz horizontal synchroniza-

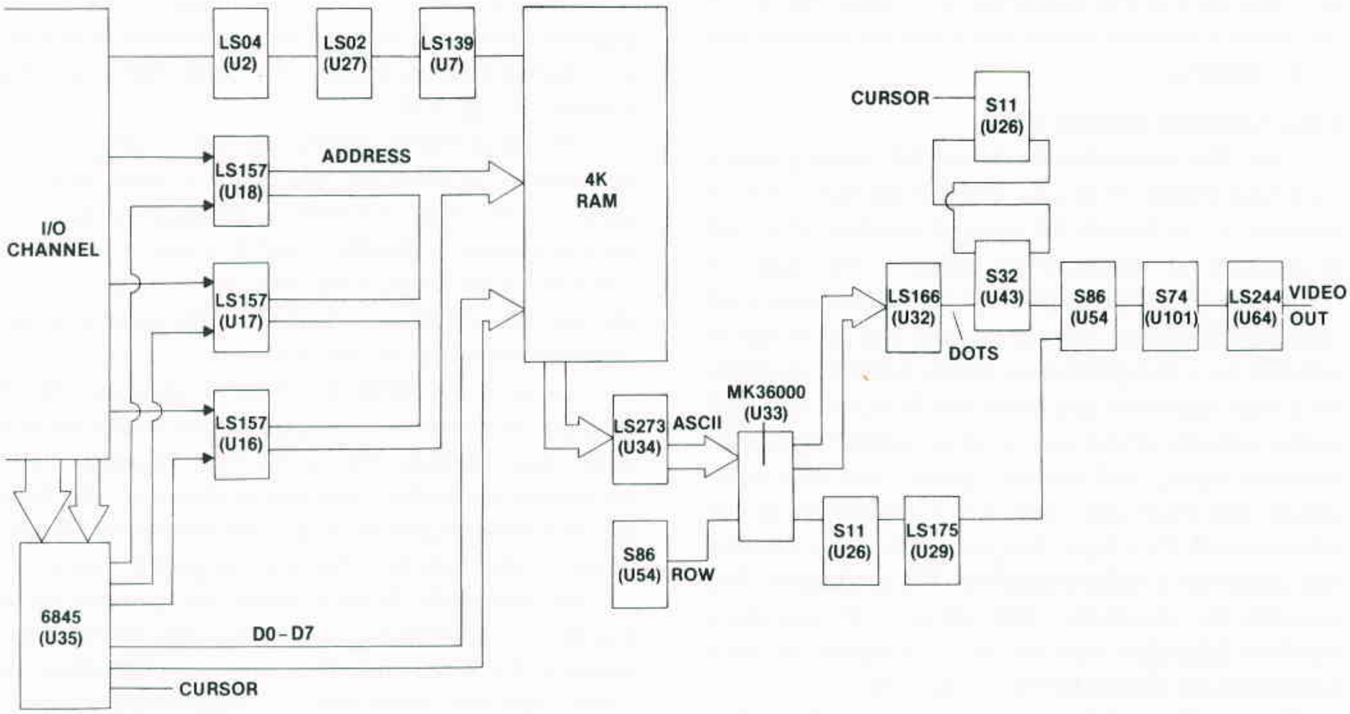


Fig. 2-20. The circuitry that produces the monochrome video signal.

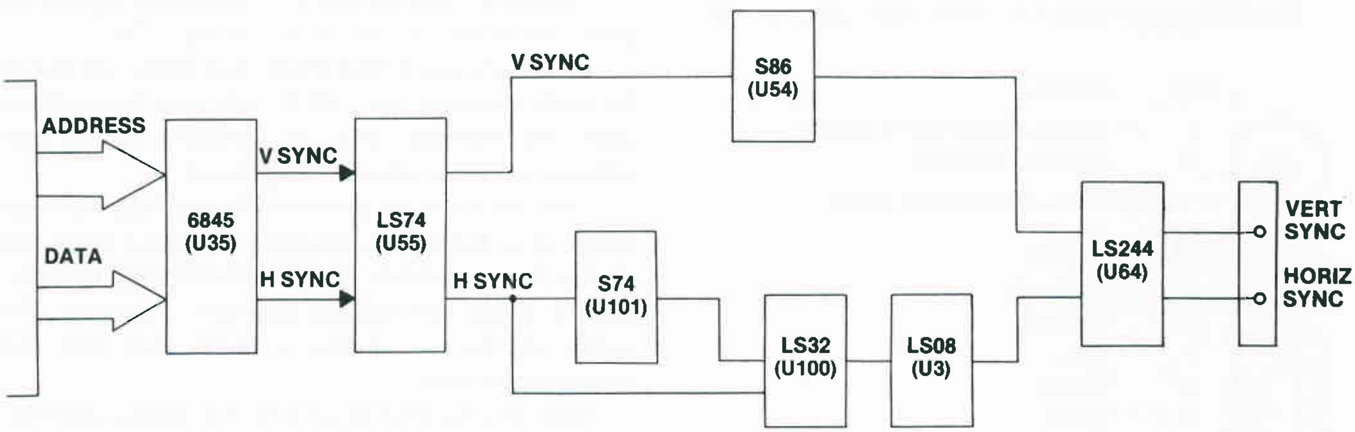


Fig. 2-21. The horizontal and vertical synchronization signals are produced in this circuitry.

tion signal is used to move the beam of electrons that leaves the CRT (cathode ray tube) cathode according to the video data dot pattern. When a dot is received, the cathode sends a stream of electrons out toward the place on the screen where the horizontal synchronization circuitry is aiming the electron beam. The electrons strike the P39 phosphor on the inside surface of the screen, causing that point or picture element (pixel) to be illuminated, or to shine. Then the dot signal passes, the horizontal sync signal moves the beam to the next pixel, and if another dot is received, another pixel is illuminated.

At the end of the horizontal sweep, the electron beam is held low (blanked) and the horizontal aiming is retraced. Simultaneously, the 50 Hz vertical sync signal is applied, moving the stream of electrons down to the next row so that the horizontal sync signal can move the beam across the screen and trace out another row of dot patterns.

Color/Graphics Adapter Card

Like the monochrome card, the color/graphics card has circuitry on it to handle alphanumeric text. In addition, it can handle bit-mapped graphics. The card produces three distinct video outputs. One output is composite video. It is available at an RCA connector on the rear of the card. Another output is a set of signals suitable for a red-green-blue (RGB) monitor, available on a 9-pin connector just below the RCA jack. The RGB output consists of the two synchronization signals, an intensity signal, and the red, green, and blue color signals. The third video output is in the chassis on the adapter card. It's a 4-pin Berg strip providing a connection point for a radio-frequency (RF) modulator. This provides the composite video signal to let you use a standard television with the PC. The signals on each connector are shown below in Fig. 2-22.

There is also a light pen connection on the color/graphics adapter card, but this input device is not often used with the PC. A mouse is the current popular input device (besides the keyboard).

The same type 6845 CRT controller used on the monochrome adapter card is also used on the color/graphics card, but it must be reprogrammed each time you change graphics modes. The color video circuitry is shown in Fig. 2-23.

The monochome adapter also has a built-in dynamic RAM. The RAM on this board is used to store alphanumeric data and bit-mapped graphics data. Its starting address is B8000H, and it is 16K bytes wide. The RAM is slower than the static RAM on the monochrome adapter, so some blinking of the screen can be observed when the display scrolls.

The same MK-36000 8K character generator ROM used on the monochrome adapter card is used on this card. Now, however, two of the three character fonts are jumper selectable. One font produces a 7-dot-high by 7-dot-wide double-dot character; the other font produces a 7-dot-high by 5-dot-wide single-dot shape.

The MK-36000 ROM contains dot patterns for a number of applications, including the 96-character standard ASCII set, 48 foreign language characters, 16 Greek alphabet characters, 15 engineering/scientific characters, 15 word processing characters, 16 game shape characters, and 48 block-line-circle shapes for use in business graphics.

Horizontal and vertical synchronization signals are produced in the circuitry shown in Fig. 2-24.

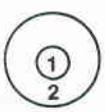
In alphanumeric text mode, two bytes are stored for each character: the ASCII code and the attribute code. The attribute code can provide a display with colored text on a colored background.

The characters are produced from a 7-dot-by-7-dot matrix in an 8-dot-by-8-dot array. There is a single line of dots for descenders, so no underlining is possible. With a single dot spacing between characters, the quality of the text display is lower than with the monochrome card.

Both 80-character-by-25-line and 40-character-by-25-line text modes are supported. The latter mode enables a color television set to be used as a display device. In both text modes, you can have up to 16 foreground colors and 8 background colors.

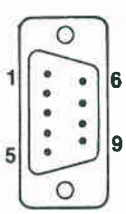
Three bit-mapped graphics modes are available: a low-resolution graphics mode with 160 dots, or pixels, horizontally and 100 pixels vertically; a medium-resolution mode with 320 pixels horizontally and 200 pixels vertically, and a high-resolution mode with 640 pixels horizontally and 200 pixels vertically.

In low-resolution graphics 16 colors are available; in medium-resolution graphics you can get 4 colors; and in high-resolution graphics, you are limited to black and white only.



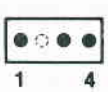
PIN	SIGNAL
1	1.5-VOLT COMPOSITE VIDEO
2	CHASSIS GROUND

RCA JACK – COMPOSITE VIDEO



PIN	SIGNAL
1	GROUND
2	GROUND
3	RED
4	GREEN
5	BLUE
6	INTENSITY
7	
8	HORIZONTAL SYNC
9	VERTICAL SYNC

9-PIN DIN CONNECTOR – COLOR DIRECT



PIN	SIGNAL
1	+ 12 VOLTS
2	–
3	COMPOSITE VIDEO
4	LOGIC GROUND

4-PIN BERG STRIP – RF MODULATOR CONNECTION

Fig. 2-22. The signals present on the pins of the three connectors of the color/graphics adapter card.

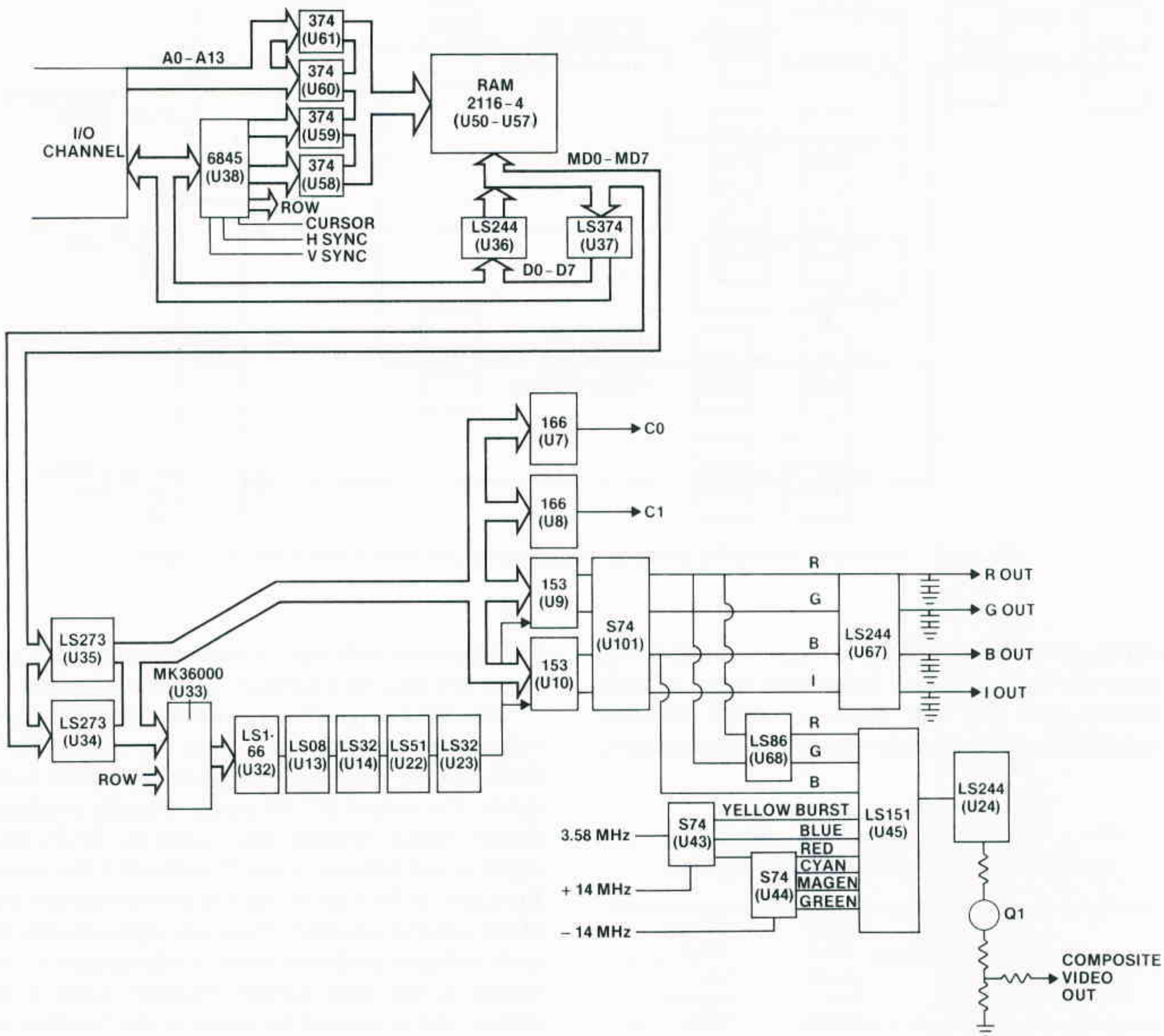


Fig. 2-23. The color video circuitry.

In medium-resolution graphics mode, each pixel on the screen is specified by two bits, so four pixels can be described in one byte. Two color sets are available as shown in Table 2-5. To select the color set, the program sends a byte to I/O address 3D9H. This is the address of the color-select register. Bit 5 selects the active color set. When bit 5 is logic 0, color set 1 is selected. A HIGH in bit 5 selects color set 2. With the color set selected, the two bits specifying the pixel can be described as shown in Table 2-6.

In high-resolution graphics (available in black and white only), each pixel is described by a single bit. A bit value of 1 means that pixel is turned on (becomes bright). This allows each of 640 pixels across by 200 rows down to be bright or dark. The status of the 128,000 pixels on the screen can be stored in 16,000 bytes of memory (128,000 bits / 8 bits per byte = 16,000 bytes).

In text (alphanumeric) mode, the color/graphics adapter card operates much like the monochrome card. The big difference is that the color/graphics card has 16K of on-board RAM. This provides the capability to store four pages of text at one time. Any one page can be displayed at a given time. Changing the starting

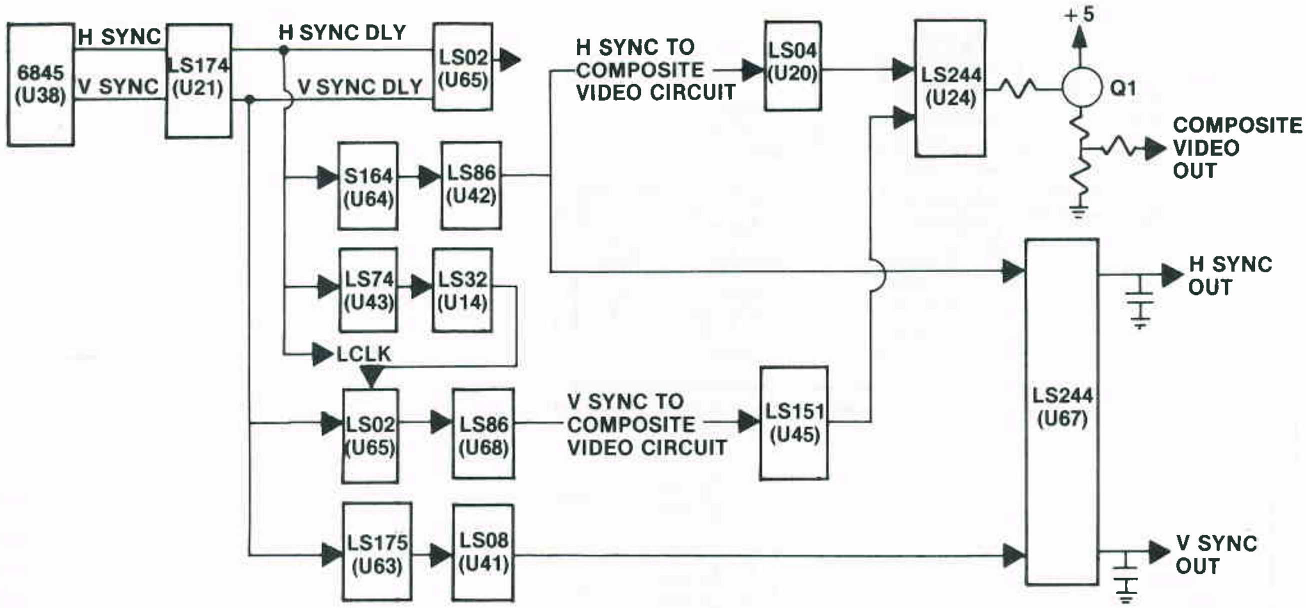


Fig. 2-24. The color circuitry that produces the horizontal and vertical synchronization signals.

address in 6845 CRT controller registers C and D will cause the card to access a particular page. As with monochrome text, two bytes—an ASCII character code and an attribute code—describe each character.

Table 2-5. The two color sets available in medium-resolution graphics mode

Color Number	Color Set 1	Color Set 2
1	Green	Cyan
2	Red	Magenta
3	Brown	White

Table 2-6. Bit settings for pixel specification

Pixel Bits C1	C0	Function
0	0	Dot becomes background color
0	1	Dot becomes color number 1
1	0	Dot becomes color number 2
1	1	Dot becomes color number 3

Cassette Input and Output

The cassette interface is probably the least used of any PC accessory. Control of this interface is only available through software written in Cassette BASIC. The simple circuit in Fig. 2-25 enables you to store programs and data on a standard audio cassette tape.

The 8253 programmable interval timer (U34) provides the cassette data stream to the cassette DATA OUT circuitry via a 74LS38 quad 2-input NAND buffer (U63). The output of U63 passes through a voltage-divider resistor network that causes the DATA OUT signal to shift between 0 and 75 millivolts if the jumper (Berg pin) on P4 is set for input to the microphone jack of the cassette recorder. These are approximately the same voltages produced when a microphone is connected to the same cassette recorder input. If the jumper is set to connect the output to the "auxiliary in" jack on the recorder, the audio signal is output at a higher voltage (0–0.68 volts).

Caution: Be careful when using a cassette recorder. The jumper pin setting is critical. If you connect the Berg pin so that the output is as much as 0.68 volts and then connect the cable to the microphone input to the recorder, you could damage the recorder electronics.

A 5-pin circular cable can be connected from the cassette port (J6) to the microphone or auxiliary input to the recorder. This special cable is not supplied or sold by IBM. The cassette recorder motor can be turned on or off by addressing bit 3 of port B (PB3) of the 8255 programmable peripheral interface (U36). Address 061H accesses this port. The MOTOR OFF signal is buffered through the 74LS138 quad 2-input NAND buffer (U63)

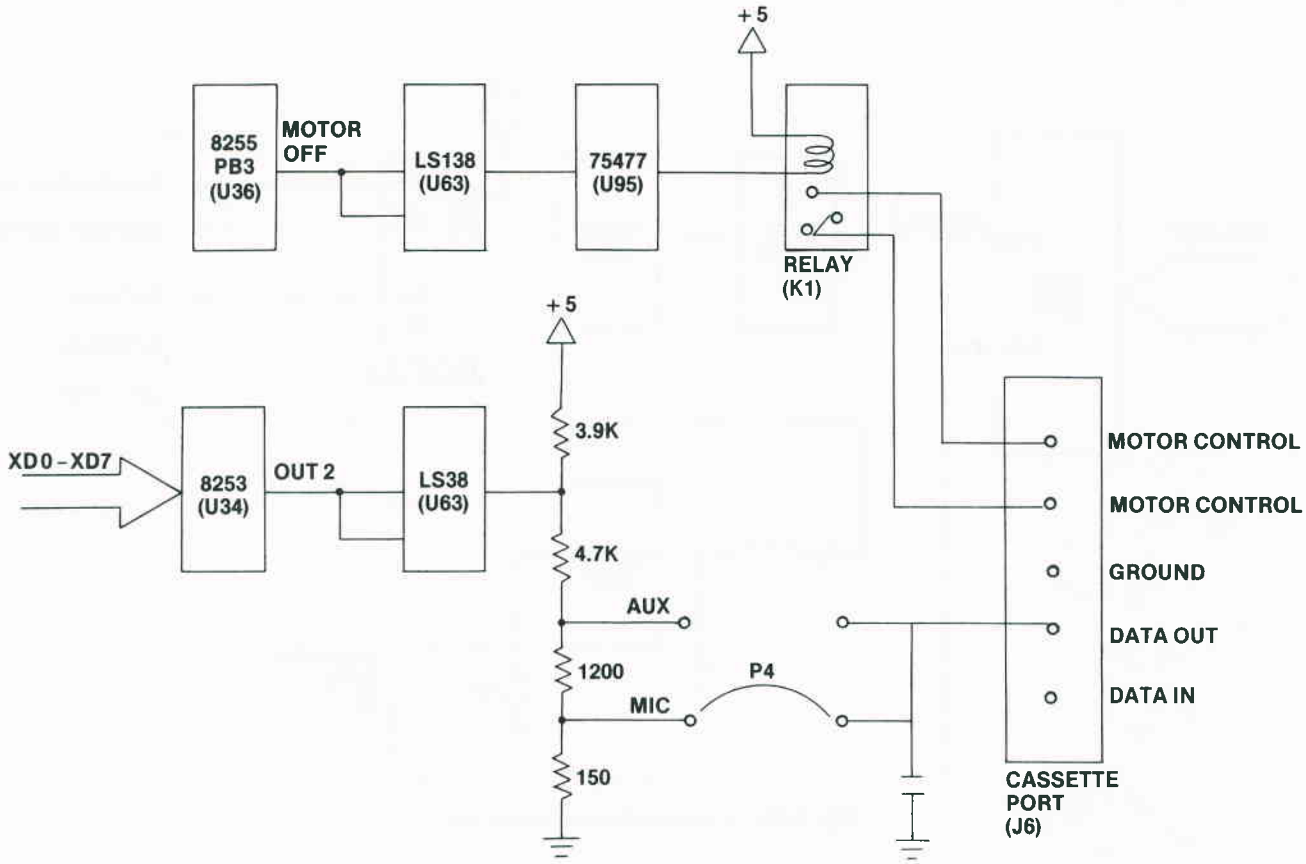


Fig. 2-25. Cassette data output circuitry.

into the 75477 relay driver (U95). When the output of U95 goes low, a relay (K1) energizes to close the motor-control lines from the recorder.

Cassette data is read into the PC via the DATA IN pin of J6 as shown in Fig. 2-26.

The 8255 programmable peripheral interface (U36) is the key device. It produces the MOTOR control signal out port B (PB3) as with data writing. The 500-nanoamp, ±13-volt DATA IN signal connects to the MC1741 operational amplifier (U1) when relay K1 is energized. Amplifier U1 modifies the data signal level to the voltages (0 and +5 volts) required for the digital logic circuitry. The data stream passes over the cassette DATA IN line into the PC4 input to port C of U36. From there it can be read on the data bus by your program. Programs are used to generate and read cassette data. Data can be read into the PC at speeds between 1,000 and 2,000 baud (approximately 100 to 200 characters per second).

The Disk Drive

The floppy disk drive used in the PC allows you to easily and quickly store and retrieve information using 5¼-inch floppy disks. Several manufacturers, including CDC's MPI, Tandon, and Teac, provide disk drives that operate within the PC system. IBM provides CDC and Tandon drives for their configuration of the PC. This guide will discuss primarily the IBM-supplied disk drive. The disk mechanism is housed in a 3.38-inch by 5.87-inch by 8.00-inch metal case. Each drive adds 4½ pounds of weight to the system.

The Disk Controller Card

Data and control signals are supplied to each drive via a ribbon cable connected to a disk controller card plugged into one of the PC system board expansion slots. Up to two internal and two external disk drives can be supported from one disk drive adapter card. The disk drive is one of the most important peripherals connected to your computer. It's the primary mass storage device used by PC owners all over the world.

The 40-track cam-positioned drive rotates at 300 rpm to write or read data on a thin mylar disk with a magnetic coating of oxide particles. During manufacture, a .003-inch-thick polyester disk is coated on both sides with a .0001-inch layer of iron oxide. The disk is called a "floppy" because it is thin and quite flexible.

The type drive determines what kind of disk (or diskette) is used in the PC. A disk can be a single- or double-sided, double-density platter whose surface is

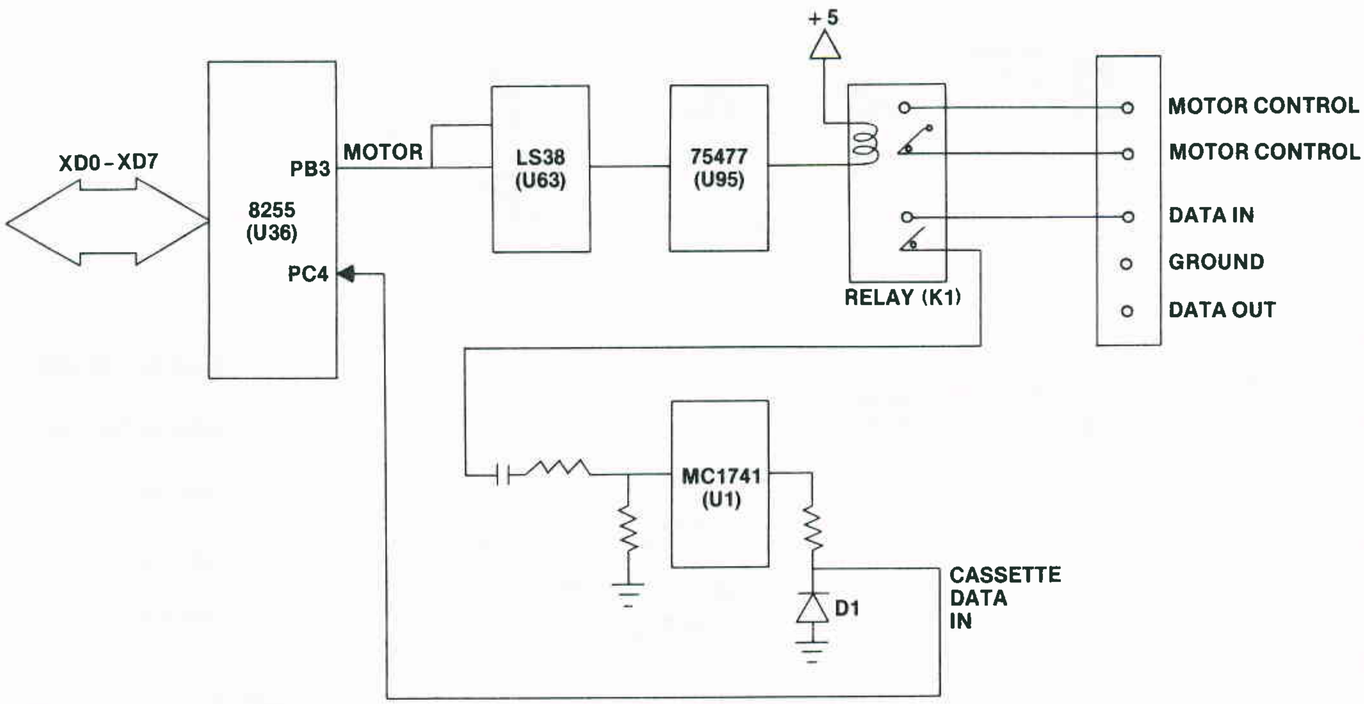


Fig. 2-26. Cassette data input circuitry.

electromagnetically divided into 40 tracks or rings leading from the center hole to the outer edge.

Each disk is soft sectored; that is, sectors are marked off by a special series of code bits written on the disk by the PC. The disk is divided into eight 512-byte sectors (nine for PC-DOS 2.x systems), providing 163,840 bytes of storage space per single-sided, double-density disk (184,320 bytes with PC-DOS 2.x), and 327,680 bytes of storage per double-sided, double-density disk (368,640 bytes with PC-DOS 2.x). One double-spaced page on 8½-by-11-inch paper can use up 1670 characters or bytes. Therefore, you can store a little over 98 pages of double-spaced text on one single-sided disk.

Data Transfer

The key to data transfer between the PC and the disk drive is a tiny chip on the system board called a DMA controller. The 8237 *direct memory access* (DMA) *controller* (U35) shown in Fig. 2-27 enables the computer to move large blocks of information (up to 64K) from disk to computer, computer to disk, or disk to disk.

The DMA controller has a 6:1 speed advantage over the CPU. It gains control of the data bus when a DMA request (DREQx) signal is received. When an external device (such as a disk drive) is ready to send data, it activates one of the four DREQ lines. The DMA controller acknowledges the request by activating the appropriate DACK line. The chip also supplies a memory address and sends a signal to all the other I/O devices, disabling them from using the data bus.

Fig. 2-28 shows how the 8237 DMA controller (U35) is used in the I/O circuitry. The 8237 DMA controller has four channels dedicated for fast data transfer. A channel can be considered the combination of a DREQ line, a DACK line, and the data bus. Channel 0 is used for memory refresh. The 8253 interval timer sends a pulse out its OUT1 line every 15 micro-

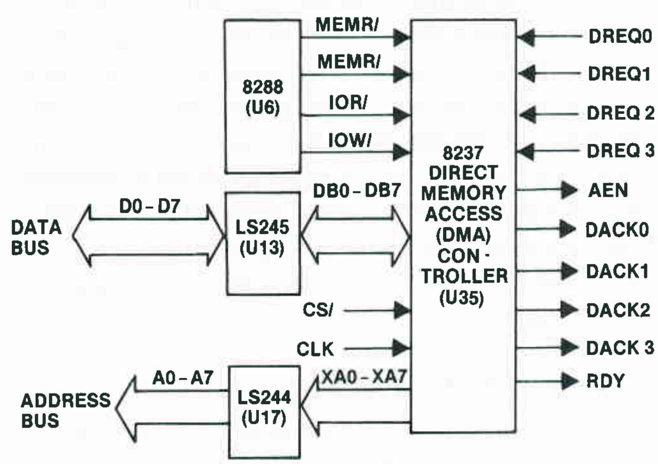


Fig. 2-27. The 8237 direct memory access (DMA) controller circuitry.

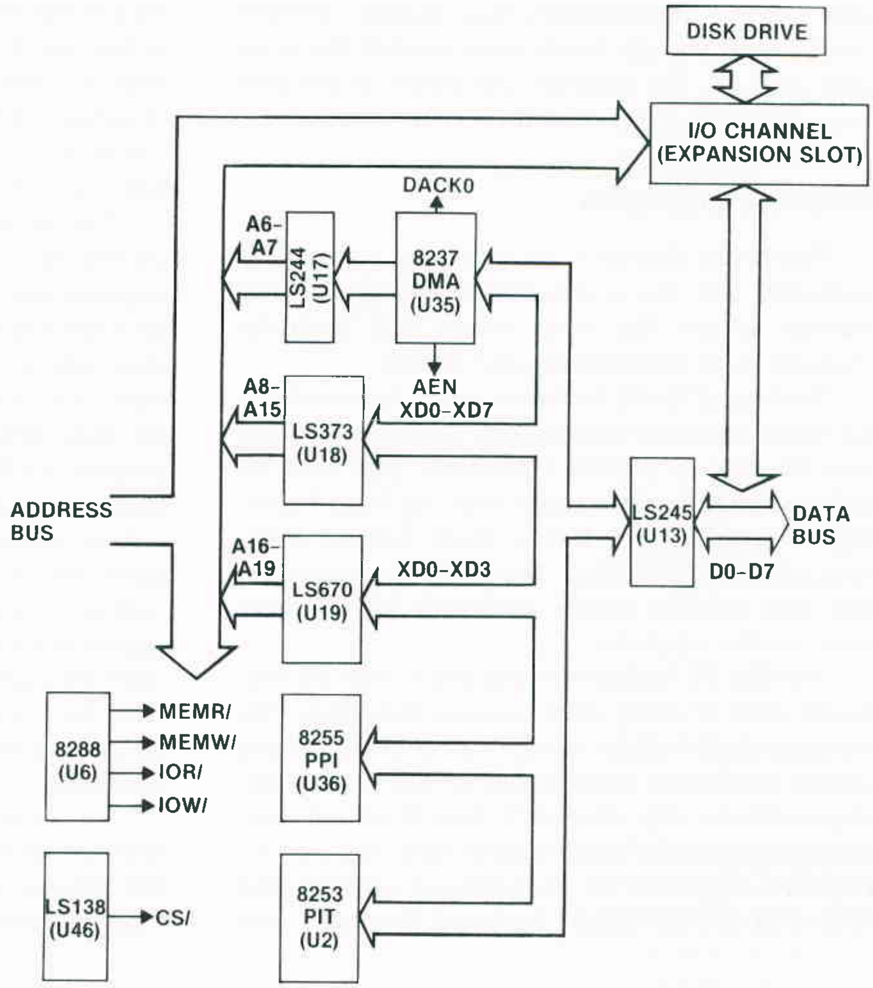


Fig. 2-28. The 8237 DMA controller interface to the I/O circuitry.

seconds. This pulse causes a flip-flop to generate a DREQ0 signal. The DACK0 response from U35 clears the flip-flop. The address placed on the address bus by the DMA chip causes some part of RAM to be accessed. The data isn't used because all the other I/O devices are disabled, but the memory was accessed, so the charges in the RAM cells are refreshed. As noted above, this occurs every 15 microseconds.

