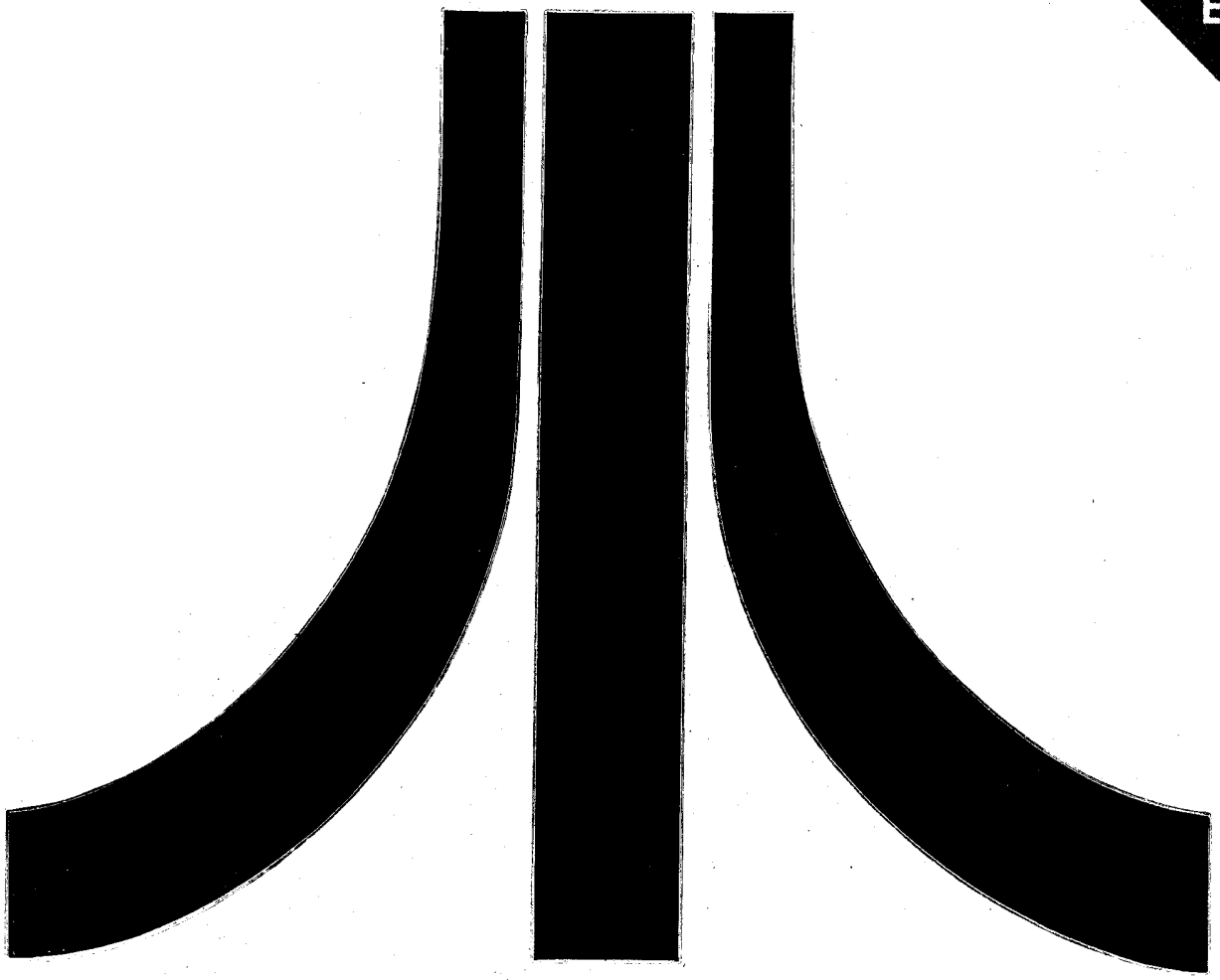
THE BOOK

A Guide to Electronic Game Operation and Servicing



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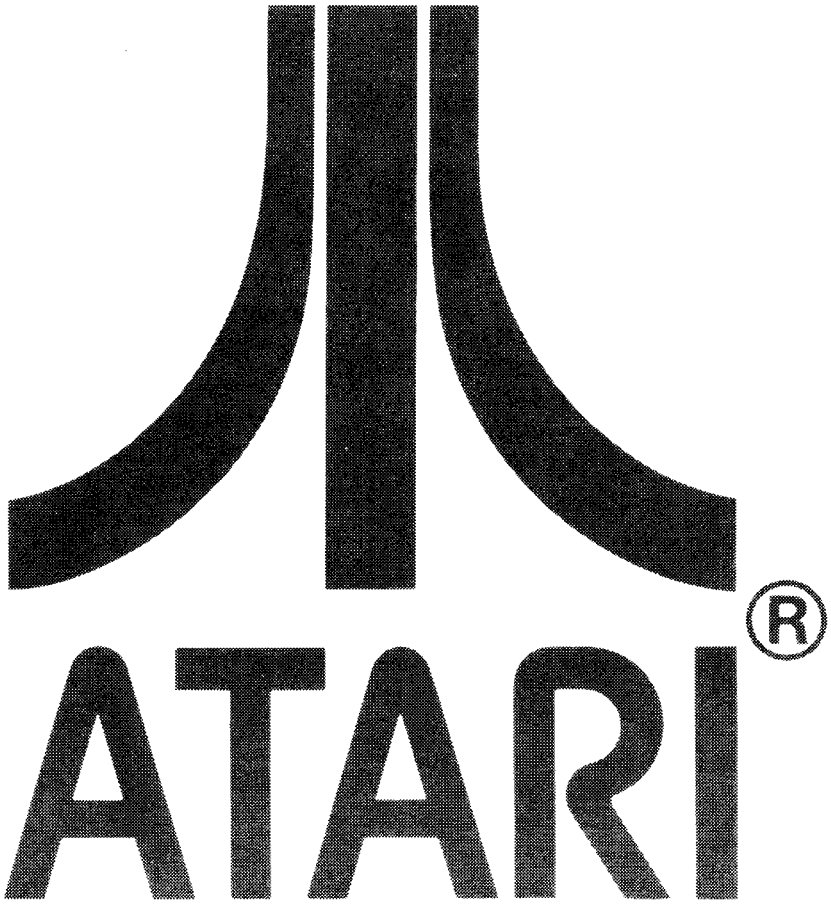
THE BOOK

A GUIDE TO ELECTRONIC GAME OPERATION AND SERVICING



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ATARI®
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The Book— a guide to electronic game operation and servicing

The Book contains seven chapters including approximately 180 pages of heavily illustrated information—geared for the operator and distributor technician who repairs Atari's electronic video and pinball games.

Chapter 1 begins with an introduction to tools and test equipment, and shows soldering techniques in many photographs. Chapter 2 covers game repair—how to isolate problems down to the major component level and how to maintain all the major player controls Atari has ever designed.

Chapter 3 contains information on how the two major types of monitors function (raster-scan and Quadrascan™ X-Y). It also includes detailed problem/solution tables to aid you in troubleshooting both types of monitors.

Chapter 4 explains the functions of various discrete PCB components, such as resistors, capacitors, transistors and diodes.

Chapter 5 introduces the reader to integrated circuits. It covers such topics as how to find ICs on a board, and how to count in the binary and hexadecimal number systems. It also includes a table for identifying IC manufacturers' logos.

The last section of *The Book*—Chapters 6 and 7—deals with circuitry and analog devices.

The Book also contains an eight-page glossary. It concisely defines terms used in electronics, and electrical and mechanical design.

The Book is loose-leaf bound in a durable attractive three-ring binder. You may obtain extra copies by sending $39.00 to:

Atari, Inc.
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This Book and You...

You should, and we expect you to, use ***The Book*** as it is intended, namely:

- As a mind-jogger when you can't quite remember one widget from another.
- To help you increase your level of proficiency.
- To assist you in decreasing your downtime.

This Book will not, nor is it intended, to:

- Make you a technician
- Turn you into an engineer
- Fix all your game problems
- Repair printed-circuit boards, or
- Make coffee.

Overall, we hope this book helps you feel more confident with the techniques, tools and terminology associated with coin-operated electronic games. We wish you good luck and good troubleshooting!

Atari, Inc.
Coin-Op Field Service

The Book

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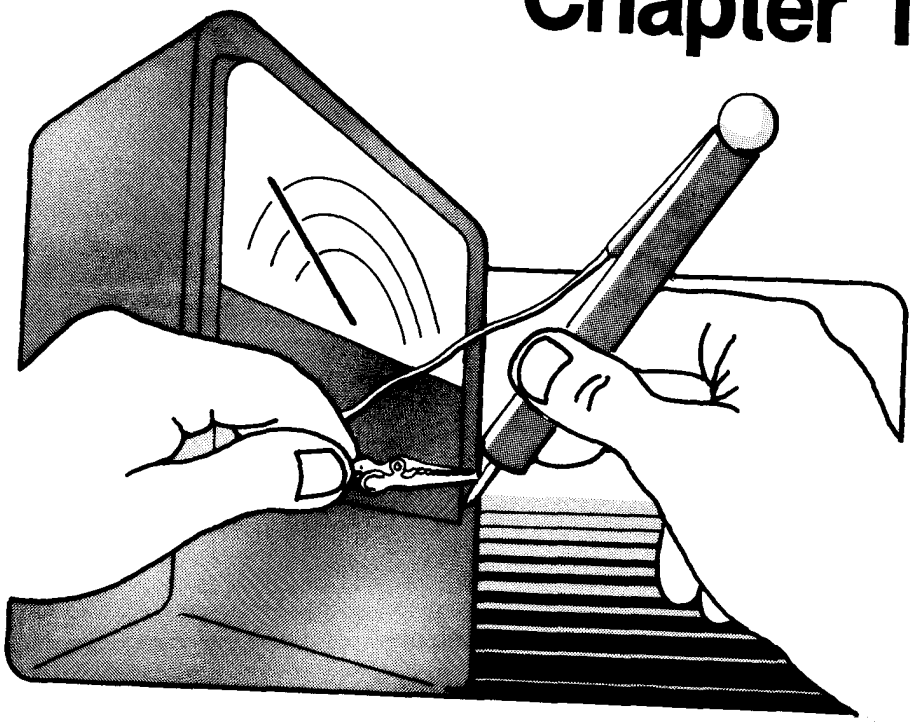
Chapter 1



Tools, Soldering and Test Equipment

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Essentially, electronic game troubleshooting consists of checking for the presence and condition of various signals produced by the game. You will need a variety of equipment to allow you to check the condition of these signals and perform the necessary repairs.

Each of these tools and instruments has advantages and disadvantages. When used to examine a certain type of signal, for example, the video probe is extremely limited in the range of signals it can examine, whereas an oscilloscope has greater flexibility. Some instruments are absolutely essential, no matter what the size of your operation, while others are desirable only because they make troubleshooting easier and quicker.

Wherever possible, we'll recommend specific instruments or tools that we've found to be most satisfactory. Our criterion for making recommendations is simple: adequate capability for the least cost. In this chapter we describe recommended tools and instruments that we've found useful in game and printed-circuit board (PCB) repair.

A. Video Probe

A video probe is a simple assembly. It is a piece of wire and a 5000-ohm variable resistor in series with the line (see Figure 1). We use a Pomona or hook-type clip on one end and a probe on the other. The video probe is used in conjunction with the video output circuit on a raster-scan type of game.

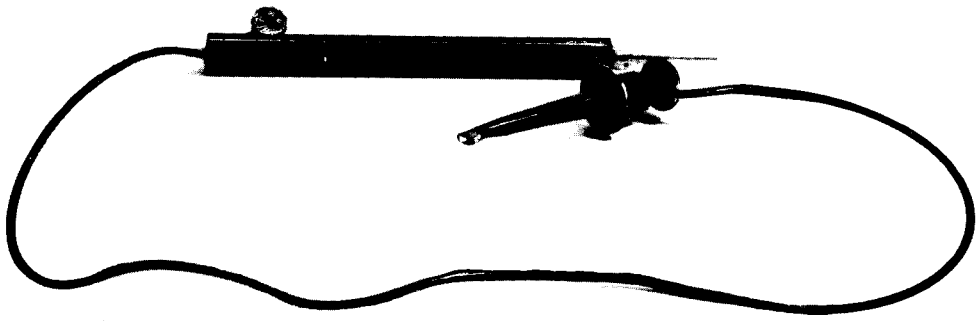

Figure 1 Video Probe

B. Logic Probe

For most troubleshooting, any logic probe is adequate. Several models are shown in Figure 2. A logic probe is used to check logic levels on a PCB. For a power source, it uses the 5V power of the board being tested. Indicators on the logic probe show the presence of logic highs, logic lows, and changing logic levels.

A logic probe will ***not*** tell you whether a signal is right or wrong: it only indicates logic states. More specific information will require using an oscilloscope.

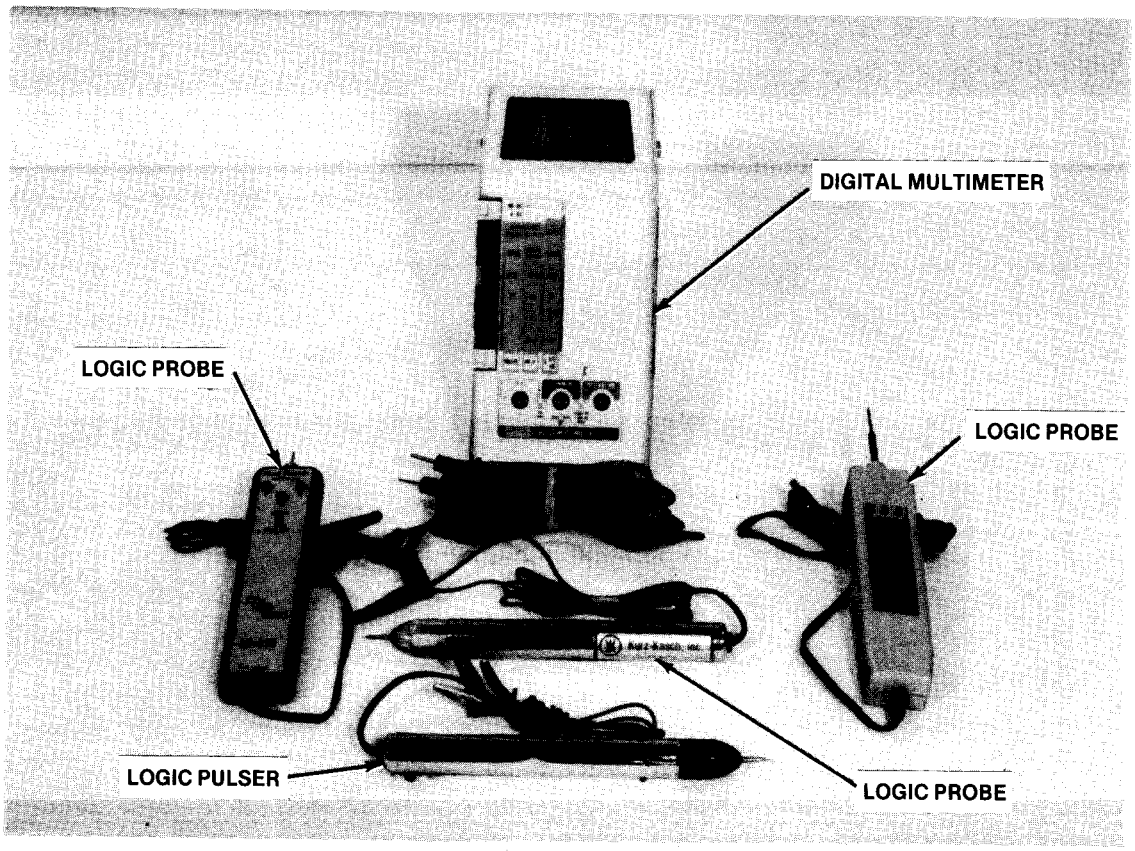

Figure 2 Various Types of Hand-Held Test Equipment

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C. Logic Pulser

A logic pulser (shown in Figure 2) isn't really a necessary test item, but is a convenience that will speed up the troubleshooting process. The pulser, similar to a logic probe, is connected to the 5V power of the board under test.

A logic pulser is used to change a logic state to the opposite level, i.e., a logic low is forced momentarily to a logic high, or vice versa.

Most logic pulsers also have a chain pulse feature on them that lets you activate score circuits or operate counter chains. This feature provides a series of fast continuous pulses that don't require using your finger to continually operate a pulse button.

D. Test Clip

The test clip for integrated circuits (ICs) resembles a wide clothespin and comes in various sizes such as 14-pin and 16-pin (to match the number of pins on the IC being tested). This clip has gold-plated contacts throughout. A spring holds the clip tightly over an IC—see Figure 3. The test clip provides easy access to the IC pins when attaching hook-type clips during testing, and prevents accidentally shorting another IC pin.

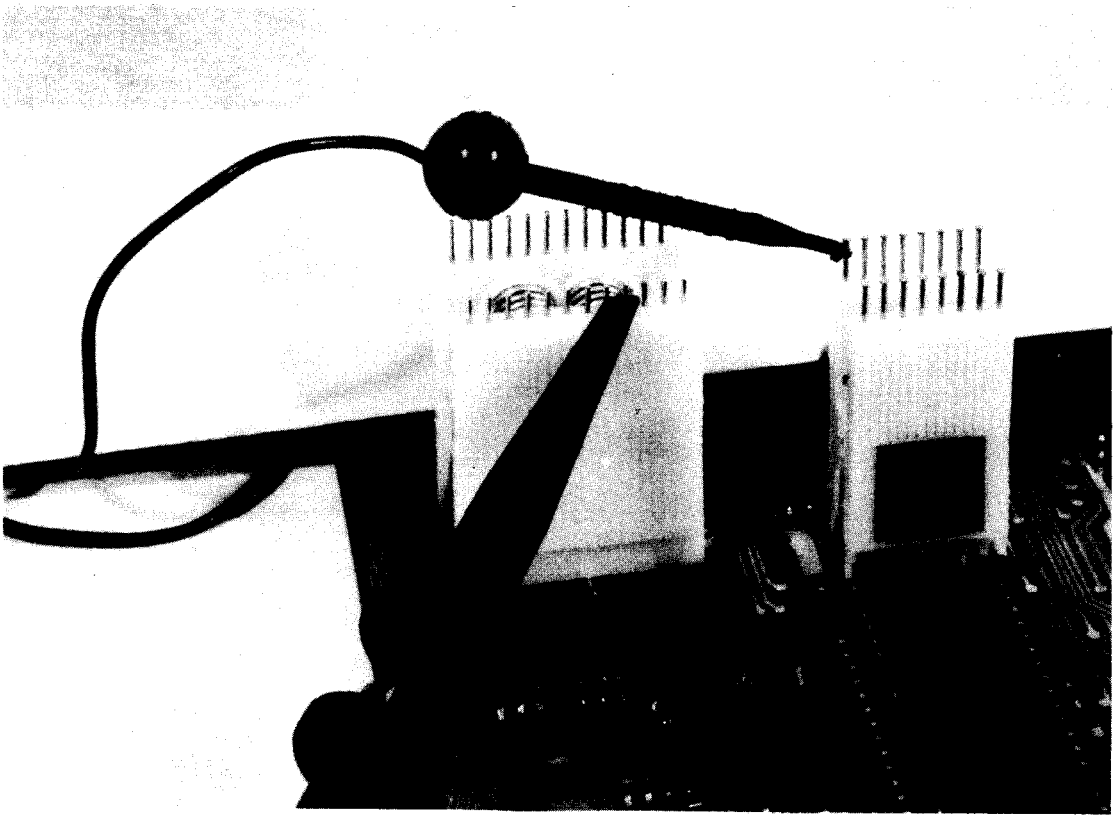

Figure 3 Integrated Circuit Test Clip

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E. Using Meters

To put electricity to work we must control electrons. Electrons are invisible to humans: we can only detect their presence by observing the effects they produce. For example, we detect the presence of electron flow in a light bulb by observing the light generated by the bulb.

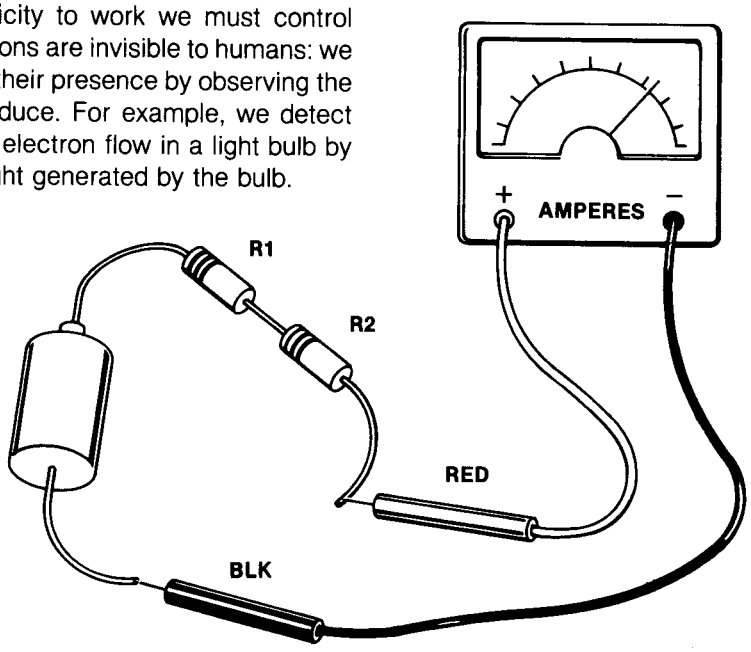

Figure 4 Measuring Direct Current with an Ammeter

Meters are the eyes that permit us to observe the invisible action in a circuit. They're indispensable when we're examining the operation of a circuit or troubleshooting a piece of equipment. Meters can indicate voltage, current, resistance and many other characteristics.

To use these meters, we must connect them properly to the circuit under test. We also have to read the scales properly. Improper meter connections can give false measurements, and in some instances damage the meters.

Most analog meters (ones with scales) contain a "0" adjustment. This is done with a small screw that connects to the meter movement. To zero-adjust the meter, insert a small screwdriver into the slot and turn the screw one way or the other until the pointer is exactly over the "0" mark on the scale. ***The meter should not be connected to any circuit during the zero adjustment.*** Once set, this adjustment rarely needs to be changed. It's there to correct for wear and loss of spring tension in the meter movement.

1. Ammeters or How to Measure Current

To measure the direct current (DC) in a circuit, you connect a DC current meter or ammeter in series with that circuit. Figure 4 shows a diagram of how to connect it for measuring current from a dry cell through two series-connected resistors. An ammeter is an instrument calibrated to measure current in amperes (amps).

The meter's pointer deflects to a point on the scale which corresponds to the amount of circuit current. If you reverse the meter leads, the pointer would deflect to the left off the scale, and the delicate meter mechanism might be damaged.

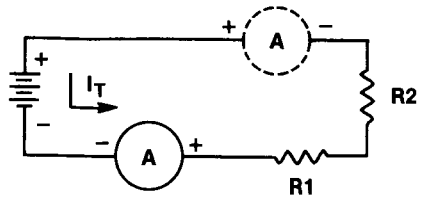

Figure 5 Measuring Current in a Series Circuit with an Ammeter

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Figure 5 shows the schematic diagram of the same circuit as in Figure 4. A circle with the letter "A" inside represents the ammeter. Note that the meter is connected so that the circuit current flows through it ***from negative to positive.***

To measure the current in Figure 5, the meter can be connected anywhere in the circuit, since the current is the same at all points in a series circuit. For example, the ammeter could be connected in the place shown by the broken circle. In this position, the ammeter would measure the same current that was measured by the ammeter represented by the solid circle.

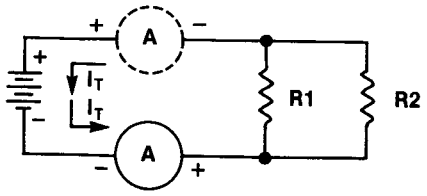

Figure 6 Reading Total Current in a Parallel Circuit

Figure 6 shows how to measure the total current (I_T) of a ***parallel circuit***. Figure 7 shows you how to measure the current of one leg of a parallel circuit. The meter might also be connected where shown by the broken circles. To measure the current through resistor R2, connect the meter in series with R2. ***Therefore, when measuring current, the meter must be connected in series so only the current to be measured flows through the meter.***

Loading Effects: An ideal current meter would have zero internal resistance. If such a meter were inserted into a circuit, it would not

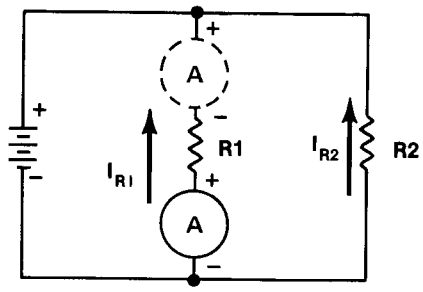

Figure 7 Reading Current of One Leg in a Parallel Circuit

alter the resistance of the circuit. However, all existing current meters do have some internal resistance. This internal meter resistance increases the resistance of the circuit. The measured current is therefore lower than the actual current in the circuit. Fortunately, in most cases the resistance of a current meter is very small compared to the circuit resistance, and therefore the error can be ignored.

Special types of ammeters are also available. One of these uses a clip-on technique for measuring current. In this meter, arms encircle a current-carrying conductor. The meter senses the strength of the magnetic field surrounding the conductor: the more current in the conductor, the stronger the magnetic field around it. The meter scale is calibrated in terms of current.

For information on reading ammeters and how to select the proper one for your needs, see Subsection 2, Voltmeters, that follows. Because of their similarity, the descriptions of reading and selecting ammeters and voltmeters have been combined.

2. Voltmeters

A direct-current voltmeter is designed to measure the DC voltage or difference of potential between two points. ***Voltage exists between two points and does not flow through a circuit as current does.*** As a result, you do not connect a voltmeter in series like an ammeter. Instead, you ***connect the voltmeter across or in parallel*** with the points between which the voltage appears.