The PC is designed so DMA channel 2 is used for floppy disk data transfers. These movements of information occur at a 32-microsecond per byte rate. After the first byte transfer occurs (in five clock periods), each following byte of data is transferred in three clock periods.

Before data is transferred, the starting address and the number of bytes to be transferred are sent to U35. Then, once the data exchange has been activated, the disk drive will continue to write data to RAM until all the bytes have been sent. Once disk drive action is complete, data bus control is returned to the bus controller on the system board, and the system board lets another device use the data and address buses. The DRIVE RUN light goes out, and the program you are running continues.

Note: Some PC users purchase disk drives separately and then install these drives in their computer system. It's important to recognize that some drives must be modified in order to be used in the PC. For example, the Tandon TM100-1 drive purchased separately has six links on a jumper dual in-line package (DIP) socket that must be broken in order for this drive to function properly in the computer. If you install disk drives yourself, be aware that they may need to be modified.

Multifunction Boards

Some interesting multifunction boards have been introduced that dramatically improve the mass storage capability of the PC. One such board (JRAM from Tall Tree Systems) provides 512K of additional RAM and software that enables you to use a quad drive (four times the density) to achieve 800K of storage on one disk. Several manufacturers now market controller cards that let you use 8-inch drives or hard disk drives with your PC. The selection and variety of enhancement interfaces grows monthly.

Keyboard Operation

When you depress a character key on your PC keyboard, you see a character displayed on your monitor screen. But what causes that particular character to be displayed on your screen?

The keys of the PC keyboard have a feel much like the highly successful IBM Selectric typewriter. Besides keys standard to electric typewriters, your IBM PC keyboard includes some special keys: the Enter, Home, Page Down, Page Up, Delete, Insert, Control, Alternate, and Print Screen keys, as well as 10 function keys. IBM also provides special keyboards for computer users in other countries.

The IBM PC keyboard works better than the keyboards used on many other personal computers. The keyboard itself includes a matrix array of momentary contact pushbutton switches and an 8-bit 8048 single-chip computer with internal 2K byte ROM and associated electronics to handle control tasks. Fig. 2-29 is a simplified schematic of the keyboard circuitry. The 8048 chip of this "smart" keyboard (keyboard with built-in electronics) can scan the matrix for key-press action four to six times faster than you can press the keys to close a keyswitch. Even the simultaneous depression of two or more keys (known as cord keying) can be handled easily with an on-board processor that can scan and react this quickly.

The 83 keys on the board are connected to a 23-row by 4-column switch matrix. Each time you depress a key, you close a switch at a crossover point of an *X* row and a *Y* column on the matrix. The signal thus generated is read by the 8048 processor and converted into a special code called a "scan code" that is sent to the 8088 CPU for interpretation. Every 3 to 5 milliseconds, the 8048 scans the keyboard matrix, checking columns one at a time to see if any line is low. First, one column is scanned, and the states of the switches in each row in that column are read and stored in memory. If a switch was closed, that crosspoint (intersection of a row and column) will be at 0 voltage. The scanning continues until all four columns have been read. Each scan code is stored in a buffer within the 8048. Thus the buffer reflects the status of the entire keyboard.

But the scan doesn't stop here. Next, the array is searched for the existence of a phantom switch condition (several switches in a rectangular pattern in the matrix depressed together and falsely encoded). If two

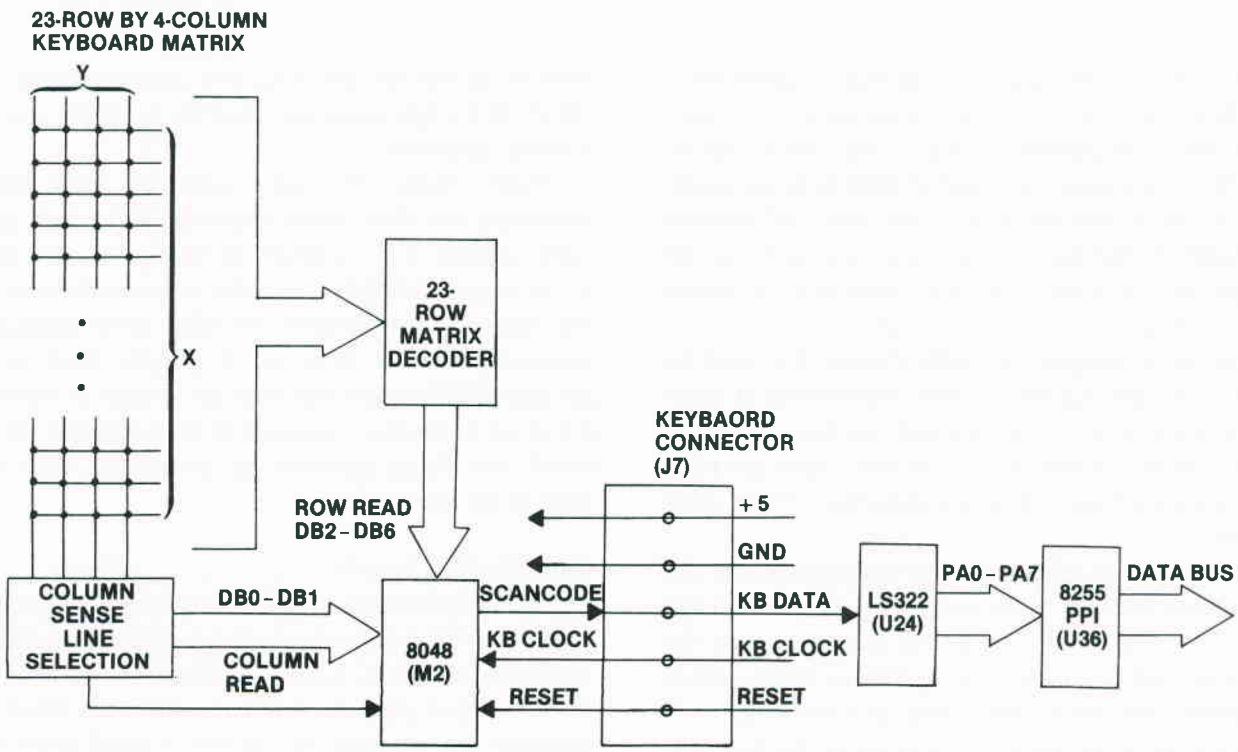


Fig. 2-29. The keyboard circuitry.

closed switches are found in the same column and one of the two rows containing the closed switch has another switch closed, a phantom switch condition has occurred. These conditions are evaluated by the 8048 and generally ignored. Only legitimate key closures (including the dual and triple key operations when one or more keys are held down while another key is pressed) are accepted. Because the scan process is performed in 3 to 5 milliseconds and there is an interval of at least 20 to 50 milliseconds between key entries, the matrix is scanned at least once every keystroke and incorrect entry is eliminated.

During the scan process, when a switch contact closure is sensed, the 8048 waits a few milliseconds to let the key closure settle out. One of the problems with mechanical switches such as keys is that they don't close cleanly. Electronically, they "bounce" several times before solid contact is achieved. This bouncing can produce noise spikes that could be interpreted as valid signals, causing such effects as four or five repetitions of a character from one key action. To counter this, the 8048 provides a short (several millisecond) delay before the key action is encoded and an interrupt is generated.

Each key action generates a unique scan code as shown in Table 2-7. Special functions and uppercase characters can be generated by depressing the Shift/Ctrl/Alt keys and one or more characters. The 8088 BIOS checks for the presence of a special key (Shift/Ctrl/Alt) signal when other keys are pressed. This signal and the character key scan code result in the special function or uppercase character generation.

The 8048 generates a scan code when a key is depressed and when the key is released. Depressing the "p" key causes the 8048 to generate the hex code 19H (00011001 in binary). When you remove your finger from the key, the 8048 generates the code 99H (10011001 in binary). Notice that only the high bit of the binary number has changed. This is the same as adding 128 (decimal) to the number. Once this code has been sent, the 8048 keyboard scan code signal drops to 0 (00H).

When you hold a key down for more than a half second, the 8048 generates the appropriate scan code 10 times each second.

The 8048 tells the PC keyboard input circuitry that it is ready to send a key scan code by producing a logic high on its KBD DATA line for 0.2 milliseconds. It then pumps out an 8-bit serial scan code, least significant bit first, each bit 0.1 milliseconds wide.

The KBD CLK signal from the 8048 to the system board is delayed and then clocked through a 74LS175 quad-D flip-flop (U26) as shown in Fig. 2-30 to produce a clock input to the 74LS322 8-bit serial/parallel-in register (U24). When the last bit of the 8-bit scan code has been serially shifted into U24, it produces a signal out its QH' line. This signal is felt on the data input to 74LS74 dual-D flip-flop (U82). When the next input clock signal from U26 is felt by U82, the flip-flop generates interrupt request signal IRQ1.

Interrupt request IRQ1 is sent to the 8259 programmable interrupt controller (U2), which generates an interrupt signal, INT. INT is sensed by the 8088 CPU.

Table 2-7. Scan codes generated by pressing the keys of the IBM PC

Key Number	Key Label	Scan Code	Key Number	Key Label	Scan Code
1	Escape	01	43	\	2B
2	1	02	44	z	2C
3	2	03	45	x	2D
4	3	04	46	c	2E
5	4	05	47	v	2F
6	5	07	48	b	30
7	6	07	49	n	31
8	7	08	50	m	32
9	8	09	51	<	33
10	9	0A	52	>	34
11	0	0B	53	/	35
12	-	0C	54	Shift	36
13	=	0D	55	Pt Sc	37
14	Backspace	0E	56	Alt	38
15	Tab	0F	57	Space	39
16	q	10	58	Caps Lock	3A
17	w	11	59	F1	3B
18	e	12	60	F2	3C
19	r	13	61	F3	3D
20	t	14	62	F4	3E
21	y	15	63	F5	3F
22	u	16	64	F6	40
23	i	17	65	F7	41
24	o	18	66	F8	42
25	p	19	67	F9	43
26	[	1A	68	F10	44
27	]	1B	69	Num Lock	45
28	Enter	1C	70	Scroll Lock	46
29	Ctrl	1D	71	7	47
30	a	1E	72	8	48
31	s	1F	73	9	49
32	d	20	74	-	4A
33	f	21	75	4	4B
34	g	22	76	5	4C
35	h	23	77	6	4D
36	j	24	78	+	4E
37	k	25	79	1	4F
38	l	26	80	2	50
39	;	27	81	3	51
40	,	28	82	0	52
41	'	29	83	Del	53
42	Shift	2A			

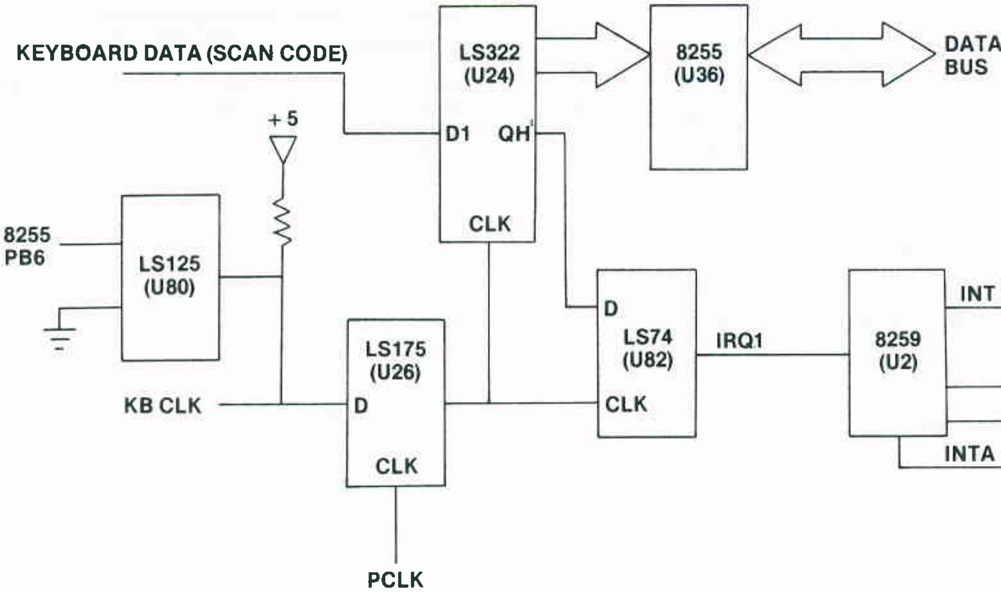


Fig. 2-30. The circuitry on the system unit that acts on each keyboard scan code.

The CPU halts what it was doing and acknowledges the interrupt request by sending a code out its S0–S2 lines to the 8288 bus controller. The 8288 responds by generating an interrupt acknowledge signal, INTA, that is sent back to the 8259 (U2). The 8259 then places an interrupt code (INT 9) on the data bus, and the 8088 CPU calls the INT 9 subroutine in the BIOS. INT 9 causes the scan code to be read into port A of the 8255 PPI (U36). The scan code is converted by the BIOS subroutine to an ASCII code for the character selected. The scan code and the character code (ASCII) are stored in a 16-character buffer. INT 9 also clears the interrupt request so another system interrupt can occur.

The ASCII character and the scan code for a single key action are read out of the buffer by another interrupt (INT 16). The INT 16 signal is called by the program or operating system. When the program you are running in your PC, or even the operating system waiting for input, requires keyboard action by you, an INT 16 is generated. It causes the BIOS to execute the keyboard I/O subroutine. Keyboard I/O reads through the keyboard buffer until it finds a character code. Then it places each code (ASCII and scan) into an 8088 register. The subroutine then reads the status of the data to determine if any special keys (Ctrl, Alt, or Shift) were pressed. Finally, it sends the ASCII character code to the calling program. The calling program uses the character as a character string or data input for its use and passes the character to the active output device (screen or printer) so you can see what character was depressed. Through programming, this last step can be skipped so that you can't see what key was depressed. This technique is used for entering passwords.

The Speaker

Fig. 2-31 illustrates how your speaker is able to make sounds. As shown, the speaker is software controlled. Whenever your program addresses 0061H, port B of the 8255 PPI (U36), a logic 1 in bit 1 (PB1) of the port can be used to turn on the modulating signal to the speaker. This lets the OUT 2 signal from the 8253 programmable interval timer (U34) combine with the enable from U36 in the 74LS38 quad 2-input NAND buffer (U63). The output from U63 is passed to the

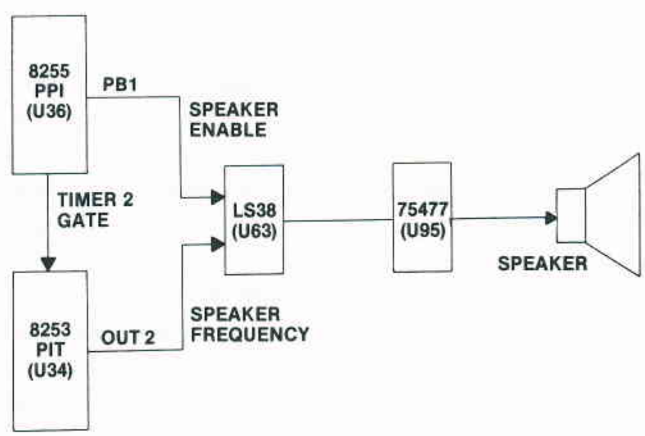


Fig. 2-31. The speaker circuitry.

75477 relay driver (U95). Each change is amplified by U95 to move the cone of the speaker in or out, producing an audible click.

By varying how often and how fast you cause these clicks, you can make your PC produce arcade sounds, music, and even crude speech. The frequency of the pulses out of the U34 timer controls the pitch (frequency) of the sound produced by the speaker. You can also control the speaker by varying the enable (ON/OFF) signal from the 8255 PPI (U36) or by varying the clock input to the 8253 timer (U34).

The range of frequencies you can generate depends on how you program your machine. If you write your program in BASIC, you can generate frequencies up to about 1000 Hz. By programming in machine language, you can easily cover the entire audio band (300 to 3000 Hz).

Your PC's BIOS ROM does not support speaker sounds. It doesn't have a general service routine stored in it that, when addressed (called by your program), will click the speaker at a certain frequency. Each speaker action must be provided by the program that is running.

The Game Control Adapter

This interface is an interesting and useful window to the PC. It lets you connect two joysticks or up to four game paddles to the system via an adapter card that plugs into an expansion slot.

As shown in Fig. 2-32, there are eight input lines available on the 15-pin D connector on the adapter card. Four of the lines are digital inputs. The other four input lines are resistive, or analog, inputs.

A joystick connection is shown in Fig. 2-33. In the figure, two joysticks are connected to the 15-pin D connector so that the *x*-coordinate inputs enter on pins 3 and 11. Likewise, the *y*-coordinate inputs enter on pins 6 and 13. Each input is produced from a 100K variable potentiometer built into the joystick. The pushbutton, or "fire" button, inputs enter on pins 2 and 10.

Together, the resistive (*xy* coordinate) and pushbutton inputs form an 8-bit data word that can be read by addressing location 00201H. The input pins of the D connector can be related to the 8-bit port 201H data word as shown in Fig. 2-34.

The game control adapter circuitry is shown in Fig. 2-35. Both hardware and software are required to use the game control adapter. The software sends a triggering signal to the adapter with an OUT to port 201H (513 in decimal). The adapter circuitry responds by setting the resistance input pins (pins 3, 6, 11, and 13) to a

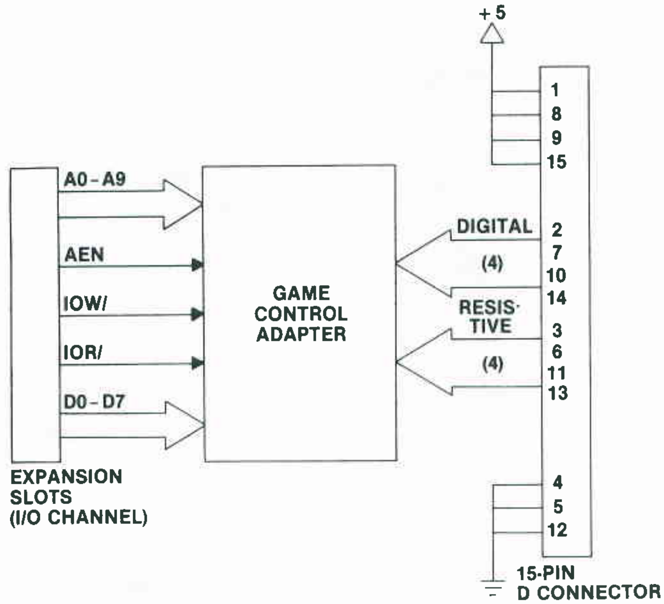


Fig. 2-32. Eight input lines connect to the game control adapter plugged into one of the expansion slots.

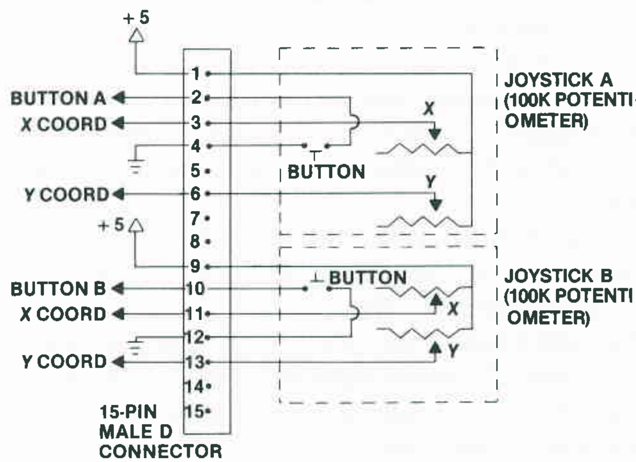


Fig. 2-33. The pin signals for connecting a pair of joysticks to the game control adapter connector.

		D CONN. PIN ASSIGNMENTS	FUNCTION	
DIGITAL INPUTS	BIT 7	14	BUTTON 2	JOYSTICK B
	BIT 6	10	BUTTON 1	
	BIT 5	7	BUTTON 2	JOYSTICK A
	BIT 4	2	BUTTON 1	
RESISTIVE INPUTS	BIT 3	13	Y COORD	JOYSTICK B
	BIT 2	11	X COORD	
	BIT 1	6	Y COORD	JOYSTICK A
	BIT 0	3	X COORD	

(ADDRESS 00201 H)

Fig. 2-34. The relationship of pin assignments to data bus bits.

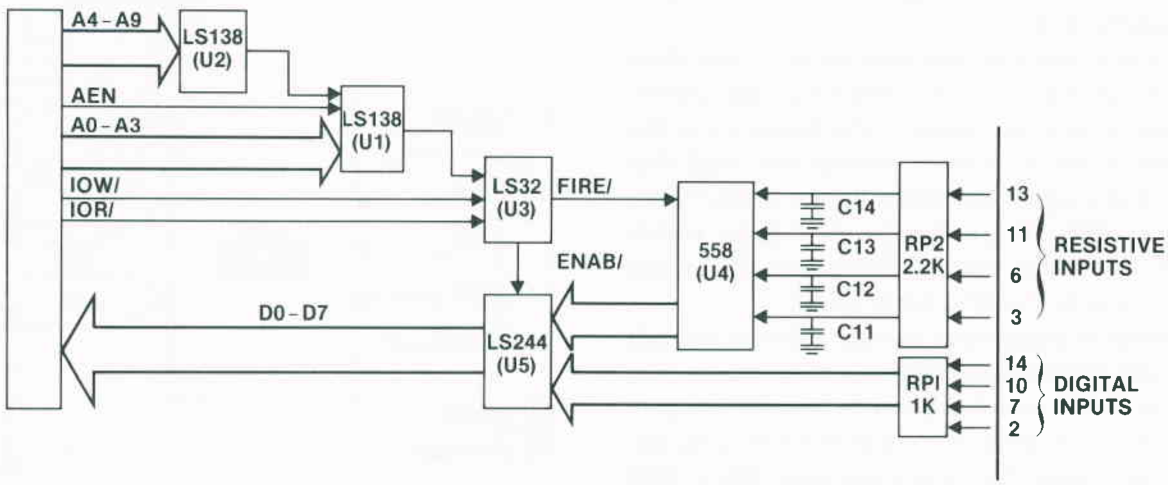


Fig. 2-35. The game control adapter circuitry.

logic 1 for a time period proportional to the amount of resistance on each of these lines.

The program performs a loop polling of port 201H to determine how long it takes for the logic 1 in each of the four connected resistive input bits to return to 0. The number of times the loop is made is directly proportional to the resistance setting in the joystick (or paddle).

The value of resistance set on the 100K ohm potentiometer (pot) in one analog input is part of a timing circuit composed of the 100K ohm pot, a resistor, a capacitor, and a part of the NE558 quad timer (U4). U4 is simply four 555 timers together in one chip package. When the 558 is triggered by addressing 00201H, all four outputs from it are set HIGH and the timing circuit begins to count down. This level remains HIGH for a time period determined by the setting of the potentiometer for each paddle.

A routine in the game program can repeatedly check to see if the timer output is still HIGH. It does this by reading address 00201H (IN 00201H). When it does so, the 74LS244 tri-state octal buffer (U5) places a byte of information on the data bus. The logic levels of each of the four lowest bits in this byte can be read by the program. These levels represent the state of each timer output of U4. A bit is HIGH or 1 as long as the timer is counting down. A counter in the program keeps track of how many times the timer is checked before its output changes to LOW, or 0.

When a 0 is read, the program stops counting at a value (between 0 and 255) directly proportional to the setting of the paddle potentiometer.

Pushbutton switches can also be read using the same technique. In this case, the upper four bits of the 8-bit data word can be read by the program. If a bit is LOW (logic 0), that pushbutton has been depressed. Likewise, a 1 in this position means that the button is open (not depressed).

In this manner a program can loop through a subroutine to continuously monitor the pushbuttons. The program can be written to act only when a button has been depressed.

Keep in mind that these pushbuttons are not "debounced." When you press a button, the switch will likely bounce several times before it settles down, so the computer must take several readings of each switch input (using IN 00201H) before acting on the switch closure.

THE POWER SUPPLY

As described on pages 1-24 through 1-27 in the *IBM PC Technical Reference Manual*, a switching power supply provides four voltages to the PC circuitry: +5.0 volts, −5.0 volts, +12.0 volts, and −12.0 volts. The maximum power dissipation is 63.5 watts, less than that of a 100-watt room lamp.

The switching power supply is described in Fig. 2-36. The +5.0 volts is used by the logic chips on the system board, the disk drive electronics card, and the adapter cards that are installed in the expansion slots. The −5.0 volts is used in the dynamic RAM chips. The +12.0 volt supply is used by the dynamic memory chips and the disk drive motors. Both +12.0 volts and

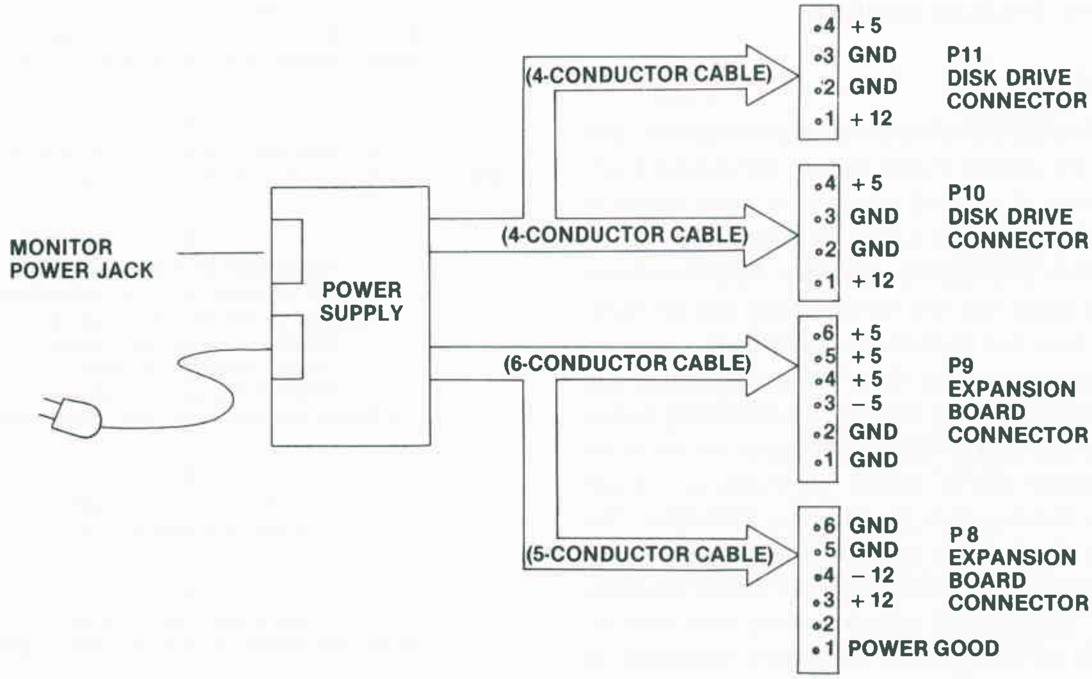


Fig. 2-36. The power supply circuitry.

− 12.0 volts are available to power the circuitry on the communication adapter card. All of these voltages are available on the I/O connectors, expansion slots J1 through J5.

The switching power supply is enclosed in steel and has a cooling fan mounted directly under its top cover as shown in Fig. 2-37. It has a built-in circuit breaker that automatically resets in a few seconds after the breaker has tripped.

The female connector in Fig. 2-38 provides power to the IBM monochrome display unit.

Because power supplies rarely fail and because this guide avoids getting you into or around high-voltage circuits, I won't discuss troubleshooting the power supply. It is best to leave power-supply problems to an experienced repair technician. IBM discourages anyone from troubleshooting the switching power supply except experienced, IBM-trained technicians. The reference manual does not even provide schematics or detail on the design and operation of the power supply.

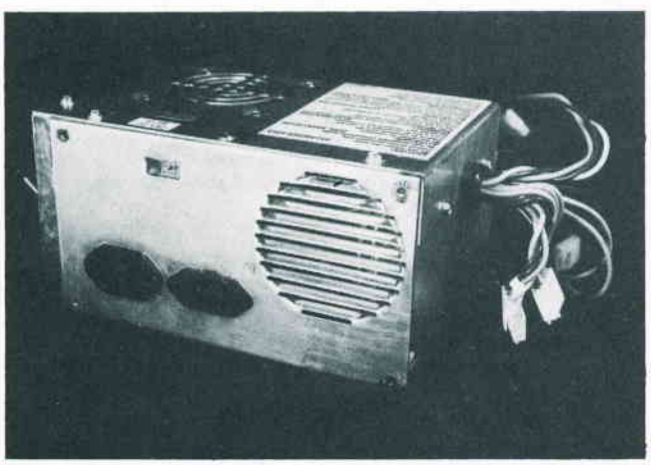


Fig. 2-37. The IBM PC power supply.

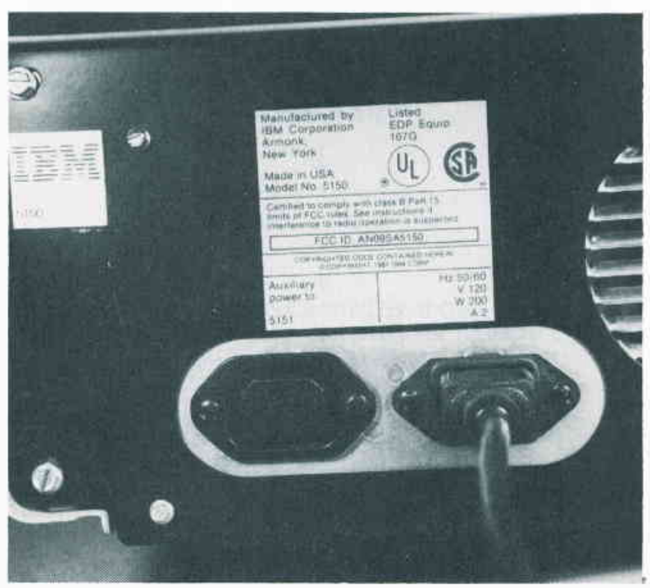


Fig. 2-38. A special connector provides power to the IBM monochrome display unit.

HOW THE SYSTEM WORKS

Cold Boot

When you turn on the power to your monitor, and then press the rocker switch to turn the machine on, your PC beeps at you and asks you to insert a disk in drive A. When you slip a disk into the drive, gently close the door, and depress the Enter key, the screen flashes and prints out the familiar IBM sign-on statement. You have just performed a cold boot.

What does it mean to "boot up" a disk? When you first apply power to your IBM PC, the switching power supply puts out a POWER GOOD signal to the 8284 clock generator (U11), which generates a +5-volt RESET pulse that is sent to pin 21 of the 8088 CPU. This signal starts the boot-up routine. It's called a "cold" because the system was not energized before the boot, and "boot" because the system is being reset and initialized with all the start-up conditions necessary to operate and enable the man-machine communication interface (the word "boot" comes from "bootstrap," and refers to the computer's pulling itself up by its own bootstrap). The bootstrap in your IBM PC is in the BIOS ROM. It is a program-starting program, so to speak.

The following flowchart shows the actions that occur in your IBM PC during a cold boot, from the time you turn on the power.

THE POWER-UP PROCESS

APPLY POWER.

↓

POWER SUPPLY SENDS "POWER GOOD" SIGNAL TO U11.
CLOCK STARTS.

↓

+5V RESET PULSE IS PLACED
ON PIN 21 OF 8088 CPU.

↓

DS, ES, SS, AND IP REGISTERS ARE CLEARED (SET TO 0).
CODE SEGMENT REGISTER (CS) IS SET TO ADDRESS 0FFF0H
(address of first instruction)

↓

CPU EXECUTES FIRST INSTRUCTION—
JUMP TO POWER-ON SELF TEST.

↓

INTERRUPTS ARE DISABLED.

↓

CPU FLAGS ARE SET.
READ/WRITE TEST OF CPU REGISTERS OCCURS
(write a pattern, verify correct pattern read back).

↓

PERFORMS CHECKSUM TEST OF BIOS ROM
(test sum of bytes in certain BIOS locations with known stored value).

↓

INITIALIZES PROGRAMMABLE
DIRECT MEMORY ACCESS (DMA) CHIP
(verifies correct 8237 timer operation;
initializes timer for RAM refresh;
writes a pattern to all registers;
verifies correct pattern read back;
initializes registers; starts DMA RAM refresh).

↓

TESTS FOR WARM START
(if YES, skip memory test).

↓

TESTS FIRST 16K OF RAM
(writes five patterns to memory; verifies correct).

↓

INITIALIZES 8259 PROGRAMMABLE INTERRUPT CONTROLLER
(sets up interrupt vectors;
tests interrupt controller;
conducts write/read test of interrupt mask register;
masks interrupts; verifies that none occur).

↓

TESTS 8253 TIMER FOR PROPER COUNT SPEED.

↓

INITIALIZES AND STARTS 6845 CRT CONTROLLER
(reads system board switch for display type;
sets video mode;
conducts write/read test of video RAM).

↓

DISPLAYS CURSOR.

↓

TESTS TO SEE WHETHER EXPANSION BOX IS INSTALLED
(if installed, performs write/read test on address
and data busses).

↓

TESTS ADDITIONAL RAM
(performs write/read test of all RAM above Bank 0).

↓

TESTS KEYBOARD
(sends software RESET to keyboard electronics;
enables keyboard; verifies scan code (0AAH) returned is correct;
clears keyboard; verifies no keys stuck—no scan code;
sets up interrupt-vector lookup table).

↓

TESTS CASSETTE INTERFACE
(performs write/read test to cassette data bus).

(Continued)

↓

TESTS OPTIONAL ROM (C8000H–F4000H)
(if CHECKSUM installed, performs this test).

↓

TESTS ROM CONTAINING CASSETTE BASIC
(performs CHECKSUM test).

↓

TESTS FOR INSTALLED DISK DRIVE
(checks system board DIP switch).

↓

TESTS PRINTER AND RS-232 PORT
(performs write/read test to printer port;
stores addresses of valid ports;
sets time-out values for printer and RS-232 ports).

↓

ENABLES NMI INTERRUPTS.

↓

BEEPS SPEAKER.

↓

PERFORMS INTERRUPT 19H (DISK DRIVE)
(if disk drive is attached, passes control to Boot Record;
if no disk drive is attached, passes control to Cassette BASIC).

↓

WAITS FOR KEYBOARD COMMAND ACTION BY YOU.

The rest is up to you. The system will sit and wait until your interaction with it via the keyboard tells it what to do. The PC has beeped at you and the disk drive may be spinning. If you have a system disk in the drive, the Boot Record is loaded into memory. The Boot Record is a simple, short program found on Track 0, Sector 1 of each program disk. It loads the IBMBIO.COM and IBMDOS.COM programs into RAM. These are hidden programs, which, with the ROM BIOS, form the basis of the disk operating system (DOS). You will be prompted for the date and time, and then the following message will appear:

The IBM Personal Computer DOS
Version 2.00 (C)Copyright IBM Corp
1981,1982,1983

The message will be slightly different if you are using a different version of DOS.

If you don't have a disk drive installed or didn't have a system disk in your drive when you pressed ENTER, the BIOS will automatically default to ROM-based Cassette BASIC and await your keyboard command. With Cassette BASIC, you will receive this message:

The IBM Personal Computer BASIC
Version C1.00 Copyright IBM Corp 1981
62940 Bytes free

Warm Boot

During the bootstrap operation, the BIOS monitor checks to see whether the system had been energized and was being used when the RESET pulse occurred. If indeed it had been powered up, all of the RAM tests described for a cold boot are bypassed.

Holding the Ctrl and Alt keys down and then depressing the Del key generates a nonmaskable interrupt (NMI). This causes a system reset to initial conditions. The Power-On Self Test (POST) is performed, but the RAM tests are bypassed.

SOFTWARE STRUCTURE

Three types of software are supplied with your disk drive IBM PC computer system:

- The system monitor
- BASIC high-level language
- The disk operating system (DOS)

The **system monitor** lets you initialize your computer and enables it to receive keyboard entry and to generate screen display. The system monitor resides in the BIOS ROM.

Each IBM PC comes with the **high-level language** Cassette **BASIC** stored in ROM. BASIC is an *interpreted language*. Each instruction is read, interpreted, converted to machine language code, and acted upon before the next instruction is read, and so on. In contrast, with a *compiled language* such as FORTRAN, all the instructions are read, interpreted, and converted into machine language before any are acted upon. Compiled-language programs run faster than interpreted-language programs. However, BASIC is a popular programming language because it is simple to learn. Several youthful entrepreneurs have become millionaires writing useful software in BASIC.

In addition to ROM-based Cassette BASIC, two extended versions of BASIC are available on the DOS disk. These programs complement and enhance the Cassette BASIC commands.

The third ingredient for a complete software system is a unique software package designed to control the way the computer communicates with peripheral equipment and other software programs. This package is called an **operating system**. Some of the operating systems in use in microcomputers today are DOS, PRO-DOS, MS-DOS, PC-DOS, TRS-DOS, RTX, CP/M, and CP/M-86.

On the IBM PC, your operating system is called *PC-DOS*, for Personal Computer Disk Operating System. You can also use Microsoft's MS-DOS. Both control programs came from the same beginnings. Your IBM PC disk operating system (PC-DOS) handles reading and writing disk-stored information and lets you format disks, copy disks, and even catalog the programs or files you've saved. PC-DOS is loaded into the PC's RAM by booting the system up with a disk containing the operating system. PC-DOS uses approximately 10K of RAM.

Sometimes neophyte programmers forget where PC-DOS is stored and inadvertently write programs that store different values in the DOS-reserved area. This changes the values in DOS, which causes trouble— usually at the most inopportune time.

A multitude of applications programs are available for the IBM PC. In reality, the software makes the machine, and many new and exciting software packages for the IBM PC are coming to market each month.

SUMMARY

In this chapter you've learned the basic parts of a computer and how the hardware of your IBM PC works. You saw that memory, I/O, and the CPU all perform vital functions in this computer system. You learned what happens inside the IBM PC when you turn power on. And you learned that several kinds of software are required to make your PC a functioning system.

CHAPTER 3

Basic Troubleshooting

Like automobiles, computers break down after lots of use. Some break down sooner than others. Finding out what broke can be easy or difficult, depending on your understanding of how to analyze a problem, identify the failed part, and step toward the correct repair. This chapter will show you how to find problems in your IBM PC in the shortest amount of time.

INTRODUCTION TO TROUBLESHOOTING

Imagine for a moment that you're in the midst of printing a lengthy analysis report when suddenly the printer halts, the screen display goes blank, and your IBM PC ceases to function. What do you do? What failed?

This chapter is devoted to a subject we often wish we could pass off or ignore—trouble. Trouble is like a flat tire: no one wants one, but when it occurs we all wish we could fix it quickly and get the experience behind us. Knowledge and action are required to overcome trouble.

You know from reading the owner's manual that came with your computer, that it's a digital machine; it operates in binary, where every condition is either true (logic 1) or false (logic 0). A digital computer such as the IBM PC generally doesn't break down slowly, with graceful degradation you can see. If it fails, it's usually with a hard, consistent failure.

The digital devices that make up your IBM PC function within strict rules of logic. The most effective way to respond to a failure in these devices is to think the problem through just as the machine operates, logically. Understand what should be happening and compare the "shoulds," one by one, with what is really happening.

An interesting deductive technique called *troubleshooting* is particularly appropriate for solving digital equipment failure problems. But troubleshooting could be a really frustrating experience if you were left to struggle through the process by yourself without a good guide. This book provides you with techniques for quick and easy troubleshooting and repair.

Steps To Successful Troubleshooting

Effective and efficient troubleshooting requires gathering clues and applying deductive reasoning to isolate the problem. Once you know the cause of the problem, you can follow a process of analyzing, testing, and substituting good components for each suspected bad component to find the particular part that has failed.

The use of special test equipment such as logic probes and logic clips can speed the analysis process, but for most failures brain power by itself will suffice. Once the problem has been isolated to a particular group of chips, deductive analysis changes to intelligent trial-and-error replacement. Reducing the number of suspected chips to just a few and using intelligent substitution is the fastest way to identify the faulty device in the least amount of time.

In general, you can follow these steps to success when your computer fails:

1. Don't panic.
2. Observe the conditions.
3. Use your senses.
4. Retry.
5. Document.
6. Assume one problem.
7. Diagnose to a section (fault identification).
8. Consult the symptom index (error code interpretation and problem matching).
9. Localize to a stage (fault localization).
10. Isolate to a failed part (fault isolation).
11. Repair.
12. Test and verify.

The steps to troubleshooting success are discussed in detail later in this chapter.

The Troubleshooting Process

Every computer is composed of the functional sections shown in Fig. 3-1. Any of these sections can fail.

When something goes wrong, the first step is to determine whether the trouble results from a component failure or just a loose connection or human error. Once you're sure a failure has occurred, the next step is to determine which functional section of the system is not operating—disk drive, keyboard, display, or some other part.

Then, step by step, break each section up into stages and try to track the trouble to a single component. If a display isn't working, for example, the problem could be in the display monitor itself, in the video cable, or in the video circuitry of the computer. Each of these can be considered a stage of the video display functional section.

Next, to troubleshoot your computer, you need to recognize the components of your IBM PC and understand how it interacts with the other parts of the system.

COMPONENT RECOGNITION

What's an IBM PC made of? Let's take a look.

That strong housing, or case, and the detachable keyboard are made of high-strength, flame-retardant molded plastic. These cases are not likely to fail under normal use. The trouble is much more likely to come from inside the cases.

Make sure the power is off and open your IBM PC computer. Use the disassembly instructions found in the Appendix.

There are a number of subassemblies inside your computer, including the system board, or motherboard, the disk drives, the input/output unit, and the power supply. Let's concentrate on the system board, since this is where most failures occur.

The motherboard (shown again in Fig. 3-2) is made of fiberglass and has many colorful devices mounted on it—sockets, connectors, and wire traces embedded into the board, integrated circuits (or chips), resistors, capacitors, and transistors.

Fig. 3-3 shows the types of devices that you will find mounted on the motherboard. The values indi-

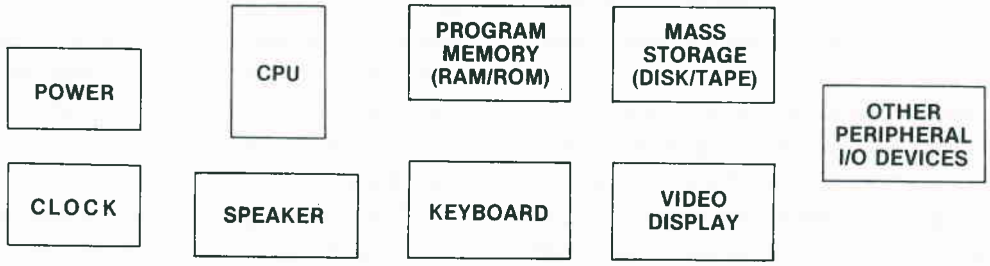


Fig 3-1. The functional units of the IBM Personal Computer.

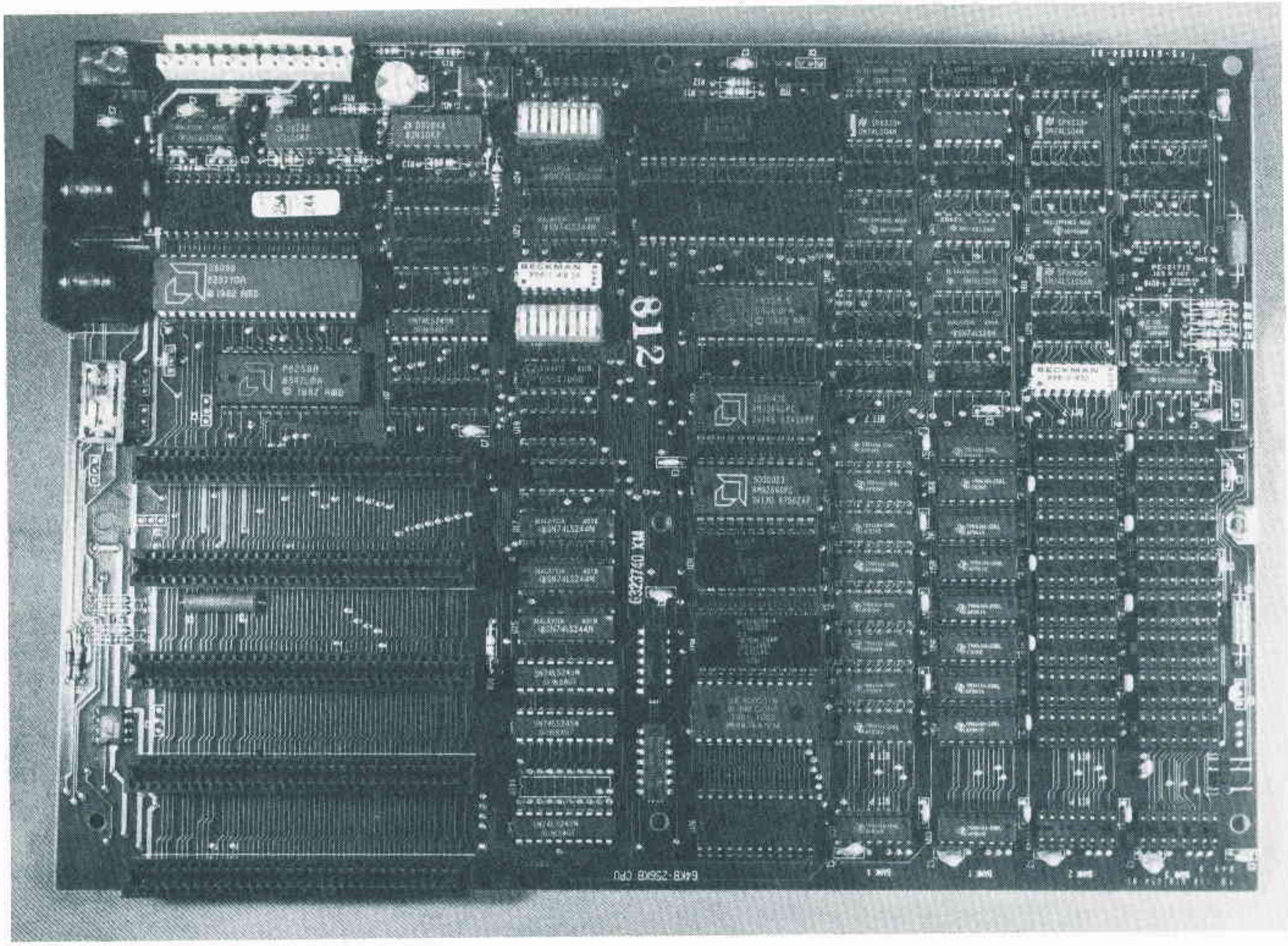


Fig. 3-2. The IBM PC system board.

cated in the figure are the actual values of components on the IBM PC system board or the color/graphics adapter board.

Chips

Those black-cased, centipede-looking things are the *chips* (see Fig. 3-3A). They serve the function of hundreds of transistors (or vacuum tubes, the predecessors of transistors), and cause the computer to work logically. The IBM PC is a Von Neumann machine: it works in binary digits (bits). All conditions are either ON (logic 1) or OFF (logic 0), and all operations occur in sequence. Dr. John Von Neumann first described his idea of a binary computer in 1945.

There are eight sizes of chips on your motherboard: 8-pin, 14-pin, 16-pin, 18-pin, 20-pin, 24-pin, 28-pin, and 40-pin. The ROMs in your IBM PC are custom chips. IBM placed some of these chips in sockets, so repair is quick and easy with no unsoldering and resoldering.

Notice how each chip has a notch or groove at one end as shown in Fig. 3-4. This notch marks the end of the chip where pin 1 can be found. Pin 1 is to the left of the groove as you look down upon the top of the chip with the groove pointed away from you. The pins are numbered counterclockwise starting from pin 1, so that the highest-numbered pin is directly across from pin 1. As you'll learn later, in chip replacement you must insert the new chip into the socket with pin 1 in exactly the right place.

Chips have special markings that tell a lot about what's inside. Look at the printing on the tops of the chips on your IBM PC's motherboard. First, you'll notice that many different companies make chips, and that some of these companies are outside the United States—in Brazil, El Salvador, Indonesia, Korea, Malaysia, Mexico, Singapore, and Taiwan, for example. Most companies place their logo on the chip. Some of

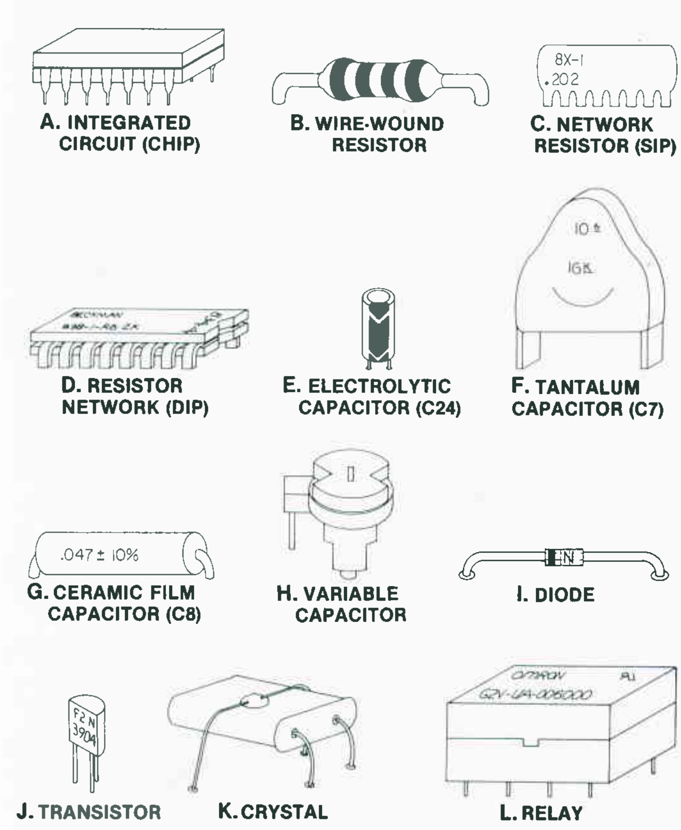


Fig. 3-3. The types of devices found on the system board.

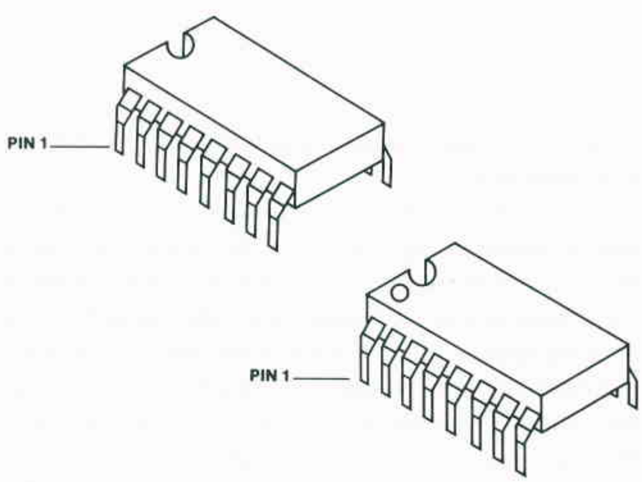


Fig. 3-4. Locating pin 1 on integrated circuits (chips).

the logos represented on your IBM PC chips are shown in Fig. 3-5.

You'll also notice letter-number combinations on the chips. Some chips have two sets of letter-numbers. One set identifies the type of device, and the other set tells when the chip was made. The first, or primary, set

ADVANCED MICRO DEVICES

FAIRCHILD

IBM

INTEL-AMD

MOTOROLA

NATIONAL

TEXAS INSTRUMENTS

Fig. 3-5. Representative logos that can be found on chips mounted on the system board.

of letter-numbers is called the *manufacturer's type number*, or *manufacturer's device code*. It appears in three sections as shown in Fig. 3-6.

The prefix ("DM" in DM74LS125AN) is usually used to identify the manufacturer, although sometimes it is used to identify the device family (also associated with a manufacturer) or a temperature range (N = commercial temperatures, S = military temperature requirements). The prefix is sometimes omitted. In Fig. 3-6, the DM represents the National Semiconductor company.

The core number is three to six digits long with a letter or letters in the middle. It indicates the basic logic family. Most of the chips in the IBM PC are of 74*xx* series; these chips use TTL logic (transistor-transistor-logic). The core number 74LS125 represents a quad tri-state buffer. The letters in the middle of the number describe particulars about the logic used in the chip, such as speed or power. In Fig. 3-6, the LS stands for *low power Schottky*, a particular type of TTL logic design.

PREFIX	CORE	SUFFIX
D M	7 4 L S 1 2 5	A N

S P 8 4 0 7

Fig. 3-6. A representative manufacturer's device code.

The suffix represents the package type or temperature range. Usually it describes the package type. In Fig. 3-6, the AN denotes a dual in-line package (DIP), a type of chip. Other package types include the flat-packs, single in-line packages (SIPs), and leadless chips.

The second letter-number combination on a chip varies with the manufacturer and the year and week the chip was made. For example, the SN74LS245N (U12) is a tri-state octal transceiver made by Motorola. Numbers such as 8407 are printed below the manufacturer's device code. The number 8407 represents the seventh week in 1984, the date of manufacture of this chip. Likewise, a chip at U27 on the IBM PC motherboard marked 74LS74 and 8347 is a quad 2-input NOR gate manufactured by Fairchild in the forty-seventh week of 1983.

All the chips on the IBM PC motherboard are listed in the Appendix.

Resistors

The three types of *resistors* found in the IBM PC circuitry are shown in Fig. 3-3B, C, and D. Resistors are used to restrict or limit the flow of electrical current through the board's circuitry. One type of resistor is the cylindrical wire-wound device shown in Fig. 3-3B. The value of resistance is given in ohms, and can be determined by comparing the color bands with the colors in Table 3-1.

Table 3-1. Resistor color code chart

Color	Digit	Multiplier
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1000
Yellow	4	10000
Green	5	100000
Blue	6	1000000
Violet	7	10000000
Gray	8	100000000
White	9	1000000000
Gold	± 5% tolerance	
Silver	± 10% tolerance	

For example, R1, located just above the expansion slots on the system board, has the color code brown-gray-yellow-gold. The first two bands describe the primary number (18). The third band represents the number of zeroes to add to the primary number—in this case four. The last band is the tolerance value, or how close to the color band value the actual value must be. The gold band represents a 5 percent tolerance value. Thus, by using Table 3-1, we find R1's value to be 180,000 ohms (180K ohms); the actual resistance value is ±5 percent. This matches the value given on schematics of the IBM PC.

A recently developed electronic device, the *resistor network*, is actually a group of resistors built into a single in-line package (SIP) or a dual in-line package (DIP) (see Fig. 3-3C and Fig. 3-3D). Several SIP resistor networks are mounted on the board. These resistors are designated RN*xx* or RM*xx*.

Fig. 3-3C shows an SIP network resistor like the one labelled RM1 located at the top left end of the color/graphics card. Resistor network RM1 is used by several components on the board at the same time.

The resistor shown in Fig. 3-3D is a DIP network resistor, RN2, located near the right end of the third row of chips on the system board.

The resistance designation of a network resistor is printed on the side of its package. RM1 on the color/graphics card is marked 8X-1 202. The 202 is a key to the resistance value in ohms. The first two numbers (2 and 0) are the significant figures. The third number (2) tells how many zeroes to add to the significant figures. Thus, 202 means 20 plus 2 zeroes, or 2,000 ohms (2K ohms).

Some network resistors, such as RN2, are marked directly with their resistance value. RN2 on the system board is marked 898-1-R8.2K. The "8.2K" labels this resistor network as a group of 8.2K ohm resistors.

Capacitors

In addition to chips, your motherboard has mounted on it a number of devices called *capacitors* (Fig. 3-3E, F, G, and H). Capacitors receive and store an electric charge. They come in four varieties: (a) electrolytic, (b) tantalum, (c) ceramic film, and (d) variable. All four types of capacitors can be found on the IBM PC motherboard and the color/graphics card.

Capacitors are measured in fractions of farads. You'll see values listed in "Mfd" (for microfarads) and "p" (for picofarads). *Micro* means "to the sixth decimal place" or 0.000001 (one millionth), and *pico* means "to the twelfth decimal place" or 0.000000000001 (one trillionth). Thus 0.022 microfarads means 0.000000022 farads, and 47 picofarads means 47 trillionths of a farad.

Capacitor (cap) value identification is one of the most challenging tasks you can encounter because most companies like to use their own identification standards. On the side of tantalum capacitor C7 located in the middle of the upper two-thirds of the system board are the numbers "10^6" and "16K." This means that C7 is a 10-microfarad capacitor and is rated at 16 volts.

Ceramic film capacitor C8 between the J3 and J4 slots on the system board has the value ".047 ± 10%" stamped on it. It's easy to see that this is a .047 microfarad capacitor. Other ceramic film capacitors are color-banded. These can be decoded using the color chart in Table 3-2. They have two more color bands added that refer to the capacitor's temperature dependence and tolerance. Capacitance varies with temperature (and to some extent with the cap's size and the applied voltage). The temperature dependence of the capacitance value is given as the coefficient parts per million per degree Celsius (PPM/C). Tolerance defines how much variation is permissible between the actual value of the capacitance and the nominal capacitance value.

Table 3-2. Capacitor color codes indicating capacitance in picofarads.

Color	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7		
Gray	8		
White	9		10%
Gold			5%
Silver			10%

An electrolytic capacitor has a polarity marked on its case. Usually, the negative pole is indicated with an arrow marking. Electrolytic capacitor C24 on the color/graphics card has a rating of 4.7 microfarads.

At the right side of the system board is a variable capacitor used to adjust the color signal. It does this by changing the frequency of the basic system clock in the 8284 clock generator chip. This capacitor can be varied between 5 and 30 picofarads.

Diodes

Diodes are tiny, usually glass devices shaped like resistors (Fig. 3-3). They permit the flow of electrons in only one direction. Diodes are marked with printing on the side (although most of the time you'll have a tough time reading it). There are several diodes on the motherboard. The key to determining whether the device in question is a diode is the glass construction and the label on the side. A 1Nxxxx label denotes a diode. Look at D1, located at the top of the system board—it's right above the expansion slots. D1 is called a "type FC" diode. This classifies it as a standard diode, much like a 1N4001 diode. D1 is part of the voltage regulation circuitry for the cassette DATA IN signal being applied to the input port of the 8255 PPI.

Transistors

The half-moon-shaped device on the color/graphics card is a *transistor*. Transistors are small, semiconductor-based devices that control the flow of electricity. The key to recognizing a transistor is its 2Nxxxx designator. Fig. 3-3J is a drawing of the transistor at Q1. On the side of it is printed F2N3904. The 2Nxxxx label tells us it's a transistor. We can look up this transistor in a parts catalog and find that the 2N3904 transistor is a general purpose device.

Crystals

A crystal is a device that vibrates or oscillates when a voltage is applied across two of its input leads. The shiny metal can on the right edge of the motherboard next to U26 is a crystal. The oscillation frequency of a crystal is determined by the physical characteristics of the crystal material inside the metal can. The can acts as a shield for stray electrical signals. Crystal X1 (Y1 on some boards) oscillates at 14.31818 MHz. This frequency is reduced by circuitry on the motherboard to produce the various clock signals used in your IBM computer.

Relays

A relay is an electromagnetic or solid-state device that isolates sensitive circuitry (such as your PC's motherboard) from different or higher-voltage circuitry (such as cassette motor circuitry).

At the rear of the IBM PC motherboard, to the right of slot 5 and outside the 8259 programmable interval timer, is a rectangular device called relay K1. It is used to control the MOTOR ON/MOTOR OFF signals in a cassette recorder if one is connected to your PC. A signal on the motherboard passes through K1, causing its output contacts to close, turning on the cassette recorder motor just as though a switch had been flipped. The relay acts as an electrically controlled switch.

Replacements

When you check the electronic parts catalogs, you'll find that the components presented here have prices that will pleasantly surprise you. Since 95 percent of microcomputer failures are chip failures, introducing the capacitors, resistors, diodes, and transistors serves only to familiarize you with what is on your IBM PC motherboard. These devices are soldered into the board and can be replaced only by those experienced in repair. Chip replacement is probably as far as you'll want to go in computer repair. You should probably let a repair technician replace the soldered-in components.

COMPONENT FAILURES

While the use of troubleshooting equipment makes it easier to analyze and isolate different computer problems, many failures can be found without expensive equipment. In fact, troubleshooting and repair can be relatively simple if you understand how electronic components fail.

Failures generally occur in the circuits that are used or stressed the most. The most frequently used chips include the RAM and ROM memory chips, the 8088 CPU, and the input/output (I/O) chips between the motherboard and the disk drive. The CPU is a highly reliable device and doesn't fail very often. Most failures involve the other chips. Except for the ROM chips, which are programmed by IBM, most of these other chips are standard, off-the-shelf devices and are so common they've earned the nickname "jelly beans"—inexpensive, easy-to-replace products.

Transistors and diodes fail by disconnecting inside, which causes an open, or break, in the circuitry, or by having their output shorted. Either kind of failure causes a total loss of signal.

Capacitors fail when they short internally or when one of the leads disconnects, causing an open circuit. Again there is a loss of signal.

Resistors can absorb too much current and actually bake. The result is usually an open circuit with shorting during the "melt-down."

All of the devices mentioned so far are solid-state components. They are constructed of materials (metals, plastics, oxide, etc.) that change as the components age or are subjected to severe temperatures or high voltages. Such a change can cause the device and the circuit or system to behave strangely. Fortunately, IBM PC motherboards are not subjected to high voltages. But they can get pretty hot (especially if you fill the expansion slots with adapter cards), and this will affect the operation of the components. When we use our computers we place the circuitry, and especially the chips, under a lot of stress. First they heat up when we turn on and use the computer. Then they cool down when we turn the machine off. Then they reheat when we turn the machine on again. This hot-cold-hot effect puts a great deal of thermal stress on the circuits. The thermal stress can cause a break in the connection of a wire leading from inside the chip to a pin, producing an open circuit, which requires chip replacement.

Even if there is no break in the chip or lead connection, after exposure to high voltages or temperatures, the operating characteristics of a device can change. A chip may work intermittently or simply refuse to work at all. An output can become stuck at 1 or stuck at 0, regardless of the input signal. Theoretically, a wear-out failure like this won't occur until after several hundred years of use, but we shorten the life span of the chips by placing them in high-temperature, high-voltage, or power-cycling environments that cause them to fail sooner.

Other problems occur outside the chip—between the chip leads and the support structure pins that connect the device to the rest of the computer through the socket. Such failures include inputs or outputs shorted to ground, pins shorted to the +5-volt supply, pins shorted together, open pins, and connectors with intermittent defects. Most commonly, trouble results from opens or shorts to ground. Chips fail far more often than diodes or transistors, because the chips that are the same size as single (discrete) diodes or transistors contain many tiny circuits that produce more heat and therefore more thermal wear.

Chapter 5, "Routine Preventive Maintenance" tells more about heat effects. If you keep your computer cool and clean, it should work well for many years.

HOW DISK DRIVES FAIL

Disk drives give us the ability to save and load software at almost unbelievable speeds. These "boxes" are some of the most complex collections of electronics and mechanical hardware ever constructed. Thousands of tiny magnetic signals are stored on each disk that is placed into one of these drives. We expect disk drives to save all of our programs and data accurately and quickly and to accurately load the information back into the IBM PC without a single lost number or letter.

And they do. Disk drives will give us months of faultless service if we do our part, operating them carefully and providing tuning and periodic cleaning.

But sometimes we forget. We operate our drives as someone nearby puffs on a cigarette, tapping ashes onto a tray at the side of the drive. We smile as we jam a disk into the drive and then slam the drive door closed. And then one day, that horrible DOS ERROR message appears and the drive "gives up the ghost." Now what? What kinds of failures can occur with disk drives?

One type of failure is a change in the drive rotation speed, which affects the reading and writing of information on the disks. The speed is adjusted for approximately 300 revolutions per minute—200 milliseconds per revolution. As the speed varies from this optimum, disk read and write errors begin to occur.

Rough handling during disk insertion and removal can cause misalignment of the read head. Misalignment is not easy to fix. It usually requires special software and alignment tools.

HOW DISPLAYS FAIL

Monitors are like television sets. And you know from experience that sooner or later your TV will develop a problem and need repair. Part of the reason displays still fail is that they are the only new electronic devices that still use vacuum tubes. The cathode ray tube (CRT) is the screen you look at when you work with your computer. It displays video information. The CRT is probably the only modern electronic component that is guaranteed to wear out.

The letters and numbers you see on your screen are displayed there by electrons striking the back side of the screen. The electron streams get weaker as the CRT ages. You can correct some of the effects of age, but others require a service center, since it's better not to open up the display unit and expose yourself to those dangerous high voltages.