Figure 8 Measuring Voltage with a Voltmeter

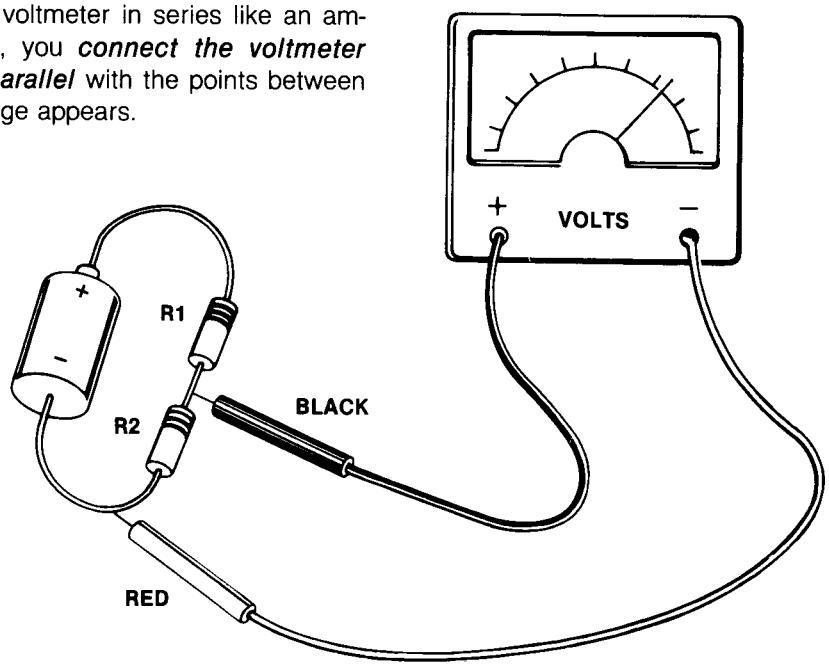

Figure 8 shows how a voltmeter is connected to measure the voltage across a resistor. You must also observe the polarity of the DC voltmeter: the negative voltmeter terminal is connected to the more negative point. If you reverse the connections, the meter's pointer deflects to the left off the scale, and you may damage the voltmeter.

Figure 9 shows a schematic diagram version of Figure 8. The voltmeter is represented by the circled "V". Note the polarity of the meter and how it is connected in parallel or across the circuit, not in series with the circuit. To measure the voltage across R1, connect the voltmeter in parallel with R1 as shown in Figure 10.

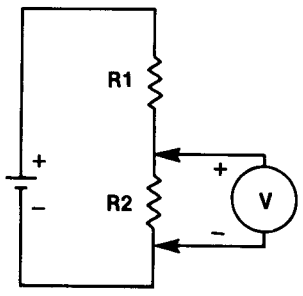

Figure 9 Schematic Diagram of Voltage Measurement Made in Figure 8

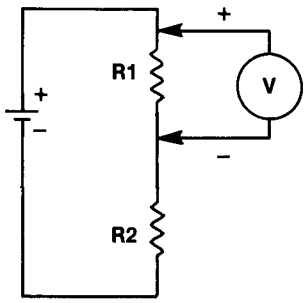

Figure 10 Schematic Diagram of Another Voltage Measurement

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Loading Effects: To some extent, a voltmeter will also affect the circuit being tested. An ideal voltmeter would have an infinite internal resistance, and when connected to a circuit, would not affect it. The higher the internal resistance of the voltmeter, the more accurate the reading.

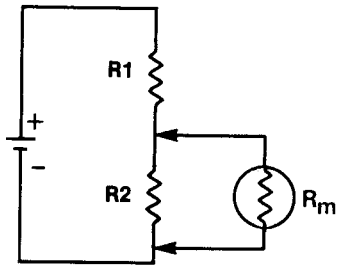

Figure 11 Schematic Diagram of Internal Voltmeter Resistance

Figure 11 shows the internal voltmeter resistance applied to the circuit being tested. R_M represents the internal resistance of the voltmeter. Remember that the meter resistance is parallel with the resistor being measured. The total resistance of a parallel circuit is always less than the resistance of the smallest individual resistor. Therefore, with the meter connected across R2, the effective resistance of R2 is decreased.

Ohm's Law says that E = IxR [Voltage (E) = Current (I) multiplied by Resistance (R)] and shows that when resistance decreases, voltage also decreases. As a result, the voltmeter indicates less than the actual voltage across R2. In most cases, the internal voltmeter resistance is much higher than the circuit resistance. The error is therefore small and can be ignored.

However, when making voltage measurements in high-resistance circuits, the meter resistance will noticeably affect the voltage reading. Electronic voltmeters have a very high internal resistance to minimize this loading effect.

Reading Ammeters and Voltmeters: In general, you read both ammeter and voltmeter scales the same way. When using an ammeter, the readings are in amperes; when using a voltmeter, the readings are in volts.

Figure 12 shows the scale of a typical ammeter—it reads from 0 to 10 amps. The maximum value indicated on the scale (in this case 10 amps) is called the ***full-scale value***.

To determine the current or voltage, you read the value on the scale under the pointer. For example, assume the pointer shown in Figure 12 deflects to position 1. Here the pointer is over the "1" mark, and a current of one amp in indicated. At position 3, the pointer is over the "9" mark and a current of nine amps is indicated.

The large numbered marks on a scale are often called the ***major scale divisions***. If the pointer deflects to a point between major scale divisions, you must use the ***smaller scale divisions*** on the meter face (see Figure 12).

The meter contains four small scale divisions or lines between each major scale division. This divides the area between major divisions into five equal spaces. Thus, each small division on the center of the meter face shown in Figure 12 has a value of one amp divided by five spaces, or .2 ampere.

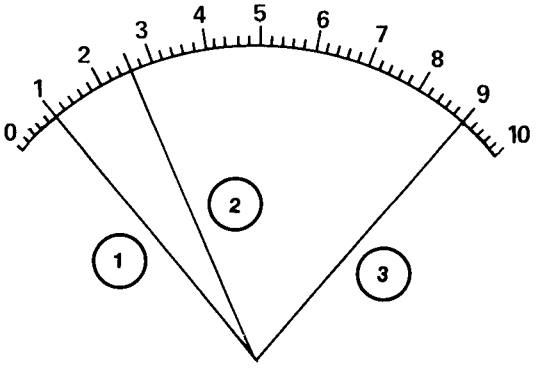

Figure 12 Scale of a Typical Ammeter

The first small scale division to the right of "0" has a value of .2 amp; the second such division has a value of .4 amp. The first small scale division to the right of the "1" mark has a value of 1 + .2, or 1.2 amps. Thus, if the pointer is at position 2 in this figure, it would indicate a current of 2.6.

In some cases, the pointer may stop between small scale divisions, such as at position 1 in Figure 13. When this happens, you must estimate the value of the current. Since here the pointer is about halfway between the "1.2" and "1.3" marks, the current is therefore about 1.25 amps.

As another example, assume the pointer is at position 2 in Figure 13. In this position, the pointer is about one-quarter of the way between "1.4" and "1.6". Each small mark represents .2 amp, and one-quarter of .2 is .05 amp. Thus, the position-2 pointer represents a current of about 1.4 + .05 or 1.45 amps.

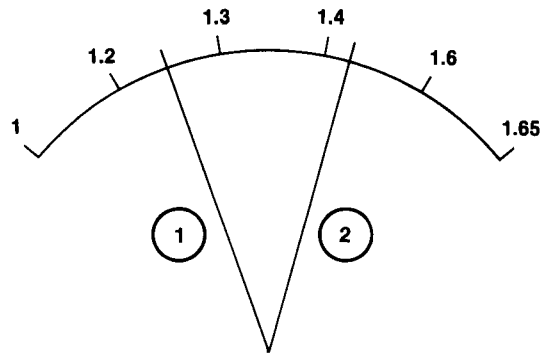

Figure 13 Detail of Ammeter Scale

The number of divisions on a meter scale depends on the range of voltage or current the meter is designed to measure. In all cases, you'll find the value of the small scale divisions as follows: simply divide the value of major scale divisions by the number of spaces between those divisions. If the pointer falls between the smaller scale divisions, you must estimate the value.

Figure 14 shows a DC voltmeter scale; it has a full scale value of 150 volts. Note that it has only one small division between the major divisions. Therefore, this divides the space between major divisions in two. As a result, each small division has a value of 5 volts.

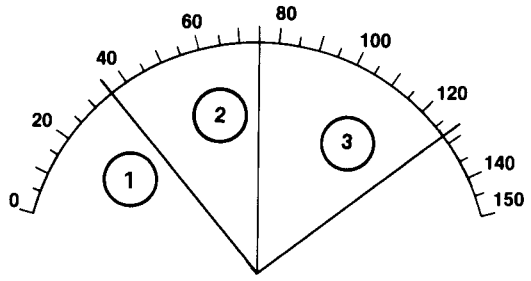

Figure 14 Scale of a Typical DC Voltmeter

If the pointer is at position 1 in this figure, it indicates 35 volts. At position 2, the pointer indicates 75 volts. In the case of position 3, the pointer is halfway between the small scale divisions, showing a voltage of 125 + half of 5, or 127.5 volts.

The scale of a DC milliammeter is shown in Figure 15: it has a full scale value of .3 milliamp. On this scale are nine small divisions between the major divisions, dividing the area between major divisions into 10 small spaces. Therefore, each small division has a value of 1/10 of the major division. Since each major division has a value of .1 milliamp, each small division has a value of 1/10 of .1, or .01 milliamp.

If the pointer in Figure 15 is at position 1, it indicates a current of .05 milliamp. At position 2, the pointer is halfway between ".25" and ".26" milliamp—indicating a current of .255 milliamp.

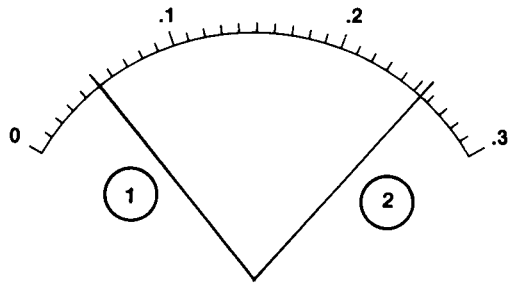

Figure 15 Scale of a DC Milliammeter

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Choosing the Correct Ammeter or Voltmeter: The maximum voltage or current that a meter can measure is its full scale value. Thus, if a voltmeter can measure from 0 to 150 volts, you should ***never*** try to measure more than 150 volts. An excessive voltage or current could damage the delicate mechanism in the meter. When in doubt, use a meter with a very high full scale value—you can always change to a lower range of the meter.

Another important point to remember concerns the low end of the meter scale. A current meter with a scale of 0 to 10, for example, cannot accurately measure currents near 0 amp. The first small division to the right of the "0" mark has a value of .2 amp. Thus, if .2 ampere is applied to the meter, the pointer only deflects to the first small scale division to the right. If a current less than .2 ampere is applied, the pointer might not even move off "0".

As a general rule, ***a meter cannot display a current or voltage lower than the value of one small scale division.*** To measure a current or voltage lower than the voltage of one small division, you must use a more sensitive meter range. Try to choose one that has a center scale value close to the value of voltage or current you wish to measure. Then if the voltage or current is a little higher or lower, you will still be able to measure it using the same meter range.

3. Ohmmeters

You measure the resistance of a circuit or component by using an ***ohmmeter***. An ohmmeter measures resistance by applying a known voltage to the circuit or component being tested, and measuring the resulting current.

The voltage for the ohmmeter is usually supplied by batteries or a built-in power supply. With a constant voltage applied to the meter circuit, the current (and thus the deflection of the meter pointer) varies with the resistance being measured. The meter scale is calibrated in ***ohms***.

To measure the resistance of a component or circuit, just connect the ohmmeter across the circuit or component, as shown in Figure 16. Note that the ohmmeter is connected across or ***in parallel*** with the resistor.

There are two precautions you must observe when connecting an ohmmeter into a circuit. First, make sure the ***power source of the circuit is turned off.*** Disconnect the equipment from the source of power, if possible.

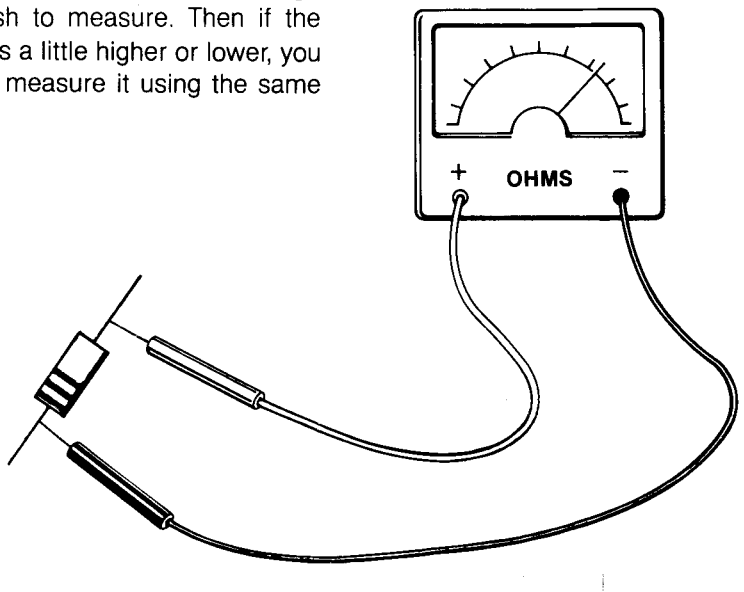

Figure 16 Measuring Resistance with an Ohmmeter

Second, when measuring the resistance of a single component, disconnect one end of the component from the circuit. This will eliminate parallel paths which would give an incorrect resistance reading. (You might use a voltmeter first to measure the circuit, making sure that no voltage is present before taking a resistance measurement.)

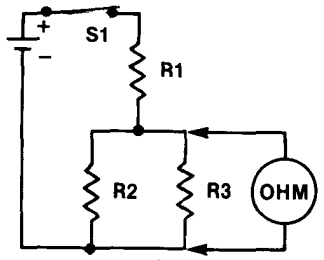

Figure 17 Wrong Way to Measure Resistance

Figure 17 shows the ***wrong*** way to connect an ohmmeter to measure the resistance of R3. With the supply still connected at switch S1, a voltage is present across R3 which could damage the ohmmeter. Also, since R2 is in parallel with R3, you would be measuring the combined resistance of R2 and R3, instead of the resistance of R3 alone.

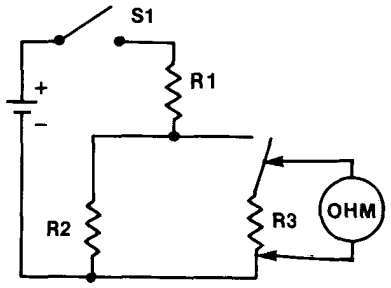

Figure 18 Correct Way to Measure Resistance

Figure 18 shows the ***right*** way to measure the resistance of R3. Notice that the supply has been disconnected at switch S1. Also note that one end of R3 is disconnected from the circuit so that the meter measures only the resistance of R3.

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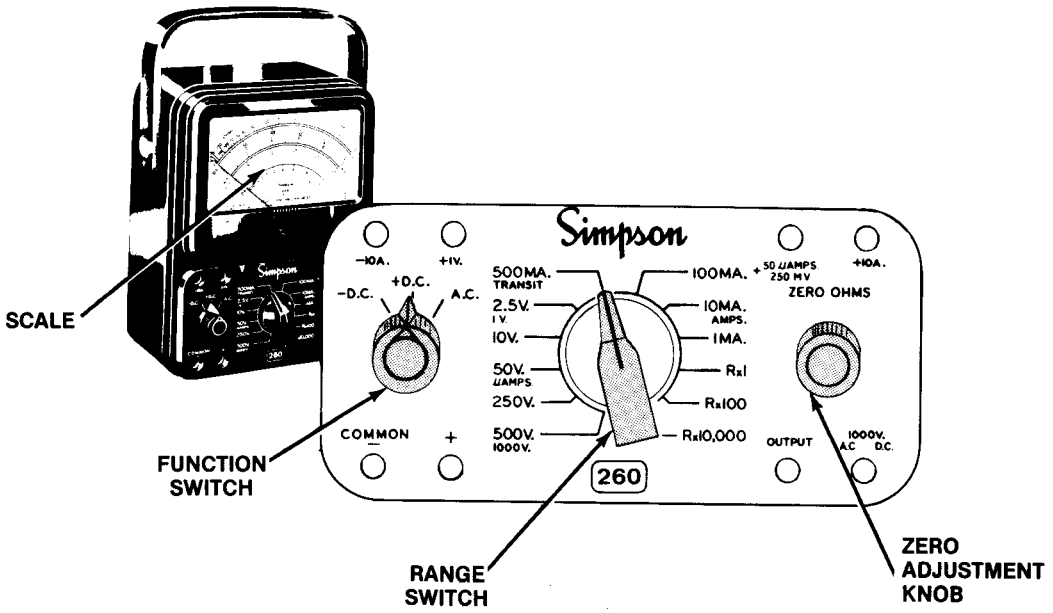

Figure 19 Simpson 260® Meter

4. Multimeters or VOMs

Engineers and technicians must make many measurements when they repair or build a piece of equipment. If a separate voltmeter, ammeter, and ohmmeter were used to measure each of these various quantities, testing would become very cumbersome.

To eliminate the need for several separate meters, the functions of all three are combined into a single instrument called a ***multimeter or volt-ohm-milliammeter (VOM)***.

To Measure Direct- or Alternating-Current Voltage: On this type of meter set the function switch to +DC or –DC (see Figure 19). These two DC settings permit you to reverse the meter's polarity without reversing the test leads. This is a timesaver when voltages are positive and negative, with respect to some reference point.

You can set the range switch to one of five positions (2.5, 10, 50, 250, or 500-volt ranges) for DC or AC voltage measurements. These positions change the range of voltages the meter can measure. Read either the "DC" or "AC" scales for all five voltage ranges (Figure 20 shows a close-up of the scale).

The range switch setting you choose indicates the maximum voltage you can measure on that particular meter setting. With the 2.5 V and 250 VDC ranges read the scale labeled ***0 to 250 DC.*** For the 50 V and 500 V ranges read the ***0 to 50 DC*** scale. And with the 10 V range read only the ***0 to 10 DC*** scale. These scales are read exactly the same as those discussed in the previous subsections of this book.

To measure an AC current, change the function switch to AC. Then set the range switch to one of the five voltage settings. Read the three AC scales just like the DC scales mentioned in the previous paragraph.

You should know that most multimeters measure the ***average*** AC voltage, which is approximately 70% of the peak voltage. These measurements are only accurate on sine waves. Digital signals will probably give AC readings that appear to be abnormal.

How to Measure Direct Current or Amperage: Set the function switch at + DC. Then select the proper current range with the range switch (100 MA, 10 MA or 1 MA).

NOTE:

The symbol μ *amp* is the abbreviation for microampere or one-millionth of an ampere. *MA* is short for milliampere or one-thousandth of an ampere.

Be careful to observe polarity when making current measurements. Also, always choose the range carefully. When in doubt always use the highest range (500 MA) first to avoid meter damage.

Use the 50 μ amps and 500 MA ranges when reading the 0 to 50 DC scale. Use the 100 MA, 10 MA and 1 MA range when reading the 0 to 10 DC scale.

How to Measure Resistance: First, be certain you *remove power* from the circuit before making a resistance measurement!

The Simpson 260® and most other multimeters do not use range multipliers for voltage and current measurements. You saw that they provide several scales on the meter face. Resistance measurements, however, *do* use range multipliers.

The basic technique is to set the function switch to +DC and set the range switch to R×1, ×100 or ×10,000. However, before making any measurements, you must zero-ohms-adjust the meter for proper pointer position. This is needed because the batteries in the meter may have varying voltage and resistance.

Short the test leads together. Turn the ohms-adjust control until you bring the pointer over the zero mark at the right end of the scale. If you can't make the pointer align with the zero, then you'll have to replace one or both of the internal batteries. Once you have done this adjustment, you can begin your resistance measurements.

When the range switch is in the x1 position, read the ohms scale directly. If the range switch is in the ×100 position, you multiply the scale readings by 100, and so on. Remember to look at the values of the major scale divisions on either side of the smaller divisions before determining the exact reading. This is necessary because the ohms scale is non-linear.

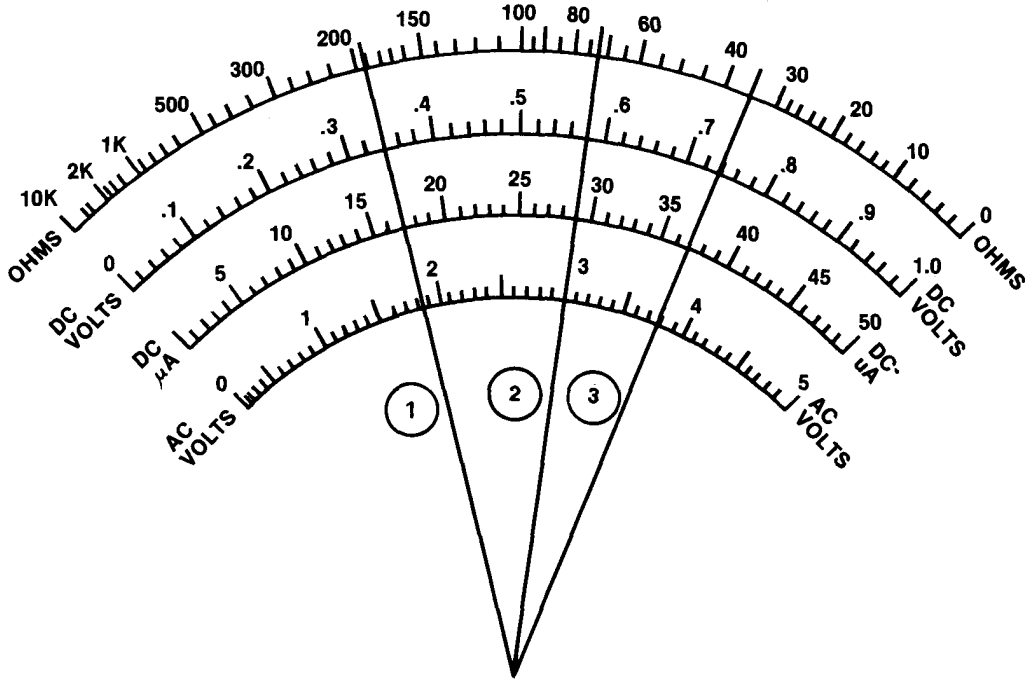

Figure 20 Scale of a Typical VOM

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Summary: Let's take a brief look at all the measurements we've discussed. ***To measure current*** in a circuit, connect an ammeter or current meter in series with the circuit. This way the current you are measuring flows through the meter. Make sure you observe the polarity (the electrons must flow from negative to positive through the meter). However, polarity is ***not*** observed when measuring amperage of direct current.

To measure voltage, connect a voltmeter in parallel with the points between which the voltage exists. Again, be sure to observe the meter polarity: the negative terminal of the voltmeter must be connected to the negative point in the circuit, and the positive voltmeter terminal to the positive point in the circuit. Polarity is ***not*** observed when measuring AC voltage.

To measure the resistance of a circuit or component, use an ohmmeter. To do so, connect the ohmmeter across the entire circuit being measured, or across the component. It's a good idea to disconnect one side, to be sure that other components won't affect the accuracy of your measurement. ***To protect the meter, you must completely remove power from the circuit before making a resistance measurement.***

F. Oscilloscope

The oscilloscope is a test instrument for measuring voltage or timing of signals in any electronic system (see Figure 21). The basic requirements for this instrument are 5 millivolts per division or better; vertical sensitivity (rise-time capability) of 5 nanoseconds or less; and internal synchronization (sync) features.

The scope should have an internal and external sync feature, along with delayed sweep, and have a Z-axis input. Frequency response of the scope should be at least 50 MHz, and it must display dual traces. The price of such a scope (new) is probably $2000-3000.

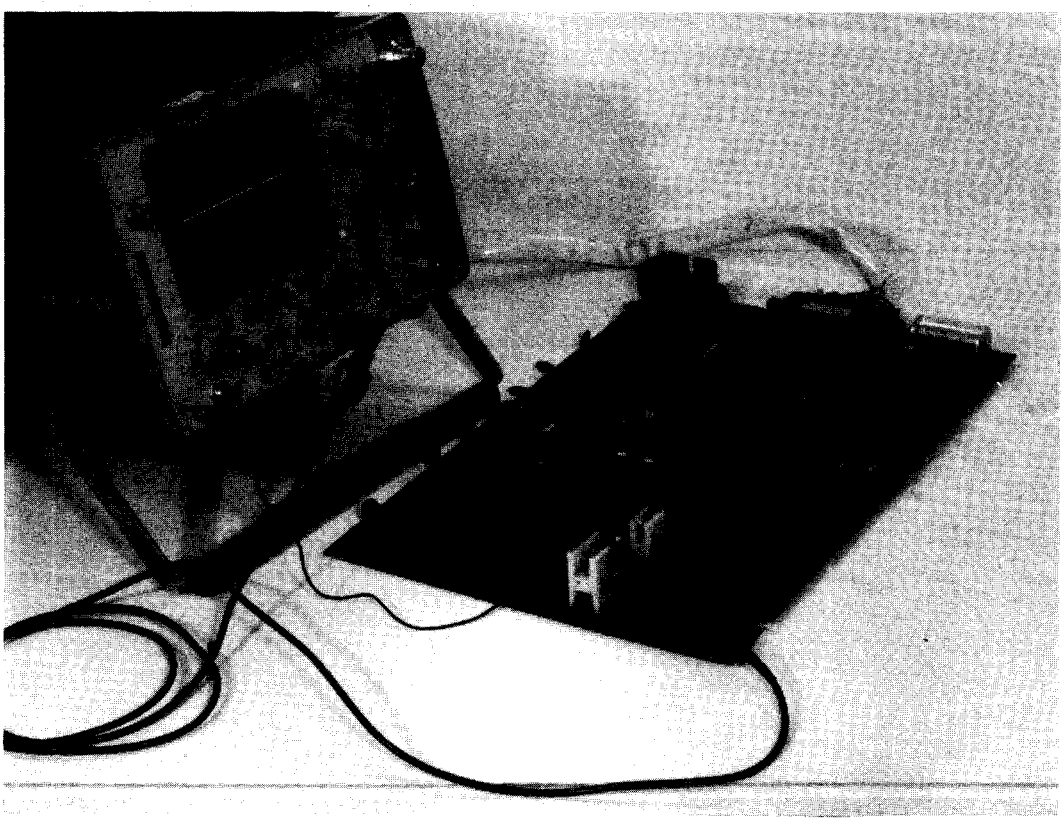

Figure 21 Oscilloscope Hooked up to a Game PCB

G. AUTOMATIC ROM/RAM Tester

This Atari-designed tester is a manual bus controller: it allows the technician to actually perform any of the functions that the microprocessor would normally take care of. You can control individual circuits and signals going to individual inputs.

You can also use it to monitor any information that would normally come into the microprocessor on any of the data lines. These same data lines, since they're bidirectional, can output from the tester and turn on I/O devices.

What the ROM/RAM Tester essentially does is take all the magic out of data buses and address buses. Normally, if you looked at a microprocessor, you would only see a jumbled mess of information, not really knowing what is supposed to be there. Using this tester, you can control the information on the address and data buses. You can single-step through all of the complex circuits and simplify your troubleshooting processes.

H. Signature Analyzer

Signature analyzers were developed to let technicians troubleshoot digital circuits ***without having to understand the game's electronic operation.*** With an analyzer, you can read unique digital data signatures (in the form of four alphanumeric digits) while testing a PCB. The signatures can be used to isolate failures down to the component level in the factory, at service centers and in the field.

Basically, a signature is formed as the tester measures the time a signal takes to travel from the microprocessor to where the probe is placed (the test point). The analyzer lets you even detect a single bit error. Since a signature analyzer can find the difference of one bit out of 65,000, this type of test equipment increases your chance of detecting an error.

To use this system, someone first collects all the signatures from a PCB that's known to be good. Then, when a bad game board comes along, you would compare its signatures with the list prepared previously. Often, this list will be printed on schematics.

For example, you might check all input pins on a decoder and find that they are all good, that is, they match up with the list of correct signatures. Then you test all the output pins; some of these might be bad (the signatures do not match up). Thus you have a bad decoder, and you've just isolated a board failure down to this individual component.

Other things a signature analyzer can do are test address decoding logic, check for proper timing, read strobes, test the function of chip selects, and detect timing problems and errors on the data bus. An analyzer can also check the contents of memory in a certain ROM: it does so by checking the data outputs from the ROM. In addition, you can check switch circuits by activating each switch and seeing if you get the proper signature for that closure on the data bus.

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I. Continuity Tester

This tester is a simple device with either a buzzer or light, a battery, and some wires (see Figure 22). When the ends of its test leads are touching, either the buzzer sounds or the light turns on. It is used for troubleshooting harnesses, switches, or to check for broken connections in Molex or edge connectors.

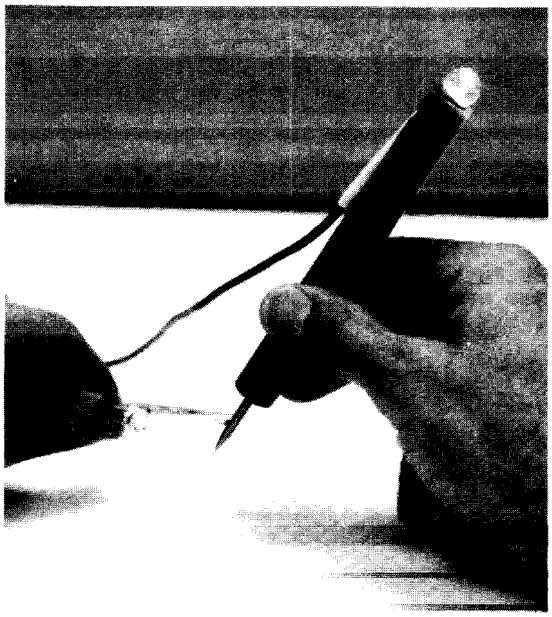

Figure 22 Continuity Tester

J. Soldering Equipment

The six pieces of soldering equipment described in this section are all pictured in Figure 23. Actual soldering techniques are described in Section M that follows.

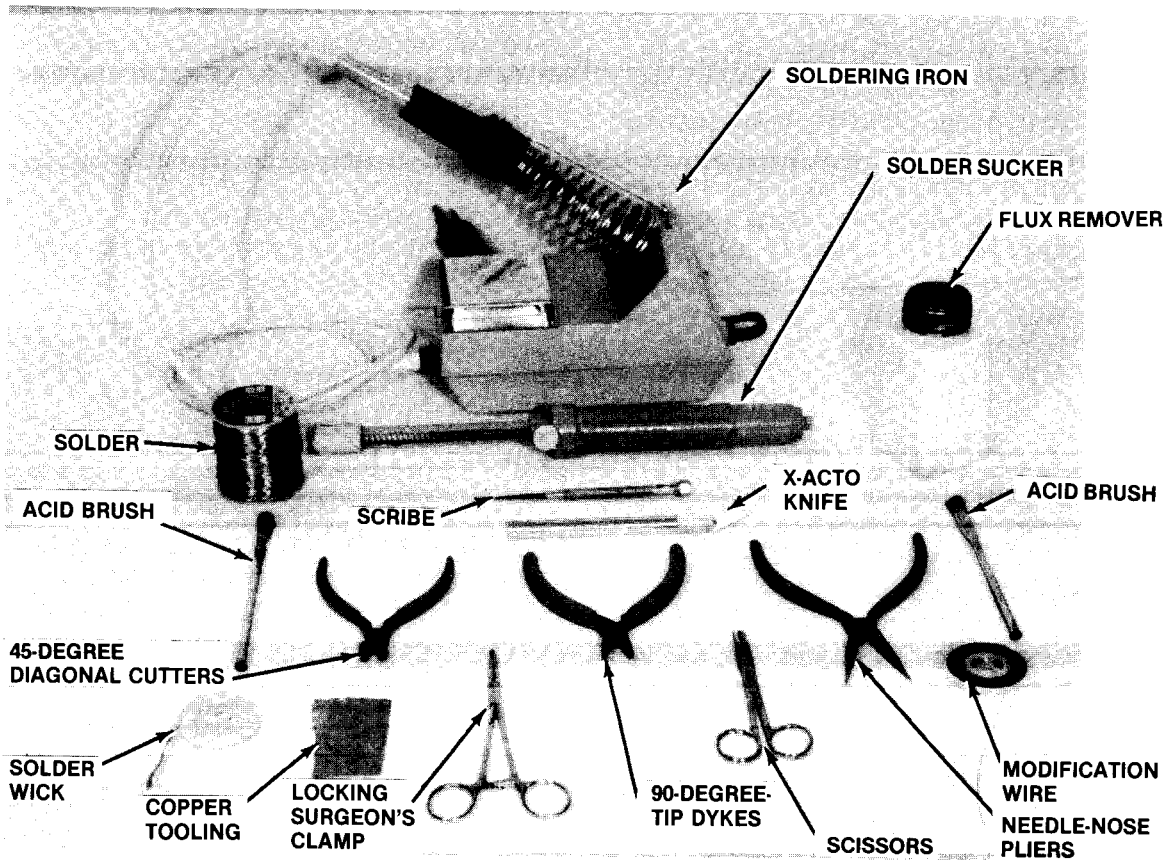

Figure 23 Soldering Equipment and Hand Tools

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1. Soldering Iron

Many people have definite preferences in their choice of soldering irons. We recommend the Weller soldering station, using the temperature-controlled tip rated at 700° F. The tip shape should be a fine cone or a very fine chisel/"screwdriver" point. The long conical tip is Weller part no. PTO7; the screwdriver tip is part no. PTB7.

Using a temperature-controlled soldering station isn't absolutely necessary: a pencil iron rated between 16 and 27 watts should be adequate for most PCB work However, for someone just starting out in electronic repairs, the tip temperatures on these uncontrolled irons will be too hot and cause trace damage.

2. Solder Sucker

This is a de-soldering tool; we recommend the top-of-the-line Soldapullt® brand. The solder sucker works as a hand-operated vacuum aid. When used in conjunction with the soldering iron, it removes liquified solder from the PCB.

3. Solder Wick

This material is a resin-soaked copper braid; it is sold on a small roll, and is about ¼ inch wide. You use it for cleaning excess solder from a board after a component has been removed.

Do not use it to remove the solder from inside the through-plated holes on the board: the amount of heat required to do that would cause too much trace damage. Instead, use the ***solder sucker*** to remove the solder from these holes. Then use the wick to clean up the area around the IC before installing a new part. Failure to heed this caution will probably result in your PCB having a lot of traces floating in mid-air.

4. Flux Remover

This is not a necessary item, but gives a professional finish to any PCB repair. Flux remover eliminates the sticky resin coating where ICs have been replaced; if not removed, the residue could collect dirt or metal particles—causing possible intermittent problems later on.

5. Acid Brush

You will need some type of stiff-bristled brush, such as a tooth brush, in conjunction with flux remover. Cut the bristles of an acid brush to half their length to make the bristles stiffer. You can also use the brush and flux remover to clean foreign materials from the PCB.

6. Solder

You should buy resin-core solder with a 60/40 alloy of tin/lead; its diameter should be about .015 inch. If you also work on game parts larger or heavier than PCBs, we recommend solder no larger than 1/8-inch in diameter.

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K. Tools

1. Heat Gun

The heat gun (see Figure 24) is used for drying a PCB after you've cleaned it with flux remover. The gun is also used for shrinking down shrink-tubing to fit (see Section L on next page), and for troubleshooting intermittent problems caused by thermal changes inside a game.

Figure 24 Heat Gun and Freon Coolant

Nozzles with different temperature ranges are available for heat guns: you should choose the 750 to 800-degree Fahrenheit nozzle. You should take great care when using a commercial-type heat gun—its high temperatures could cause damage to the PCB components (ICs are very sensitive to high heat). Therefore, when you use the heat gun always keep the nozzle in motion so that the heat isn't concentrated on just one component.

It is possible to use any type of squirrel-cage blower that directs its air flow down to a small area. Even a typical home hair dryer with a flow concentrator attachment would be adequate for many uses. However, it does not reach the high temperatures of a commercial heat gun, so it would take much longer to dry an area on the PCB. In addition, you may have trouble getting the shrink-tubing to shrink down.

2. Freon Coolant

You will use the heat gun in conjunction with freon coolant spray or freeze spray. This spray (see Figure 24) is usually sold in TV repair stores as circuit cooler or component cooler. The can contains commercial freon, just like the coolant in air conditioners or refrigerators, but it does not have an oil base that would gum up a PCB.

When troubleshooting a thermal problem, alternate between using the heat gun and the freon coolant until you isolate the defective component. ***Be very careful to never spray the coolant on your skin: you may cause frostbite!***

3. Modification Wire

Sometimes technicians accidentally cut traces on a PCB, or sometimes do so intentionally to troubleshoot problems. If the gap in the trace is small, simply run a bit of solder over it.

However, if the gap is too large to do this, or if you are doing ***any*** modifications to the board, you must use ***30-guage solid-conductor copper wire***. Usually this type of wire has vinyl insulation on it.

Try to keep these wires as short as possible to avoid noise problems, and run them ***under*** the ICs, in order to hold them in place. Large loops of wire on top of the board are not only sloppy, they would eventually snag on something and get torn loose.

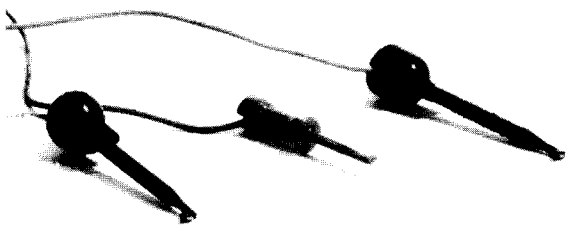

Figure 25 Various Types of Jumper Wires

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4. Jumper Wire

This consists of about one foot of insulated wire, with a small hook clip at each end. Jumper wires are used for troubleshooting PCBs. Alligator clips that you may already be familiar with are ***not recommended for use on PCBs***—they are too big for the ICs' pins and almost always cause shorts. Figure 25 shows several types of jumper wires.

L. Hand Tools

1. 90-Degree-Tip Cutters

This tool is used for cutting IC pins in hard-to-get-at places on the PCB. It resembles a pair of pliers, and is intended for wire no heavier than IC pins. The 90-degree cutter is often called a ***90-degree-tip dyke***, with the word ***dyke*** being short for diagonal side cutter. See Figure 23 for an illustration of this cutter.

2. 45-Degree Diagonal Cutters

This flush-cutting tool is approximately 4½ inches in length. Use it to cut .010 to .030-inch nickel ribbon (such as IC pins) and 24-guage or smaller copper wire. ***Do not use it to cut material heavier than these dimensions,*** as you will damage the jaws of the pliers.

You will probably also need a smaller version of these flush-cutting diagonal pliers, approximately 4 inches in length, with a 7/16-inch nose. These are used for cutting larger-guage wires and components on PC boards. Again, note that you shouldn't cut material larger than 24-guage with these pliers or you'll damage them. (See Figure 23 for a photograph of this cutter.)

3. Needle-Nose Pliers

These are also called ***long-nose or chain-nose pliers***; they have smooth jaws and beveled edges to prevent nicking or marring of component leads (see Figure 23). Leaf- or coil-spring handles are nice to have but not mandatory. Their overall length should be 4½ inches, with the nose itself being 1 1/16 inches.

4. Scribe

This simple tool is a sharp, very pointed instrument with any type of handle, as long as it's comfortable for you to hold (see Figure 23). It is used on PCBs to scratch away solder bridges or tiny shorts between traces. A scribe is also a great tool to use in a confined area for holding down an object while soldering.

5. X-Acto® Knife and Blades

You may already be familiar with these tools. In PC repairs you use them to cut metal traces—not to cut IC pins or component leads. You will probably feel most comfortable with the #2 handle; use the #24 blades with it (see Figure 23).

6. Shrink-Tubing

This material is a plastic insulation used for harness repairs and modifications—not on PCBs. It's sold in 36-inch lengths or on rolls. The ***unshrunk*** size or inside diameter is the dimension to use when you buy the tubing. For example, 1/8-inch shrink-tubing has an inside diameter of 1/8 inch before you heat it.

First choose a size of shrink-tubing that will slide over the wire you are splicing; then splice and solder the harness wires. Slide the tubing over the splice. Use a heat gun to shrink down the tubing tight over the conductor. Shrink-tubing gives a very professional finish, compared to plastic tape, and it's a much more permanent insulation.

7. Blade Adjustment Tools

These simple tools make it easy for you to reach open-blade leaf switches. Such switches are used on video-game control panels and extensively on pinball-game playfields. The different shapes and lengths (see Figure 26) are made to accomodate switches hidden by harnesses or mechanical assemblies.

These tools have narrow ends to allow you to bend the blades in an arc, instead of a sharp angle. To describe this technique briefly, you run the tool down the length of the blade, while

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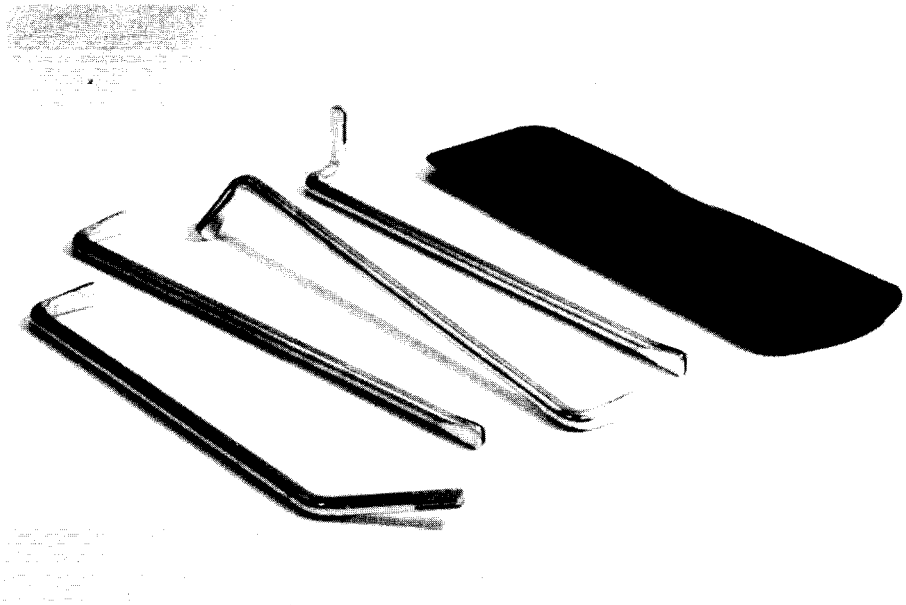
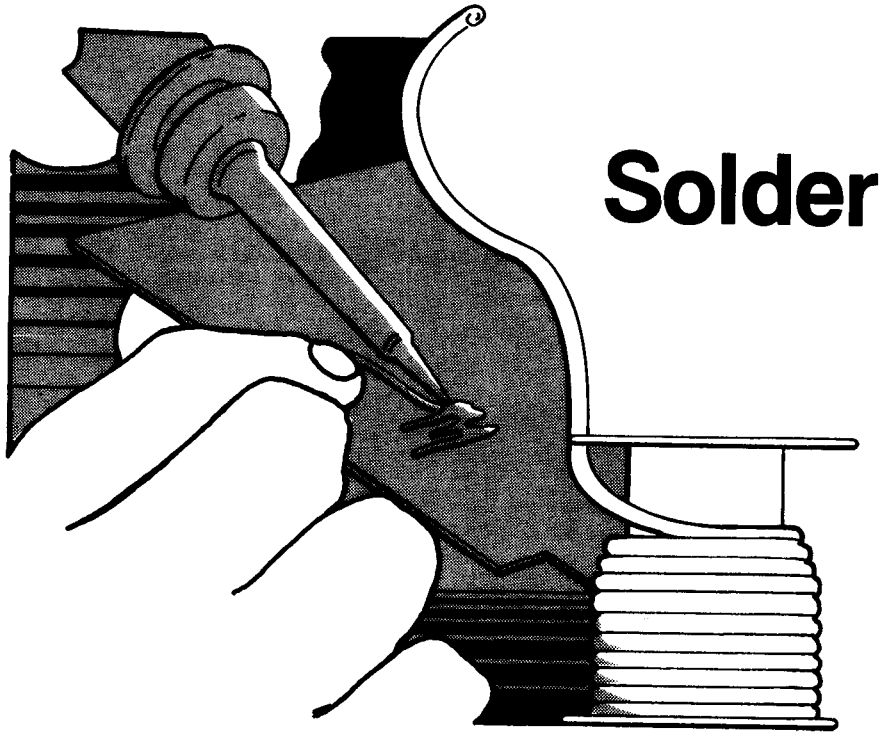


Figure 26 Tools to Adjust Leaf-Switch Blades

exerting slight pressure on the blade (either outwards or inwards) every quarter-inch or so. A sharp bend will damage the blade.

Switch-adjustment tools should be available from any Atari distributor. For more detailed information on adjusting leaf-switch blades with these tools, see ***Chapter 2—Game Repair*** in this handbook.


Solder

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M. Soldering Techniques

1. Applying Solder

Soldering is a bonding process. It plates the electrical circuit after two conductors have been physically joined together. This joining is an important part of soldering a component to a PCB.

First, both the component and the PCB must be cleaned of any grease or dirt with flux remover. Second, the pieces to be joined must have a good mechanical connection.

Also, the soldering process will be simplified if the pieces are located closely together—so solder can flow between them more easily. The closer those pieces are and the tighter they are mechanically joined with one another, the better the heat transfer will be, and the better the solder will flow onto the connection.

Third, you must heat up the solder joint with the soldering iron. You do this with a pencil-type iron on most PCBs. The easiest way to accomplish this is to first establish a ***heat bridge.*** The bridge is nothing more than a drop of solder on the tip of a pencil iron.

The solder bridge will make up for any irregularities in the shape of the components being joined or on the iron tip itself. The bridge also gives you a larger surface over which to distribute heat.

Once the components have been heated to the right temperature, it's time to apply resin-type solder. Note that one characteristic of solder is that it always flows ***towards*** the heat source (the iron). Therefore, apply solder to the opposite side of the components from where the iron is placed, if at all possible.

Look at the illustration in Figure 27 showing a component lead going through a PCB. The solder is being applied to one side of the component lead, and 180 degrees on the other side is the soldering iron tip with its heat bridge.

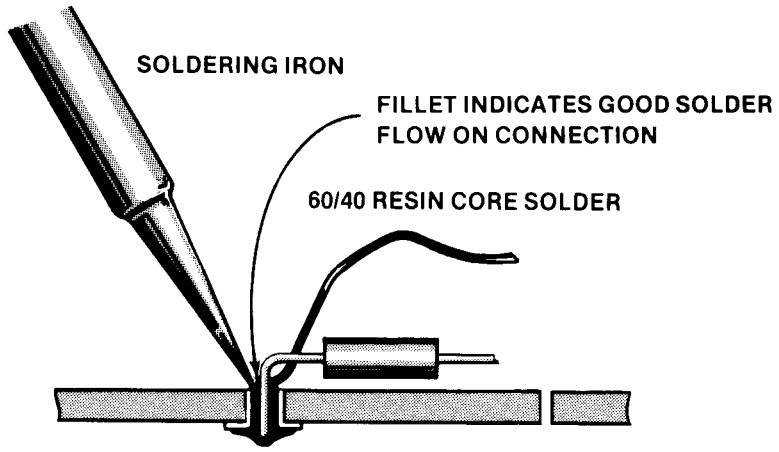


Figure 27 Good Solder Connection

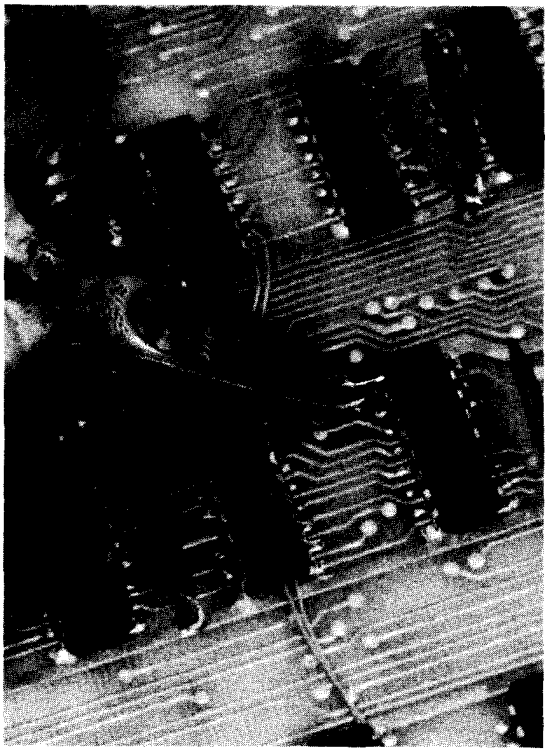
Use enough solder so that it flows evenly all around the component pin. This will insure that you make a complete connection. The shape of the solder, when cool, should be smooth and concave (a ***fillet***) between the component and the PCB. Refer to Figure 27.

2. Using Flux Remover

Once the parts are soldered together and cooled down, you should clean the connection with some type of ***flux remover.***

Flux remover is a chemical that's used to clean the board of any impurities so the solder can flow onto the connections. You also need to use it to prevent boards from collecting any metal particles, dust, or dirt. In addition, using flux remover will give you a better view of the solder connection just completed. This will insure that there aren't any hairline solder bridges at adjoining connections hidden by the gooey resin flux.

Figure 28 Proper Use of 45-Degree Tip Dykes



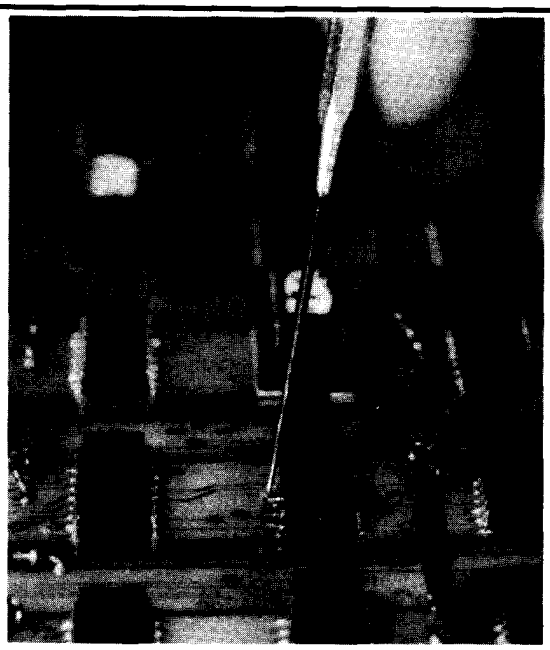


Figure 29 Raised IC Pin

You can use different types of chemicals to remove flux. One of the most readily available is ***isopropyl alcohol.*** Atari recommends isopropyl because it doesn't leave behind any film.

Use a stiff-bristled brush (like an acid brush) to clean the resin from the PCB, and use the cleaner generously to wash this resin away from the solder connections. Once the resin is removed, use a scribe and scratch between the solder connections to ensure that you have no hairline solder bridges between adjoining connections.

3. Lifting IC Pins

Figure 28 shows the proper way to use a pair of 45-degree tip dykes for lifting an IC pin. (You would lift an IC pin to isolate it during the troubleshooting process.) Lift the pin just far enough so that it does not touch the trace to which it was originally soldered. Figure 29 shows in detail the height to which the pin should be lifted.

After finishing the troubleshooting, use a scribe or some similar pointed tool to push the pin back down to its original position. Complete the electrical connection by resoldering the pin onto the trace.

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4. Removing and Replacing ICs on Boards

To remove an IC from a PCB, you should first cut each of the pins and remove the body (i.e., on a 16-pin IC package, all 16 pins should be cut). Only then should you do any de-soldering. Figure 30 shows the proper way to hold the 45-degree tip dykes, in order to cut each of the IC pins.