Here are some possible video display failures:

1. *Short inside the CRT*—can result in a "hum" noise and a bar across the screen, very poor contrast, a bright beam on the screen, or even diagonal lines on the screen.
2. *Open or disconnected circuit inside the CRT*—no characters are displayed on the screen.
3. *Center of the CRT has worn*—bright, "bloomy" letters, poor intensity control; caused by tube age. You can get normal brightness with the intensity turned down as far as possible, but black is very black, and gray shades are poor or not displayed.
4. *Deposit on the inside of the screen*—screen edge won't display, reduced brightness and fuzzy display.
5. *CRT worn out*—No picture; brightness and intensity controls have no effect.
6. *Dust and dirt inside chassis*—marginal performance; display monitor performance less than optimal.

In general, CRT failures cannot be corrected by anyone other than a trained service technician. The voltages inside the chassis of your monitor reach as high as 25,000 volts. These levels can be lethal if you make a mistake.

The only adjustments you should attempt are those that can be accomplished from outside the chassis. If you see holes in the back of the chassis for alignment, you'd be better off keeping out of these, too; but if you feel experimental, be sure you use a plastic alignment tool (it looks like a thin pen with screwdriver-shaped ends).

REPAIR-GENERATED FAILURES

Failures can be caused by overzealous or undertrained repair technicians. In the following list are some of the repair-generated "failures" that are possible:

1. *Devices "blown up" in handling*. This problem occurs when someone picks up ROM or CPU chips without first grounding any static electricity that he or she might be carrying.
2. *Bent or broken pins*. Watch the way you put those chips in. You can only straighten those pins so many times before they break off completely (Fig. 3-7A).
3. *Solder "splashes."* These are caused by dropping tiny balls of solder from the end of the soldering pencil right on top of the board, shorting out some of the circuit (Fig. 3-7B).
4. *Liquid "fry."* This occurs when someone holds or sets a liquid on top of or too close to the computer and then accidentally spills the liquid into the top of the keyboard while the computer is running. It's a real mess to clean up; lots of components will need replacing.

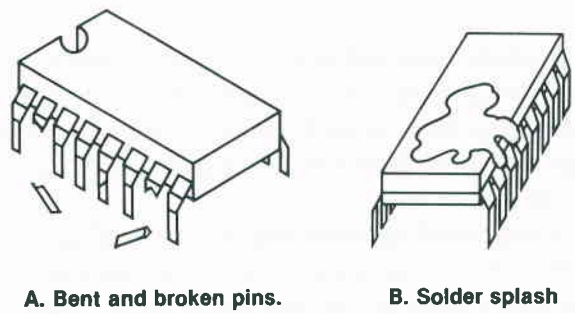


Fig. 3-7. Failures can be caused by overzealous or undertrained repair people.

5. *Component failure by asphyxiation*. This is caused by blocking the IBM PC vent openings or stuffing your computer with piggyback expansion boards that produce lots of heat without providing additional cooling. It "kills" components.
6. *The interface that doesn't*. This can be caused by improper connection of cables. Plugging cables in one pin off blows chips. Also, if cable connectors are badly corroded, no signal can get through the cable.
7. *RFI wipeout*. Ribbon cables don't have much protection from radio frequency interference (RFI) or magnetic fields produced around high-voltage machines or even power cords. Printers may print garbage, or nothing at all, if the ribbon cable connecting the computer to the printer runs alongside or through a loop in a power cord.

HOW TO LOCALIZE FAILURES AND MAKE REPAIRS

O.K. You're convinced that computer parts are pretty durable, but they can fail. How do we locate the failure?

There are three ways to localize failures, or find out which computer part is broken: (1) the hardware approach, (2) the software approach, and (3) the IBM-Easy approach.

Hardware Approach

In the hardware approach, we use troubleshooting tools to measure voltage (logic) levels in the circuitry of the IBM PC. These tools include the logic probe, logic pulser, current probe, oscilloscope, multimeter, logic analyzer, and signature analyzer.

This approach requires some knowledge of electronics and test equipment. It is usually used as a last resort, so we'll save the hardware approach for Chapter 6, "Advanced Troubleshooting."

Software Approach

The software approach is a troubleshooting method used widely by IBM PC repair technicians. As long as the disk drive will boot up properly, we can often find the failure by using diagnostic software. As you know, your PC has a built-in diagnostic software program that checks out the machine each time you apply power. This program is well written and does much to ease your mind that all is well inside.

Diagnostic Software

Watching strange things happen to your computer system can be frustrating. Often you can't be sure immediately if you caused those weird characters on the screen or if your IBM PC just got sick. It's better not to start taking the system apart for failure analysis if the machine isn't really broken.

There is a way to determine that the system is healthy and that the errors are in the software program you're trying to run. If the error is repeatable and the system drive still boots up, you can insert a diagnostic disk into your IBM PC system and run a series of programs that test the condition of the computer. These self-test routines can give you a 95 percent or greater confidence indicator that your PC is working properly and that you need to check your software.

Diagnostic programs can also indicate possible faults before they become hard problems. For example, some diagnostic software tells if the disk speed is too fast, too slow, or within a speed range where reading and writing data can occur without errors. These diagnostics measure the mechanical operation of your disk drives and are helpful in periodic preventive maintenance.

The effectiveness of self-test packages is measured by the level of confidence one can have that the component identified as bad by the software is indeed faulty. Some diagnostics are advertised as only 60 percent accurate; other companies say that their software test packages have an 85 percent confidence factor.

Most minicomputer diagnostics only identify faults to the board or module level. That's because customers in the large companies that own most minicomputers usually depend on the computer manufacturer's field service representatives for repair. In this case, the diagnostic software is used as an improved user interface. The user can relay to the computer service center what the diagnostic tests have determined, reducing the time and cost involved in a troubleshooting and repair visit. This is exactly the situation with your IBM PC. If it fails during diagnostic testing, a number is printed on the screen. It is a key number to an IBM repair technician. The technician can use that number to identify the bad part. (As Chapter 4 will describe, you can also use this number to your advantage.)

Fortunately, most of the IBM PC microcomputer diagnostics can call out faults to the chip level (especially faults in memory). Besides the diagnostic software provided with the machine, several companies provide other diagnostic programs for the IBM PC. These programs test main memory, system ROM, the CPU, the monitor, the keyboard, the disk drive speed, and many peripherals.

The most common diagnostic programs check the system's RAM and some of the input/output components. Some routines check the operation of the CPU itself, but these usually locate only minor errors. It's difficult for a CPU like the 8088 to run a test on itself. Most diagnostics assume that the CPU is working properly.

Some memory diagnostics test to see if the computer is properly setting and clearing individual bits in memory and also if store or write operations are affecting more than one memory address location at one time.

Common Memory Tests

The main memory tests find out whether test data can be correctly loaded into one and only one location in RAM. If a *storage error* occurs—that is, the data stored is not the same as the test data—a message is printed on your screen. If the correct data is stored, but into several different memory locations at the same time, an *addressing error* has occurred and this too is noted on your screen.

There are many algorithms (routines) for testing memory. Here is a list of the most common memory tests:

- Simple store and read
- Sequential numbers test
- Rotating-bit test
- Walking-bit test
- Dual-address test
- Butterfield test
- Sum test

A **simple store and read test** stores a known value in every location in a selected block of memory. Then it reads the contents of each location to ensure that the value was correctly stored. It is a quick and easy, but not too precise test.

A **sequential numbers test** involves storing all the binary number combinations for an 8-bit word sequentially into a block of 256 memory locations. Then the program starts at the first address location and reads out the data word stored, comparing it to the value that should be there. If the data is correct, the routine displays the words "all O.K." and the test moves on to the second location. If an error is found, the program displays an "error" symbol on the screen before the test starts over at the next address location. The test repeats until you reset your system.

A better memory test, the **rotating-bit test**, checks each address location to see if a binary bit stored in any one of the eight positions in a binary 8-bit data word will falsely set another bit in the same word. This test starts by loading the binary number 0000 0001 in the lowest RAM address. The contents of this address are then read back out and verified. If the 0000 0001 was correctly stored, the 1 bit is shifted one place to the left to 0000 0010 and the test is repeated. After the set bit (the 1) is shifted through all the binary combinations, stored in that same address location, read out, and verified, the entire test starts over at the next memory address location.

The **walking-bit test** improves on the rotating bit test somewhat. All 8 bits in a starting location are set to 0, or *cleared*. Then the first bit is set to 1 (0000 0001), as in the rotating-bit test. The program tests all 7 other bits to see if they have changed from 0 to 1. Then the second bit position is set to 1 and all other positions to 0 (0000 0010). Again all 7 other bit positions are tested. This process walks through each bit in that memory location, setting each bit to 1 and testing all 7 other positions.

Then the values are all reversed; all the cleared bits are set to 1 and the set bits are cleared to 0; and the entire process begins once more, but now as a rotating 0 test.

This test is quite time consuming. Apparently, it can take over 13 hours to check a 16K-byte area of RAM. And it can take over 52 hours to test 32K bytes of memory! You can just imagine how long it would take to test a fully packed IBM PC.

A **dual-address test** provides a thorough addressing check. Starting with the lowest memory address in a selected block of memory, the program stores all 0's into the area (clears it to 0). It then stores all 1's (1111 1111) into the first location and checks all other locations to see if any other memory address falsely received any 1's. If all other locations are still "zero-loaded," the test location is cleared and the test shifts to the next higher address, storing all 1's in this location and then testing all other memory locations. This test repeats until the program reaches the end of the selected memory area.

A man named Jim Butterfield wrote a program that is a variation of the dual-address test. This test is in the public domain; that is, it is not copyright protected, and anyone is welcome to reproduce and use it. In the **Butterfield test** program, all 1's are stored in every location of the selected memory area. Then all 0's are stored in every third address location, starting with the first address. The algorithm then checks the contents of every memory address to make sure the values have been stored correctly.

Next, the program shifts the position of the "all 0's" word twice using the second and then the third locations in the memory as starting points. After the three-pass test using 0's in a memory field of all 1's, the bits are reversed and all 1's are stored in every third location of an all 0's memory field.

If an error is found, the program stops and the address of the error is displayed. If no error is detected, the program ends and the top address plus one is displayed on the monitor.

The **sum test** is probably the most sophisticated memory diagnostic test. It generates a unique data word to be stored in each location of memory to be checked. The data word is the sum of the two bytes that comprise that memory address. (Recall that it takes 16 bits to address 64K bytes of memory; 16 bits is two 8-bit bytes.) Since each succeeding address is one location higher, the value stored increases, and each value is unique to an address. A variation on this scheme can be used with the 20-bit address word in the PC. The algorithm then checks for correct value storage. If an error is found, the program displays the error and its location on the screen.

This diagnostic test is also time consuming. It's a good idea to run these kinds of dual-address tests on small blocks of memory rather than testing all of the RAM. It has been determined that the testing time quadruples for each doubling of the amount of memory tested.

Self-diagnosis

There is a trend toward building diagnostic capability into peripheral equipment such as printers and plotters. There is also a strong incentive to place diagnostics in CRT displays and disk drives, because so many of these devices are being sold.

Disk drives and printers function both electronically and mechanically. The electronic controller portions of these machines can contain their own diagnostics and, indeed, many controllers now do some form of self-diagnosis each time the system is powered up. These tests check for faults in the electronics.

Mechanical components are inherently less reliable than electronic ones, so peripherals containing mechanical parts have diagnostics that regularly check their internal operation. Most of the conditions monitored are operator related; for example, "paper out" or "ribbon out." Disk drive diagnostics measure mechanical parameters such as speed and head alignment. We'll cover disk speed adjustments and head alignment in Chapter 5, "Routine Preventive Maintenance."

All of the "canned" diagnostic packages use some version of the seven test algorithms previously described. Each diagnostic program is a valuable addition to your "troubleshooting toolbox," but no software diagnostic can help if your system won't boot or display.

The IBM-Easy Approach

Usually, when a chip comes to the end of its useful life, a catastrophic failure occurs—it cooks itself internally. While your eye can't always see the defect, you can find the problem without much effort. In most cases, the use of the "Troubleshooting Index" in Chapter 4 will enable you to locate and correct the trouble quickly; but for those problems that are not as easy to identify, let's refer again to our guidelines for success.

1. **Don't panic**. You now have a troubleshooting guide that will help.
2. **Observe the conditions**. What conditions existed at the time of failure? What actions were in progress? What program was running? What was on the display screen? Was there an error message?
3. **Use your senses**. Is there any odor present from overheated components? Does any part of the system feel overly hot?
4. **Retry**. If the display is dark, check the brightness control, the power plug, and the power cord. Is the plug snug in the back of the computer? Is the other end of the power cord

plugged into a wall socket? Is the wall socket working? If any of these isn't right, correct the problem and try again.

If your problem involves an external display, the printer, or other I/O peripheral equipment connected to your IBM PC by cable, make sure the power to the system is off, disconnect the power plug from the computer, and then reseat all the connector cables associated with the failure. Cables have a habit of working loose if they aren't clamped down. Once you've checked the cable connections, reconnect the power plug, power up, and retry.

If a disk didn't boot (was not read in and acted on by the disk drive), try booting the disk in the other drive or try booting another copy of the program disk. You could also try booting the disk in another IBM PC computer. It's a good idea to always use a *copy* of the the program disk rather than the original. That way any failure of a disk drive won't cause as much frustration if it destroys data on the disk as it would if the disk were the program master. If data is altered by a malfunctioning drive, the disk can be recopied again from the program master once the drive problem is resolved.

If the system still won't work, disconnect all the external equipment connected to the computer, and try to operate the system unit alone. Sometimes, failure in a peripheral device shows up as trouble in another part of the computer. If the computer works by itself, the problem is probably in an external device or in the connecting interface.

5. **Document**. Document all that you see and sense. Write down all the conditions that you observed at the time of failure. Write down what conditions exist now that failure has occurred:

   - What is your PC doing?
   - What is it not doing?
   - What is being displayed?
   - Is there an error message?
   - What is still operating?
   - Is power still indicated on each part of the system?

6. **Assume one problem**. In digital circuitry, the likelihood of multiple simultaneous failures is low. Usually, a single chip malfunctions, causing one or more symptoms.

7. **Diagnose to a section**. If the system worked when the peripherals were disconnected, turn the power off and reconnect one of the peripherals. Power up and test. If the unit still works, turn the power off and reconnect another peripheral. Power up and test. Follow this procedure until the unit fails. The built-in diagnostic tests are a big help here. Once failure occurs, you know what device or what interface section has the problem.

   If you disconnect all the peripherals and test the computer alone and it still won't work, try to determine what section or division of the machine failed. Describe the failure in simple terms—drive B won't read a disk, for example.

8. **Consult the symptom index**. Chapter 4 includes an index of the troubles most commonly encountered with the IBM PC. It includes a section on system error displays. If any error codes are displayed, these self-diagnostic results can guide you to locate the problem. If the symptoms that you see match a problem described in the "Troubleshooting Index," turn to the referenced page and follow the instructions under "Troubleshooting Procedure."

   Caution: Any time you open the computer, ensure that the power is off and touch a metal lamp or other grounded object to remove any static electricity your body may be carrying.

9. **Localize to a stage**. Turn off the power to the computer and disconnect the power plug. Disassemble the computer as shown in the Appendix. Follow the troubleshooting steps and procedures in Chapter 4, "Specific Troubleshooting & Repair for the IBM PC," to localize the failed stage.

10. **Isolate to a failed part**. Closely following the procedures in Chapter 4 should guide you to the failed part. Here are some hints for determining why a part is failing.

    Loose chips. Chips have a tendency to work themselves out of their sockets under normal operation. A loose chip could be the cause of your whole problem. "Loose chips sink MIPS" (MIPS stands for millions of instructions per second—a measure of computer capability).

Noise. Sometimes a problem is caused by noise. Not audible noise, but electrical noise, the kind that produces "static" on your radio. Noise in the computer system can cause data to be lost or incorrect data to be stored or displayed. Noise will be discussed in greater detail in Chapter 5.

Note: To avoid noise problems, keep cables clear and away from power cords, especially coiled power cords.

Intermittent failures. Sooner or later you're going to be confronted with those once-in-a-while failures called *intermittents*. These can be really frustrating. Unlike a hard (constant) failure, an intermittent problem shows up randomly, or only at certain times (usually when you expect it least). Intermittent failures are difficult to handle using standard troubleshooting methods.

Since intermittent failures can be caused by shock, vibration, or temperature change, these conditions can be used to find and sometimes even correct them. Here are some helpful hints regarding intermittent failures:

Caution: The following steps are conducted with the computer open and operating. Be careful not to short out any connectors or pin leads.
Use only a nonmetallic or wooden object to probe components inside an energized IBM computer.

a. Check, clean, and reseat all connector boards and cable plugs.
b. Tap gently at specific components on the suspected board using a nonmetallic rod or screwdriver.
c. Heat the suspected area with an infrared lamp or hair dryer. Don't overheat it.
d. Spray canned coolant on a suspected component. A component that fails intermittently can sometimes be found with this technique used by service technicians. Several companies sell pressurized cans of coolant spray that have long plastic extender nozzles for pinpoint application on top of a suspected chip. By cooling the device with the computer energized and operating the system, you can identify chips on the verge of total failure. The system works for a few moments until the chip heats up again and starts causing problems again.
e. After you've found the area where the problem is located, make sure the power is off, and use a strong light and a magnifying glass to look for small cracks in the wiring or solder connections.
f. The final method for fault isolation to a component is signal tracing. This technique will be covered in Chapter 6, "Advanced Troubleshooting."

A large section of Chapter 6 is devoted to identifying and solving the intermittent problem. For now, let's say that good cleaning, careful pin and board reseating, and inside-the-case temperature control will prevent the occurrence of most random failures. Board reseating need not be a problem on the PC since the boards can be secured with screws.

11. **Repair**. A disassembly and reassembly guide is located in the Appendix. If the problem is a marginal or blown chip, you can replace it but be sure your replacement chip is of the same logic family as the original (i.e., replace *74LS74* with another *74LS74*).

Removing socketed chips. It takes a little practice before you can remove a socketed chip without it jumping out, flipping in mid-air and sticking you right in the thumb or index finger with that double row of tooth-like pins. Fortunately there are two devices that make the job much easier. These are the tiny screwdriver, or "tweaker," and the IC extractor tool. Fig. 3-8 shows how each tool can aid in removing stubborn chips from their sockets.

The extractor tool was designed to make chip removal easier, and its use is recommended. Slip the tweaker under the chip to start it out of the socket and then use the chip extractor to complete the removal. This prevents the tweaker from slipping or the extractor tool from inadvertently hooking onto the socket for the chip and pulling the socket up out of its solder connections along with the chip.

Replacing socketed chips. Getting the chip out is only part of the repair challenge. Replacement of chips that are in sockets may look easy, but there are some pitfalls you should be aware of. Those fragile pins on your

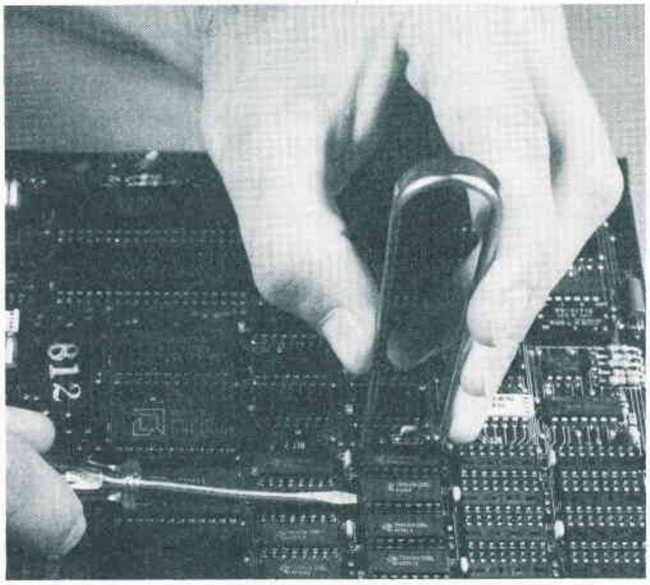


Fig. 3-8. ICs can be removed with a chip extractor or by gently prying up with a tiny screwdriver (tweaker).

chips bend easily, and it doesn't take very many straightening actions to break a pin completely off. Here's how to do it:

a. Line up the pin-1 end (with the notch or dot) with pin 1 on the socket. (Notice how all the other chips around this socket are mounted.)

b. Place the chip over the socket, lining up one row of pins with its socket holes as shown in Fig. 3-9.

c. With the chip at a slight angle, press down gently, causing the row of pins in contact with the socket to bend slightly, which lets the other row of pins slip easily into their sockets, as shown in Fig. 3-10.

d. Press the top of the chip down firmly to seat the chip completely into the socket. Be careful not to flex the board too much. If necessary, support the motherboard with the fingers of your other hand as you press the chip into place.

It is pretty easy to make mistakes in chip replacement. Here are some more things to be careful of:

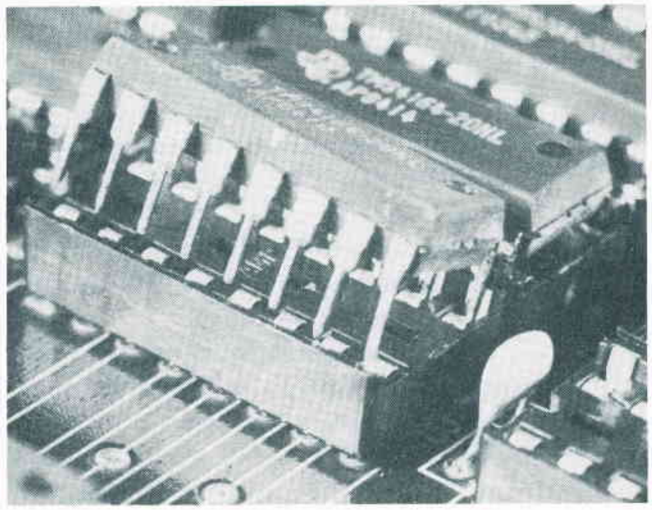


Fig. 3-9. Place the chip over the socket as shown.

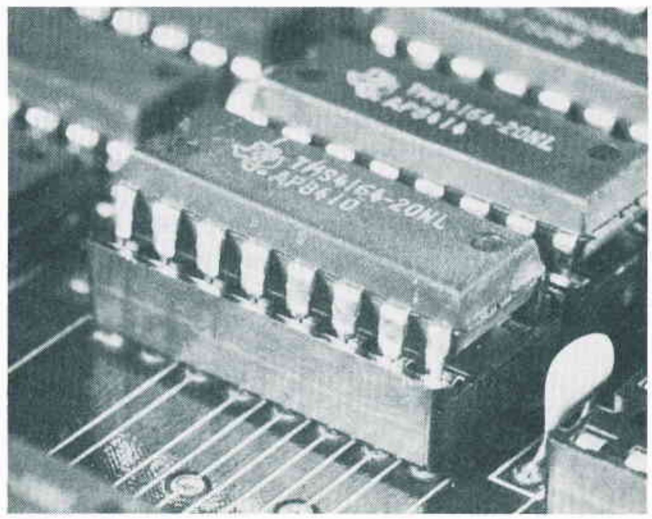


Fig. 3-10. Once each row of pins has been started into the socket, press down gently to complete the chip insertion.

- Make sure you don't put the chip in backwards. The notch or dot marking the pin-1 end of the chip is intended to help you correctly line up pin 1 on the chip with pin 1 on the socket.
- Don't offset the chip over the socket by one pin as shown in Fig. 3-11.
- Don't force the chip down so one of the pins actually hangs out over the edge of the socket or is bent up under the chip.

Soldered chips. Removing and reinstalling chips that are soldered into the motherboard are difficult actions and require more than a passing knowledge of soldering techniques.

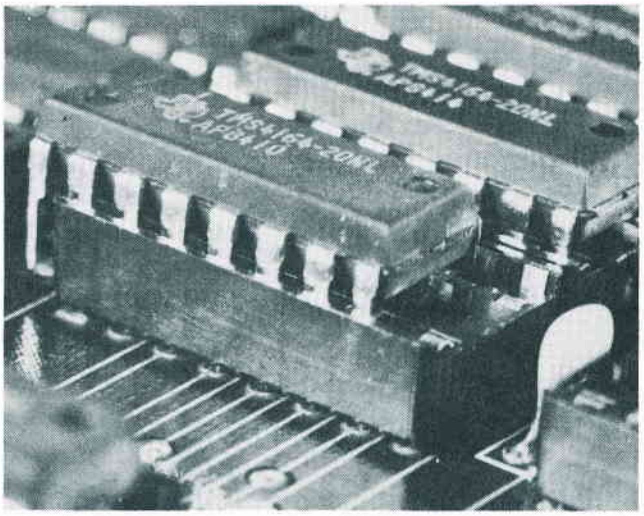


Fig. 3-11. Be careful not to offset the chip by one pin.

Only attempt this part of the test-repair procedure if you have experience soldering and desoldering multilevel printed-circuit boards. Otherwise, bite the bullet, and take your machine to someone who has the knowledge, experience, and equipment to successfully make this type of repair.

If a chip to be replaced is soldered into the motherboard, whether you do it yourself or have a repair technician do it, always replace the chip with a socket. Solder the socket in, and then plug the new chip into the socket. This will make it much easier to replace this chip next time.

Checking. After each repair action, test the system for correct operation. In some cases, substitution of a good chip corrects the problem. After each substitution, reassemble the system enough to power up and test the repair. This process is very likely to locate the trouble.

12. **Test and verify**. This is an important step. We need to know that all is now well with the system. After booting up and testing using a copy of your DOS program disk, run the same program that was in the machine at the time of failure.

Note: It's a good idea to log the repair action in a record book to develop a history of the maintenance conducted on the machine. Record sheets are included at the back of this book.

Obtaining Replacement Parts

Finding that a trouble really exists is only part of the problem. You must locate the specific chip (if the software doesn't) and then make the repair. This too, can be somewhat challenging. Fortunately, most of the chips on your IBM PC system board are standard 74*xx* chips and are readily available. Your local Radio Shack store carries most of the 7400-series chips. In fact, just about any electronic parts store will have a supply of 7400-series chips. Most of the 8*xxx* series chips are also easy to obtain. You can make a list of the spare parts you'd like to have on hand from the listing in the Appendix.

The custom IBM PC chips—the five ROMS—are proprietary to IBM, and I recommend you buy all of these custom chips directly from IBM or from your local IBM PC repair center.

Should you be using an 8087 coprocessor in your PC, and need to replace the 8087 or the 8088, be aware that these are often sold as a matched pair. To see whether your 8088 will work properly with your 8087, check the copyright date marking on the top of the chip. If the copyright date is "78," it *may* work with the 8087. If the date is '"78'81," it is certain to work with the coprocessor chip. Any other date stamp might not work, unless it is stamped "P8088" or "D8088" followed by "S4716." Chips with these markings are revisions of earlier 8088 devices and will also work.

The trade magazines sometimes advertise inexpensive packages of IBM PC repair parts. Some of the PC chips can be replaced only by a board swap-out, or board exchange. The exchange price may seem high, but you do get a new board, and the kind of failure that necessitates this action does not occur very often, so this kind of expense is required very infrequently.

If It Still Doesn't Work

If the IBM-Easy troubleshooting steps don't solve the problem, you have two choices: either take the machine to a service repair center or break out (or borrow) some test equipment, open the schematics, and start hunting for the failed or malfunctioning stage. Try signal tracing with a logic probe and a logic clip. Use an oscilloscope and a digital voltmeter (DVM) to test the discrete components such as transistors, capacitors, and resistors. Connect a logic analyzer or signature analyzer to the system and step though the circuitry. Make voltage and resistance tests to locate the bad part. Test hardware and advanced troubleshooting methods are discussed in greater detail in Chapter 6.

IF YOU MUST USE A SERVICE CENTER

Before you disassemble your system and take it down to the repair shop (if that's your alternative), there are some things that you can do to minimize your expense. The following Repair Service Checklist is a guide to be used before, during, and after the service center repair. Each step is expanded here for clarity.

1. **What is affected**? Find out if the problem is "catastrophic" and affects the operation of everything. If it affects only a part of the system (such as a disk drive) you may be able to take the drive only in for service center repair.
2. **Is the problem in software**? Be certain it isn't. Try to run a program that you know is good.
3. **Was the problem caused by operator error**? Try a different operation that uses the same hardware or function.
4. **Is it an intermittent failure**? If your problem is intermittent and you take it in for repair, it could take quite a while (at quite a fee) for the problem to occur and be found and fixed. You may just want to live with the problem until the intermittent becomes permanent (a hard failure). At least then you will have something concrete to troubleshoot.
5. **Describe the problem in writing.**
   - What was the system doing at the time of failure?
   - What were you doing at the time of failure?
   - What is the system doing now?
   - What isn't it doing now?
   - Is there an error code?

   Provide a copy of the written description to the service technician.
6. **Ask for recommendations**. Your local users group can probably provide the names of some good, reasonable service centers.
7. **Log the serial numbers of all system components you'll be turning over for repair.**
8. **Request an estimate of time and charges.**
9. **Request a repair listing**. Ask to have a detailed listing of what was repaired or replaced, including a break-out of charges.
10. **Check on warranties**. The repair may be covered by a current warranty. In any case, make sure the work and parts are warranted for at least 90 days.
11. **Test before acceptance**. Test run the system before taking it out of the shop.

SAFETY PRECAUTIONS DURING TROUBLESHOOTING AND REPAIR

As you do with all devices that use or operate on electrical power, you must observe certain precautions to prevent damage to yourself or your IBM PC system:

1. **Keep out of the display monitor chassis.** The voltages inside your monitor or television are dangerous, and only trained technicians should ever troubleshoot and repair a display unit. Voltages can be as high as 25,000 volts, so stay out!
2. **Don't troubleshoot your IBM PC power supply**. The circuits in the power supply convert the 115-volt line power in your home or office to the 5–12 volts used by the motherboard. That 115-volt electricity can be harmful! Apparently IBM feels the same way; they use some special screws to secure the metal shield over the power supply. This guide does not discuss power supply troubleshooting and repair.
3. **Always turn the power off, ground yourself, and pull the plug**. Touch a grounded metal object such as a desk lamp, and then pull out the power cord before touching anything inside. Many failures are caused by people who don't follow this rule.
4. **Handle diskettes carefully**. Don't write on a label once it is attached to the disk jacket. Don't lay disks on a dusty, dirty surface. Keep cigarette ash away from your disks and your computer system. Don't touch the disk surface. Don't try to see how flexible a floppy disk is. Don't set your disks on, or in front of, a TV or color monitor.
5. **Don't cycle the power on and off quickly**. Wait 7 to 10 seconds to let the capacitors in the power supply discharge fully and to allow the

circuits to return to a stable (quiescent) condition.

6. **Use a power strip to apply power to all components** (except a hard-disk drive). This saves wear and tear on the PC's ON/OFF switch. Most power strips also have a built-in overload protection for voltage spikes. Voltage spikes can harm your computer system. (Don't connect a hard-disk drive to the same power strip if it must be energized and up to speed before the computer is turned on.)
7. **Keep liquids away from the computer**. If you ever spill a soda on the keyboard, you'll be amazed at how sticky soda becomes after frying components all over the inside of the keyboard.
8. **Handle components with care**. Don't let chips lie around—the pins can get bent or the integrated circuits can be ruined by static electricity.

   Some logic devices require extra care when you touch or handle them. With TTL (74xx series) chips you have no problem removing or inserting these devices. But the metal oxide semiconductor (MOS) chip family (MOS, CMOS, NMOS, etc.) needs some extra care since these chips are more susceptible to static electricity than TTL chips are.

   The MOS chips in your IBM PC are:

   - The 8088 CPU
   - The ROM chips
   - The 8237 DMA controller chip
   - The 8253 PIT chip
   - The 8255 PPI chip
   - The 8259 PIC chip
   - The 8284 clock generator chip
   - The 8288 bus controller chip

   Don't be afraid to touch the chips in your computer. Most guides for handling MOS chips lean far toward the supersafe zone and sometimes cause more problems than they prevent. These chips can be damaged by the static charge built up by scuffing your feet across a carpet; so be sure to ground yourself by touching a metal lamp or grounded object before you reach for a chip inside the IBM PC chassis. In addition, conductive foam provides static charge protection during storing or transporting of MOS-type chips.

   Additional precautions should be observed when you use test equipment with your IBM computer. These will be covered in Chapter 6, "Advanced Troubleshooting Techniques."

SUMMARY

So there you have it. In this introductory chapter on troubleshooting, you've learned the troubleshooting steps to success; how to recognize the components inside the IBM PC; how components, disks, and displays fail; and various methods for finding failures in your computer system.

CHAPTER 4

Specific Troubleshooting & Repair for the IBM PC

Chapter 4 is an IBM PC – specific troubleshooting and repair guide focusing on a large variety of computer failures. The section is divided into five parts as follows:

1. Start-up problems
2. Run problems
3. Display problems
4. Keyboard problems
5. Other I/O problems

Each fault can be associated with one of these areas. By letting your "fingers do the walking" through the Troubleshooting Index, you can quickly locate the page where your particular problem is addressed.

Part 1 covers all symptoms that can occur at the time you turn the power on, or at start-up, including no power available, no boot up of the disk, and system error problems. The PC comes with a built-in diagnostic test program, and most users also receive a diagnostic disk to use in conjunction with the built-in diagnostics. Therefore, it's possible to get a system error number printed on your screen if your system experiences a malfunction during start-up.