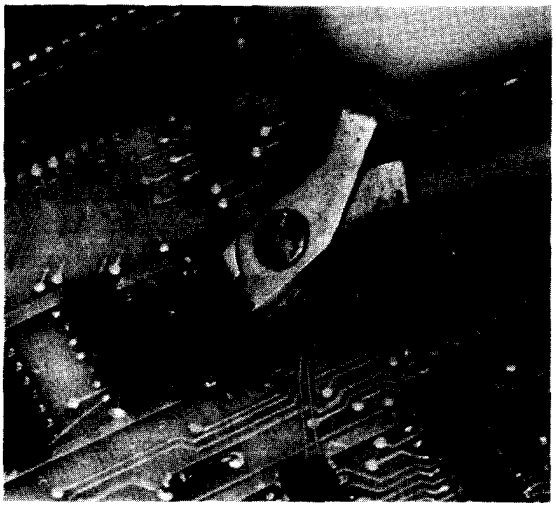
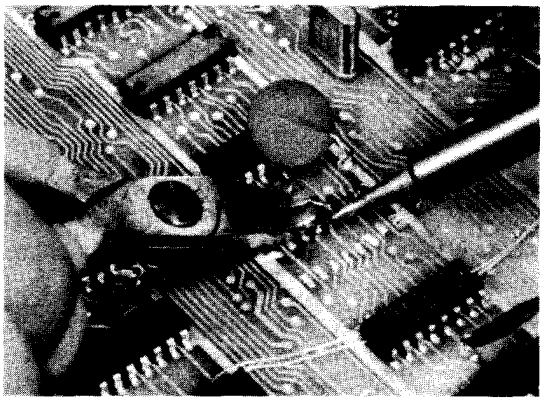


Figure 30 Cutting IC Pin with Tip Dykes

Once the body is removed, you must remove the pins individually. First bring the pin up to solder-melting temperature. Immediately after you see the solder starting to flow, grab the top of the pin with the dykes and pull the pin out of the PCB (see Figure 31). ***Be sure*** that you see the solder flow before you try to pull the pin out.

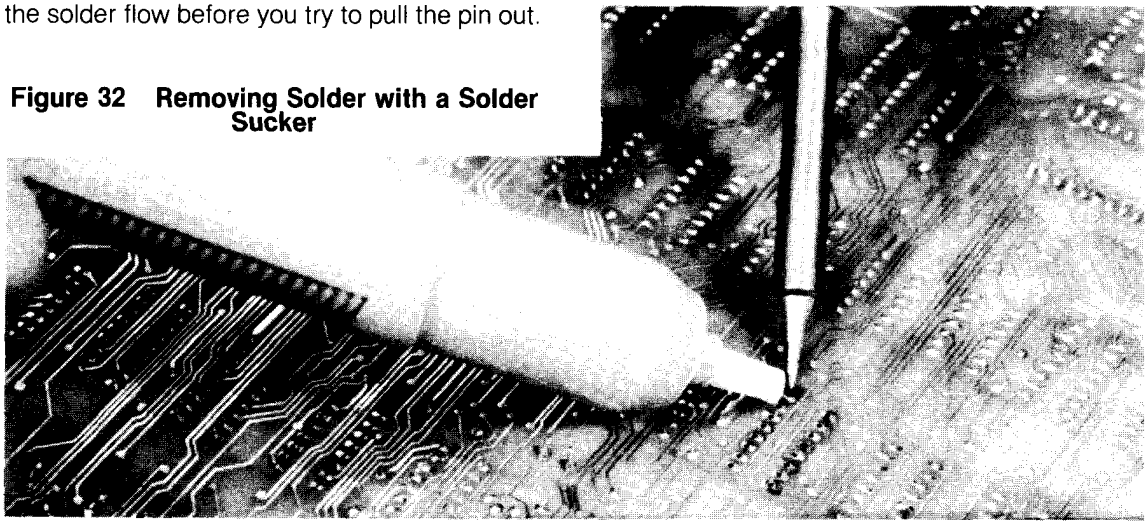
Figure 31 Removing IC Pin with Tip Dykes



After you've removed all the IC pins, you have to remove the solder from the through-plated holes in the PCB. Figure 32 shows the proper technique for using a solder sucker or solder-removing tool (a vacuum device). The one illustrated is the Soldapullt® brand. Notice the relationship between the tip of the solder sucker and the tip of the soldering iron.

To use the solder sucker, first depress the plunger until it locks into position. Then heat the connection on the PCB to the melting point. When you see the solder starting to flow, put the Soldapullt right next to the tip of the iron. ***Make sure the tool is not pointing towards your face!*** Press the release button, and the plunger will pop out, causing the solder to be sucked out of the hole in the PCB.

Figure 32 Removing Solder with a Solder Sucker



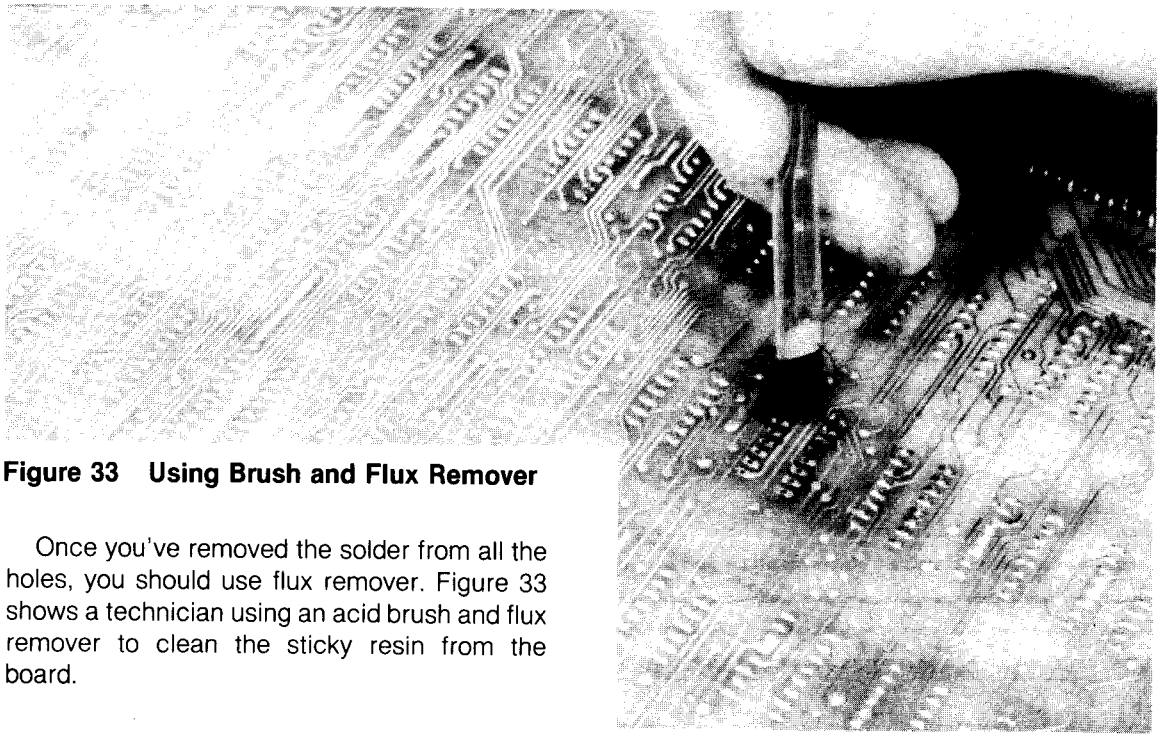
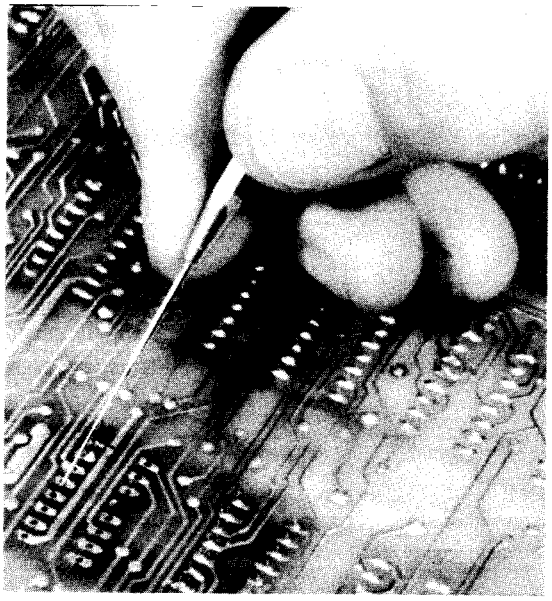


Figure 33 Using Brush and Flux Remover

Once you've removed the solder from all the holes, you should use flux remover. Figure 33 shows a technician using an acid brush and flux remover to clean the sticky resin from the board.

Next, use a scribe to remove any solder bridges or slag from the PCB that might be between the pads (see Figure 34). ***Make sure that the PCB has no solder bridges before inserting a new IC,*** as this could cause problems.

Figure 34 Using a Scribe for Cleanup



You are now ready to insert the new IC into the PCB. When you buy ICs, you'll see that their pins are always spread apart slightly. To fit the IC into the PCB, you have to bend the pins inwards, so they are ***parallel*** instead of splayed outwards.

Figure 35 Pre-Forming IC Pins

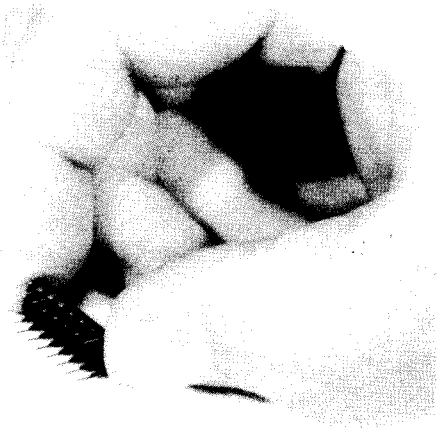


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Figure 35 shows the proper technique for holding the IC. The two functions being performed here are aligning all the pins on one side of the chip, and bending that row inwards, so it will be parallel with the other row (instead of spread apart).

As previously described in Subsection 1 (***Applying Solder***), solder the IC into the board by holding the iron on one side of the pad and applying solder to the opposite side (see Figure 36). Remember that solder flows ***towards*** the heat source. Once the solder has flowed across the pad to the tip of the iron, remove both iron and solder.

Use the flux remover all around the new IC, and clean any tiny solder bridges with a scribe.

If you have any problems getting solder to flow onto the connections, the probable reasons are: 1) the soldering iron isn't hot enough, or 2) the connections weren't cleaned properly (see Figure 37). Therefore, check the temperature of the iron if the solder balls up or lies on top of the connection and refuses to flow.

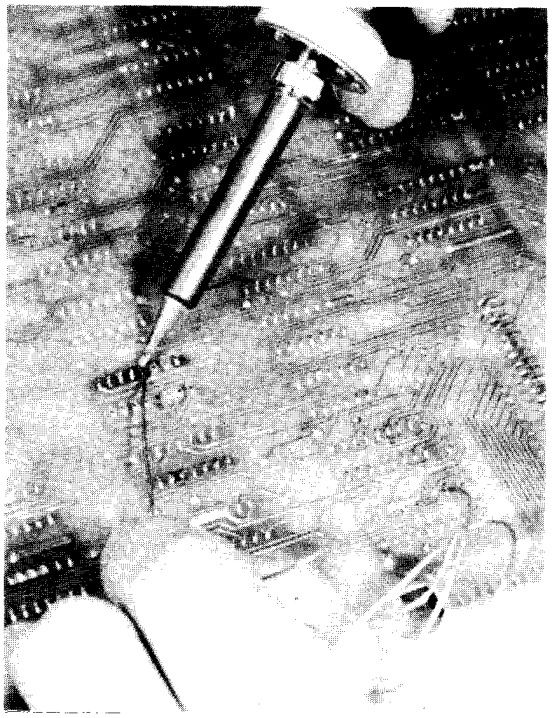


Figure 36 Soldering New IC into Board

If the solder ***does*** melt on the tip of the iron very easily, then look at the area around the connections, to be sure they aren't covered with any oxide, grease or dirt.

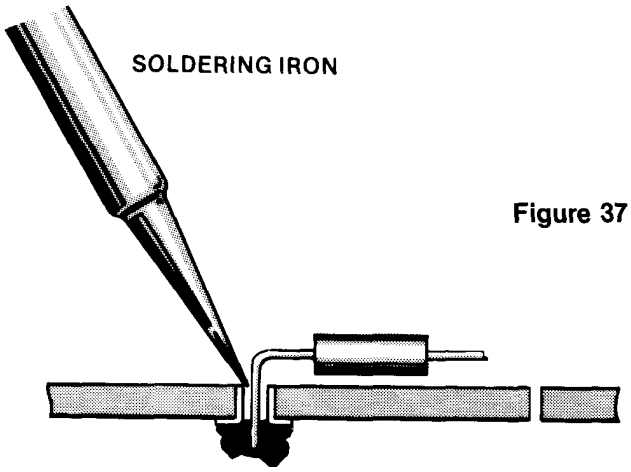
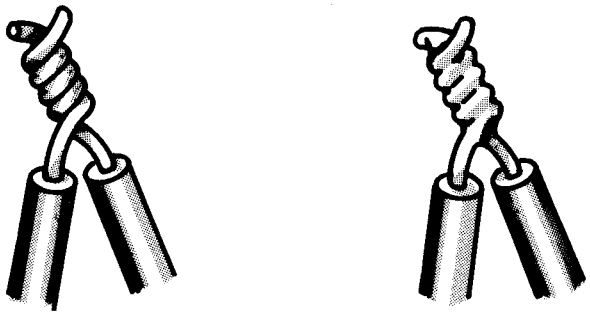


Figure 37 Common Soldering Problems

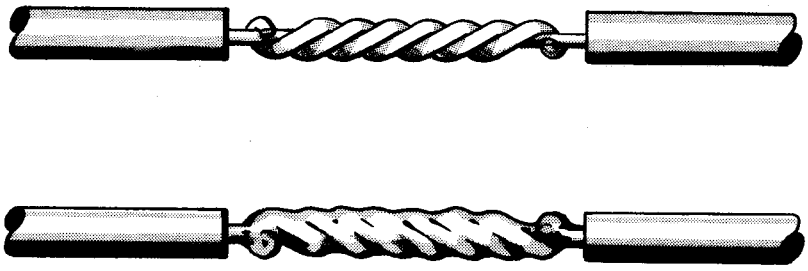
TOO MUCH SOLDER AND COLD SOLDER JOINT—DID NOT FLOW THROUGH TO THE COMPONENT (TOP) SIDE

NOT ENOUGH SOLDER—DID NOT FLOW THROUGH TO THE COMPONENT (TOP) SIDE

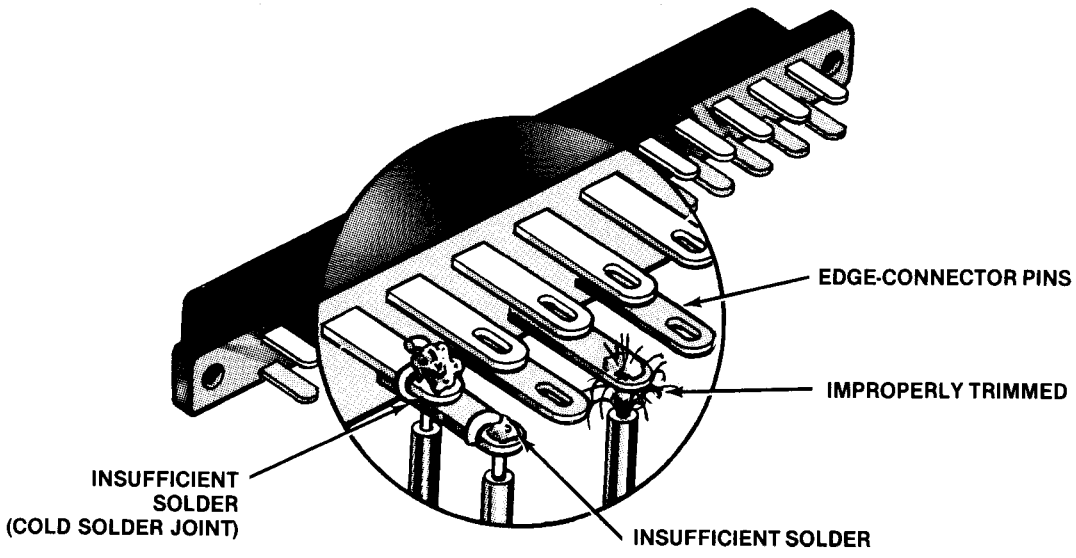
Figure 38 Good and Bad Solder Connections



1. SHORTING TWO WIRES TOGETHER (GOOD)



2. SOLDERING TWO WIRES TOGETHER (GOOD)



3. BAD SOLDER CONNECTIONS

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5. Repairing Edge-Connector Pads

The pads on edge connectors may need repair either because they were damaged from abuse, or because they were burned. Regardless of cause, the technique of repairing them is the same.

First, you will have to remove the damaged part of the pad (see Figure 39). This is necessary so that later you won't have any dirt or debris causing short circuits between adjoining edge-connector pads. Cut through the pad with an X-Acto® knife and lift the pad with a scribe. Then scrape off any carbon, loose dirt or debris on the fiberglass part of the edge connector, to leave a smooth clean surface.

Now you will recreate the pad using ***copper tooling***: this is a copper foil, and can be purchased in almost any hobby shop in the country. You should ask for copper foil, because most hobby shops will not know what "tooling" is. The material is sold in a 12-inch-wide sheet.

Do not buy thin adhesive-backed copper foil available at electronic hobby shops. This is generally too thin for edge-connector repairs.

Cut the copper tooling to the exact width of the edge-connector pad (see Figure 40). Thoroughly clean the small strip with a pencil eraser to remove any oxide. The through-plated hole has been tinned—meaning a small amount of solder was applied to the PCB.

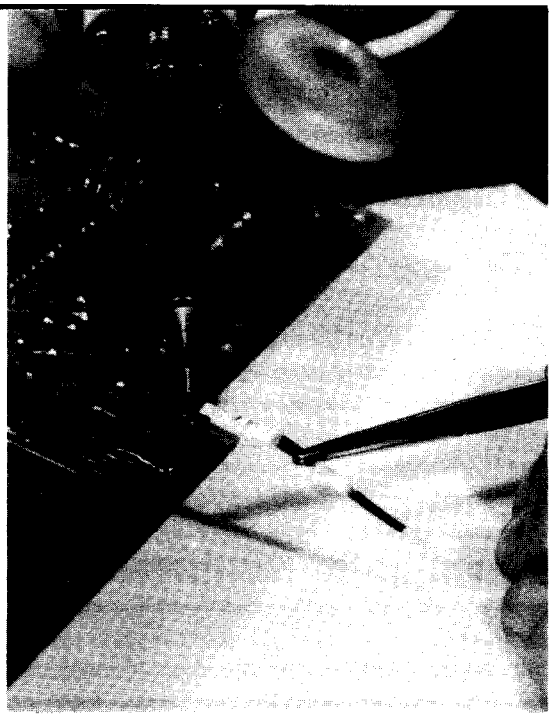
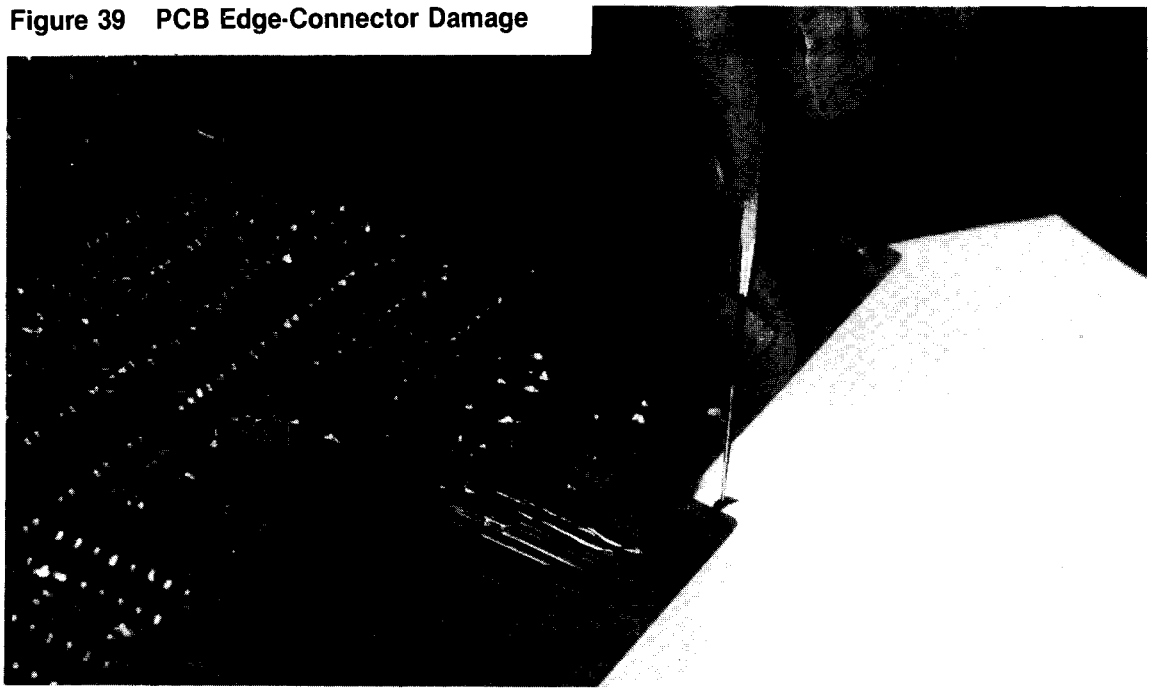


Figure 40 Applying Tooling to Edge-Connector Pad

Figure 39 PCB Edge-Connector Damage



Edge Connectors with Common Pins 1 and A: Solder one side of this copper strip onto the bottom or circuit side of the board. Turn the board over, wrap the copper tooling around the end, and make sure the tooling closely conforms to the surfaces of the board.

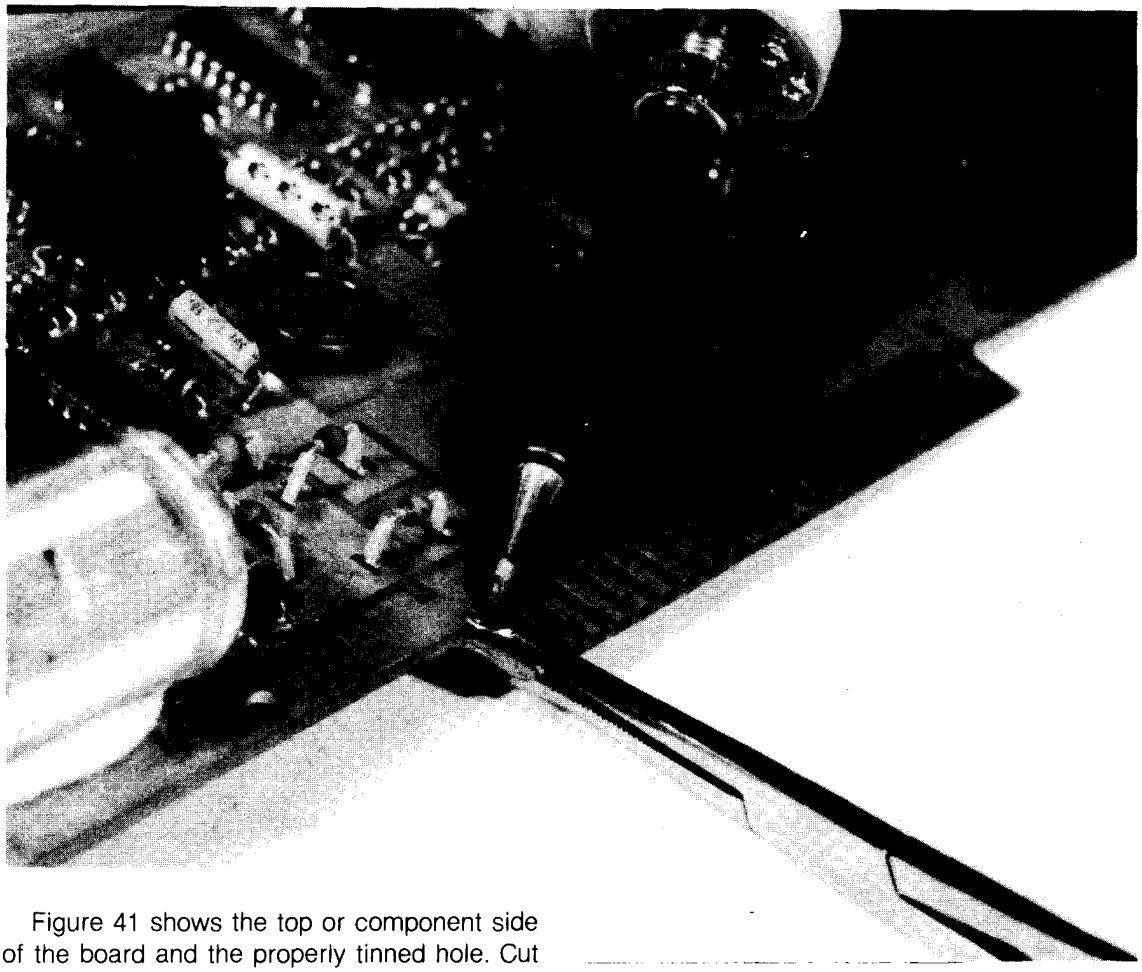


Figure 41 Final Soldering on Edge-Connector Pad

Figure 41 shows the top or component side of the board and the properly tinned hole. Cut the tooling to the right length, so it just covers up the through-plated hole—***not longer.*** Then use a clamp such as a locking surgeon's clamp, and lock it onto the copper tooling. This will ensure that the tooling is flush with the board's surface.

Apply the soldering iron to the connection to just barely heat the previously tinned area—***do not apply more solder***. This will complete the bond. After the solder is cool, remove the clamp. Clean the whole area with flux remover, and scrape away any hairline solder bridges between edge-connector pads.

As the final step, clean the whole edge connector with a regular soft pencil (not ink) eraser, as shown in Figure 42.

Edge Connectors with Pins 1 and A Not Common: If you are working on a PCB that does not have through-plated holes along the edge connector (pins 1 and A are not common), then you cannot wrap the copper tooling around the board—you would cause a short.

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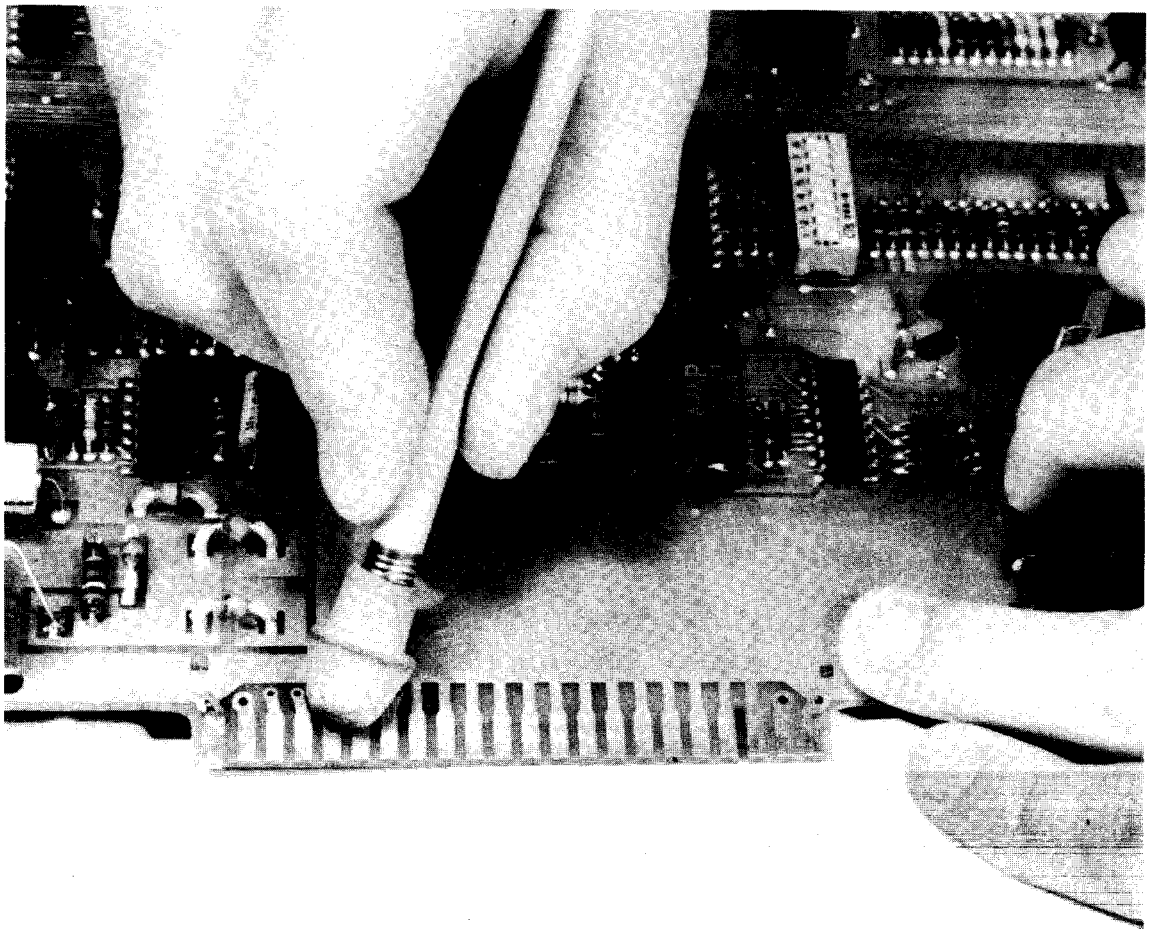

Figure 42 Cleaning Edge Connector on Board

Instead, bond the copper to only one side of the board with a small amount of solder. Then fold the foil down over the edge and cut off the overhang with an X-Acto knife.

Slightly lift the end of the copper tooling, and apply Krazy Glue or another instant adhesive under the end of the copper. This will hold the copper tooling down on the fiberglass part of the board. So now you have a solder bond at one end of the copper strip, and Krazy Glue underneath the other end.

Note that cutting off the overhanging copper tooling at the edge of the board should give you a convex surface on the copper. That will keep it from catching on the edge connector when you plug the connector back on.

6. Using Modification Wire

Mod wire, as it's commonly called, is a material you would need to repair broken or missing traces, or to change the layout of traces on a PCB.

The photograph in Figure 43 shows the ***proper*** way to run mod wires. The picture shows an IC that has one pin lifted, a mod wire has been soldered to the pad where the pin used to be connected, and a second mod wire is soldered to the IC.

It's important to note that the wire is ***lying flat*** on the PCB, and that it's run ***underneath*** components to help secure it. If you don't follow this procedure, the wire will vibrate during normal game play or during game transit. This vibration will fatigue the wires next to solder connections, and eventually will cause them to break.

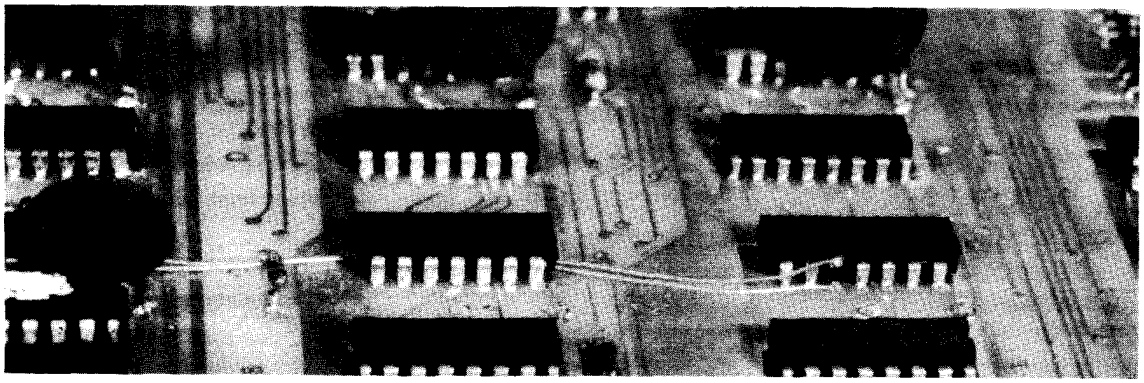

Figure 43 Correct Use of Modification Wires

Figure 44 shows the ***incorrect*** way to run mod wire. If you look closely, you'll see that the IC on the right has excessive solder—almost to the point of causing a solder bridge.

Also in this figure, IC on the left has a dirty solder connection. In addition, the mod wire is sticking up in the air. The danger here is that the loop can be caught on something when removing the PCB from the game. Besides, the wire's large unsecured loop can vibrate heavily, causing it to break off after a while.

Observe the ***lead dress***, the amount of insulation that is stripped off the wire. The insulation should stop ***right next to the IC pin*** that terminates the wire, so the wire won't cause any shorts. Mod wire should be kept as short as is physically possible.

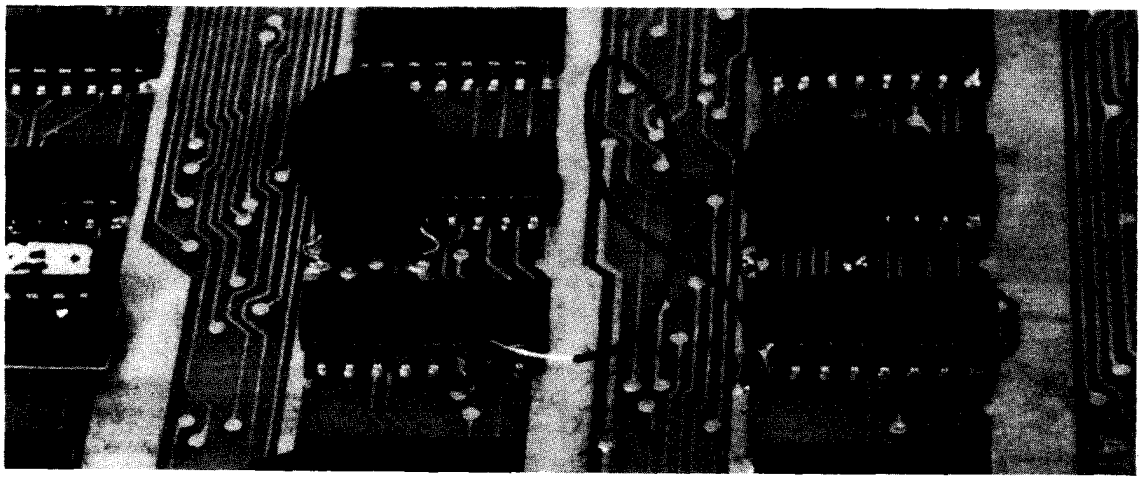

Figure 44 Wrong Use of Modification Wire

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7. Cutting Traces

Correct: During troubleshooting you may have to cut a trace. Use an X-Acto knife and follow the technique shown in Figure 45. Notice the angle of the knife, and how the knife has undercut the trace, leaving an overlapping section of foil. This makes it easier to resolder when you rejoin the connection.

The technician made ***only one cut,*** so considerable pressure has to be applied to the knife. If you make one smooth cut, you'll have to lift up only one side of the foil as shown. And when you rejoin the connection, you simply push that side of the foil back down and solder over it.

The photograph in Figure 46 illustrates the proper way to repair the damage of a wide gap cut in a trace. The technician placed a mod wire or jumper wire across the gap. This lets the solder flow smoothly across the connection instead of balling up.

The last and important step the technician would take, which is not shown in this figure, is cutting the two ends of the jumper wire. The ends should be trimmed right next to the solder.

Incorrect: The ***improper way*** to cut a trace is shown in Figure 47. This picture shows several cuts in the trace. Instead of slicing cleanly through the foil, a wide gap was cut. To repair this damage, you would have to apply a jumper wire (solder will not flow across such a large gap). In addition, a pocket knife is a tool you should ***not*** use—an X-Acto knife is the proper tool.

Figure 48 shows the results of using a pocket knife and trying to improperly repair the damage to the trace (no jumper wire was used). This picture shows a ***cold solder joint.*** The joint is dull grey, has excessive solder, and is not smooth at all. Eventually the big lump of solder will cause problems on the board due to vibration, and the connection will open up.

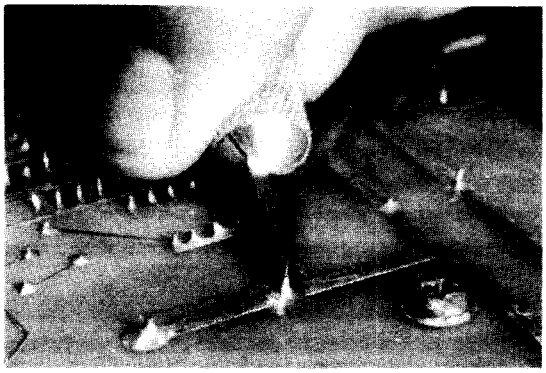

Figure 45 Correct Way to Cut a Trace

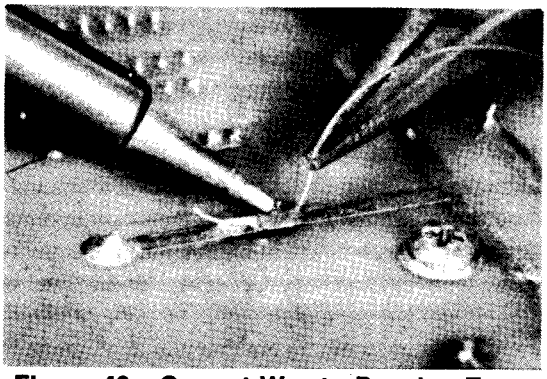

Figure 46 Correct Way to Repair a Trace

Figure 47 Wrong Way to Cut a Trace

Figure 48 Cold Solder Joint

8. Using Solder Wick

You should use this braided material to remove excess solder from any area on the PCB. The wick soaks up the solder like a sponge (refer to Figure 49 for the proper technique of using a solder wick).

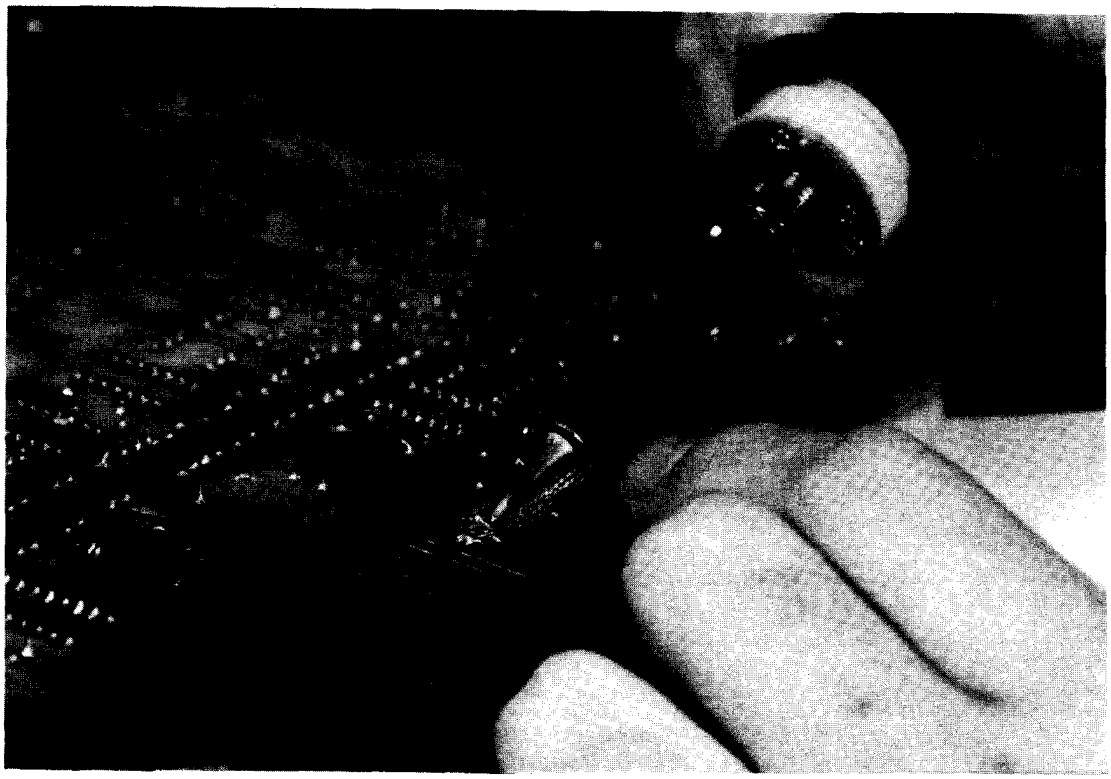

Figure 49 Using Solder Wick and Soldering Iron

The picture shows the tip of the soldering iron heating the wick and drawing up the excess solder. ***Important: when using this material, keep the wick moving on the PCB.*** If you apply heat constantly to one area, you'll cause the traces to come loose and damage the board.

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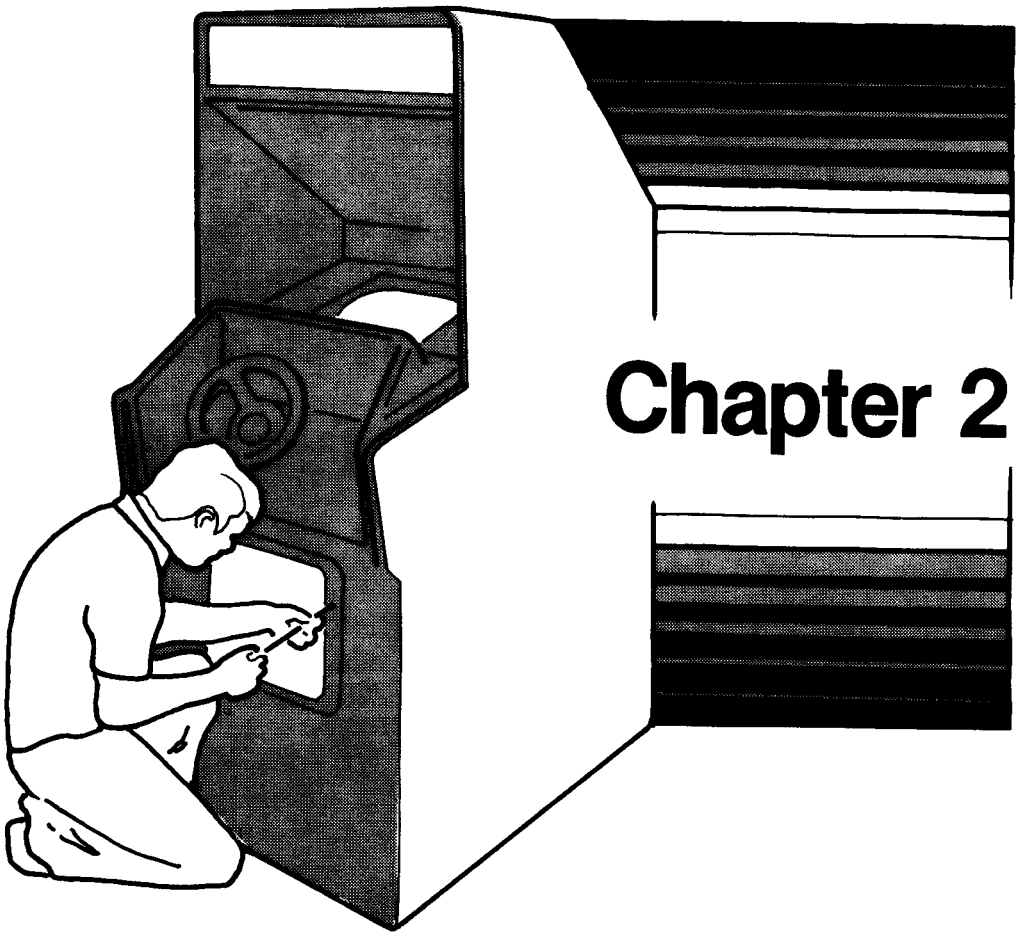

Chapter 2

Game Repair

This chapter of *The Book* is designed to steer you in the right direction if you encounter a problem with your game. It covers general problems and how to isolate them down to the individual part that needs to be repaired.

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One tool is perhaps even more important for repairing your Atari games than any tool you could buy in a hardware or electronics store—it's the manual. Atari spends a lot of effort in writing and illustrating the game manuals to provide you, the operator and distributor, with easily-found repair information.

If you haven't looked at a recent Atari manual, do so now. Chapter 1 tells you everything about setting up the game on location and checking it out, in addition to a description of game play.

Chapter 2 describes any maintenance necessary for that particular game, such as lubricating Trak Ball™ controls. It also covers detailed disassembly and repair or replacement of all the major game components.

Chapter 3 contains the parts lists and illustrations needed to identify and order any field-replaceable part in your game. Most of the illustrations have been specially drawn by the Publications Department illustrators to help you quickly identify parts.

The parts in each list are arranged in alphanumeric order for quick identification. The figure called ***Cabinet-Mounted Assemblies*** and its parts list are always first in this chapter, to give you an overview of the whole game. These are followed by all major assemblies.

A. Observing Problems

The key to troubleshooting and repair of any electronic game is the accurate analysis and definition of the problem. Rather than immediately trying to determine what is wrong, it is sometimes more sensible to identify and eliminate everything that is ***not wrong.*** If you follow this approach, you will narrow down your problem to one or two well-defined areas.

The troubleshooting process has four basic steps:

1. Define the Problem: What part of the game is operating correctly? What part is malfunctioning?

2. Localize the Problem: Is the power supply working? Do the switches and controls work? If the game has a monitor, is that working? Does the self-test check out OK?

3. Isolate the Problem: If you know which part of the game has failed (such as the power supply, harness or monitor), find out which specific component has failed.

4. Replace the Defective Component.

B. Looking for Obvious Problems

Check the self-test feature in the game. Self-test will immediately supply you with clues to speed up the troubleshooting process. Note which parts function, and those that don't. Consult the game manual for the self-test procedure.

Normally the first step in the self-test will check the RAM and ROM in the board's microprocessor circuitry. Usually an audio or video signal will indicate a bad ROM or RAM.

After the ROM and RAM tests, the game will test the input and output circuits. If the self-test fails for some reason, check for obvious problems. For example, chips may be loose in their sockets. If switch tests fail, check for proper switch operation and adjustment.

Also look for damage to the harness and connectors before trying to touch the PCB. If output circuitry fails the self-test, first test the obvious items. Are any coils shorted? Test them with an ohmmeter for proper resistance, don't just eyeball them.

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Are light bulbs or light-emitting diodes burned out? Again, test them with an ohmmeter. ***Learn to trust and use test equipment.***

Always check all power supply outputs before assuming that you have a PCB failure. Be sure to take notes on voltages, where they were taken, and what you found. The reason for this is that you may be called away from the game for some reason: then you won't have to start from the beginning again.

C. Harness Problems

Harness problems seem to cause headaches for the novice technician. Probably the major cause of harness failure is abusive handling or excessive flexing of harness or connector components (called ***fat fingering***—see the Glossary at the end of this book).

Learn to use test equipment to troubleshoot cabinet problems. The efficient use of a volt-ohmmeter (VOM) can reduce downtime considerably. Use the PCB edge connector as a test point for troubleshooting, instead of pulling and flexing the harness assembly.

You should move the harness as little as possible during this process.

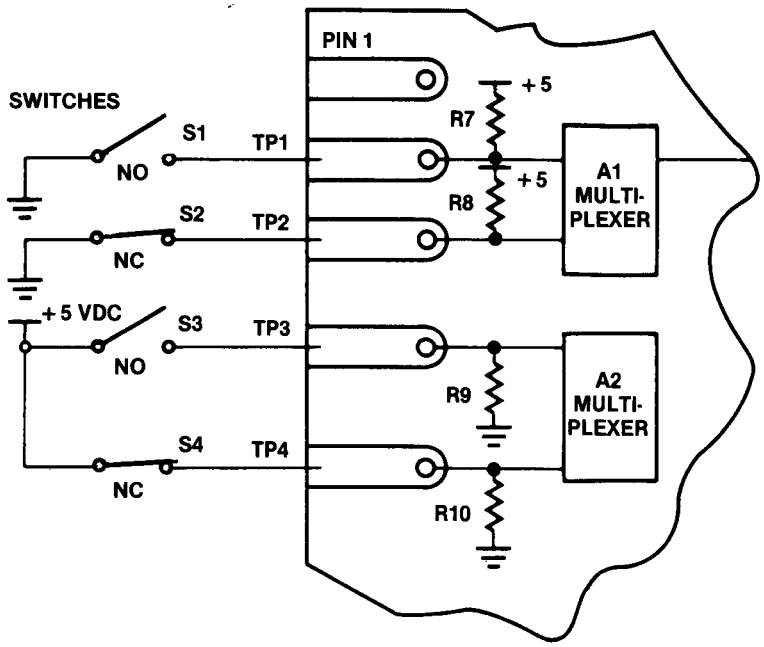

Figure 1 Troubleshooting Switches

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1. Switches

Figure 1 shows every possible combination of switch inputs in a game. Using a VOM on test point 1 (TP1) will normally show 5 V or a logic high present. When switch 1 is closed, TP1 should have 0 V present, or a logic low.

TP2 will normally have 0 V or a logic low. When the switch is opened, TP2 will go high.

Notice that these two switches have one side tied to ground. Also note that on the PCB they are connected to pull-up resistors R7 and R8.

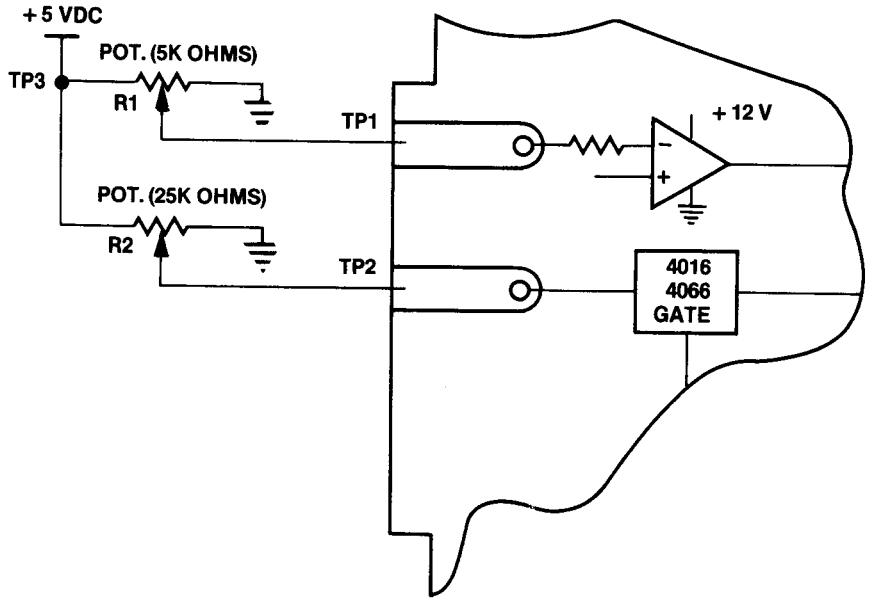

Figure 2 Troubleshooting Potentiometers

These pull-up resistors supply the 5-volt source for the switch circuit. The switches force the 5 V to 0 V when they are closed.

TP3 will normally have 0 V or a logic low present. When S3 is closed, TP3 will go to 5 V. TP4 will normally have 5 V present. When S4 opens, TP4 will go low or to 0 V. Notice that this arrangement is different from TP1 and TP2: the switches are tied directly to 5 V and the other side is using a pull-down arrangement on the PCB switch input circuit.

2. Potentiometers

Figure 2 illustrates two potentiometer inputs used in video games. TP1 should be tested with a voltmeter. When R1 is moved from one mechanical limit to another, you should see a change in voltage. This voltage will vary, depending on the resistance of the PCB input circuits being tested.