Part 1 lists the meanings of most system error codes. This listing includes system error numbers that identify the specific RAM chip that has failed. If no system error is displayed, or if a system error cannot be displayed, the remainder of Part 1 and the following sections will provide guidance in locating the trouble.

Part 2 discusses all symptoms that can occur after initial boot up, such as faulty disk read or write, bad memory, and program lock-up.

Part 3 addresses difficulties associated with the display portion of the computer; for example, no display, no text mode, no hi-res or no lo-res, video synchronization failures, character faults, bad graphics, and others.

Keyboard problems are detailed in Part 4. This section covers such faults as bad key operation.

Part 5 encompasses all the other input and output problems, including speaker faults, cassette I/O failures, and light pen malfunctions.

Each part is subdivided into specific failures and provides symptom, problem, possible cause, and repair action. This data is followed with step-by-step troubleshooting instructions illustrated with applicable schematic drawings and a chip location layout diagram to make replacement easy.

If any step seems too complex, stop where you are and seek help from a service center technician. You should be able to find and correct most problems, but occasionally a component such as a resistor, capacitor, or diode fails. Finding these failures requires advanced troubleshooting techniques, and this book does not assume you have these skills. If you'd like to try the advanced methods, refer to Chapter 6 for guidance. Always observe good troubleshooting procedures.

Note: The following troubleshooting techniques may require soldering, if you are uncomfortable with this, go as far as you can without soldering and then consult your local IBM Service Center.

Note: Desoldering or soldering on the IBM PC motherboard may void your warranty.

TROUBLESHOOTING INDEX

START-UP PROBLEMS

SYMPTOM: System errors during start-up

Four types of error indicators may appear during the initialization, or start-up process:

- Beep indicators from the built-in speaker
- System error codes
- I/O error codes
- Other error displays

The following listings will assist you in isolating the module, subunit, or peripheral that has failed.

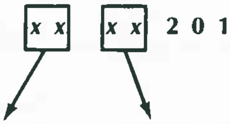
Beep Indicators

Indicator	Failure location
No beep, nothing happens	Power, power supply
Continuous beep	Power, power supply
Repeating short beep	System board
1 long, 1 short beep	System board
1 long, 2 short beeps	Display circuit
1 short beep, blank or incorrect display	Display
1 short beep, Cassette BASIC display, no disk boot	Diskette, disk drive

System Error Codes

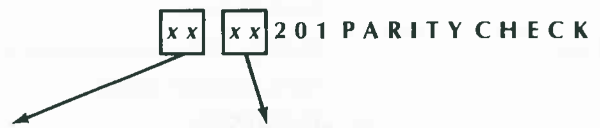
These error codes can appear alone or in conjunction with other numbers.

Code		Problem
100		Option configuration wrong
	199 100	Software option configuration installation wrong. Check switches.
101		System board malfunction
	131	Cassette port error
201		RAM failure
	xxxx = 201	Memory failure (see Fig. 4-1)
	1055 = 201	DIP switches set wrong
	2055 = 201	DIP switches set wrong
	xxxx = 201 PARITY CHECK x	RAM chip malfunction (see Fig. 4-2)
301		Keyboard malfunction, keyboard cable disconnected
	xx301	Keyboard circuitry malfunction (xx is a hexadecimal value representing the scan code of the malfunctioning key)
401		Monochrome adapter card malfunction
501		Color/graphics adapter card malfunction
601		Diskette or disk drive interface malfunction (drive adapter, cable, drive A)
	606	Drive assembly or drive adapter malfunction
	607	Disk is write protected; disk not inserted right; write-protect switch bad; analog card malfunction
	608	Diskette is bad
	611	Drive data cable or disk drive adapter card is bad
	612	Drive data cable or disk drive adapter card is bad
	613	Drive data cable or disk drive adapter card is bad
	621-626	Drive assembly is bad



SYSTEM BOARD MEMORY (Bank xx)	FAILED CHIP
0 0 = Bank 0	0 0 = Parity
0 4 = Bank 1	0 1 = D0 chip
0 8 = Bank 2	0 2 = D1 chip
0 C = Bank 3	0 4 = D2 chip
	0 8 = D3 chip
	1 0 = D4 chip
	2 0 = D5 chip
	4 0 = D6 chip
	8 0 = D7 chip

Fig. 4-1. Memory failure error codes.



BANK	FAILED CHIP
1000 201 PARITY CHECK 1	Bank 1, parity bit
1004 201 PARITY CHECK 1	Bank 1, D2 bit
1008 201 PARITY CHECK 1	Bank 1, D3 bit

Fig. 4-2. Some examples of parity check RAM chip malfunctions.

I/O Error Codes

Code		Problem
199		Printer adapter card or printer malfunction
432		Printer adapter card or printer malfunction
7xx		System unit I/O malfunction
9xx		System unit I/O (parallel printer adapter) malfunction
	901	Printer adapter card or printer itself is bad
11xx		System unit malfunction
12xx		System unit malfunction
13xx		Game control adapter card malfunction
14xx		Printer interface malfunction

Code	Problem
15xx	System unit or communications adapter cable malfunction
18xx	Expansion unit or cable malfunction
1819	Expansion unit malfunction
1820	Expansion unit cable malfunction
1821	Expansion unit cable malfunction
20xx	System unit or communications adapter cable malfunction
21xx	System unit or communications adapter cable malfunction

Other Error Displays

Display	Meaning
Blank display, beep, drive starts to boot, but no Cassette BASIC message on screen	System Monitor BIOS ROM (U33) 8284 clock generator bad
F600 ROM	Cassette BASIC ROM (U29) problem
F800 ROM	Cassette BASIC ROM (U30) problem
FA00 ROM	Cassette BASIC ROM (U31) problem
FC00 ROM	Cassette BASIC ROM (U32) problem
KEYBOARD NOT FUNCTIONAL	Keyboard problem
PARITY CHECK 1	Power supply problem
PARITY ERROR 1	Try reseating RAM chips
PRINTER PROBLEMS	Printer problem, check interface

SYMPTOM: System won't boot

If booting won't work, the IBM PC DOS manual suggests you reread the manual. You can probably deduce the problem faster by noting the condition of the machine at time of "failure" and following the logical troubleshooting steps outlined in this chapter.

A number of things can cause the computer to boot improperly or not to boot at all: wrong diskette in the drive, no operating system on the diskette, cables loose, adapter card not fully seated, disk drive failure, memory chip bad, no clock pulses, or even a forgotten unplugged power cord.

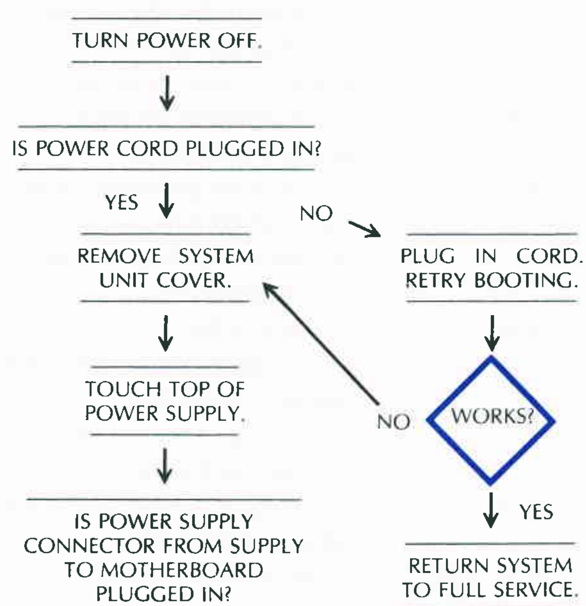
To find the problem, select the subcategory that best describes the symptoms and turn to the appropriate page for a step-by-step troubleshooting guide:

Subcategory **Page**

SYMPTOM: Won't boot, no power light, nothing works, nothing on screen

Problem	Possible cause	Repair action
No power	Power cord not plugged in	Plug in cord.
	Power supply faulty	Replace.
	Power cable not connected	Plug in cable.

Troubleshooting Procedure



(Continued)

YES

NO

DISCONNECT POWER PLUG, REPLACE POWER SUPPLY (see Appendix, page 184).

PLUG IN POWER SUPPLY CONNECTOR.

TEST—TURN POWER SWITCH ON.

RETURN SYSTEM TO FULL SERVICE.

To locate the power supply, power cord, and power supply connector, refer to Fig. 1-4, which shows the inside of the IBM PC system unit.

Circuitry Affected

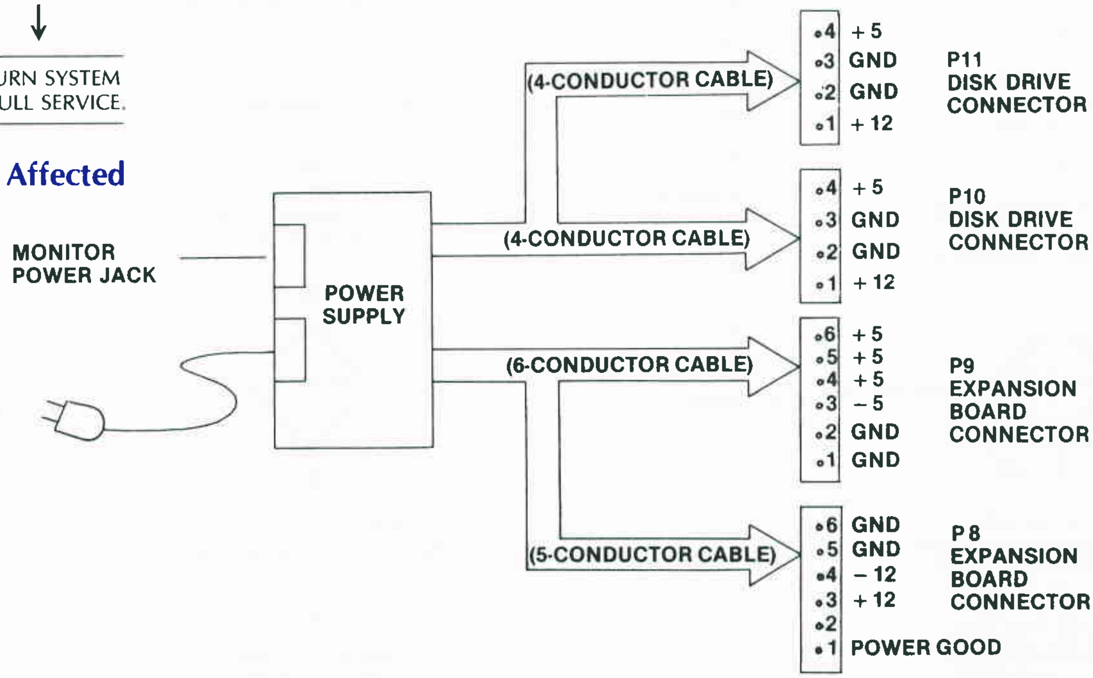


Fig. 4-3. Simplified power supply circuitry.

SYMPTOM: Won't boot, power light on, nothing works, nothing on screen

Problem	Possible cause	Repair action
No clock	8284 at U11 bad	Replace and test.
	8088 at U3 bad	Replace and test.
	Bad crystal	Replace and test.
No start-up data	Bad ROM at U33	Replace and test.

Troubleshooting Procedure

TURN POWER OFF.

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

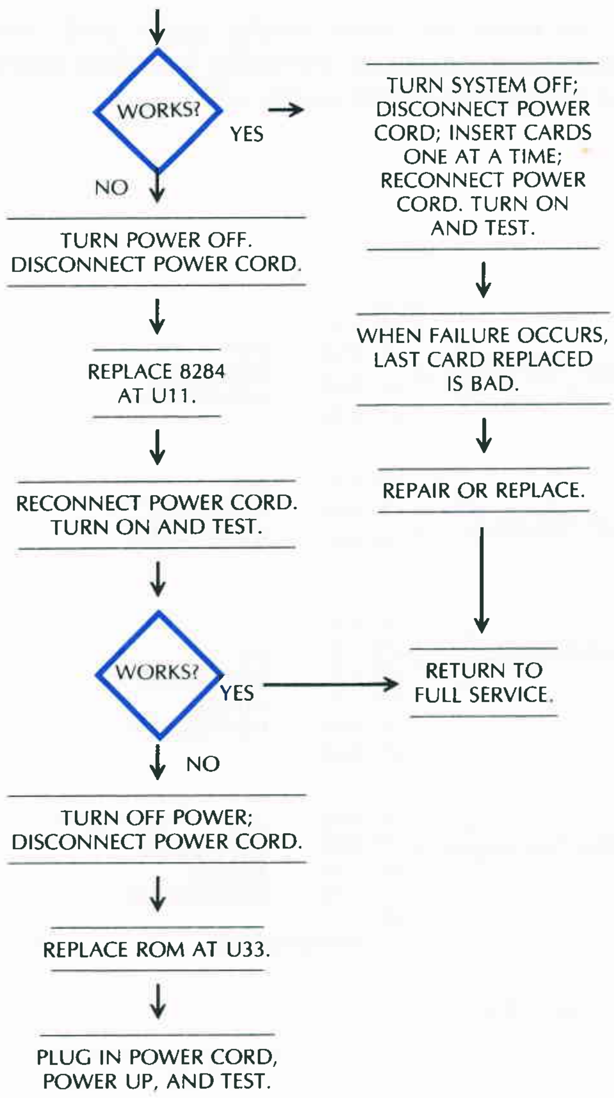
REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.

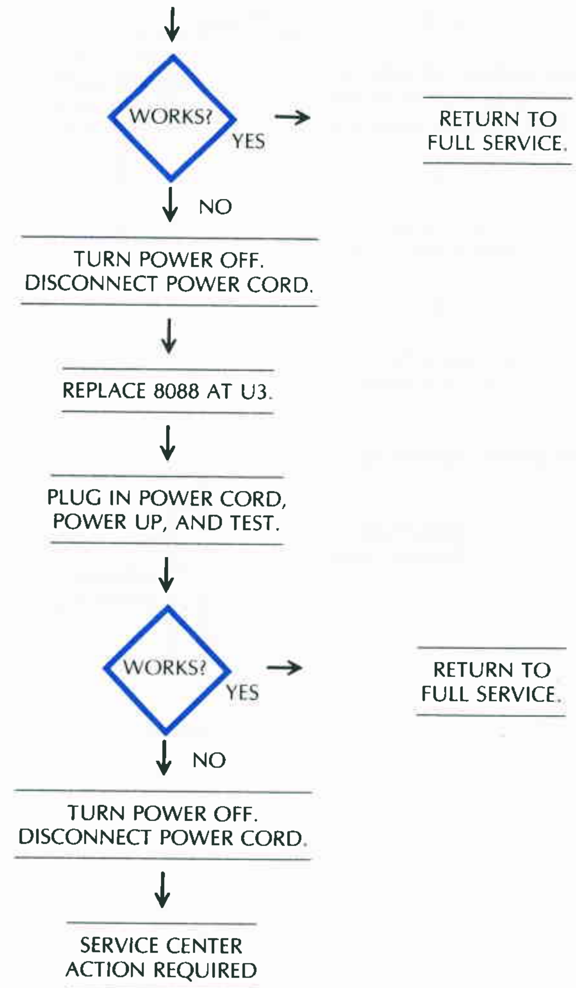
DISCONNECT ALL PERIPHERAL HARDWARE, INCLUDING DISK DRIVE INTERFACE.

CONNECT MONITOR TO COMPUTER.

RECONNECT POWER CORD; TURN ON COMPUTER AND MONITOR.

(Continued)





Circuitry Affected

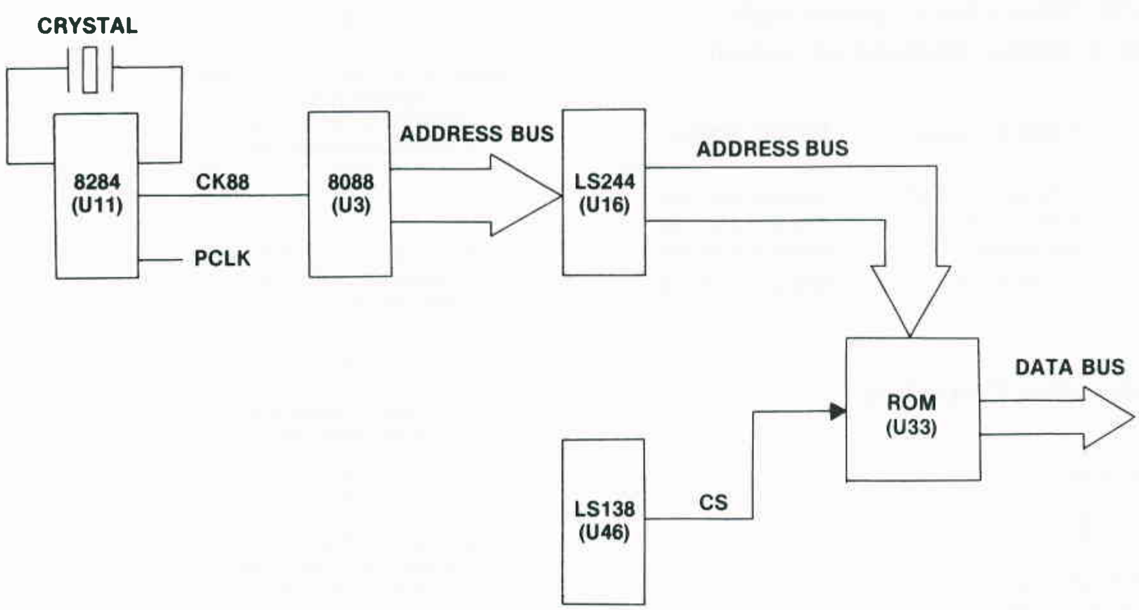


Fig. 4-4. Clock circuitry.

Chip designation	Description	Location
8284	Clock generator	U11
8088	Microprocessor	U3
Monitor ROM	8K × 8-bit static ROM	U33

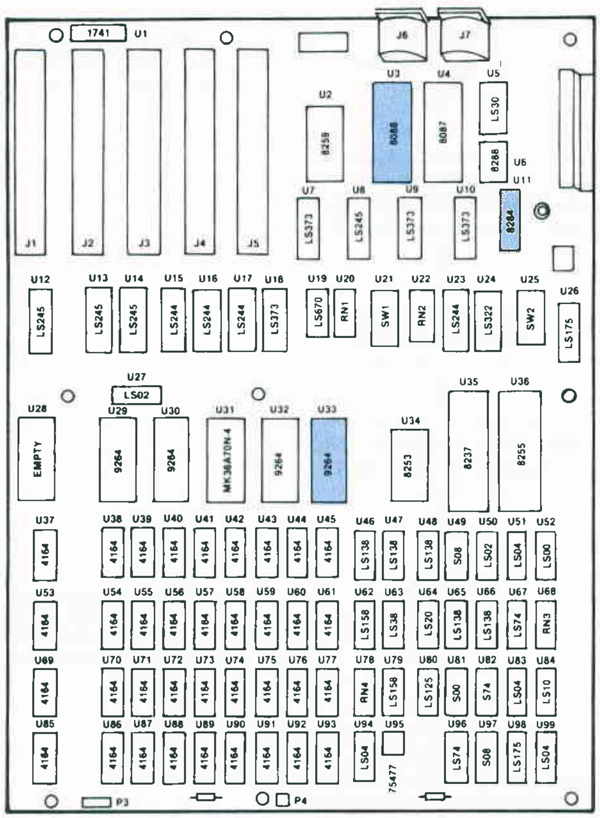


Fig. 4-5. Chip location guide. This represents the IBM PC system board and is a guide to help you locate the chips of interest.

SYMPTOM: Power light on, drive won't boot a disk

(See "One drive won't read" or "Neither drive will read" section.)

RUN PROBLEMS

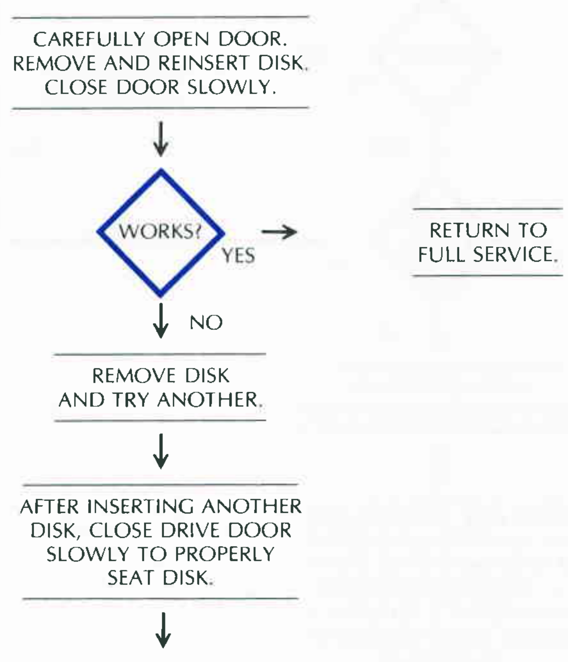
Symptom Category: **Page**

This section covers those problems you might encounter while your system is running. For example, you might attempt to do something and get a response entirely different from what you expected.

SYMPTOM: One drive won't read

Problem	Possible cause	Repair action
Data not coming from disk	Bad disk	Replace disk.
	Bad data on disk	Try another disk.
	Disk not seated properly	Reseat disk.
Read head not reading	Bad read head	Ask service center to replace head.
Data not coming out of drive	Cable bad or loose	Reseat or replace.
Bad IC on analog card	Bad 74S38 at 1F	Replace and test.
	Bad 221 at 5E	Replace and test.
	Bad 74LS86 at 5D	Replace and test.
	Bad 74LS74 at 5C	Replace and test.
	Bad 311 at 5B	Replace and test.
	Bad 592 at 4A	Replace and test.
	Bad 733 at 3A	Replace and test.

Troubleshooting Procedure



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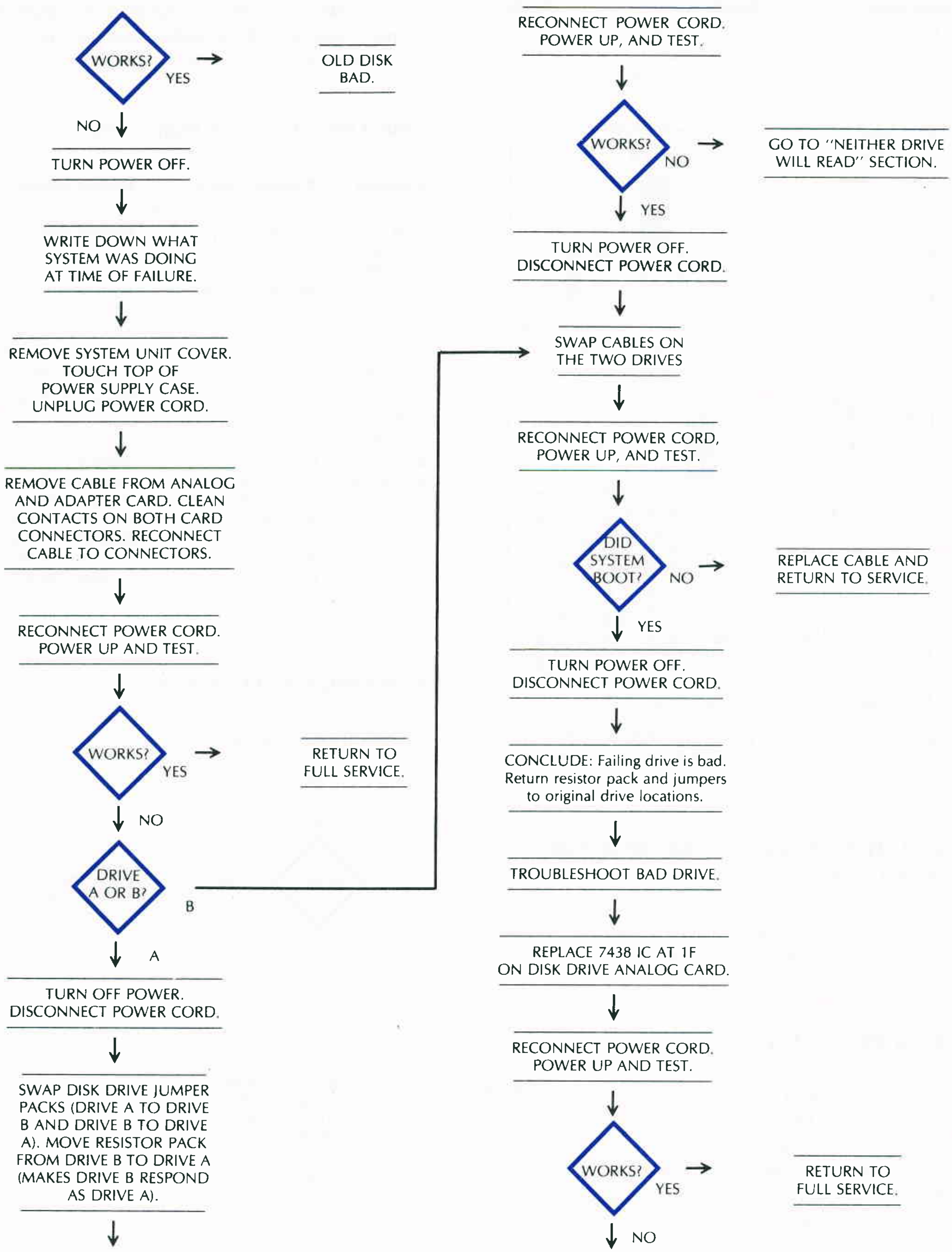
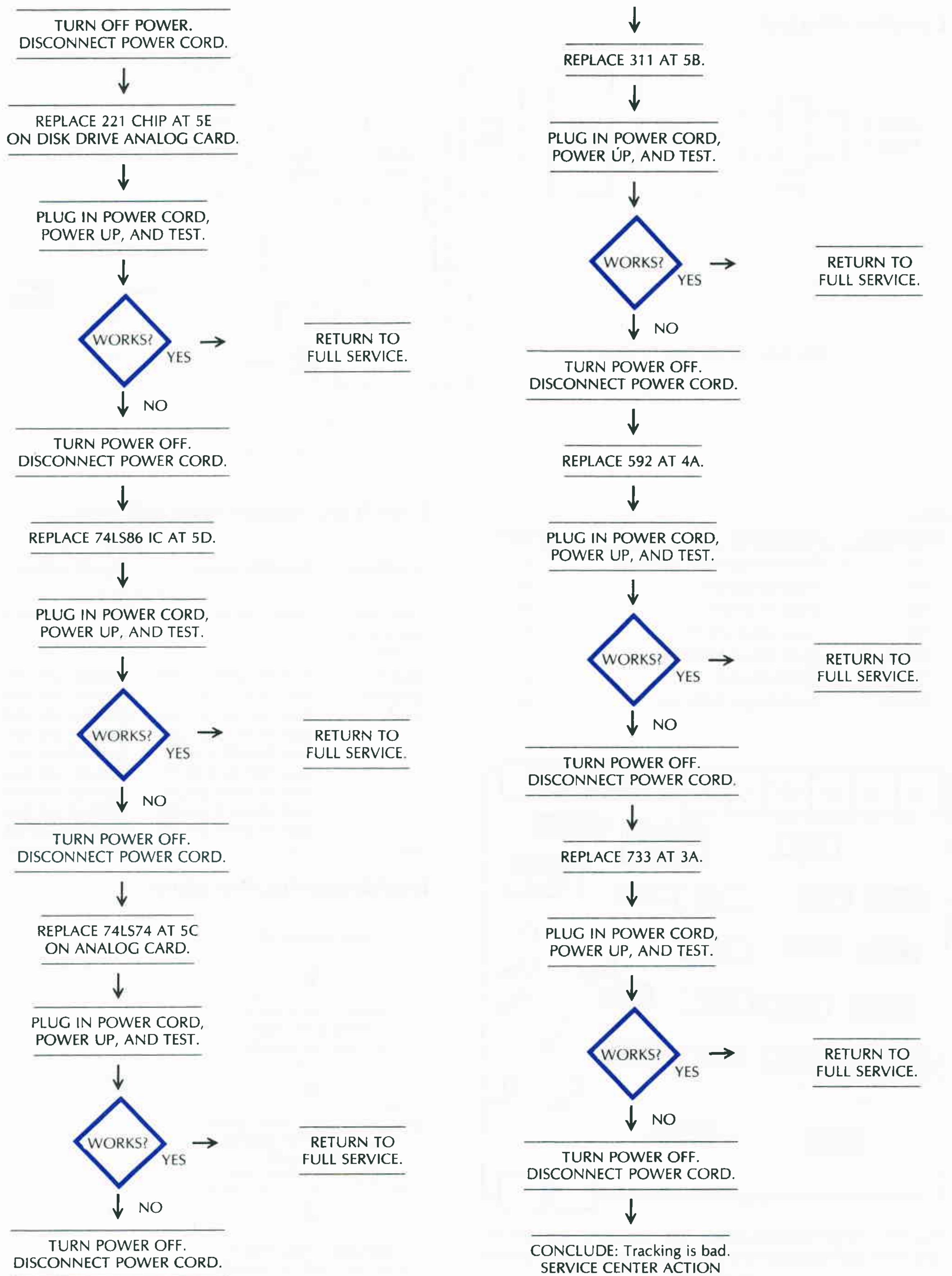

WORKS?
YES
OLD DISK BAD.
NO
TURN POWER OFF.
WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.
REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.
REMOVE CABLE FROM ANALOG AND ADAPTER CARD. CLEAN CONTACTS ON BOTH CARD CONNECTORS. RECONNECT CABLE TO CONNECTORS.
RECONNECT POWER CORD. POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
DRIVE A OR B?
B
A
TURN OFF POWER. DISCONNECT POWER CORD.
SWAP DISK DRIVE JUMPER PACKS (DRIVE A TO DRIVE B AND DRIVE B TO DRIVE A). MOVE RESISTOR PACK FROM DRIVE B TO DRIVE A (MAKES DRIVE B RESPOND AS DRIVE A).
RECONNECT POWER CORD. POWER UP, AND TEST.
WORKS?
NO
GO TO "NEITHER DRIVE WILL READ" SECTION.
YES
TURN POWER OFF. DISCONNECT POWER CORD.
SWAP CABLES ON THE TWO DRIVES
RECONNECT POWER CORD, POWER UP, AND TEST.
DID SYSTEM BOOT?
NO
REPLACE CABLE AND RETURN TO SERVICE.
YES
TURN POWER OFF. DISCONNECT POWER CORD.
CONCLUDE: Failing drive is bad. Return resistor pack and jumpers to original drive locations.
TROUBLESHOOT BAD DRIVE.
REPLACE 7438 IC AT 1F ON DISK DRIVE ANALOG CARD.
RECONNECT POWER CORD. POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO

(Continued)


TURN OFF POWER.
DISCONNECT POWER CORD.
REPLACE 221 CHIP AT 5E
ON DISK DRIVE ANALOG CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
REPLACE 74LS86 IC AT 5D.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
REPLACE 74LS74 AT 5C
ON ANALOG CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
REPLACE 311 AT 5B.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
REPLACE 592 AT 4A.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
REPLACE 733 AT 3A.
PLUG IN POWER CORD,
POWER UP, AND TEST.
WORKS?
YES
RETURN TO
FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
CONCLUDE: Tracking is bad.
SERVICE CENTER ACTION

Circuitry Affected

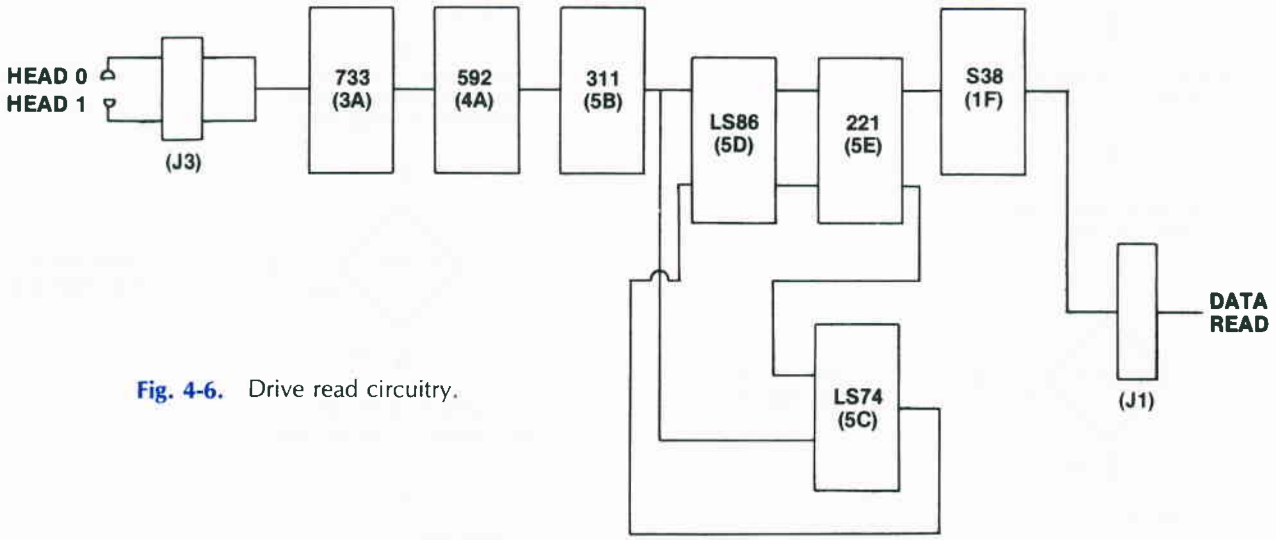


Fig. 4-6. Drive read circuitry.