TP2 is very similar to TP1. The difference is the larger resistance of R2. The voltage swing on TP2 should be greater if the potentiometer is turned from one limit to another. It is not uncommon for a potentiometer to either open (infinite resistance) or have a dead spot due to dirt or other foreign material. This appears as jumpy or erratic needle movement on your meter as you slowly rotate the potentiometer from one extreme to the other.

Voltage measurements should be made between the test points and ground. If no voltage appears at TP1 or TP2, you should check the voltage at TP3.

3. Steering PCB

Figure 3 illustrates a typical Steering PCB input to a game PCB. You should use an oscilloscope to watch the activity on TP1 and TP2. As you rotate the steering wheel, you'll see waveforms as shown.

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The most common failure in this circuit is in the square or rectangular connectors on the Steering PCB. When no waveforms appear on TP1 and TP2, check the voltage on the Steering PCB. If there is 5 VDC present, check the outputs of the PCB to verify that it is working. Remember, you may have a harness problem.

You can also check the steering in a two-player driving game or a game with a Trak Ball™ assembly by switching the connectors from one Steering PCB to another. You are actually substituting a known-to-be-good component or circuit with a suspected bad one, thus isolating the problem to the connector or Steering PCB. If this works, reconnect the harness assembly as per the original configuration. If the game still works, tighten the connectors in the harness.

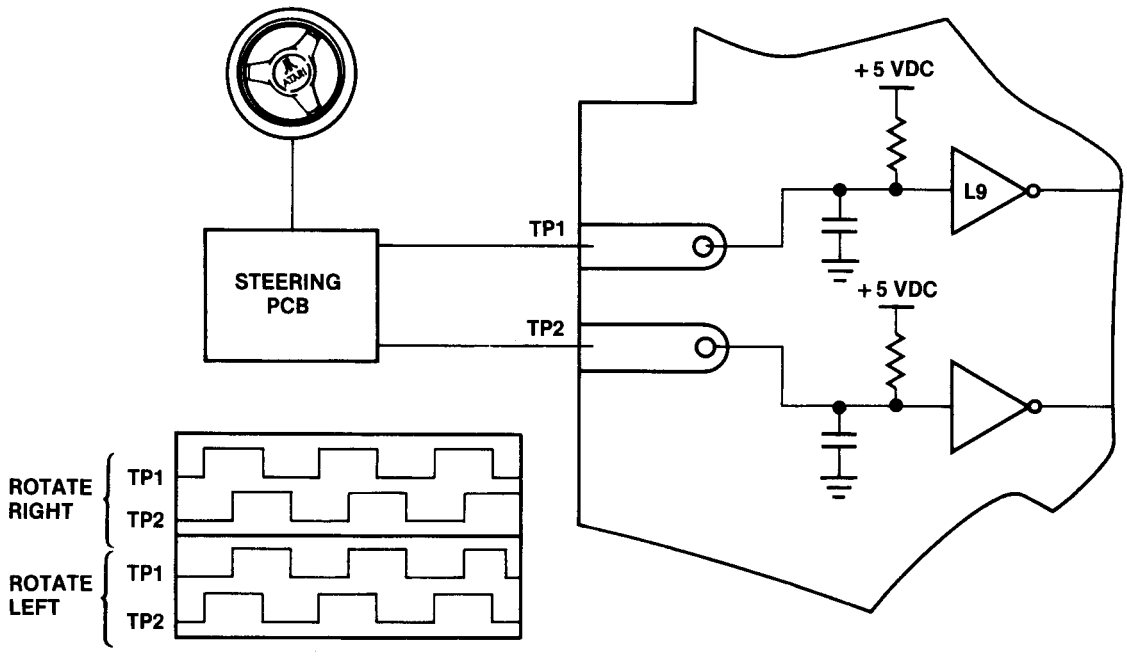

Figure 3 Troubleshooting Steering PCBs

4. Audio

Figure 4 shows a recent audio circuit. Use a voltmeter or an oscilloscope to test these circuits when you find a no-audio condition. You can easily isolate a fault by measuring across the speaker terminals and checking for voltage changes or an audio output.

If voltage changes occur on the speaker terminals, but you have no sound, the speaker is at fault.

Use TP2 when no audio is present on the speaker terminals to determine whether or not the amplifier is working. If there aren't any voltage changes on TP2, check all voltages necessary to operate the audio amplifier.

Also check TP3 for the presence of an input to the amplifier. TP3 should have approximately *5 V* peak-to-peak input. (This voltage will vary from game to game.) What you are looking for is voltage changes that represent audio. The most common failure in this circuit is the audio amplifier IC itself and related power supplies.

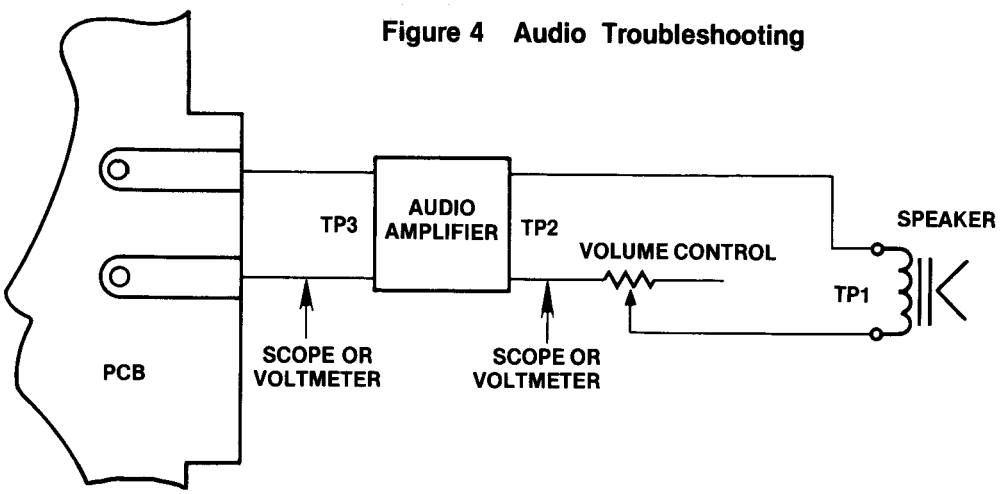

Figure 4 Audio Troubleshooting

5. Lamps and Light-Emitting Diodes

Figure 5 illustrates typical lamp and LED outputs. TP1 should normally have the lamp voltage *present* when the lamp is *off.* When the lamp is on, TP1 should be almost 0 V.

If TP1 is always 0 V, check the power supply and lamp socket for presence of 6.3 V. Either the lamp or the harness could be bad. If 6.3 V is present at TP1, visually inspect the bulb and

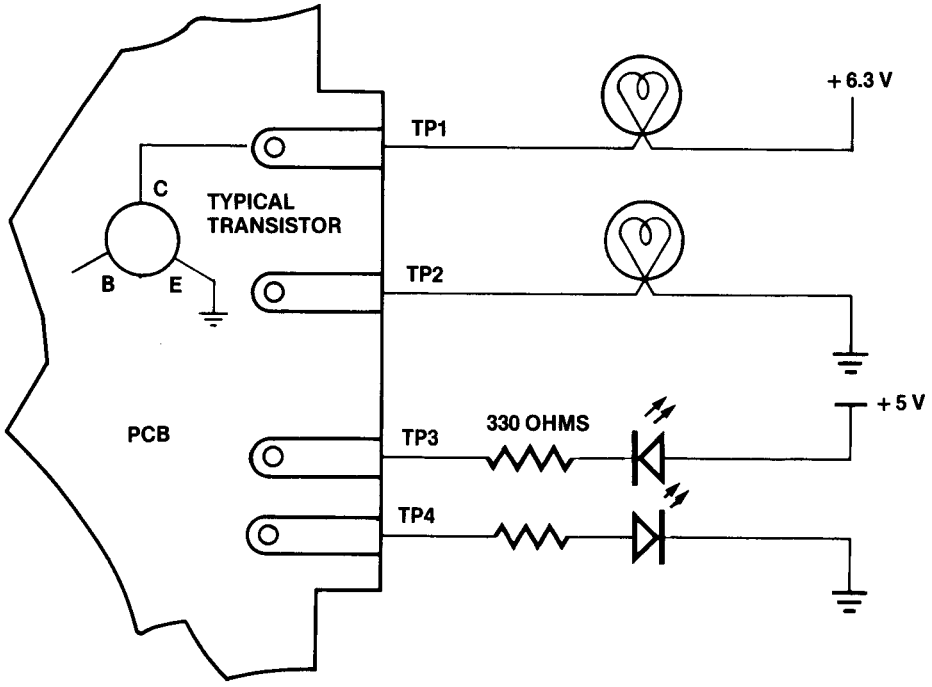

Figure 5 Troubleshooting Lamps and Light-Emitting Diodes

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socket for shorts. Try grounding TP1. If the bulb lights up, you probably have a bad lamp driver on the main game PCB.

TP2 should normally have 0 V present when the lamp is off, and 6.3 V when turned on. If you measure 0 V, then the lamp driver on the game PCB is probably at fault.

TP3 should normally be 5 V with the light-emitting diode turned off, and read almost 0 V when on. TP4 should normally be 0 V when the LED is off, and go high when the LED is turned on.

You can troubleshoot LEDs with an ohmmeter exactly the same as lamp circuits, except in this regard: the LED should measure around 500 ohms one way, and with reversed meter leads should read infinity. ***Note that you should do all ohmmeter tests with the game unplugged.***

6. Solenoids

Figure 6 illustrates two possible solenoid arrangements found in games. TP1 should normally be 40 VDC when the coil is off. When it is turned on, TP1 should go to almost 0 VDC.

If the coil fails to turn on, check the coil for shorts. Resistance should be low, but not 0: 7-10 ohms DC resistance is typical of pinball playfield coils.

Check for 40 V at TP1. If it's OK, the problem is on the game PCB. You can ground TP1 to verify this.

TP2 should normally be 0 V when the coil is off, and approximately 24 VDC (or rated voltage) when turned on. You should test the coil as in the lamps and LED circuits.

Typical failures in the coil circuits relate to driver transistors, coils, or solenoids. Sometimes these components fail as a pair. Generally failure in pairs occurs because the fuse protecting that circuit reacts too slowly to protect the driver transistor from damage.

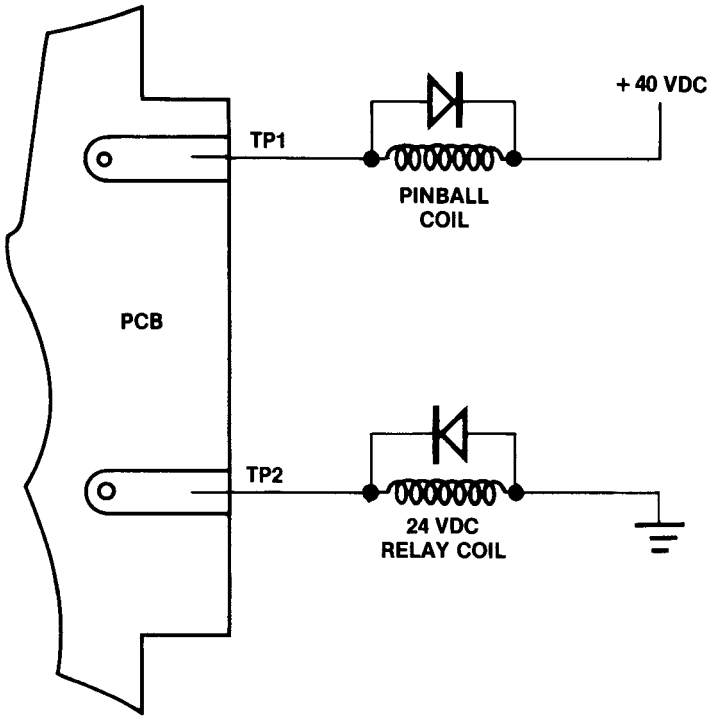

Figure 6 Troubleshooting Solenoids

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D. Monitor Problems

1. Raster-Scan Monitors

You can easily troubleshoot raster-scan monitors if you approach them correctly. First determine if the monitor even has a problem.

If the screen is black, the first step is to turn off the power; then disconnect the game-PCB connector from the game board.

Then turn on the power. Does the screen light up? If it does, touch the video-output pin on the game PCB connector. You should see some change on the screen such as dark wide vertical lines. If not, you probably have a faulty video amplifier in the monitor or its associated circuitry, or an open harness.

If the screen does change, then the game PCB has no video output.

If there is no raster when the brightness is turned up, check for 115 VAC present on the harness connector at the rear of the monitor. Also check if the monitor fuses are blown.

Caution: If the monitor fuses are blown, do NOT replace any of them with larger fuses. This will cause the main power transformer to overheat and fail! Refer to Chapter 3 of this book for further troubleshooting information on monitors.

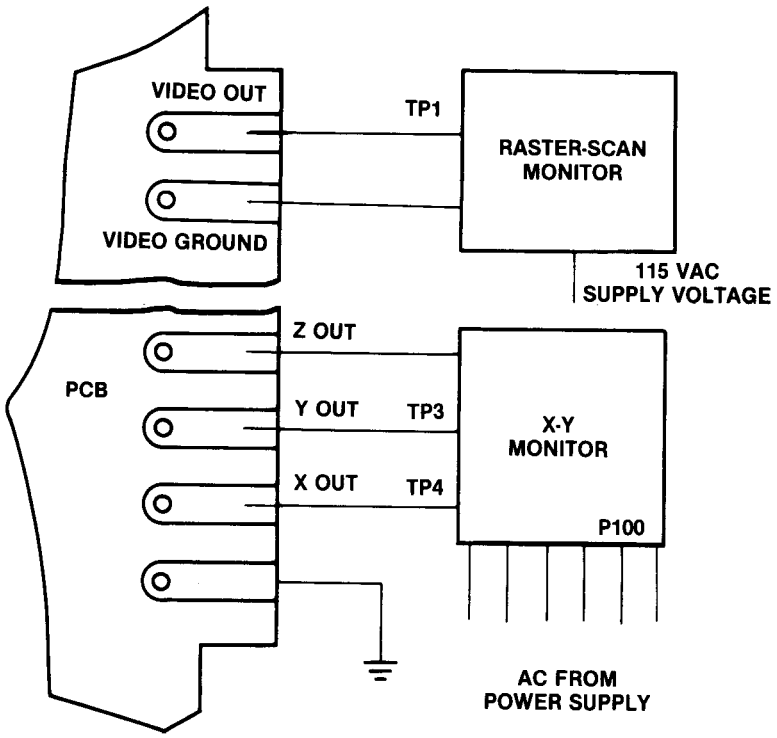

Figure 7 Troubleshooting Monitors

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2. Quadrascan™ X-Y Monitors

To determine if an X-Y monitor is bad, you must use some test equipment, but you can still accomplish the troubleshooting fairly easily. First check for the presence of all voltages necessary to support the monitor.

At ***P100*** of the Electrohome monitor, measure across the following pins and check for the presence of these voltages:

Pins 1 & 2—37 VAC
Pins 2 & 4—37 VAC
Pins 3 & 6—6.3 VAC

Next, with a voltmeter or scope, check the X, Y and Z outputs on the game-PCB test points. (These should be made using ground as a reference.) If all these prove to be OK, then the monitor is bad. Refer to Chapter 3 for further information on how to deal with a bad monitor.

E. Connector Problems

Typical connector problems you might find in a game are due to such factors as dirt, loss of spring tension and heat. The life of a connector will vary from game to game, depending on its application.

Use test equipment to examine signals coming from the game PCB, instead of fat-fingering the harness assembly. Most harness problems tend to be intermittent, meaning sometimes the object works and sometimes it doesn't.

When looking at a suspected harness problem, ask yourself a few questions. Is this an input problem? Do some or all of the switches work? Is this an output problem? Do all the lamps operate? Is there any video? Does the audio work?

If you start at the edge connector and look for logic changes on all the switch inputs, this will tell you whether or not you have a harness or a PCB problem. If you see that there is no change on a switch input, look for connectors in the middle of the harness assembly, instead of immediately wiggling all the connectors.

Try testing at the harness in this manner: poke a straight pin or safety pin into the wires on both sides of the connector. Don't disturb the connector. Then use these pins as test points.

If a problem seems to fix itself, ***don't assume it's gone—it's not!*** The problem is just waiting for you to walk away from the location. If you don't make a physical change to correct the problem, that problem still exists and will continue to haunt you!

All connectors depend on spring tension to maintain pressure enough to support current flow. If the spring weakens, the connector will no longer perform its job as a conductor. Instead the connector will act as a high-resistance connection.

In a switch circuit, this resistance will cause intermittent switch operation and eventually complete failure. Output circuits usually use higher current levels, and a high-resistance connection will heat up. ***The heat will make the connector oxidize and eventually burn if left alone long enough.***

If you trace an intermittent problem to an edge connector, you can cure the problem in most cases by cleaning the pads on the game PCB with a pencil eraser. In the more persistent cases, you may have to re-tension the connector itself. ***This is not a permanent solution:*** eventually you will have to replace the connector anyway.

Connectors such as those made by Molex can also present the same problems. You can prolong eventual replacement by re-tensioning the female pin in this connector.

F. Power-Supply Problems

The heart of any electronic game and also another potential source of problems is the power supply. Figure 8 shows one example of a game power supply.

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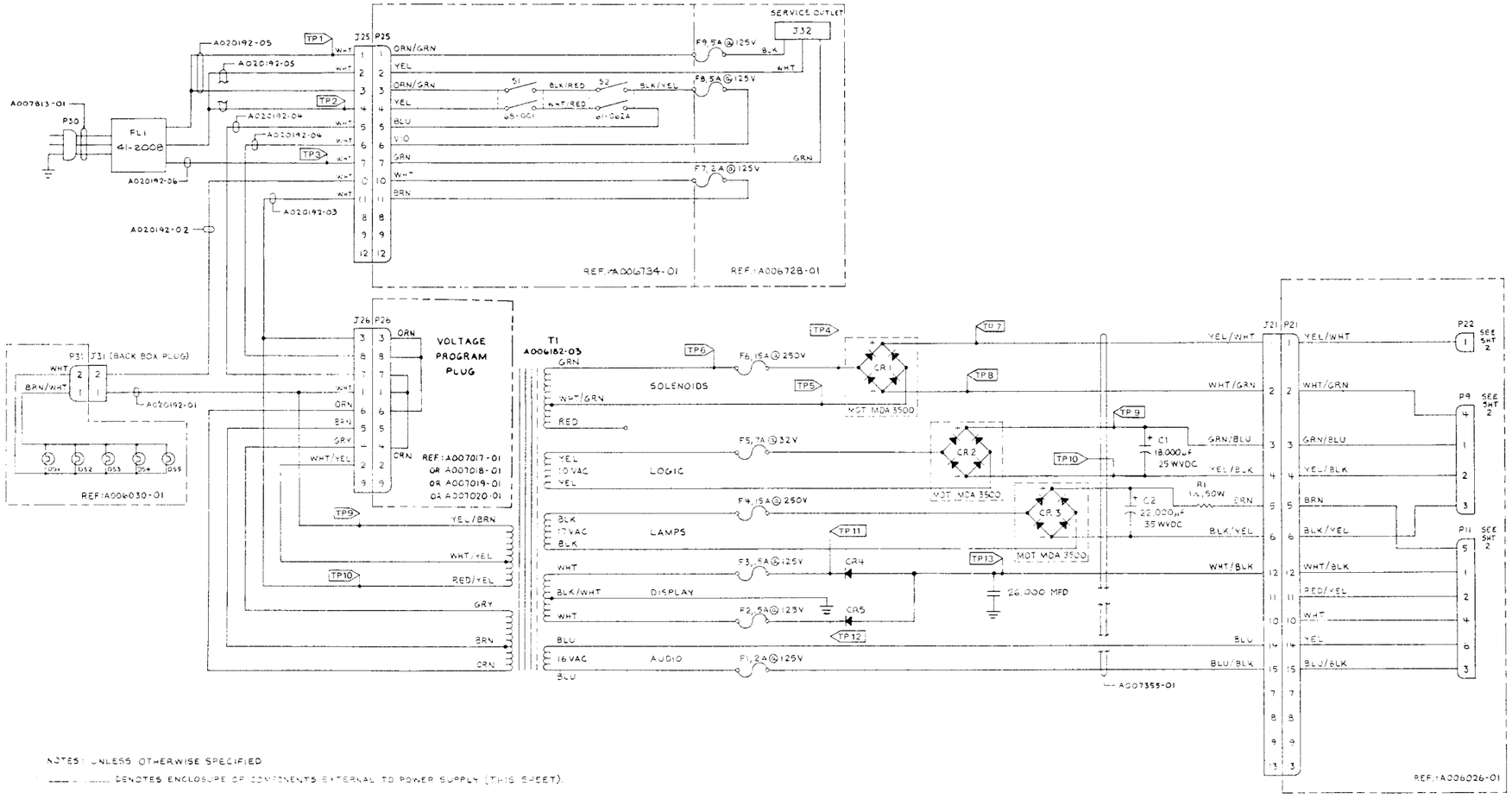

NOTES: UNLESS OTHERWISE SPECIFIED

1. ——— - ——— DENOTES ENCLOSURE OF COMPONENTS EXTERNAL TO POWER SUPPLY (THIS SHEET).
2. LAST DESIGNATIONS USED ARE : C2, CR22, DS79, F9, J32, K20, P31, R18, S62, T1, FL1.
3. RESISTORS ARE 39Ω, 2 WATT, 5%.
4. DIODES ARE IN4001

Figure 8 Troubleshooting Power Supplies

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Normally the AC voltage reading across TP1 and TP2 should be approximately 115 VAC. It should read the same across TP1 and TP3.

Check the transformer output by measuring across TP4 and TP5, for example. If you get no reading, then measure across TP5 and TP6, to test fuse F6 (15 amps, 250 V). Finally, test the transformer inputs to verify if the transformer is bad.

If TP5 and TP6 have no AC reading across them, and the inputs TP9 and TP10 read approximately 115 VAC, then the transformer is bad.

If the reading across TP4 and TP5 checks out OK, then your next step would be to measure DC voltage across TP7 and TP8. These are most easily reached on the diode assembly's positive and negative terminals.

In the case of the diode bridge assembly CR2, you can more easily test the TP9 and TP10 on the filter capacitor terminals. You should loosen and retighten the screws on the filter capacitors, to insure that corrosion doesn't build up on the wire lugs.

Diodes CR4 and CR5 made up a typical 5-volt power supply arrangement. TP11 and TP12 are used to test the AC input to the supply. These test points should measure approximately 16.5 VAC. You should test the DC output of this rectifier assembly at TP13, measured with a ground reference. This reading should be from 8.5 VDC to 11 VDC.

Should you find this voltage too low, you probably have a bad filter capacitor. Test this component by substitution. Dirty connectors, wire lugs, and crimp connections of any kind should also always be checked out.

You should always make all voltage tests with the power supply in the cabinet, and the game should operate under full load. Otherwise, your measurements may not reflect full load problems.

If possible, make all voltage tests on the actual assembly. For instance, test for the 8.5 to 11 VDC on the game PCB input or on the Regulator/Audio PCB assembly, if the game has this board. If the latter is the case, test the voltages needed to run the game PCB ***on the game PCB***. This board has special test points provided for this purpose.

G. Cleaning the Printed-Circuit Board

Occasionally, a PCB will be asked to perform under conditions above and beyond the call of duty. They usually cannot operate while covered with beer, Coke, pizza, juice or metal particles from control assemblies.

If you find this condition, your first step should be to remove the PCB from the game and give it a thorough soaking with any general non-abrasive household cleaner, such as Formula 409®. Brush and scrub the PCB if necessary. Remove any ICs from their sockets; clean and rinse the board and ICs thoroughly. Be careful of any mod wires which might exist.

After washing the PCB, thoroughly dry it with compressed air, a heat gun or blow dryer. ***Insure that it is COMPLETELY DRY before applying power!*** We do NOT recommend that you do this cleaning procedure if the board has light-emitting diodes or fluorescent 7-segment displays.

You should also be careful of getting components, such as large filter capacitors wet, as they may leak and cause problems later on. If in doubt, remove them before cleaning the PCB.

H. Mechanical Hardware and Its Adjustments

1. Gear Shifter Assembly

What we will discuss in this section is typical problems found in gear shifter assemblies that were first used in the Trak 10® and Formula K games.

The most frequent failure is a broken shift housing. You can help this problem by strapping two radiator hose clamps around the housing. Place them approximately one-third from each end of the housing. This will add stiffness so they last longer in abusive locations.

As Night Driver® and Sprint 2® became popular, a new problem came up. The aluminum shifter rivets (used as switch actuators) began to mushroom and stick. This requires trimming them occasionally to keep the game working. These rivets have been replaced with steel ones to reduce maintenance time.

Recent changes in shifter design have improved reliability and lowered maintenance time. See Figures 9 and 10 for details on the old and new style of gear shifter.