Chip designation	Description	Location
221	Quad analog switch with latch	5E
311	Linear comparator	5B
592	Linear RF amplifier	4A
733	Linear video amplifier	3A
74S38	Quad 2-input NAND buffer	1F
74LS74	Dual-D flip-flop	5C
74LS86	Quad 2-input EXOR gate	5D

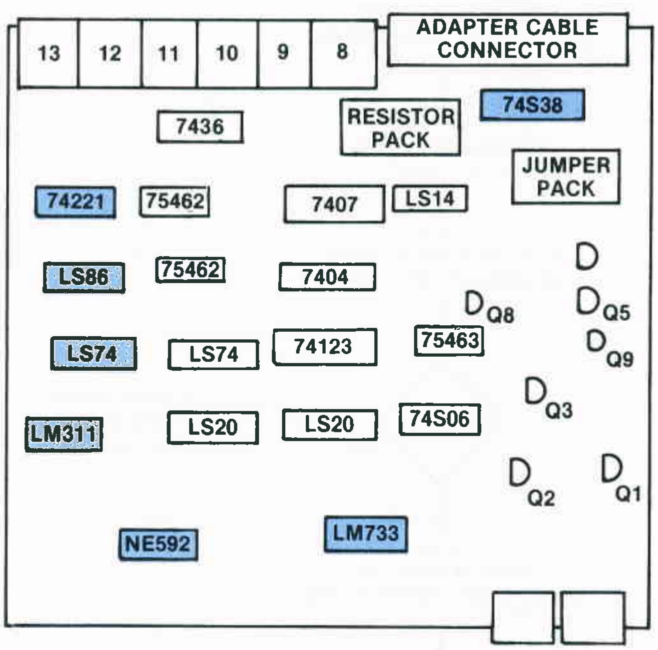


Fig. 4-7. Chip location guide. This represents the IBM PC disk drive analog card and is a guide to help you find the chips of interest.

SYMPTOM: Neither drive will read

Problem	Possible cause	Repair action
Data not coming out of drive	Cable bad or loose	Reseat or replace.
Bad IC on adapter card	Bad 74LS240 at U18	Replace and test.
	Bad 74LS112 at U22	Replace and test.
	Bad 74LS161 at U23	Replace and test.
	Bad 74LS112 at U25	Replace and test.
	Bad 74LS02 at U26	Replace and test.
	Bad 74S153 at U24	Replace and test.
	Bad MC4044 at U21	Replace and test.
	Bad MC4024 at U20	Replace and test.
	Bad 74LS191 at U19	Replace and test.

Troubleshooting Procedure

TURN POWER OFF.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.

↓

REPLACE CABLE FROM ADAPTER CARD TO DRIVES.

(Continued)

RECONNECT POWER CORD. POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN OFF POWER. DISCONNECT POWER CORD.

REPLACE 74LS240 AT U18.

POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN OFF POWER. DISCONNECT POWER CORD.

REPLACE 74LS112 AT U22.

PLUG IN POWER CORD, POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF. DISCONNECT POWER CORD.

REPLACE 74LS161 AT U23.

PLUG IN POWER CORD, POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF. DISCONNECT POWER CORD.

REPLACE 74LS112 AT U25.

PLUG IN POWER CORD, POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF. DISCONNECT POWER CORD.

REPLACE 74LS02 AT U26.

PLUG IN POWER CORD, POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF. DISCONNECT POWER CORD.

REPLACE 74S153 AT U24.

PLUG IN POWER CORD, POWER UP, AND TEST.

(Continued)

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF. DISCONNECT POWER CORD.

↓

REPLACE MC4044 AT U21.

↓

PLUG IN POWER CORD, POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF. DISCONNECT POWER CORD.

↓

REPLACE MC4024 AT U20.

↓

PLUG IN POWER CORD, POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF. DISCONNECT POWER CORD.

↓

REPLACE 74LS191 AT U19.

↓

PLUG IN POWER CORD, POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

SERVICE CENTER ACTION

Circuitry Affected

See Fig. 4-9.

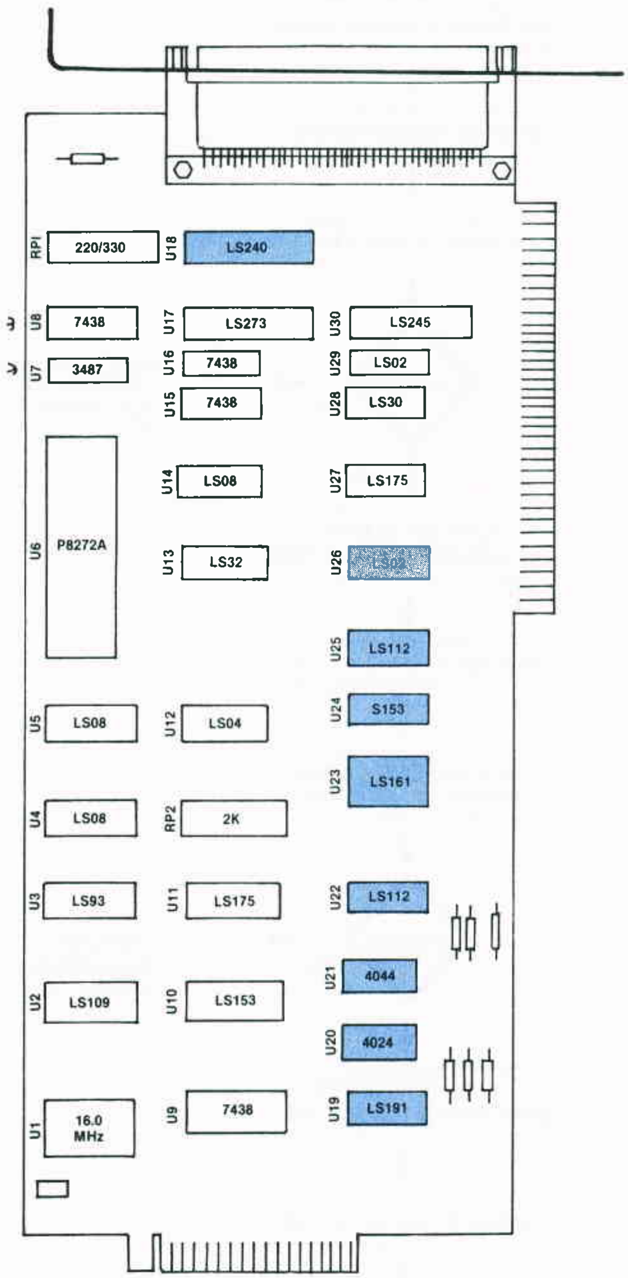


Fig. 4-8. Chip location guide. This represents the IBM PC disk drive adapter card and is a guide to help you find the chips of interest.

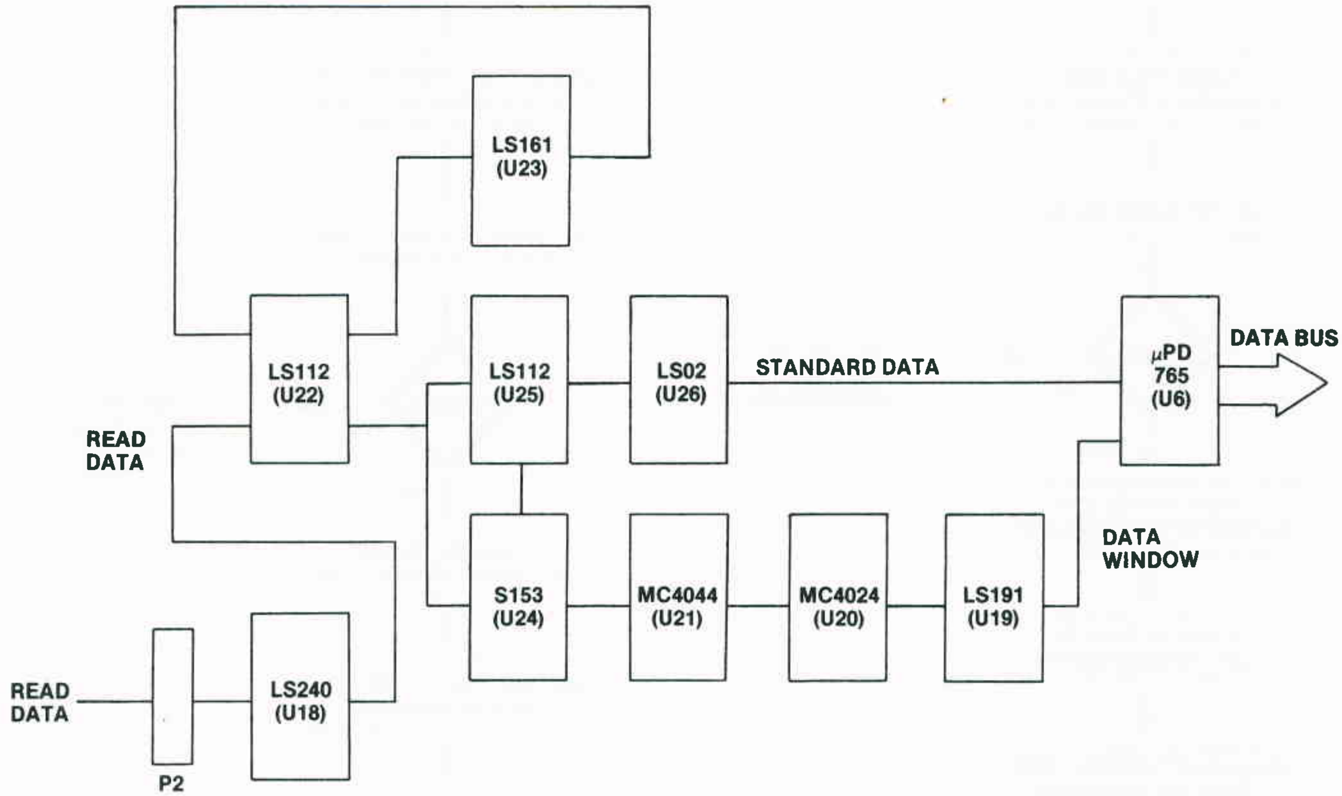


Fig. 4-9. Circuitry for "neither drive will read."

Chip designation	Description	Location
MC4024	Dual voltage-controlled multivibrator	U20
MC4044	Phase frequency detector	U21
74LS02	Quad 2-input NOR gate	U26
74LS112	Dual-JK flip-flop	U22, U25
74S153	Dual 4/1 multiplexer	U24
74LS161	4-bit binary counter	U23
74LS191	Presettable 4-bit binary UP/DOWN counter	U19
74LS240	Tri-state octal inverter buffer	U18

SYMPTOM: One drive won't write (read functions properly)

Problem	Possible cause	Repair action
Disk is write protected	Write-protect tab installed	Remove write-protect tab.
	Write-protect switch bad	Replace switch.
Drive can't tell where to write	Disk not formatted	Format disk.
Write signals not getting to drive electronics	Cable bad or loose	Check cable.
	Analog card connectors corroded	Clean connectors.
Drive electronic signals improper on analog card	Bad 74LS14 at 2E Bad 74LS74 at 5C Bad 74LS06 at 2B	Replace and test. Replace and test. Replace and test.
Drive mechanics bad	Bad write head Bad head alignment	Replace and test. Align head.

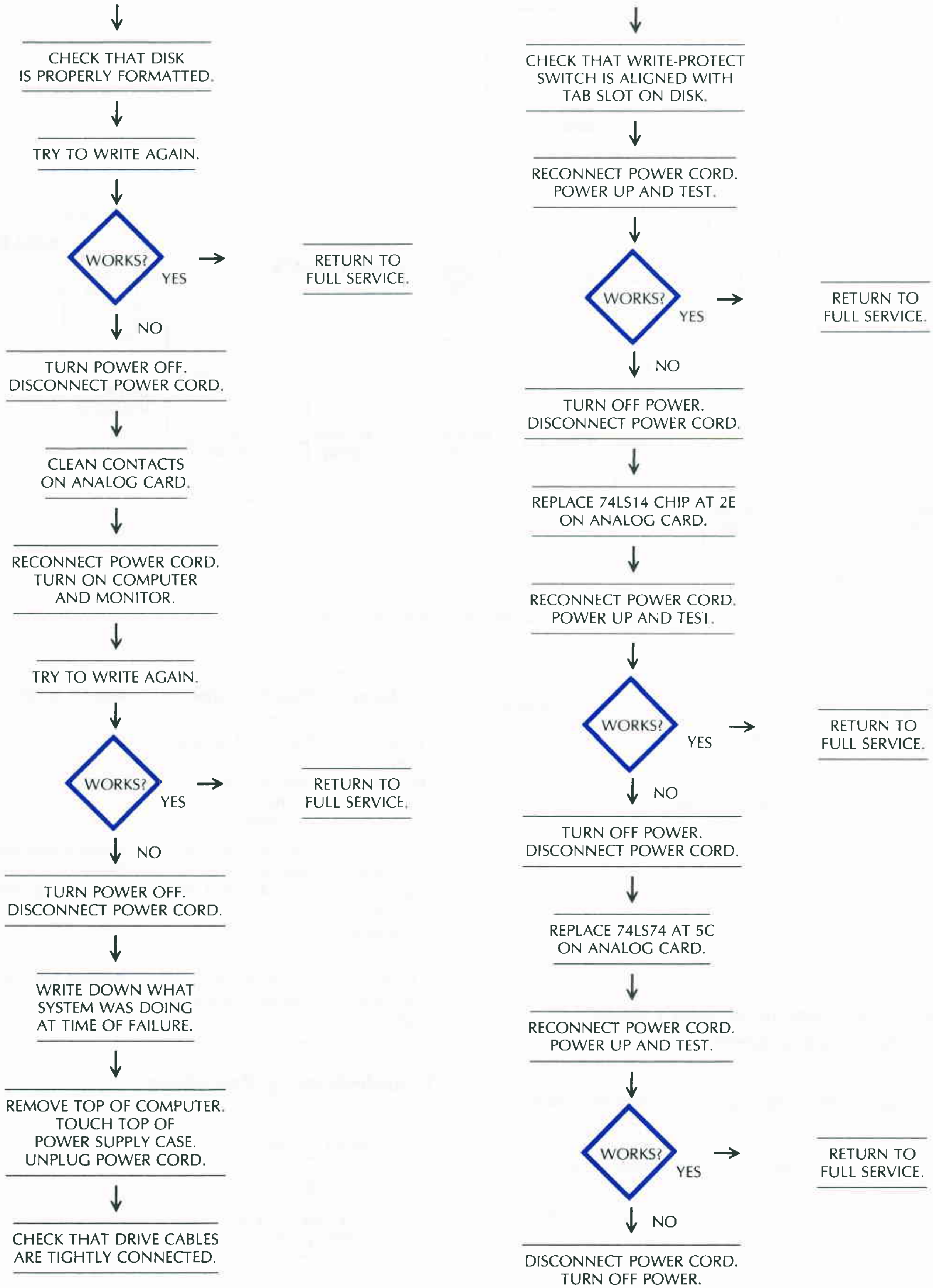
Troubleshooting Procedure

RESET SYSTEM.

↓

CHECK THAT DISK IS NOT WRITE PROTECTED.

(Continued)



CHECK THAT DISK IS PROPERLY FORMATTED.
TRY TO WRITE AGAIN.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF. DISCONNECT POWER CORD.
CLEAN CONTACTS ON ANALOG CARD.
RECONNECT POWER CORD. TURN ON COMPUTER AND MONITOR.
TRY TO WRITE AGAIN.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF. DISCONNECT POWER CORD.
WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.
REMOVE TOP OF COMPUTER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.
CHECK THAT DRIVE CABLES ARE TIGHTLY CONNECTED.
CHECK THAT WRITE-PROTECT SWITCH IS ALIGNED WITH TAB SLOT ON DISK.
RECONNECT POWER CORD. POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN OFF POWER. DISCONNECT POWER CORD.
REPLACE 74LS14 CHIP AT 2E ON ANALOG CARD.
RECONNECT POWER CORD. POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN OFF POWER. DISCONNECT POWER CORD.
REPLACE 74LS74 AT 5C ON ANALOG CARD.
RECONNECT POWER CORD. POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
DISCONNECT POWER CORD. TURN OFF POWER.

(Continued)

↓

REPLACE 74LS06 CHIP AT 2B ON ANALOG CARD.

↓

RECONNECT POWER CORD. POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN OFF POWER.

↓

CONCLUDE: Tracking is off or head is bad. SERVICE CENTER ACTION

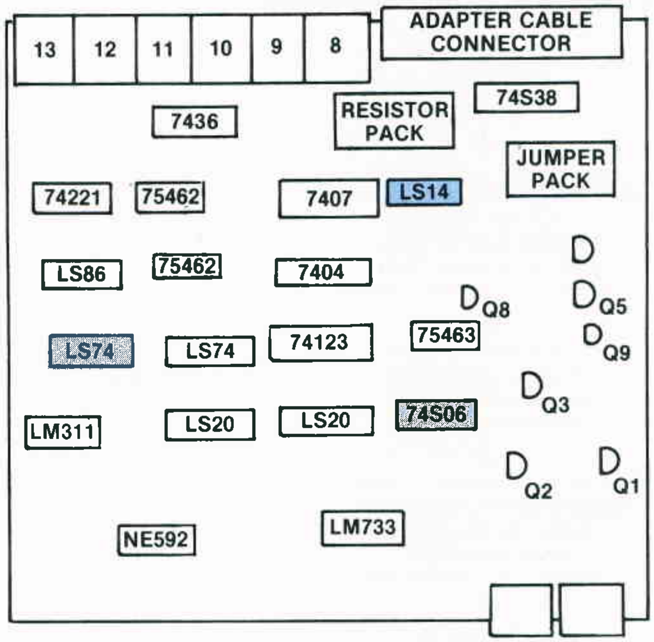


Fig. 4-11. Chip location guide. This represents the IBM PC disk drive analog card and is a guide to help you find the chips of interest.

Circuitry Affected

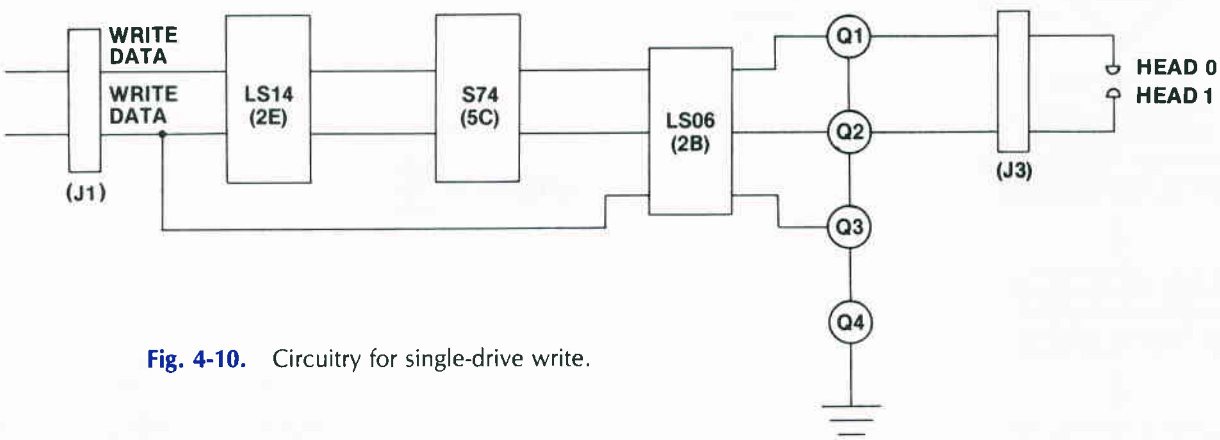


Fig. 4-10. Circuitry for single-drive write.

Chip designation	Description	Location
74LS14	Hex inverter Schmitt trigger	2E
74LS74	Dual-D flip-flop	5C
74LS06	Hex inverter buffer/driver	2B

SYMPTOM: Neither drive will write (read functions properly)

Problem	Possible cause	Repair action
Write signals not getting to drive electronics	Cable bad or loose	Check cable.
	Adapter connectors corroded	Clean connectors.
Drive electronic signals improper on adapter card	Bad 74LS175 at U11	Replace and test.
	Bad 7438 at U9	Replace and test.

Troubleshooting Procedure

RESET SYSTEM.

↓

REMOVE SYSTEM UNIT COVER.
TOUCH TOP OF
POWER SUPPLY CASE.
UNPLUG POWER CORD.

↓

CLEAN CONTACTS
ON ADAPTER CARD.

↓

RECONNECT POWER CORD.
TURN ON COMPUTER
AND MONITOR.

↓

TRY TO WRITE AGAIN.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

WRITE DOWN WHAT
SYSTEM WAS DOING
AT TIME OF FAILURE.

↓

REPLACE 74LS175 CHIP AT U11.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

NO ↓

TURN OFF POWER.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 7438 AT U9.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN OFF POWER.

↓

SERVICE CENTER ACTION

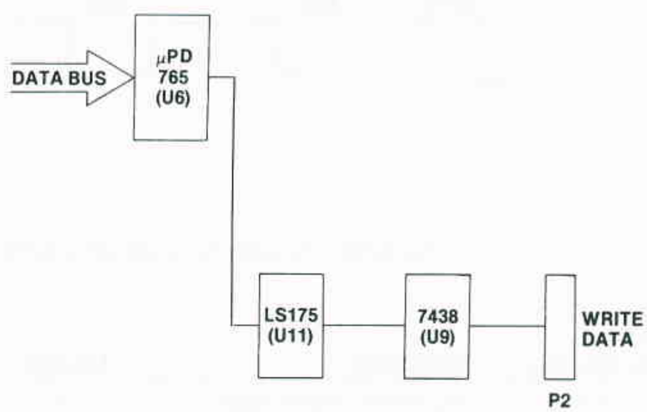


Fig. 4-12. Circuitry for "neither drive will write."

Circuitry Affected

Chip designation	Description	Location
74LS175	Quad-D flip-flop	U11
7438	Quad 2-input NAND buffer	U9

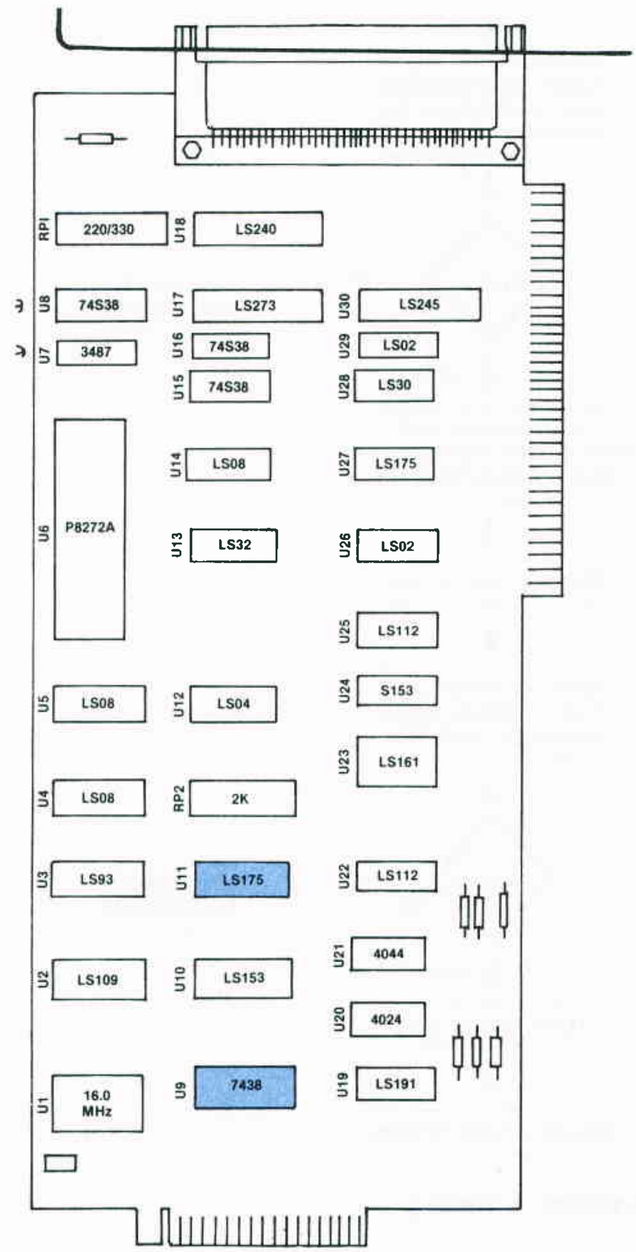


Fig. 4-13. Chip location guide. This represents the IBM PC disk drive adapter card and is a guide to help you find the chips of interest.

SYMPTOM: Drives can't be accessed

Problem	Possible cause	Repair action
Signals not getting into analog card	Corrosion on cable connector pins	Clean cable connector pins.
Adapter electronics not working	Bad 74LS273 at U17	Replace and test.
	Bad 74LS04 at U12	Replace and test.
	Bad 74LS02 at U29	Replace and test.
	Bad 74LS08 at U14	Replace and test.
	Bad 7438 at U16	Replace and test.

Troubleshooting Procedure

TURN POWER OFF.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.

↓

CLEAN CORROSION FROM CONNECTORS AND PINS.

↓

POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

NO ↓

TURN OFF POWER. DISCONNECT POWER CORD. REMOVE ADAPTER CARD.

↓

REPLACE 74LS273 AT U17.

↓

INSERT ADAPTER CARD. PLUG IN POWER CORD, POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF. DISCONNECT POWER CORD. REMOVE ADAPTER CARD.

↓

REPLACE 74LS04 AT U12.

(Continued)

INSERT ADAPTER CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

REPLACE 74LS02 AT U29.

INSERT ADAPTER CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

REPLACE 74LS08 AT U14.

INSERT ADAPTER CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

REPLACE 7438 AT U16.

INSERT ADAPTER CARD.
PLUG IN POWER CORD,
POWER UP, AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.

SERVICE CENTER ACTION

Circuitry Affected

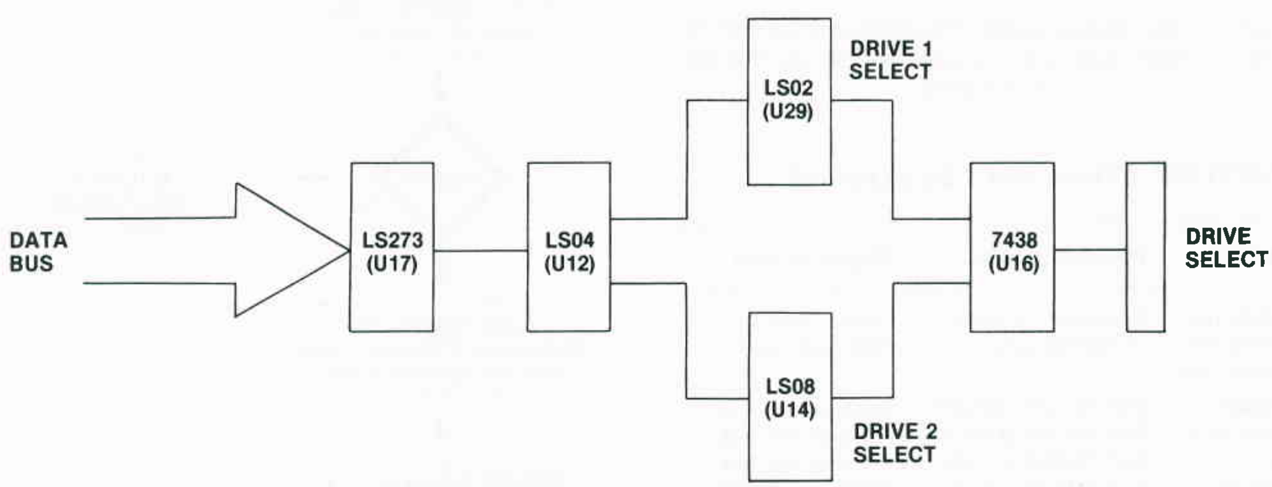


Fig. 4-14. Drive select circuitry.

Chip designation	Description	Location
74LS02	Quad 2-input NOR gate	U29
74LS04	Hex inverter	U12
74LS08	Quad 2-input AND gate	U14
7438	Quad 2-input NAND buffer	U16
74LS273	Octal-D flip-flop	U17

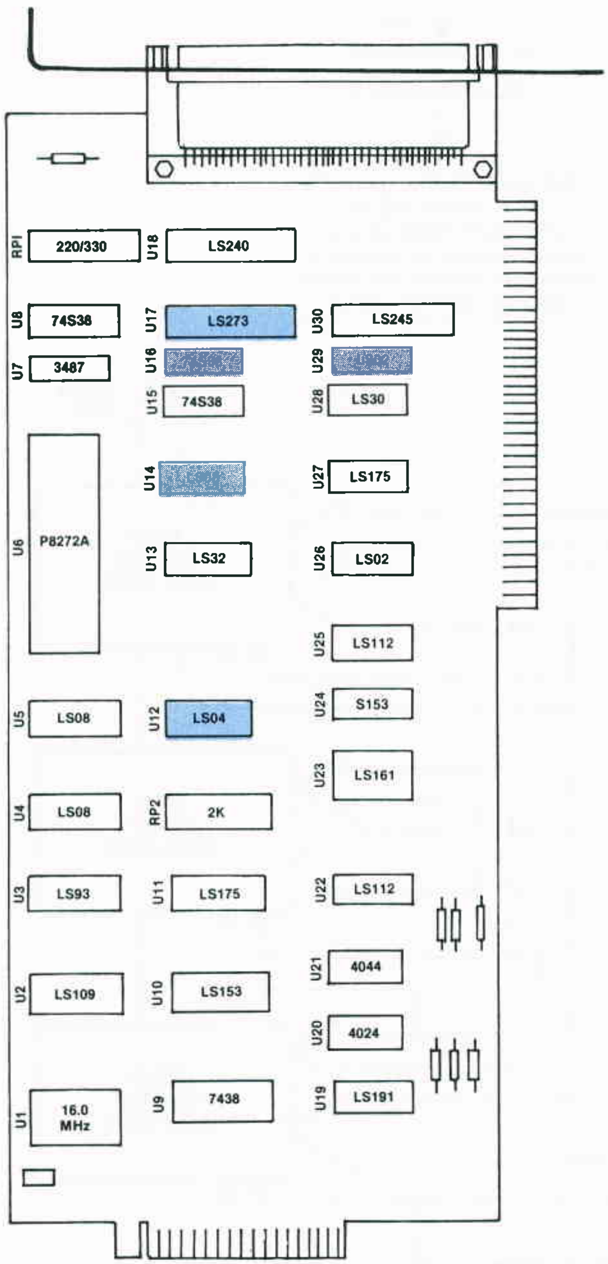


Fig. 4-15. Chip location guide. This represents the IBM PC disk drive adapter card and is a guide to help you find the chips of interest.

SYMPTOM: Computer locks up, keyboard entries won't work

Problem	Possible cause	Repair action
Programming lock-out	Error in program	Debug program.
No output from keyboard circuitry	Failure in keyboard circuitry	Go to "Keyboard won't respond" section.
Heat problem on motherboard	Bad RAM chip	Replace and test.
No RAM chip-select signal	Bad 8288 chip at location U6	Replace and test.
CPU failure	Bad 8088 chip at location U3	Replace and test.

Troubleshooting Procedure

TURN POWER OFF.
REMOVE SYSTEM UNIT COVER.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE DISK FROM DRIVE.

↓

RESET COMPUTER.

↓

TEST KEYBOARD KEYS.
PRESS EVERY CHARACTER KEY.

↓

WORKS? — NO → GO TO "KEYBOARD WON'T RESPOND" SECTION.

↓ YES

TRY RUNNING PROGRAM WITH COVER REMOVED.

↓

WORKS? — YES → PROBLEM IS PROBABLY CAUSED BY HEAT.

↓

↓ NO

(Continued)

TURN OFF POWER.
TOUCH TOP OF
POWER SUPPLY CASE.
UNPLUG POWER CORD.

↓

REPLACE 8288
AT LOCATION U6.

↓

RECONNECT POWER CORD,
POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

INSTALL EXTERNAL
FAN.

↓

RETURN TO
FULL SERVICE.

REPLACE 8088
AT LOCATION U3.

↓

RECONNECT POWER CORD,
POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN OFF POWER.