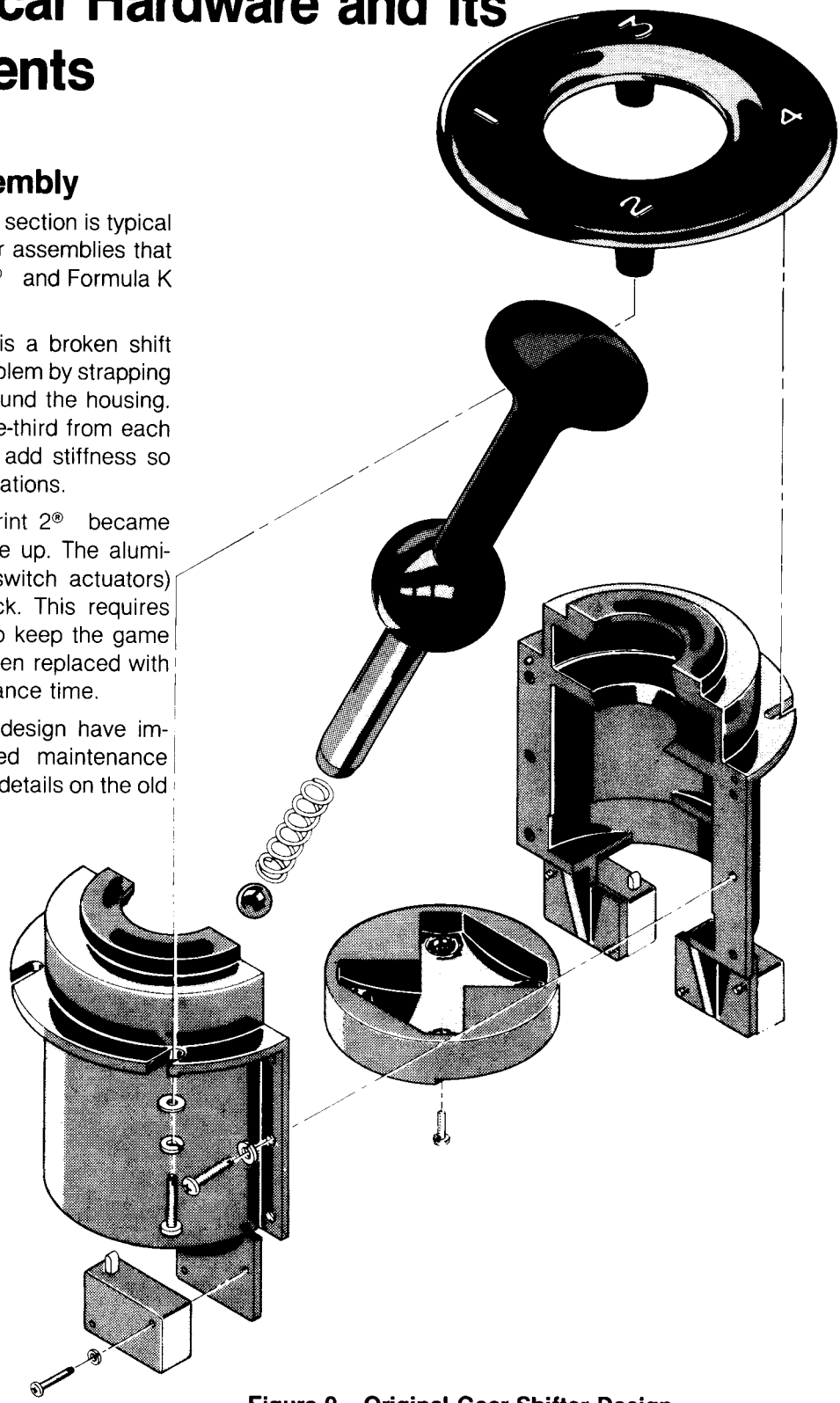

Figure 9 Original Gear Shifter Design

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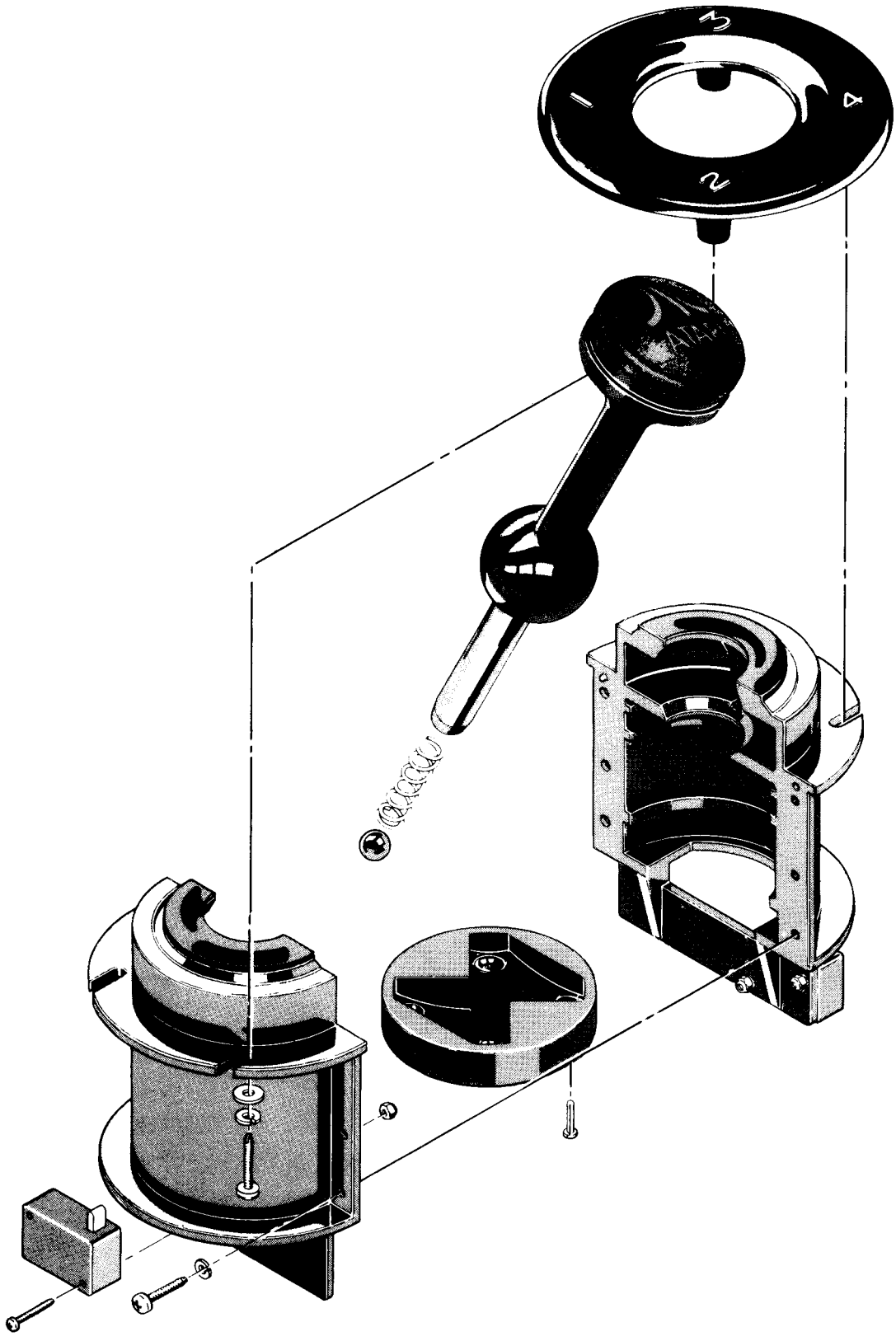


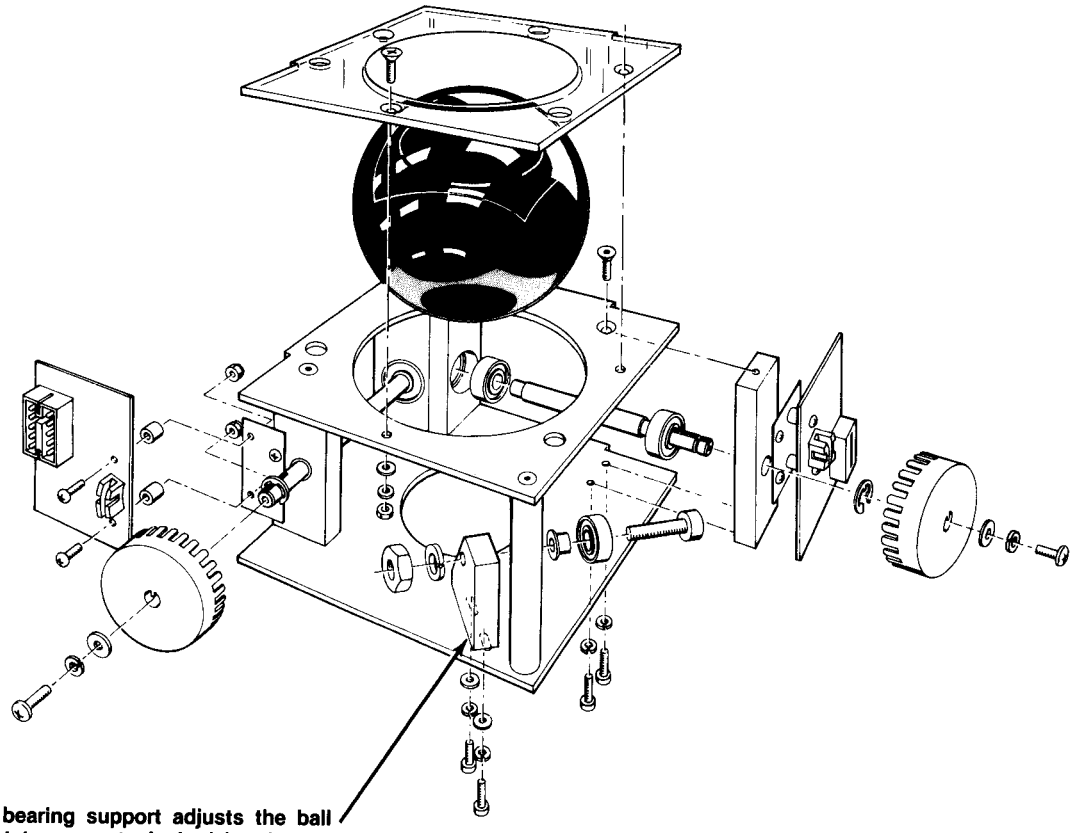
Figure 10 New Gear Shifter Design

2. Trak Ball™ Assembly

The Trak Ball™ assembly used in recent games needs periodic cleaning, lubrication and inspection to insure that all hardware is tight.

Use only two drops of 3-in-One® oil to lubricate each of the five bearing races. The shafts should spin freely. Then clean the shafts as well as the ball of all excess oil and dirt.

Some other cautions: 1.) do not use dry graphite lubricant; 2.) do not roughen up the bearing surface that the Trak Ball rides on; 3.) do not allow Loctite® to contact any plastic parts; and 4.) do not allow the Trak Ball height to drop down, as ***this may cause the players to pinch their fingers!***



This bearing support adjusts the ball height to prevent pinched hands and fingers.

Figure 11 Trak Ball™ Assembly

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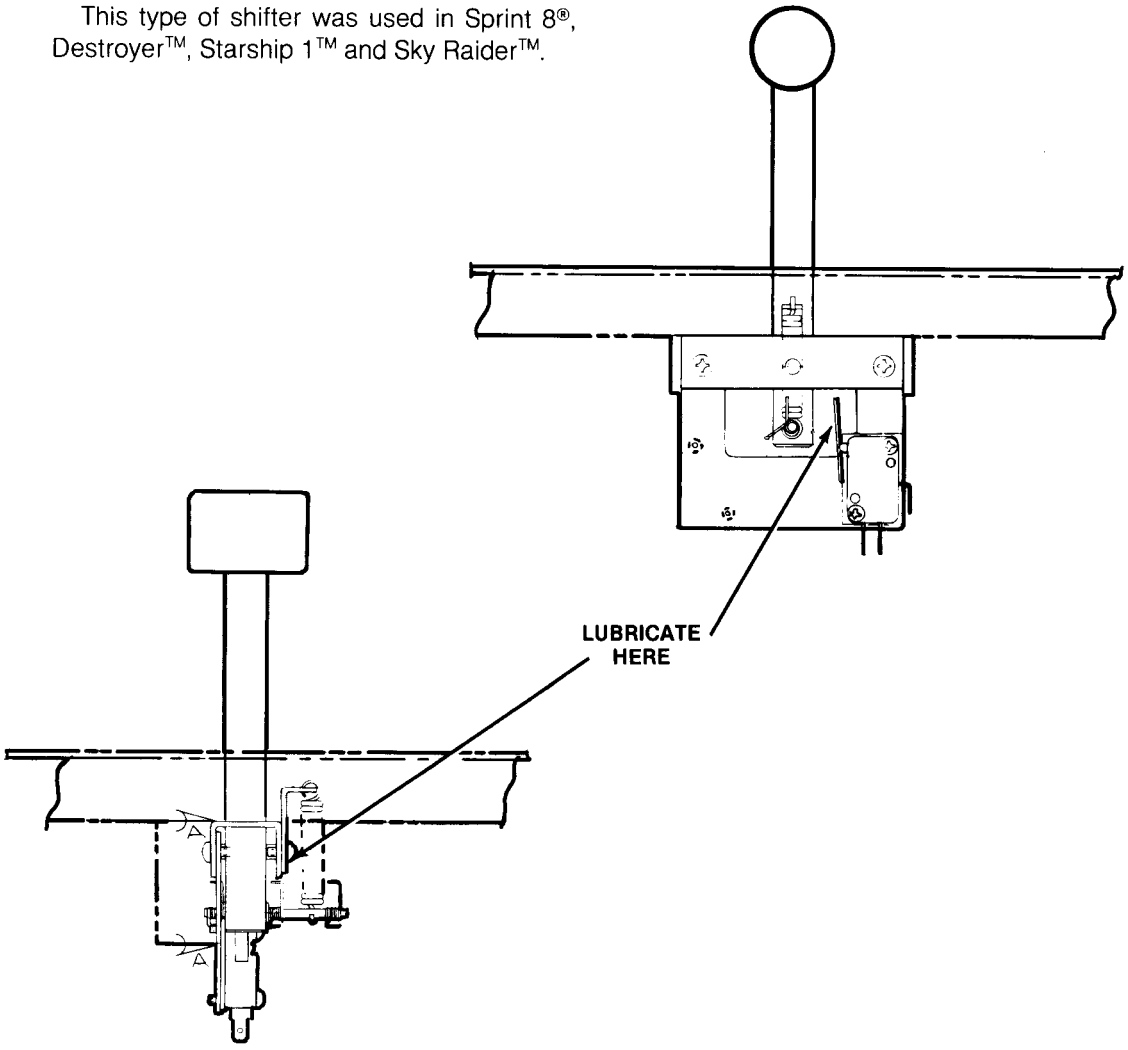
3. Two-Speed Shifter

Because of the nature of this control, it undergoes severe stress and vibration. Therefore, you should secure all screws with Loctite® glue. To maintain the control, you should lubricate the switch activator and shift handle pivot pin with light silicone grease.

This type of shifter was used in Sprint 8®, Destroyer™, Starship 1™ and Sky Raider™.

Figure 12 Two-Speed Shifter



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4. Gas Pedal Control

Figure 13 shows the first gas pedal design from Atari. A beryllium spring was used to activate the switch.

This design was improved first by using the washer (1) to activate the switch. Later we found that the rubber bumper (2) would allow the washer to overtravel and damage the microswitch.

Figure 14 shows the next step in improving this assembly. The spring activator was added to protect the switch. The activator prevented the washer from damaging the plastic switch body, and it absorbed any excess pedal travel. This kept the switch from being damaged internally.

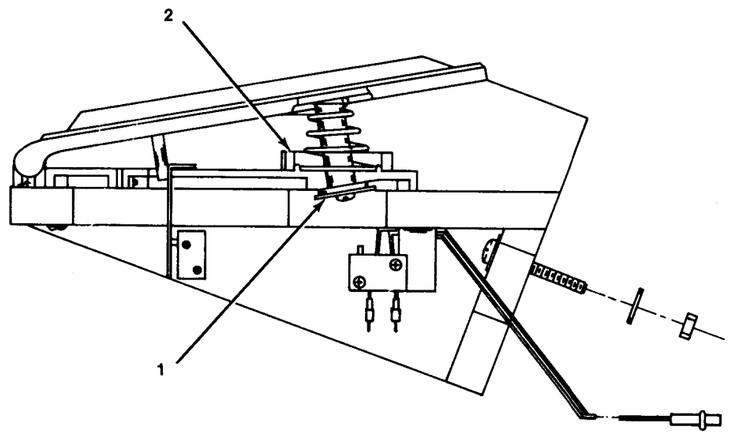

Figure 13 Original Gas Pedal Assembly

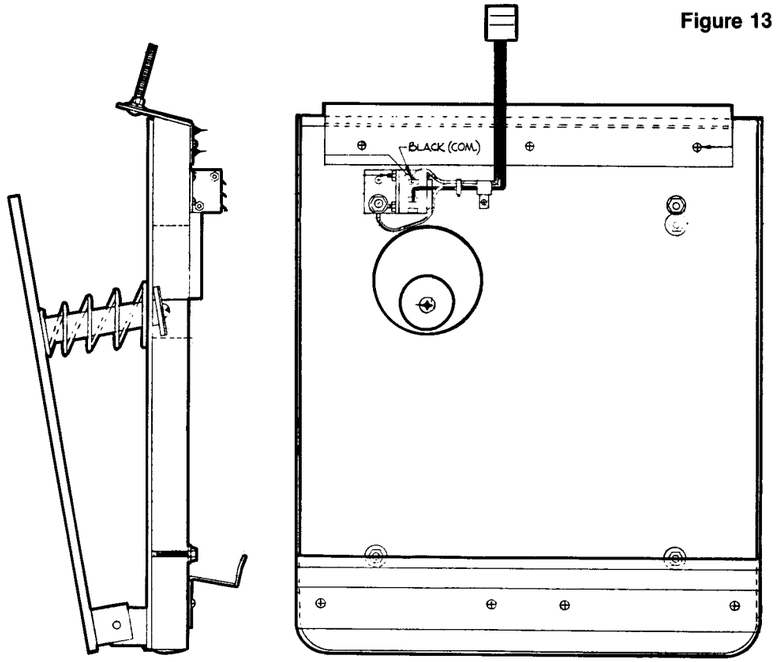

Figure 14 Improved Gas Pedal Assembly

Figure 15 shows the newest gas pedal assembly (introduced in early 1980). Notice that the microswitch activator has been changed to a spring, to prevent flexing sideways. This keeps the activator from slipping off the washer (3).

Also notice the hinge location: it has been moved from the player's heel to the toe area. This relieves stress on the hinge pin, resulting in longer assembly life.

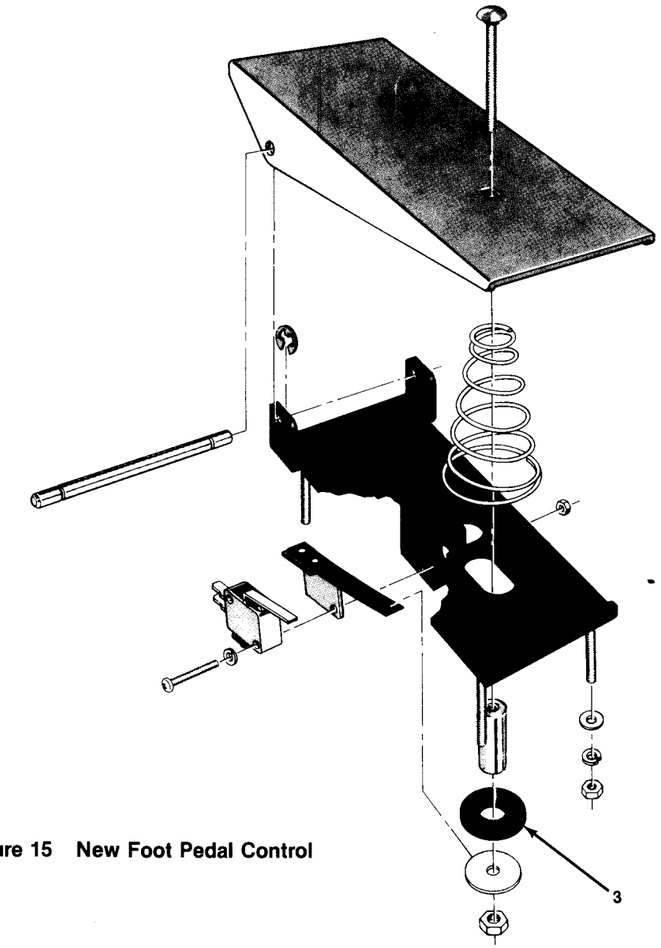

Figure 15 New Foot Pedal Control

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5. Steering Wheel Assembly

The steering assembly is basically trouble-free. However, it does require periodic cleaning and lubrication with a light silicone grease. Apply this lubricant to the steering shaft and bearings.

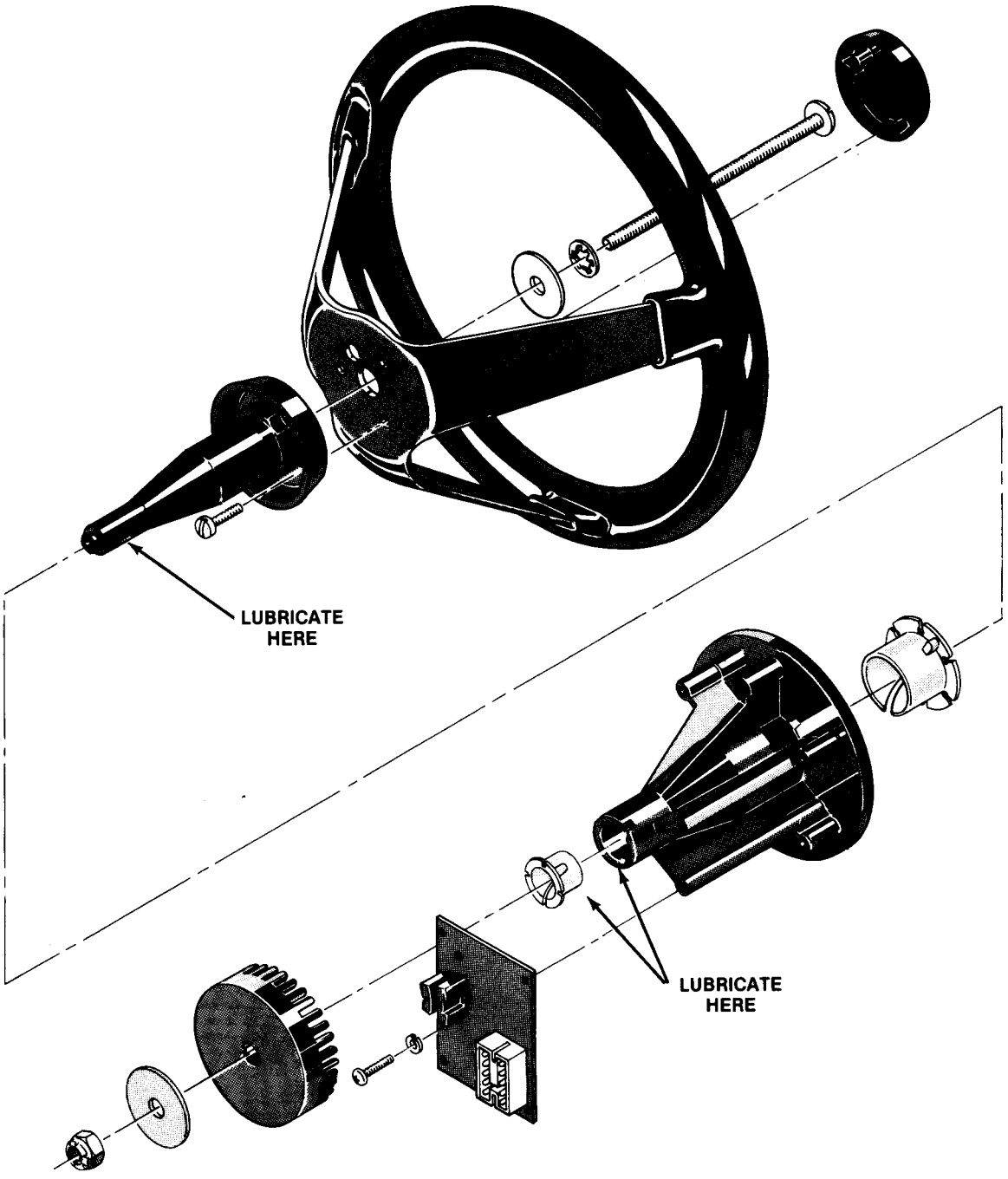

Figure 16 Steering Wheel Assembly

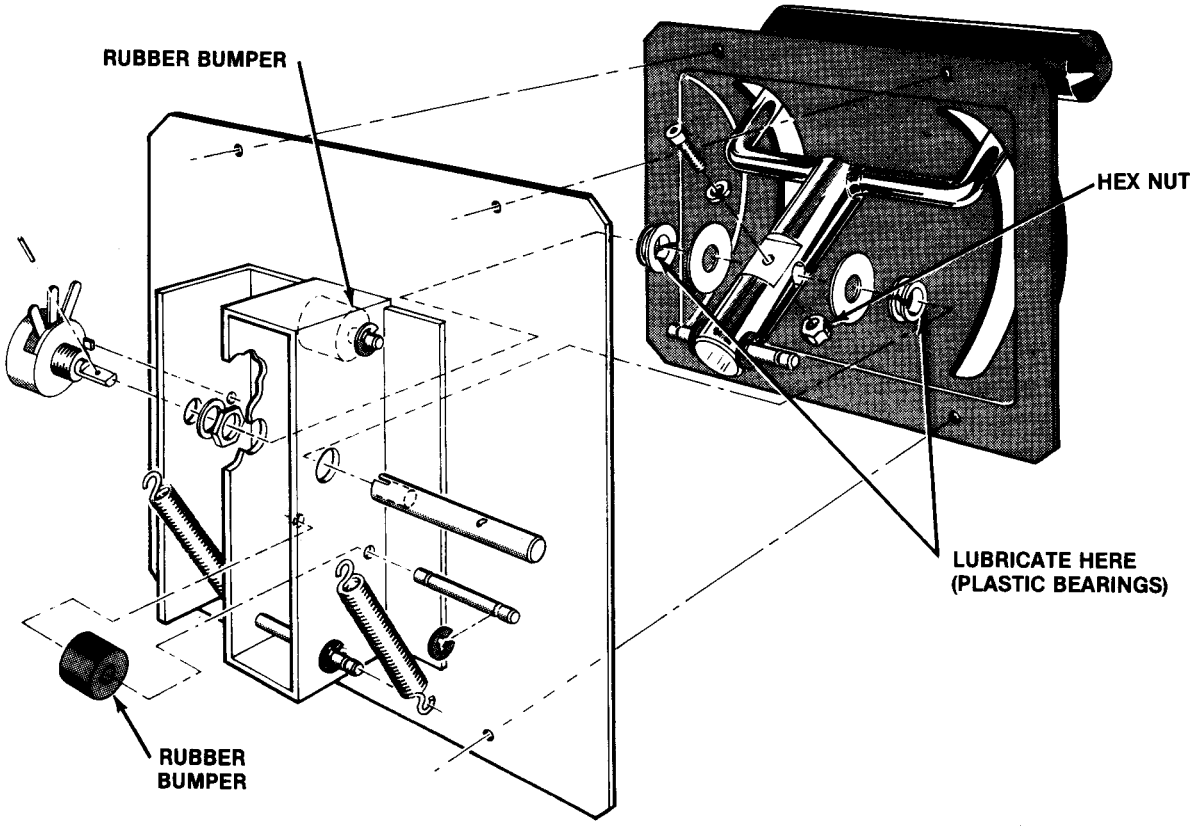

Figure 17 Thrust Control Assembly

6. Thrust Control Assembly

This assembly was first used in the Lunar Lander™ game, and has proved to be very reliable. It requires only periodic lubrication with a light silicone grease.