↓

CONCLUDE: Problem probably a
weak, failing chip on
motherboard. Need advanced
troubleshooting techniques in
order to locate bad component.
SERVICE CENTER ACTION

Circuitry Affected

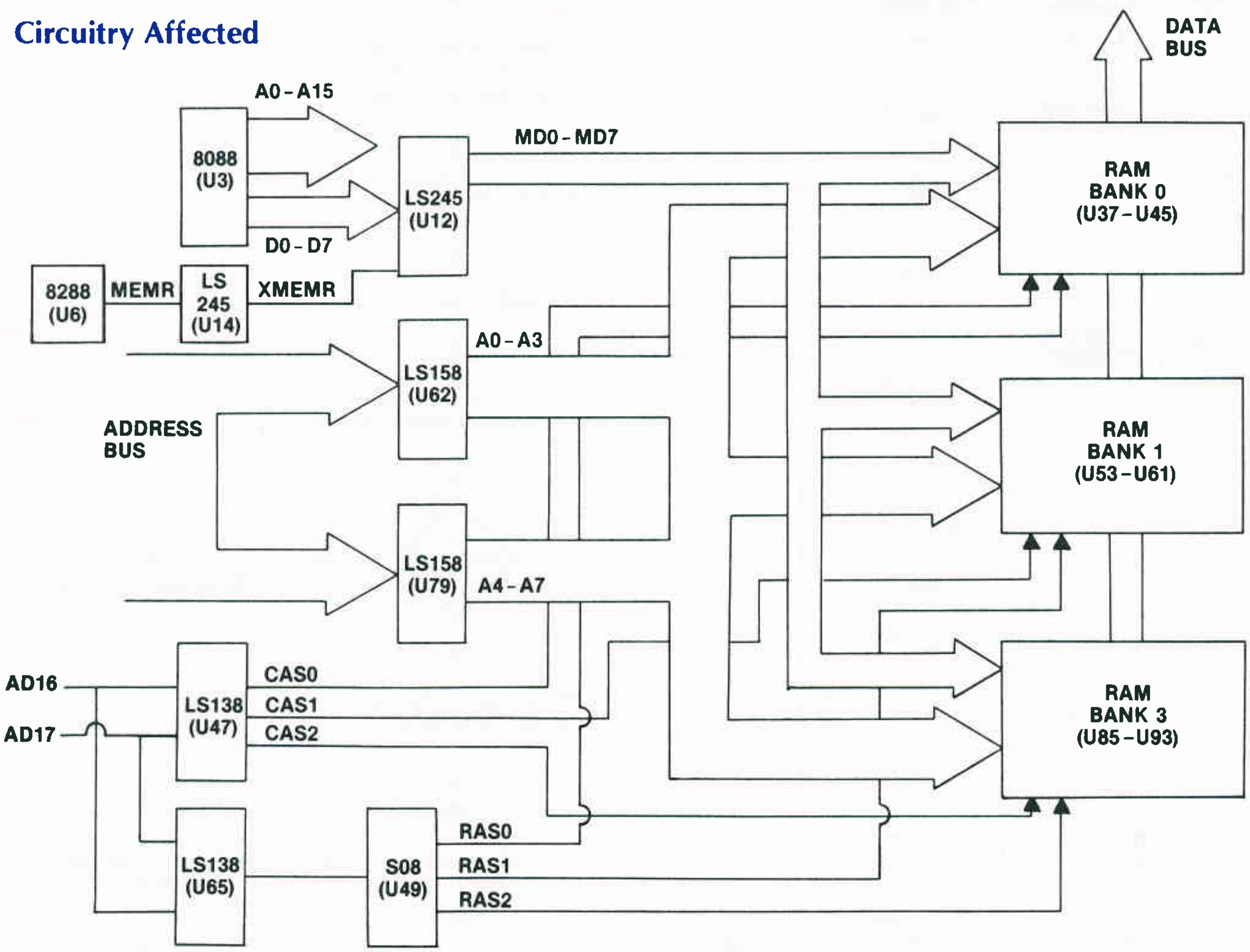


Fig. 4-16. Circuitry for "computer locks up" problem.

Chip designation	Description	Location
8088	Microprocessor (central processing unit)	U3
8288	Bus controller	U6
74S08	Quad 2-input AND gate	U49
74LS138	1/8 decoder/demultiplexer	U47, U65
74LS158	Quad 2-input data selector multiplexer	U62, U79
74LS245	Tri-state octal transceiver	U12

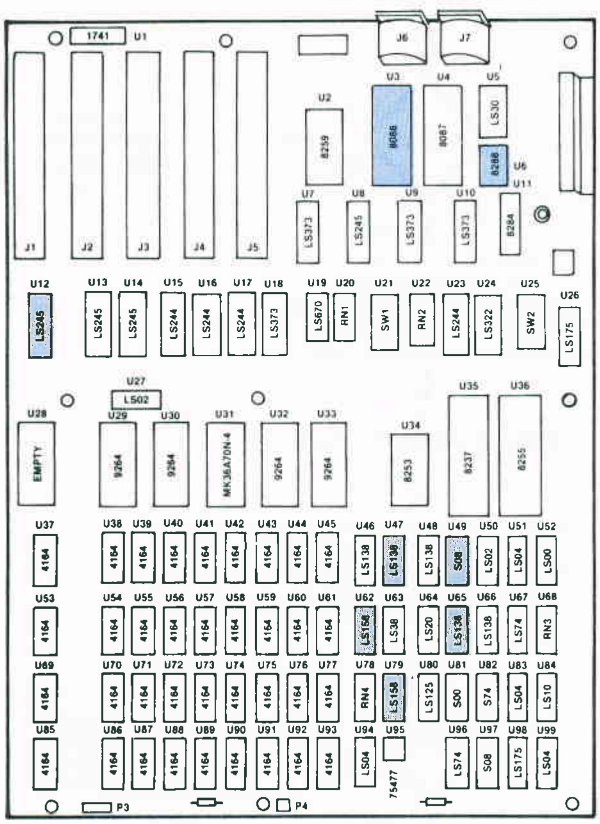


Fig. 4-17. Chip location guide. This represents the IBM PC system board and is a guide to help you find the chips of interest.

DISPLAY PROBLEMS

Symptom Category **Page**

MONOCHROME MONITOR AND ADAPTER CARD

SYMPTOM: No display

Problem	Possible cause	Repair action
No video into monitor	Bad cable	Reseat or replace.
Video signal too small	Brightness out of adjustment	Adjust brightness.
	Bad monitor	Check and replace if necessary.
No video signal being generated	Bad 74LS244 at U64	Replace and test.
	Bad 74S74 at U101	Replace and test.
	Bad 74S86 at U54	Replace and test.
	Bad MK36000 at U33	Replace and test.
	Bad 74LS273 at U34	Replace and test.
	Bad 6845 at U35	Replace and test.

Troubleshooting Procedure

CHECK VIDEO CABLE.

↓

CHECK VIDEO BRIGHTNESS.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF. DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

(Continued)

REMOVE SYSTEM UNIT COVER.
TOUCH TOP OF
POWER SUPPLY CASE.

↓

DISCONNECT ALL PERIPHERAL
HARDWARE EXCEPT
VIDEO INTERFACE.

↓

CONNECT MONITOR TO IBM PC.

↓

REMOVE MONOCHROME
ADAPTER CARD.

↓

REPLACE 74LS244 AT U64.

↓

REINSTALL ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74S74 AT U101.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74S86 AT U54.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE MK36000 AT U33.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

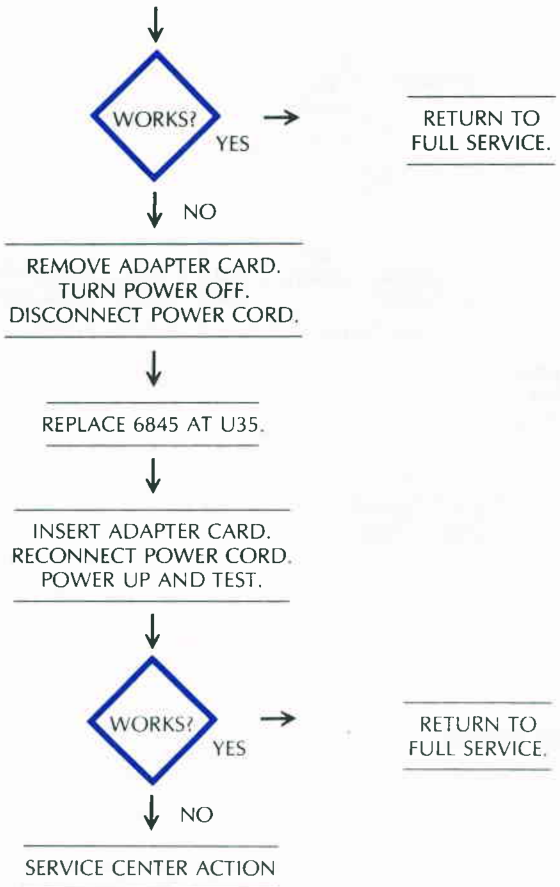
↓

REPLACE 74LS273 AT U34.

↓

INSERT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

(Continued)



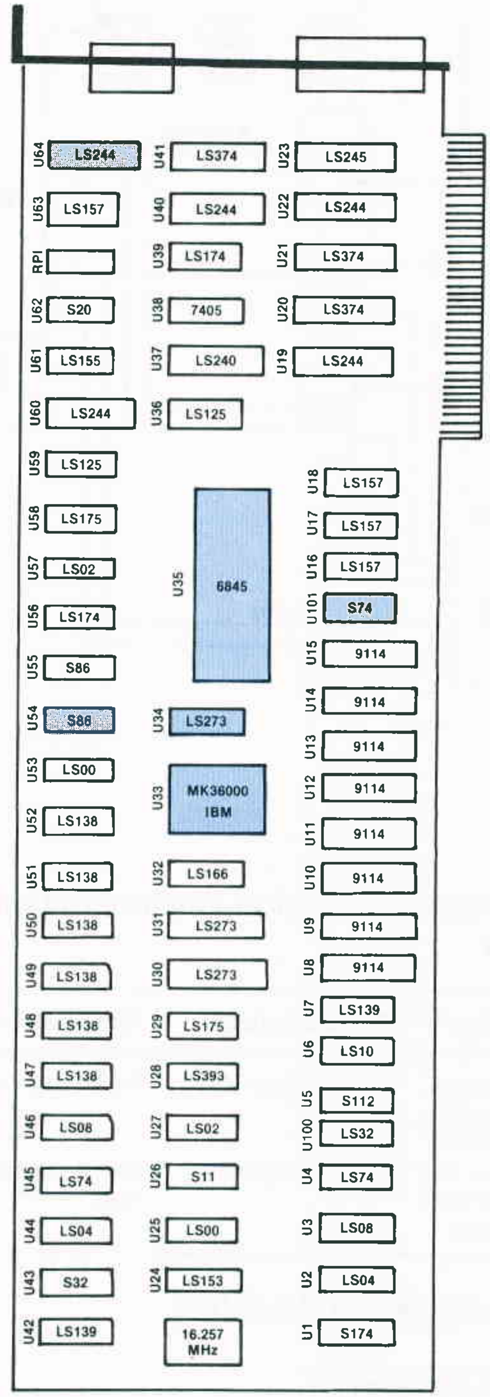


Fig. 4-18. Chip location guide. This represents the IBM PC monochrome adapter card and is a guide to help you find the chips of interest.

Circuitry Affected

See Fig. 4-19.

Chip designation	Description	Location
6845	CRT controller	U35
74S74	Dual-D flip-flop	U101
74S86	Quad 2-input EXOR gate	U54
74LS244	Tri-state octal buffer	U64
74LS273	Octal-D flip-flop	U34
MK36000	Character generator ROM	U33

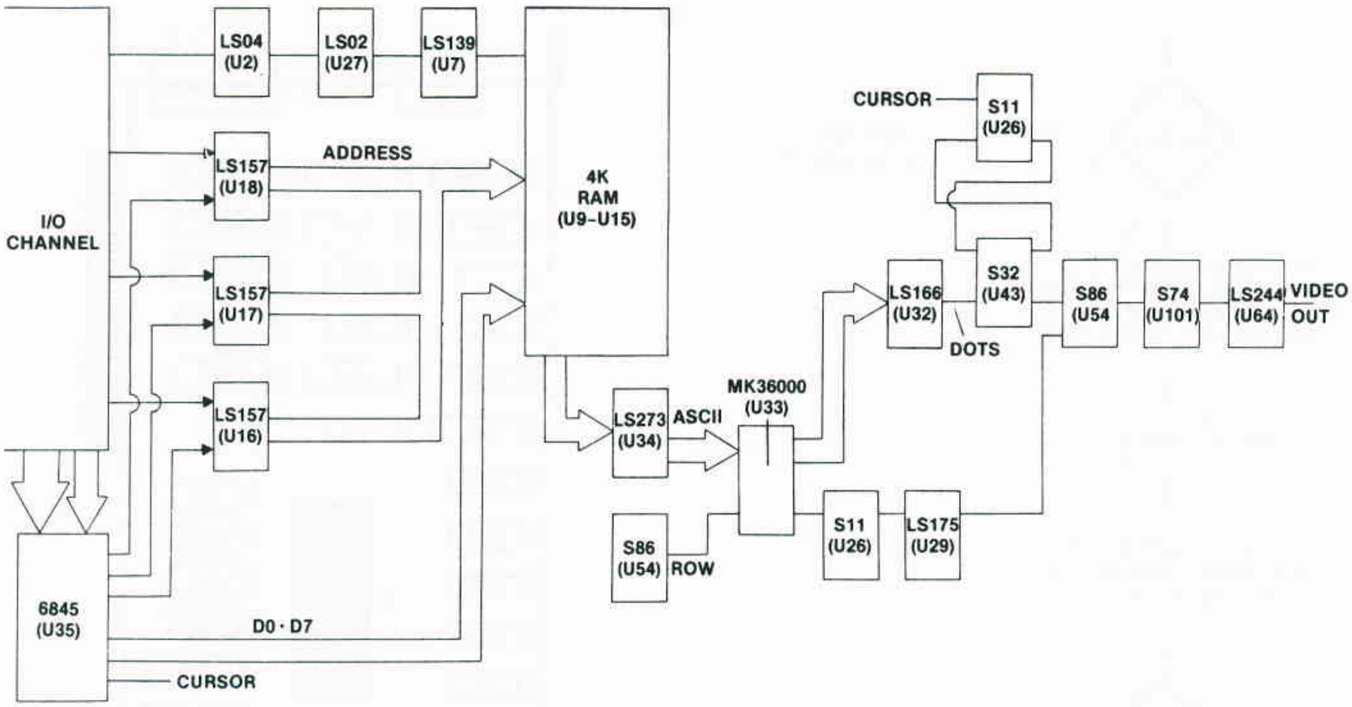


Fig. 4-19. Monochrome video circuitry.

SYMPTOM: No vertical synchronization (sync)

Problem	Possible cause	Repair action
No vertical sync signal to monitor	Bad 74S86 at U54	Replace and test.
Monitor not in sync with computer	Monitor adjustment	Adjust vertical hold.

Troubleshooting Procedure

TURN POWER OFF.

↓

ADJUST VERTICAL SYNC ON MONITOR.

↓

POWER UP AND TEST.

↓

WORKS? — YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.

↓

REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE. UNPLUG POWER CORD.

↓

REMOVE MONOCHROME ADAPTER.

↓

REPLACE 74S86 AT U54 ON ADAPTER CARD.

↓

REINSTALL ADAPTER CARD. RECONNECT POWER CORD. RECONNECT MONITOR, POWER UP AND TEST.

(Continued)

WORKS? — YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

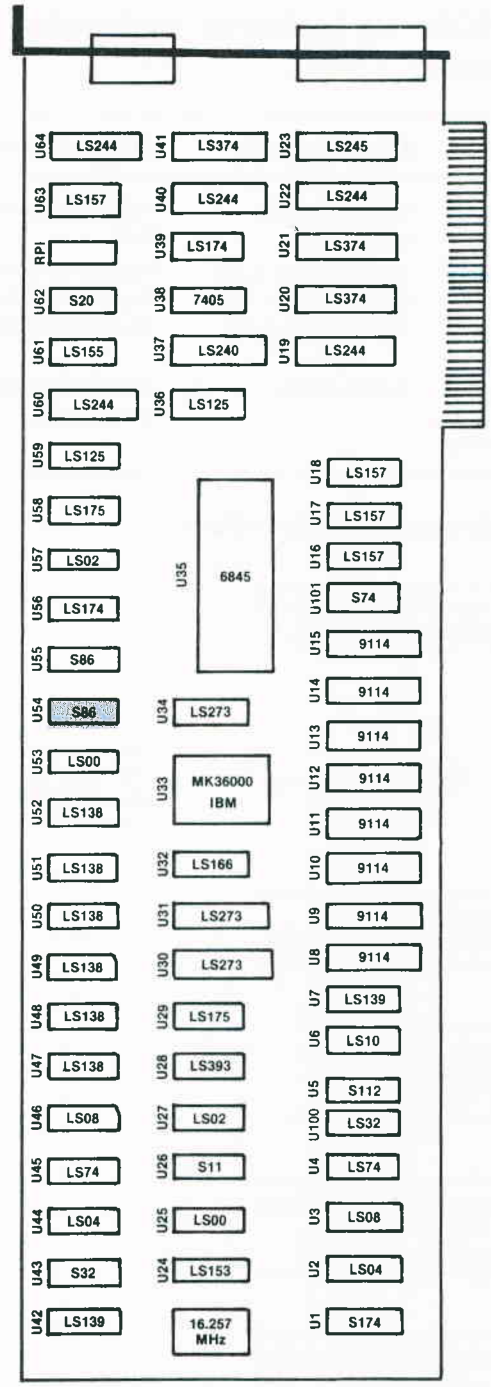
CONCLUDE: Problem is not caused by chip failure.
SERVICE CENTER ACTION

Circuitry Affected

See Fig. 4-21.

Chip designation	Description	Location
74S86	Quad 2-input EXOR gate	U54

Fig. 4-20. Chip location guide. This represents the IBM PC monochrome adapter card and is a guide to help you find the 74S86 chip. →



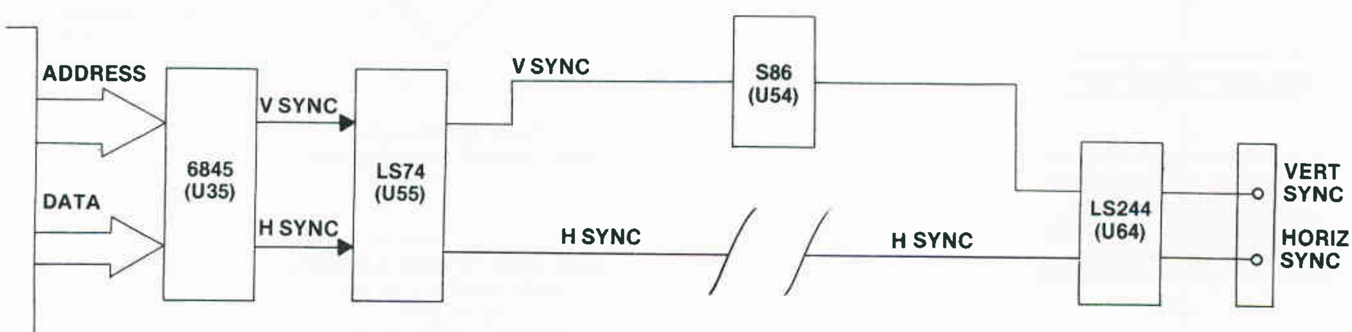


Fig. 4-21. Vertical synchronization circuitry.

SYMPTOM: No horizontal synchronization (sync)

Problem	Possible cause	Repair action
Monitor not in sync	Monitor needs adjusting	Adjust horizontal hold.
Horizontal sync not being produced	Bad 74S74 at U101 Bad 74LS32 at U100 Bad 74LS08 at U3	Replace and test. Replace and test. Replace and test.
Monitor not functioning	Bad monitor	Check and replace if necessary.

Troubleshooting Procedure

CHECK MONITOR HORIZONTAL HOLD (SYNC) CONTROL.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE.

↓

DISCONNECT MONOCHROME ADAPTER CARD.

↓

REPLACE 74S74 AT U101.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS32 AT U100.

↓

RECONNECT POWER CORD.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS08 AT U3.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP, AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

CONCLUDE: Problem is probably in the monitor or at least not in an IC.
SERVICE CENTER ACTION

Circuitry Affected

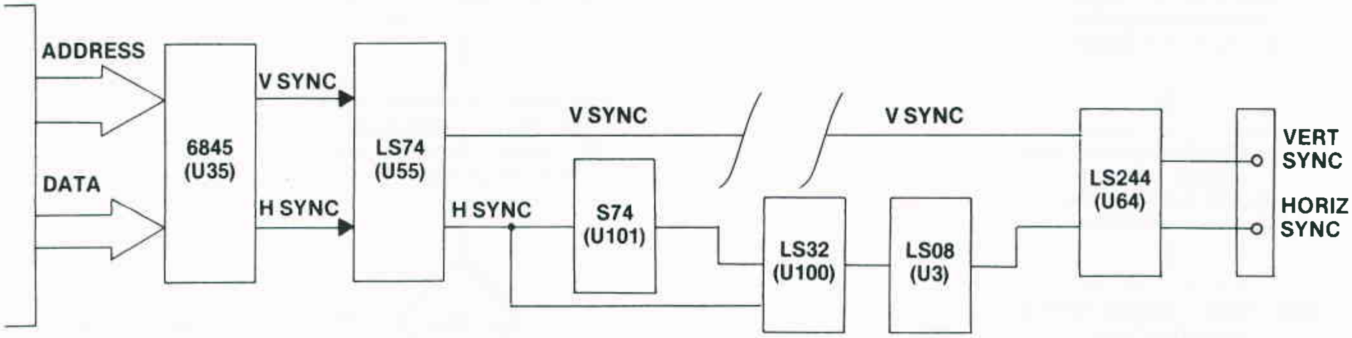
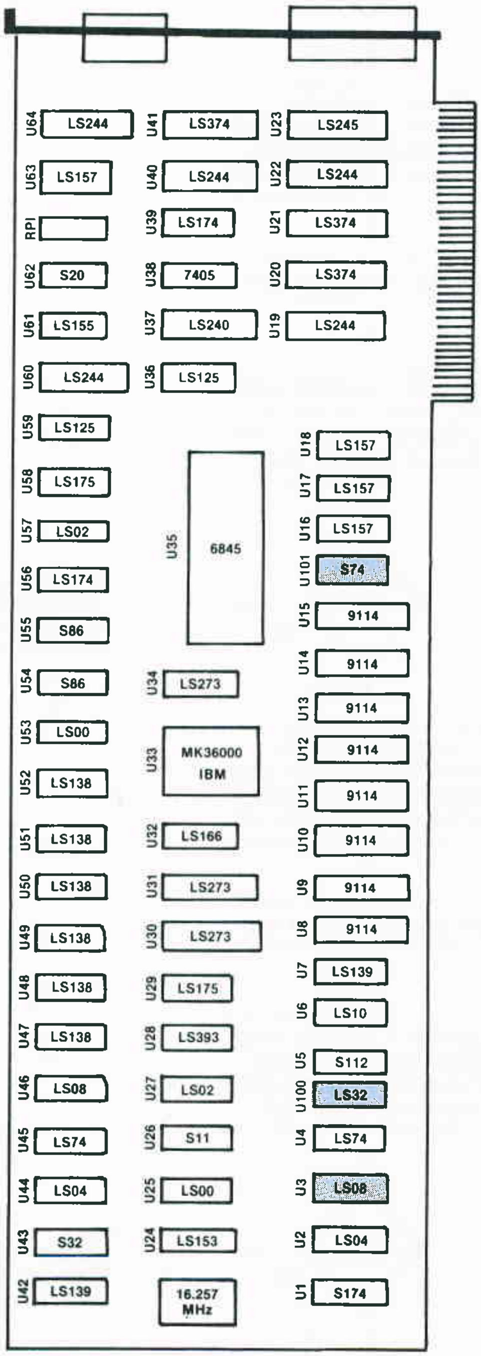


Fig. 4-22. Horizontal synchronization circuitry.



Chip designation	Description	Location
74LS08	Quad 2-input AND gate	U3
74LS32	Quad 2-input OR gate	U100
74S74	Dual-D flip-flop	U101

Fig. 4-23. Chip location guide. This represents the IBM PC monochrome adapter card and is a guide to help you find the chips of interest.

SYMPTOM: Bad characters displayed

Problem	Possible cause	Repair action
Data not being latched properly	Bad 74LS157 at U16 Bad 74LS157 at U17 Bad 74LS157 at U18	Replace and test. Replace and test. Replace and test.
Data not staying in RAM correctly	Bad RAM IC at U9–U15	Replace and test.
Characters not generated properly	Bad 74LS273 at U34 Bad MK36000 at U33 Bad 74S86 at U54 Bad 74LS166 at U32 Bad 74S11 at U26 Bad 74LS175 at U29 Bad 74S32 at U43	Replace and test. Replace and test. Replace and test. Replace and test. Replace and test. Replace and test. Replace and test.

Troubleshooting Procedure

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

(Continued)

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE SYSTEM UNIT COVER. TOUCH TOP OF POWER SUPPLY CASE.

↓

DISCONNECT MONOCHROME ADAPTER CARD AND MONITOR CABLE.

↓

REPLACE 74LS157 AT U16.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS157 AT U17.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.
DISCONNECT MONITOR.

↓

REPLACE 74LS157 AT U18.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS273 AT U34.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.

↓

REPLACE MK36000 AT U33.

↓

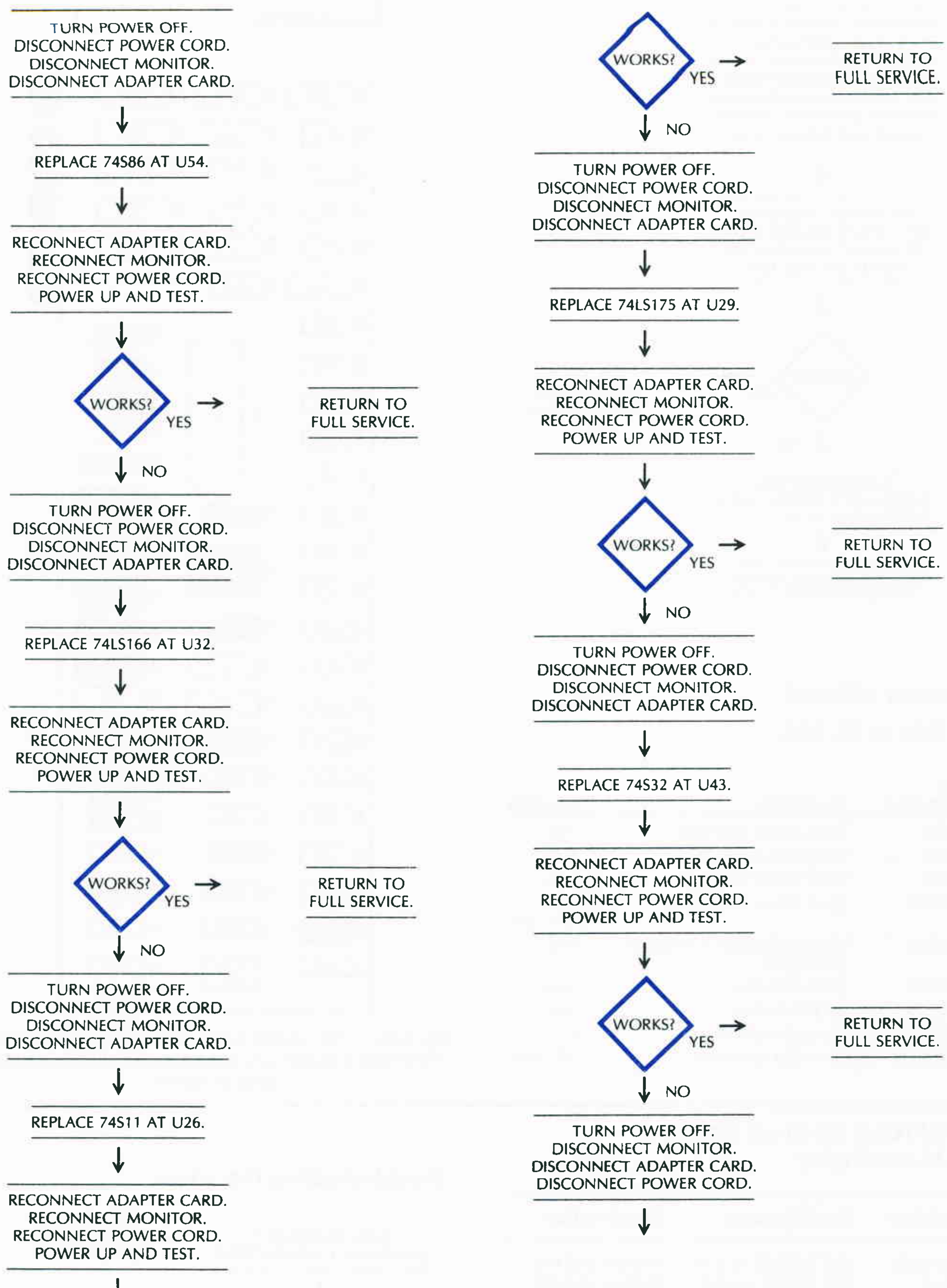
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

(Continued)


TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
REPLACE 74S86 AT U54.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
REPLACE 74LS166 AT U32.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
REPLACE 74S11 AT U26.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
REPLACE 74LS175 AT U29.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
REPLACE 74S32 AT U43.
RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.
WORKS?
YES
RETURN TO FULL SERVICE.
NO
TURN POWER OFF.
DISCONNECT MONITOR.
DISCONNECT ADAPTER CARD.
DISCONNECT POWER CORD.

(Continued)

CONCLUDE: Problem is likely to be in the RAM section. Replace each RAM chip starting with U9 and working through U15. Test after each replacement. When the problem is corrected, the last chip replaced is bad.

↓

RECONNECT MONITOR.
RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? → YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

SERVICE CENTER ACTION

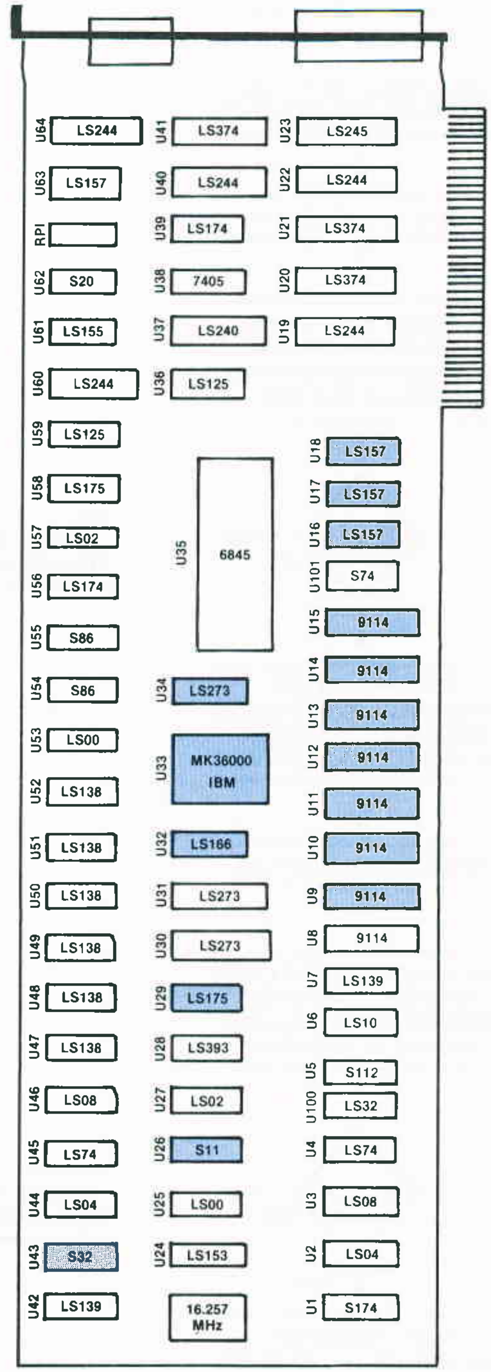


Fig. 4-24. Chip location guide. This represents the IBM PC monochrome adapter card and is a guide to help you find the chips of interest.

Circuitry Affected

Refer to Fig. 4-19.

Chip designation	Description	Location
74S11	Triple 3-input AND gate	U26
74S32	Quad 2-input OR gate	U43
74S86	Quad 2-input EXOR gate	U54
74LS157	Quad 2-input multiplexer	U16, U17, U18
74LS166	8-bit serial/parallel in, serial-out shift register	U32
74LS175	Quad-D flip-flop	U29
74LS273	Octal-D flip-flop	U34
MK36000	8K × 8-bit static ROM	U33
2114/9114	1K × 4-bit static RAM	U9–U15

SYMPTOM: No lo-res display or no hi-res display

Problem	Possible cause	Repair action
No mode select	Bad 74LS175 at U58 Bad 74LS00 at U53 Bad 74LS10 at U6	Replace and test. Replace and test. Replace and test.

Troubleshooting Procedure

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

(Continued)

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

REMOVE TOP OF COMPUTER. TOUCH TOP OF POWER SUPPLY CASE.

DISCONNECT MONOCHROME ADAPTER CARD AND MONITOR CABLE.

REPLACE 74LS175 AT U58.

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.
DISCONNECT MONITOR.

REPLACE 74LS00 AT U53.

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.
DISCONNECT MONITOR.

REPLACE 74LS10 AT U6.

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.

CONCLUDE: Problem is probably not a chip.
SERVICE CENTER ACTION

Circuitry Affected

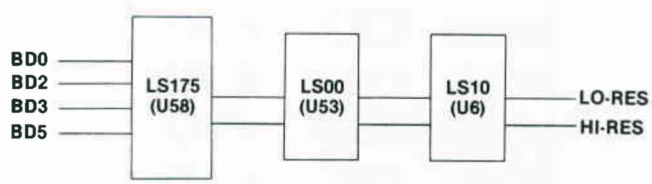


Fig. 4-25. Low-resolution graphics circuitry.

Chip designation	Description	Location
74LS00	Quad 2-input NAND gate	U53
74LS10	Triple 3-input NAND gate	U6
74LS175	Quad-D flip-flop	U58

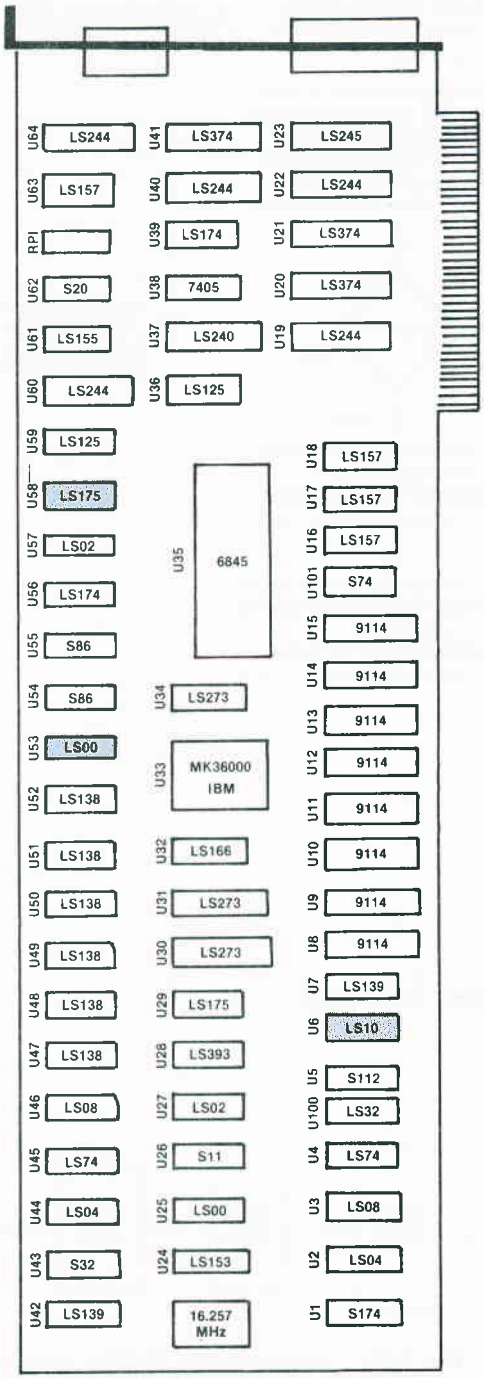


Fig. 4-26. Chip location guide. This represents the IBM PC monochrome adapter card and is a guide to help you find the chips of interest.

COLOR/GRAPHICS MONITOR AND ADAPTER CARD

SYMPTOM: No display

Problem	Possible cause	Repair action
No video into monitor	Bad cable	Reseat or replace.
Video signal too small	Brightness out of adjustment	Adjust brightness.
	Bad monitor	Check and replace if necessary.
No video signal being generated on color/graphics adapter card	Bad 74LS244 at U67	Replace and test.
	Bad 74LS151 at U45	Replace and test.
	Bad 74S174 at U101	Replace and test.
	Bad 74LS32 at U23	Replace and test.
	Bad 74LS51 at U22	Replace and test.
	Bad 74LS32 at U14	Replace and test.
	Bad 74LS08 at U13	Replace and test.
	Bad 74LS166 at U32	Replace and test.
	Bad MK36000 at U33	Replace and test.
	Bad 6845 at U38	Replace and test.

Troubleshooting Procedure

CHECK VIDEO CABLE.

↓

CHECK VIDEO BRIGHTNESS.

↓

WORKS? — YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE TOP OF COMPUTER.
TOUCH TOP OF POWER SUPPLY CASE.

↓

(Continued)

DISCONNECT ALL PERIPHERAL HARDWARE EXCEPT VIDEO INTERFACE.

↓

CONNECT MONITOR TO IBM PC.

↓

REMOVE ADAPTER CARD.

↓

REPLACE 74LS244 AT U67 ON ADAPTER CARD.

↓

RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74LS151 AT U45.

↓

RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74S174 AT U101.

↓

RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
RÉMOVE ADAPTER CARD.

↓

REPLACE 74LS32 AT U23.

↓

RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74LS51 AT U22.

↓

RECONNECT ADAPTER CARD.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

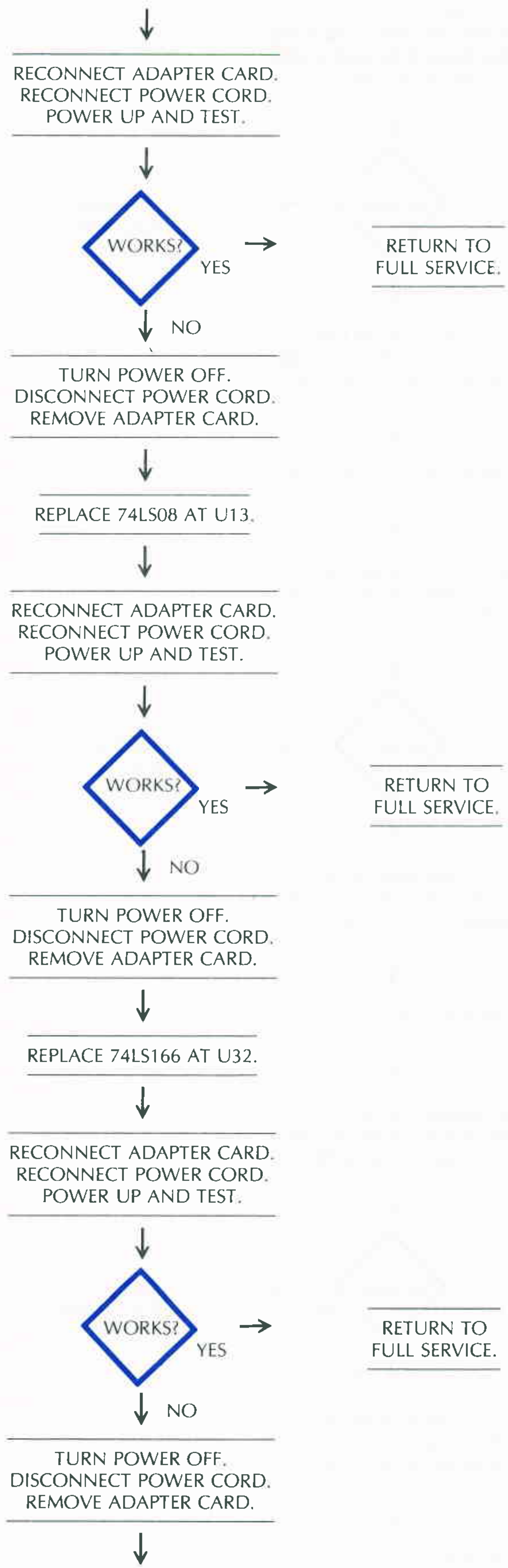
↓ NO

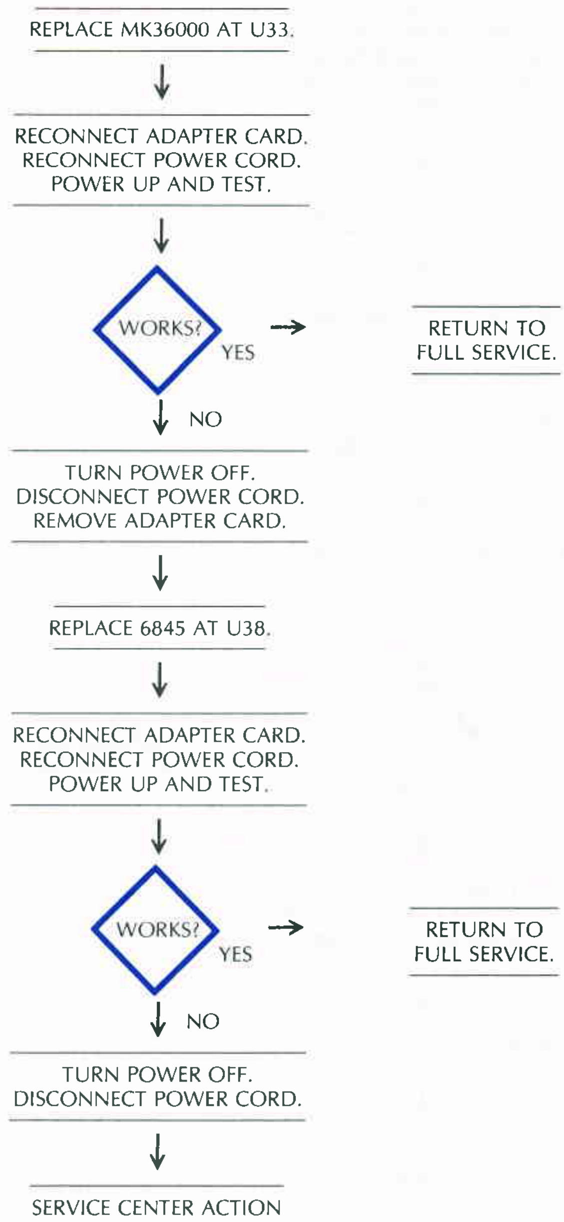
TURN POWER OFF.
DISCONNECT POWER CORD.
REMOVE ADAPTER CARD.

↓

REPLACE 74LS32 AT U14.

(Continued)





Circuitry Affected

See Fig. 4-28.

Chip designation	Description	Location
74LS08	Quad 2-input AND gate	U13
74LS32	Quad 2-input OR gate	U23, U14
74LS51	Dual 2-wide 2-input AND-OR-invert gate	U22
74LS151	8-input multiplexer	U45
74LS166	8-bit serial/parallel-in serial-out shift register	U32
74S174	Hex-D flip-flop	U101
74LS244	Tri-state octal buffer	U67
MK36000	8K × 8-bit NMOS static ROM	U33
6845	CRT controller	U38

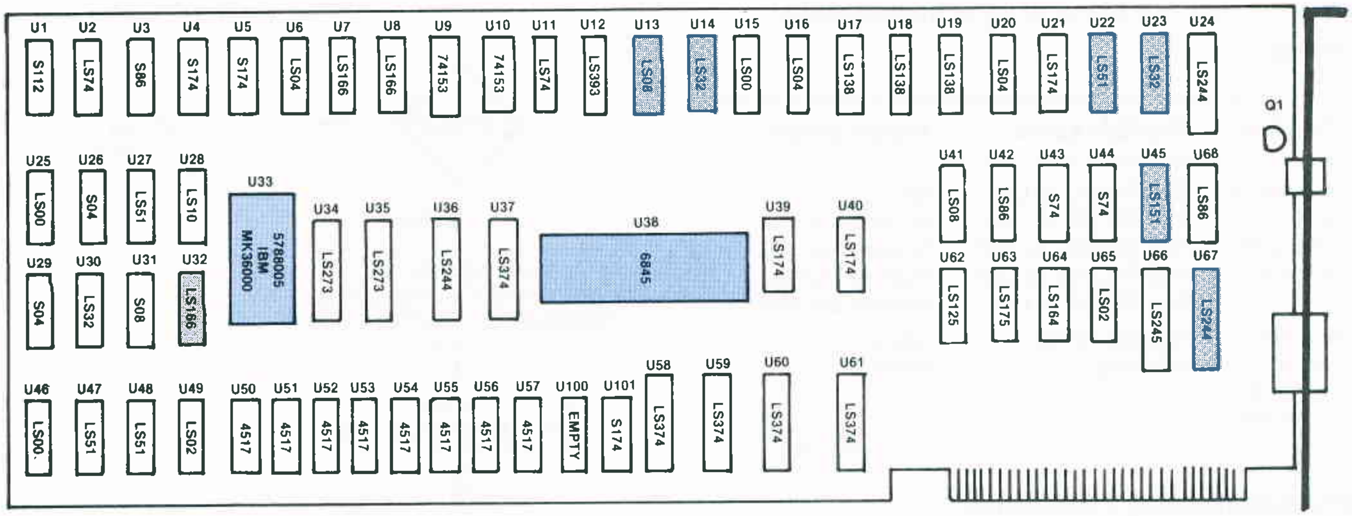


Fig. 4-27. Chip location guide. This represents the IBM PC color/graphics adapter card and is a guide to help you find the chips of interest.

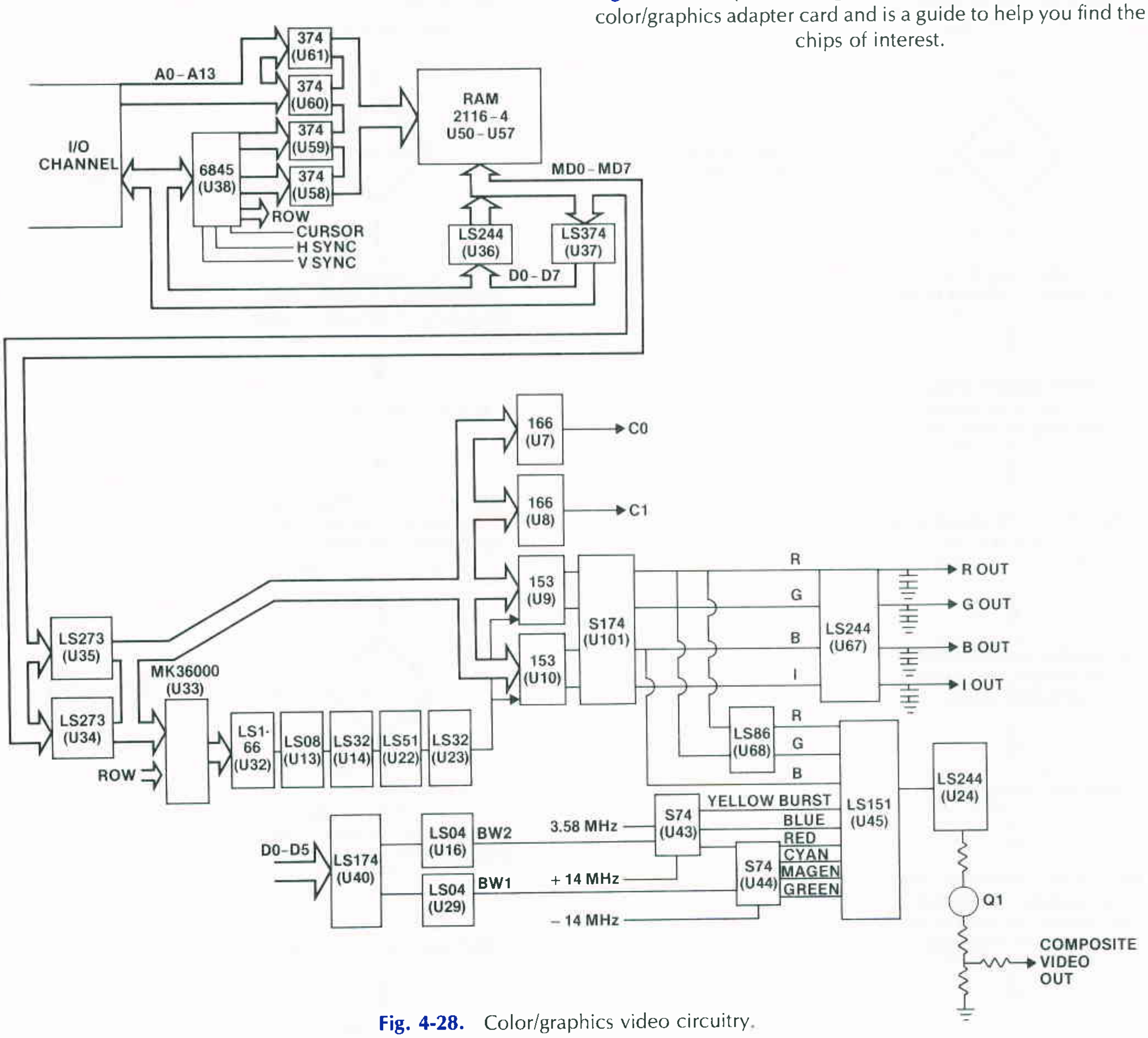


Fig. 4-28. Color/graphics video circuitry.

SYMPTOM: No vertical synchronization (sync)

Problem	Possible cause	Repair action
No vertical sync getting to monitor	Bad 74LS02 at U65	Replace and test.
	Bad 74LS86 at U68	Replace and test.
	Bad 74LS151 at U45	Replace and test.
	Bad 74LS175 at U63	Replace and test.
	Bad 74LS08 at U41	Replace and test.
Monitor not in sync with computer	Monitor needs adjusting	Adjust monitor controls.

Troubleshooting Procedure

CHECK MONITOR VERTICAL SYNC CONTROL.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE TOP OF COMPUTER.
TOUCH TOP OF POWER SUPPLY CASE.

↓

DISCONNECT COLOR/GRAPHICS ADAPTER CARD AND MONITOR CABLE.

↓

REPLACE 74LS02 AT U65.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS86 AT U68.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS151 AT U45.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

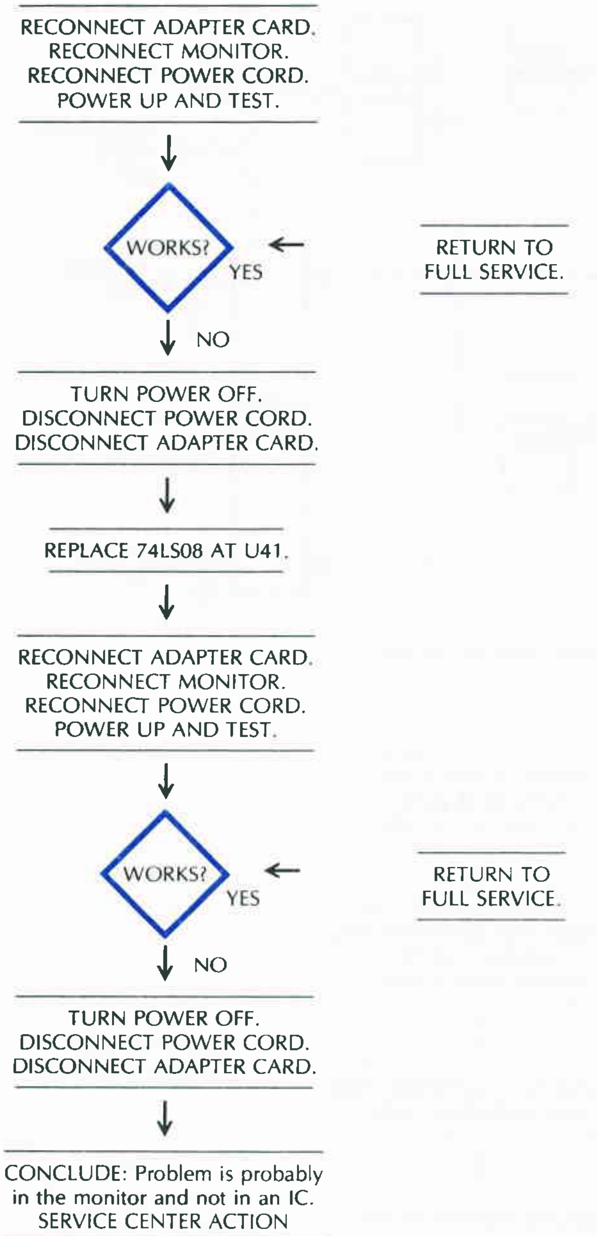
TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

↓

REPLACE 74LS175 AT U63.

↓

(Continued)



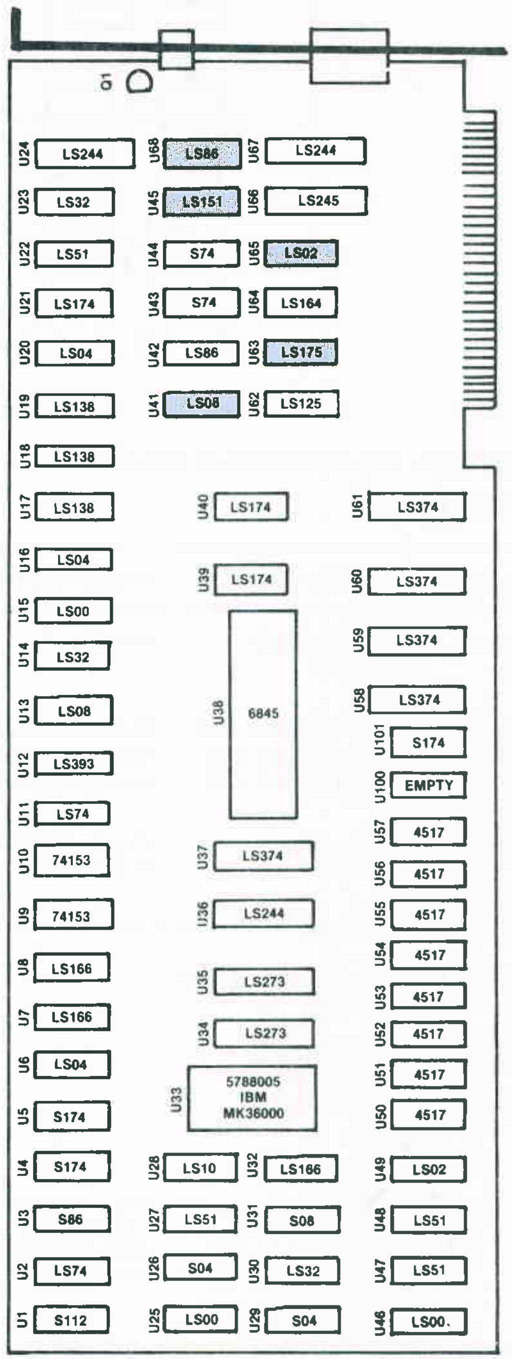


Fig. 4-29. Chip location guide. This represents the IBM PC color/graphics adapter and is a guide to help you find the chips of interest.

Circuitry Affected

See Fig. 4-30.

Chip designation	Description	Location
74LS02	Quad 2-input NOR gate	U65
74LS08	Quad 2-input AND gate	U41
74LS86	Quad 2-input EXOR gate	U68
74LS151	8-input multiplexer	U45
74LS175	Quad-D flip-flop	U63

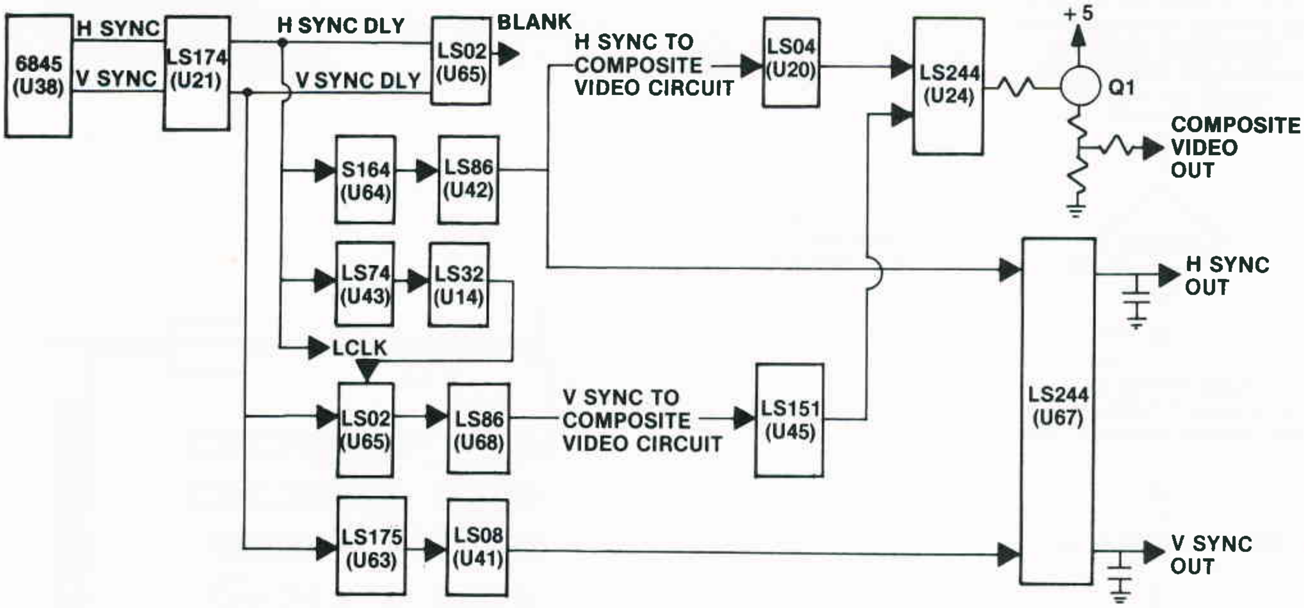


Fig. 4-30. Vertical and horizontal synchronization circuitry.

SYMPTOM: No horizontal synchronization (sync)

Problem	Possible cause	Repair action
Monitor not in sync	Monitor needs adjusting	Adjust.
Horizontal sync not being produced	Bad 74LS164 at U64 Bad 74LS86 at U42 Bad 74LS04 at U20	Replace and test. Replace and test. Replace and test.
Monitor not functioning	Bad monitor	Check and replace if necessary.

Troubleshooting Procedure

CHECK MONITOR HORIZONTAL SYNC CONTROL.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT SYSTEM WAS DOING AT TIME OF FAILURE.

↓

REMOVE TOP OF COMPUTER.
TOUCH TOP OF POWER SUPPLY CASE.

↓

DISCONNECT ADAPTER CARD AND MONITOR CABLE

↓

REPLACE 74LS164 AT U64.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

(Continued)

REPLACE 74LS86 AT U42.

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

REPLACE 74LS04 AT U20.

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

WORKS? YES → RETURN TO FULL SERVICE.

NO

TURN POWER OFF.
DISCONNECT POWER CORD.

CONCLUDE: Problem is probably in the monitor and not in an IC.
SERVICE CENTER ACTION

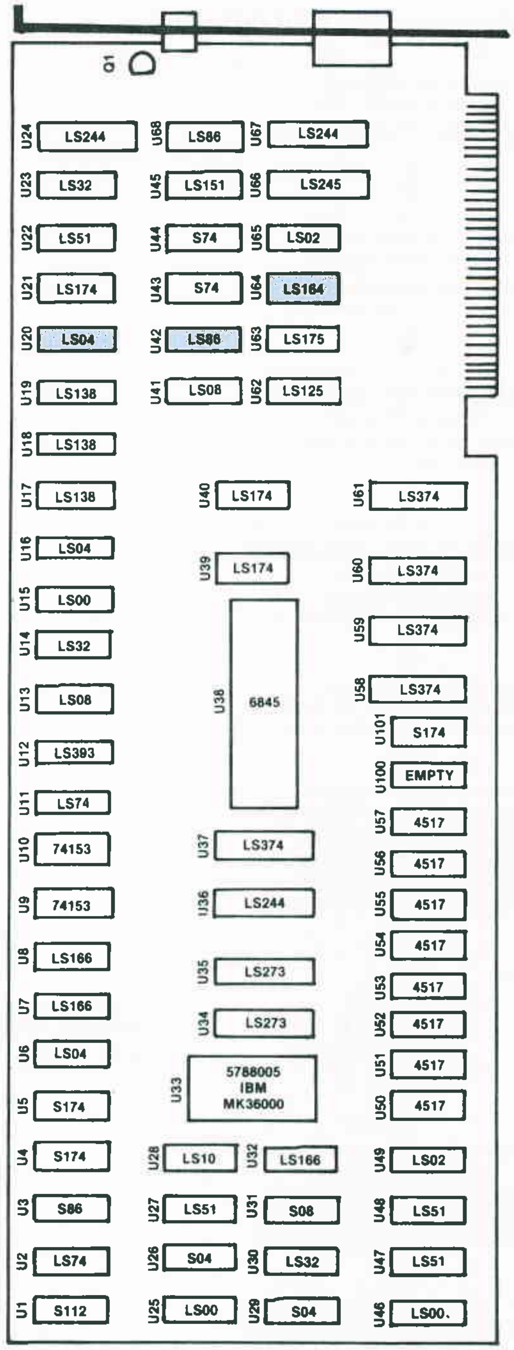


Fig. 4-31. Chip location guide. This represents the IBM PC color/graphics adapter card and is a guide to help you find the chips of interest.

Circuitry Affected

Refer to Fig. 4-30.

Chip designation	Description	Location
74LS04	Hex inverter	U20
74LS86	Quad 2-input EXOR gate	U42
74S164	8-bit serial-in parallel-out shift register	U64

SYMPTOM: No text, but graphics works

Problem	Possible cause	Repair action
Mode not being selected	Bad 74LS174 at U40	Replace and test.

Troubleshooting Procedure

TURN POWER OFF.
DISCONNECT POWER CORD.

↓

WRITE DOWN WHAT
SYSTEM WAS DOING
AT TIME OF FAILURE.

↓

REMOVE TOP OF COMPUTER.
TOUCH TOP OF
POWER SUPPLY CASE.

↓

DISCONNECT COLOR/GRAPHICS
ADAPTER AND
MONITOR CABLE.

↓

REPLACE 74LS174 AT U40.

↓

RECONNECT ADAPTER CARD.
RECONNECT MONITOR.
RECONNECT POWER CORD.
POWER UP AND TEST.

↓

WORKS? → YES → RETURN TO FULL SERVICE.

↓ NO

TURN POWER OFF.
DISCONNECT POWER CORD.
DISCONNECT ADAPTER CARD.

↓

CONCLUDE: Problem is probably
not in an IC.
SERVICE CENTER ACTION

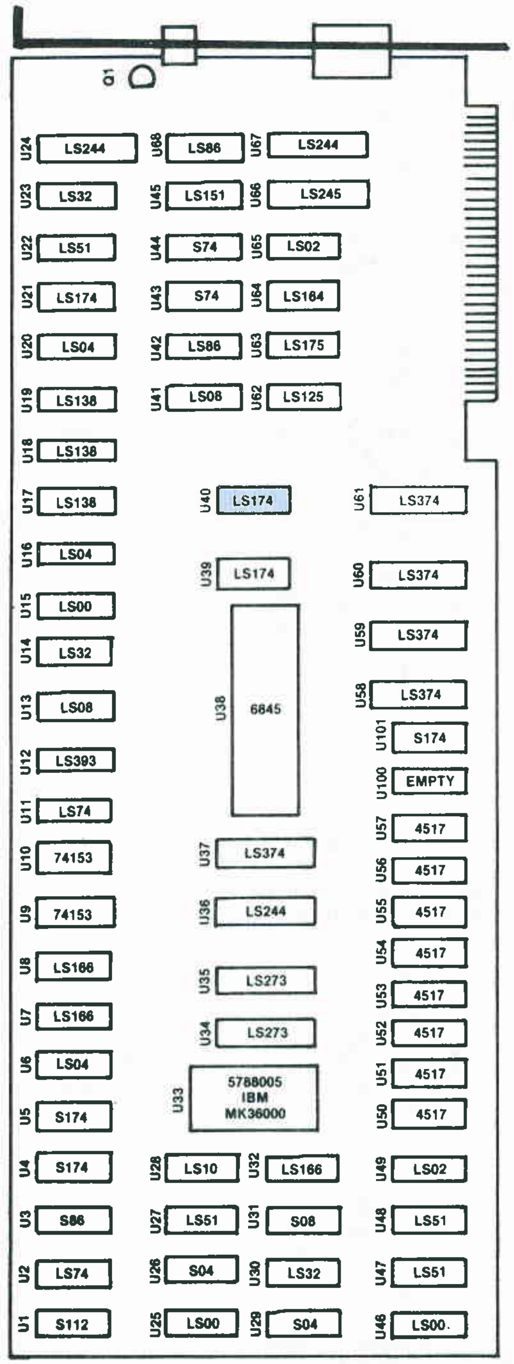


Fig. 4-32. Chip location guide. This represents the IBM PC color/graphics adapter card and is a guide to help you find the chips of interest.

Circuitry Affected

Refer to Fig. 4-28.

Chip designation	Description	Location
74LS174	Hex-D flip-flop	U40

SYMPTOM: Bad characters displayed

Problem	Possible cause	Repair action
Data not being latched properly	Bad 74LS244 at U36	Replace and test.
	Bad 74LS374 at U37	Replace and test.
	Bad 74LS273 at U34	Replace and test.
	Bad 74LS273 at U35	Replace and test.