Apply this grease to the plastic bearings. Also check that the rubber bumpers have not been damaged. When assembling this unit, apply a drop of Loctite® to the hex nut. This will keep the nut from vibrating loose. As an alternative, you can replace it with a self-locking type of nut.

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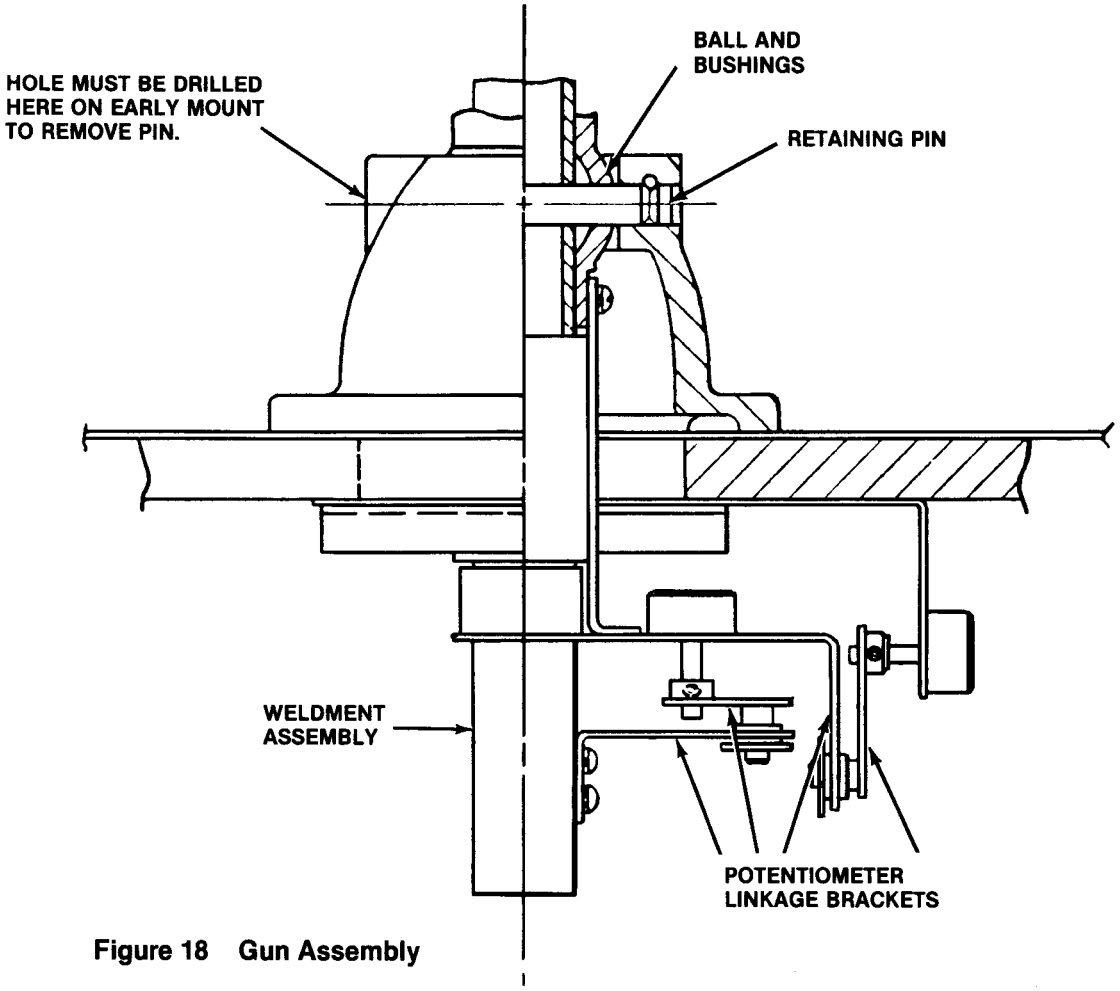

Figure 18 Gun Assembly

7. Gun Assembly, Flight Control Assembly

This assembly was used as a flight control in Starship 1™ and Sky Raider™, and as a gun in Triple Hunt™. The control requires periodic inspection and lubrication to extend its useful life.

Its weak point is the retaining pin (see Figures 18 and 19). When this pin wears, it allows the potentiometer linkage brackets to overtravel, causing them to deform. This bending will eventually cause control failure.

To replace this pin on early models, the gun mount must be drilled on one side. This will provide access for using a punch to remove the retaining pin.

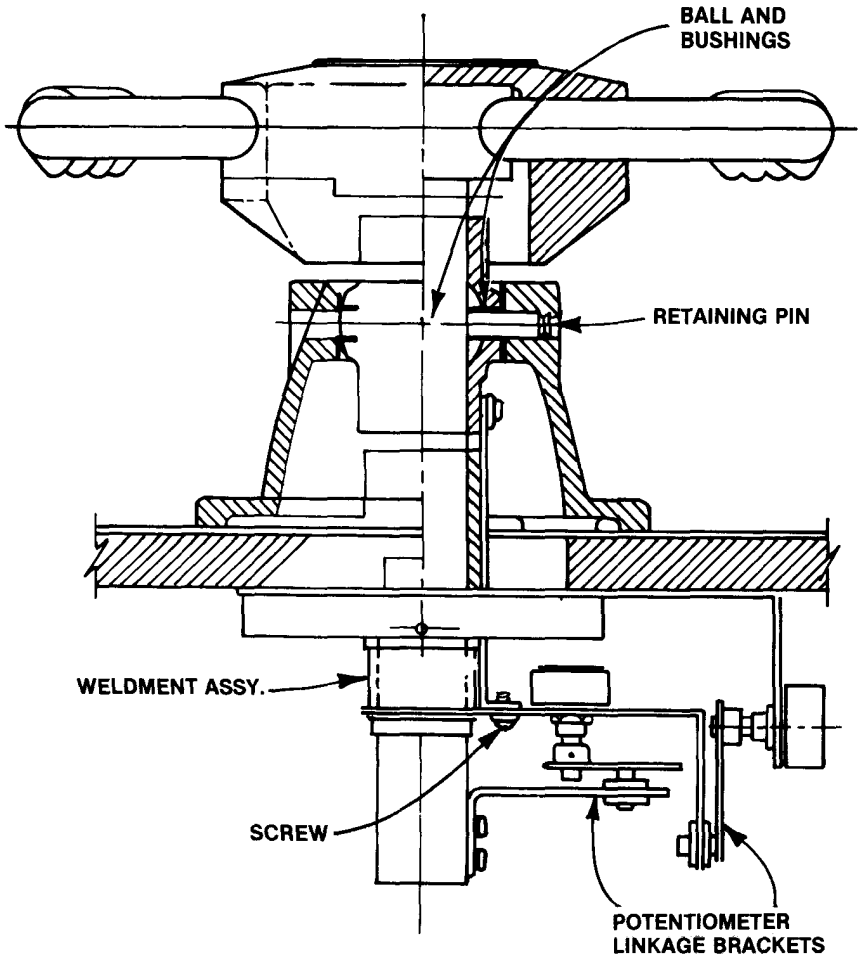

Figure 19 Flight Control Assembly

Inspect the weldment assembly near the oval retaining-pin hole. Should this hole become enlarged, it, too, can cause the potentiometer linkage brackets to distort and break.

When you reassemble this control, you should lubricate the retaining pin, the weldment assembly, and the ball and bushing assembly with a light silicone grease. Also be sure to use hardened screws to mount all potentiometer linkage brackets. Use Loctite to eliminate loosening due to vibration.

To replace the pushbutton fire control, first remove the hand grip. (This will destroy the grip, since a permanent glue was used to mount the hand grip.) Then remove the set screw. While you are doing this, you can also prevent future problems by inspecting the fire button harness for insulation wear. The most likely point of wear is near the retaining-pin hole.

When replacing potentiometers or linkage arms, tighten the screw only after you are sure that the linkages will move freely from one extreme to the other.

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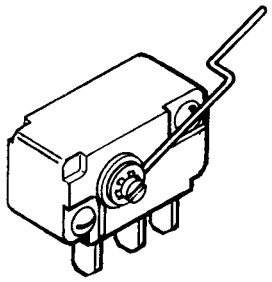
I. Electrical Hardware

1. Switches

Two types of switches are used in electronic games—microswitches and open-leaf or open-blade switches. These are quite different in their design and function, and we will discuss them separately below.



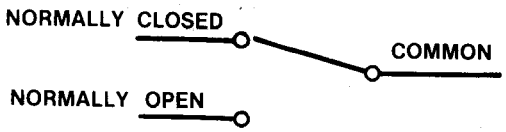


Figure 20 Microswitch

Microswitches: These usually don't need any adjustment. In applications such as end-of-stroke switches and motor stops where adjustment is necessary, you should note that they have a snap action. This means the switch actuator must travel some predetermined distance before it clicks on. Also, before it clicks off, it must travel a proportional distance.

Mechanically, this type is superior to an open-leaf switch because it is enclosed and will usually need much less service. However, it also has some limitations. The range of adjustment is limited by its snap action. This can reduce the feel of a pinball or similar game, that would need some switches set to very close tolerances.

The top illustration shows a typical microswitch; just below it is its schematic symbol. This symbol is always drawn in its normal position in the game—before it is activated by the player. A pushbutton-type microswitch uses the same symbol as the lever-actuated switch.

Open-Blade Switches: The second type of switch is widely used in the game industry. The major advantage of this type is its wide range of possible adjustments and its lack of snap action. In addition, the contacts are easily cleaned, making it more serviceable in most applications.

Adjustment of these switches requires only that the contacts wipe or rub against each other to keep them clean. When you adjust these switches, ***take care to never put a sharp bend in the blades.*** The switch blades should be radiused or gently curved to maintain adjustment. A sharp bend or kink in the spring blades will cause the switch to fall out of adjustment much more frequently.

To be self-cleaning, when this type of switch is used, the actuating blade must rock the contact back and forth. In other words, the contacts must move out of alignment or rub against each other (refer to Figure 21 below).

On switches with gold-plated contacts, you should ***never use*** a rough cleaning tool such as a file or burnisher: this will remove the gold plating, and ruin the conductive surface. Instead, use a clean business card or something similar to clean the gold contacts.

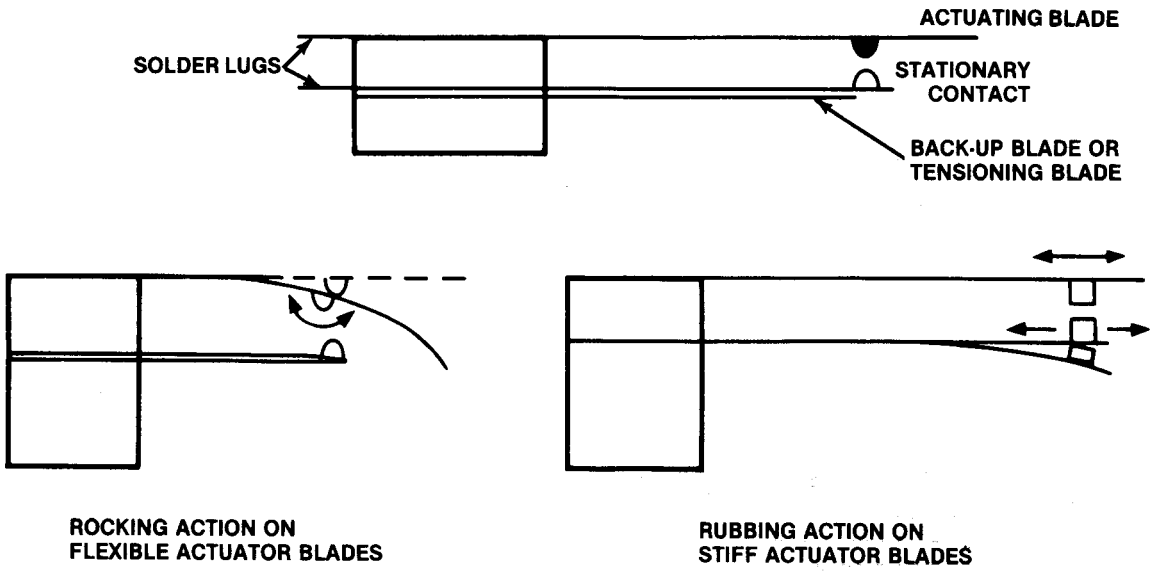


Figure 21 Proper Functioning of Open-Blade Switches

2. Transformers

Transformers are used in games to lower the AC line voltage from 115 or 220 VAC to some lower voltage such as 16.5 or 25 VAC. The schematic symbol for this part is shown to the right.

Transformers in electronic games are normally very reliable. When properly fused, they should last indefinitely. If you make voltage tests on transformers, measure across the winding, not in reference to ground.

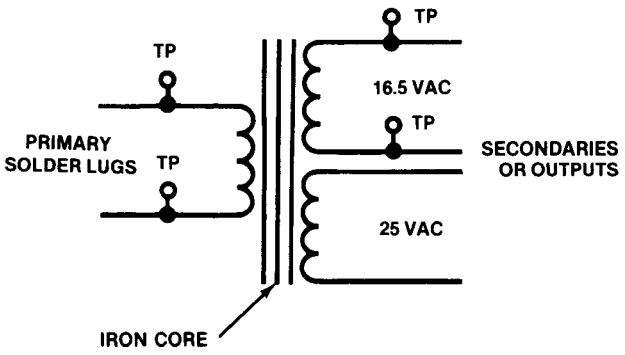


Figure 22 Schematic Diagram of a Transformer

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3. Potentiometers

A potentiometer or "pot" is nothing more than an adjustable resistor. You should note that this type of part will not always look the same. Normally they have three legs or solder lugs. In most cases, the two outside legs are connected as shown below, and the wiper is in the center.

In some cases, the wiper may be moved over to one side instead of in the center, as shown below. When this occurs, the pot will always be marked to indicate this change from the norm. For more information on potentiometers refer to *Chapter 4, Section B-2 Variable Resistors.*

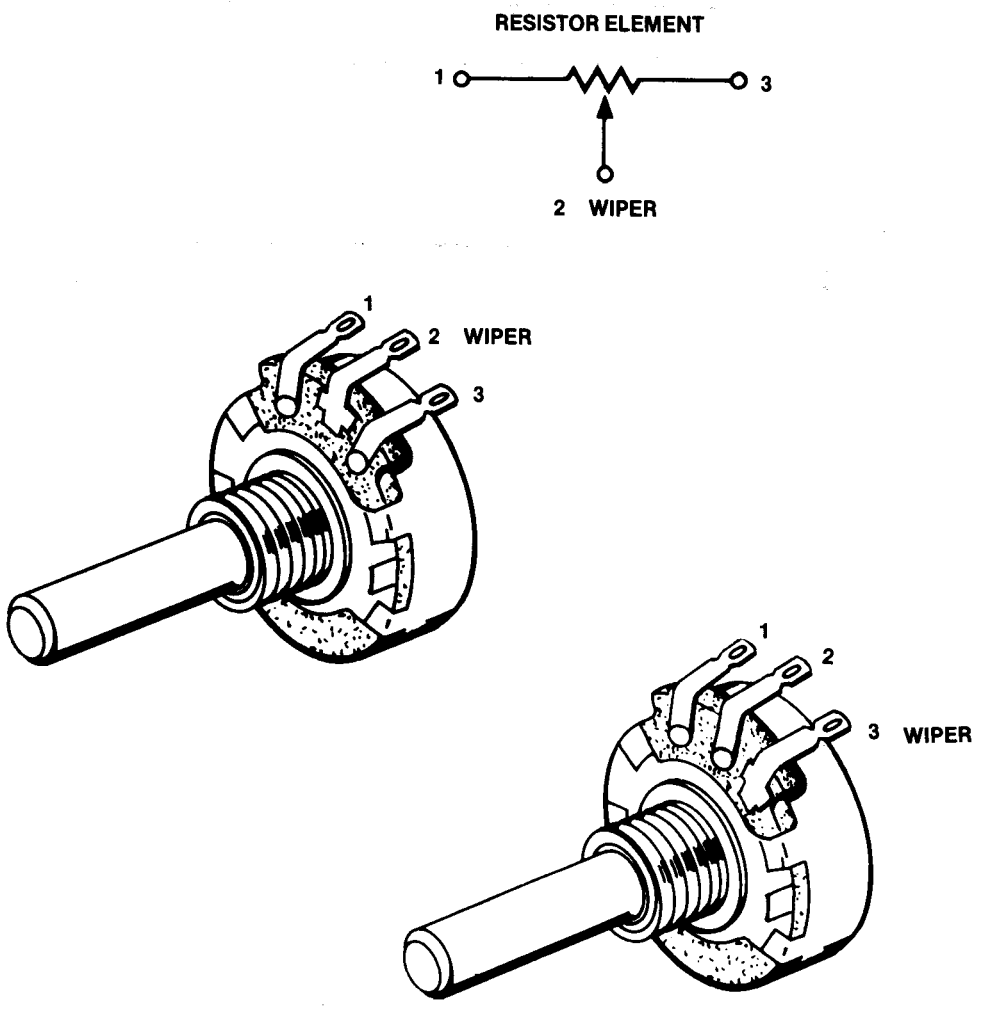
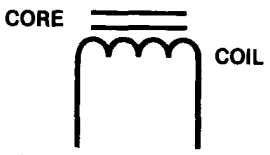


Figure 23 Potentiometers

4. Solenoids

Solenoids are coils of wire used as electromagnets. You will find them in relays and parts where very simple motions occur. Flipper mechanisms or coin counters, for example, need only momentary motion—which can be provided by a coil or solenoid.



The example above shows a solenoid with an iron core such as those in relay assemblies. A flipper solenoid, however, will ***not*** have the iron core, and is represented by the symbol below.

When a coil is turned on and off by a driver transistor, you will usually find a damping diode across the coil to suppress any large voltage spikes. (These are generated when the coil turns off.) The cathode end of the diode—the end with the band—always goes towards the positive supply voltage, as shown in Figure 24.

In some cases, solenoids will have more than one winding. Such an arrangement usually has a heavy wire used in the power or start winding, and a fine wire in the hold or high-resistance winding. This type of coil is almost always used in flipper circuits because players tend to capture the ball and hold the flipper assembly on. The fine wire provides current limiting, in order to prevent the coil from overheating and burning up.

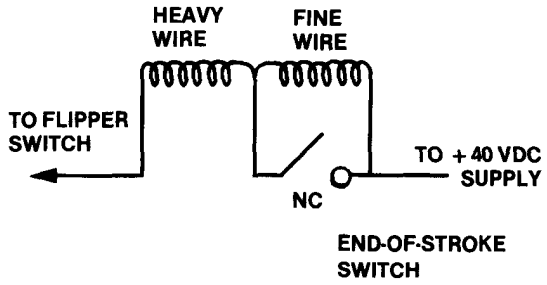


Figure 25 Double-Wound Solenoid

Flipper coils will almost always have end-of-stroke switches: these take over the function of the fine windings until the coil is turned on. At the end of the flipper stroke this switch is opened, increasing the resistance of the coil. This resistance, in turn, limits the current flowing in the circuit.

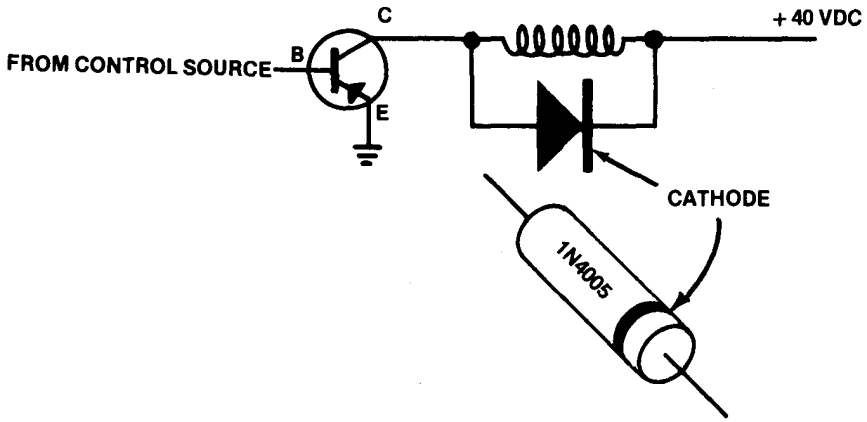


Figure 24 Diode Arrangement Across a Solenoid

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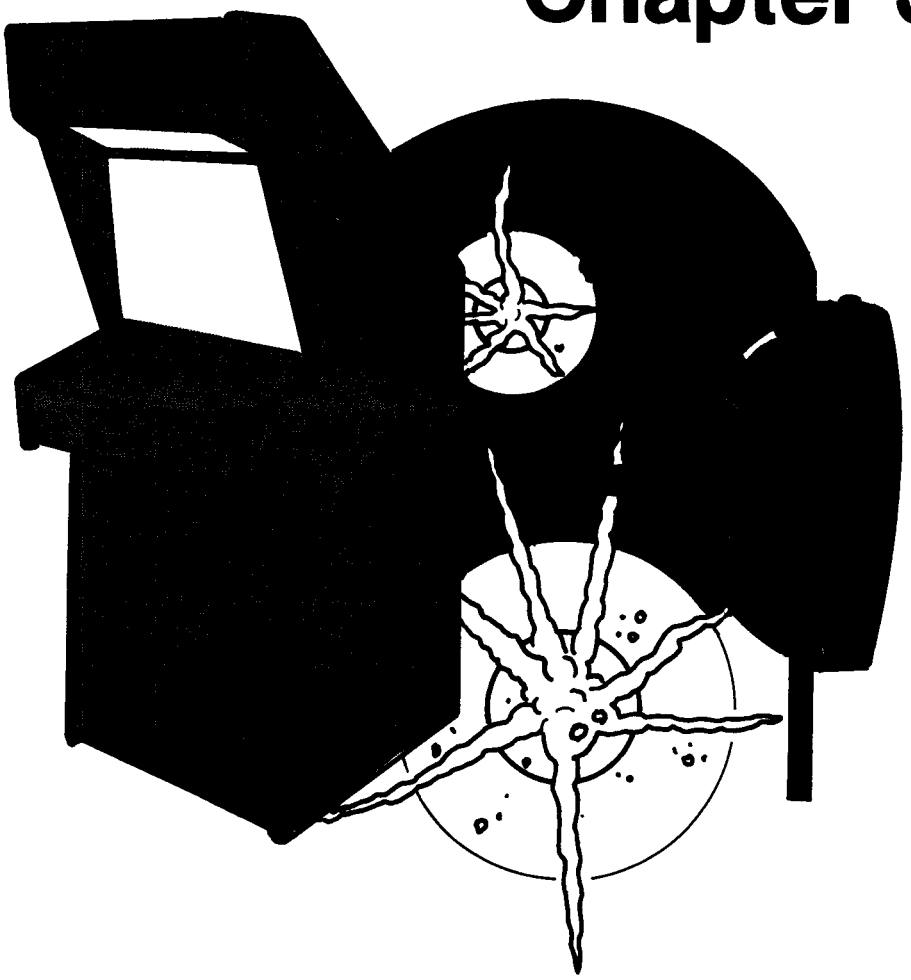
Chapter 3



Monitors

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Virtually all timing relationships between the many computer-generated events that occur in a game are engineered to be compatible with the monitor's operation. Because of this, you should have some understanding of the relationship between the game PCB's various sync signals and the movements of the monitor's electron beam.

A. Types of Monitors

1. Raster-Scan Monitors

Some video-game monitors and all TV receivers use the ***raster-scan*** display method. The electron beam in this type of monitor scans the inside of the cathode-ray tube (CRT) in an endlessly repeated pattern or ***raster***. The monitor creates images by ***modulating*** or ***intensifying*** the beam when it has reached the correct point.

Depending on the degree of modulation, the beam illuminates points with differing intensity. In other words, the greater the amplitude of the incoming video signal, the more powerful the electron beam becomes. As a result, certain areas of the phosphor glow more intensely.

The beam could be turned off so the screen would be totally dark, or the beam could be various medium shades, up to a bright shade. The various shades (usually white, grey and black) of information superimposed on the raster are called the ***video.***

The type of phosphor used in the monitor is chosen for its color (green or white) and its degree of ***persistence.*** Persistence is the phenomenon that causes the screen image to linger for a moment, even after the electron beam has moved on to a new point.

If a very bright image is displayed on the same place on the CRT for a long time (say several months), the phosphor in that area may become permanently burned. On a monitor with no power applied, you can identify a phosphor burn as a beige-brown area. This burned area will probably not be visible when the monitor is turned on and displaying an image. Replace the CRT only if the phosphor burn becomes objectionable.

How a Screen Image is Generated: Figure 1 shows a simplified illustration of the non-interlaced raster. In this case, the electron beam begins creating the picture in the upper left corner of the CRT and sweeps out one horizontal line, ending at the right side. The beam is then repositioned back to the left side by a process called ***horizontal retrace.***

During retrace, the electron beam is ***blanked out*** so no undesired illumination can occur. Retrace blanking is an internal function of the monitor and is not related to blanking signals produced by the game computer, except that

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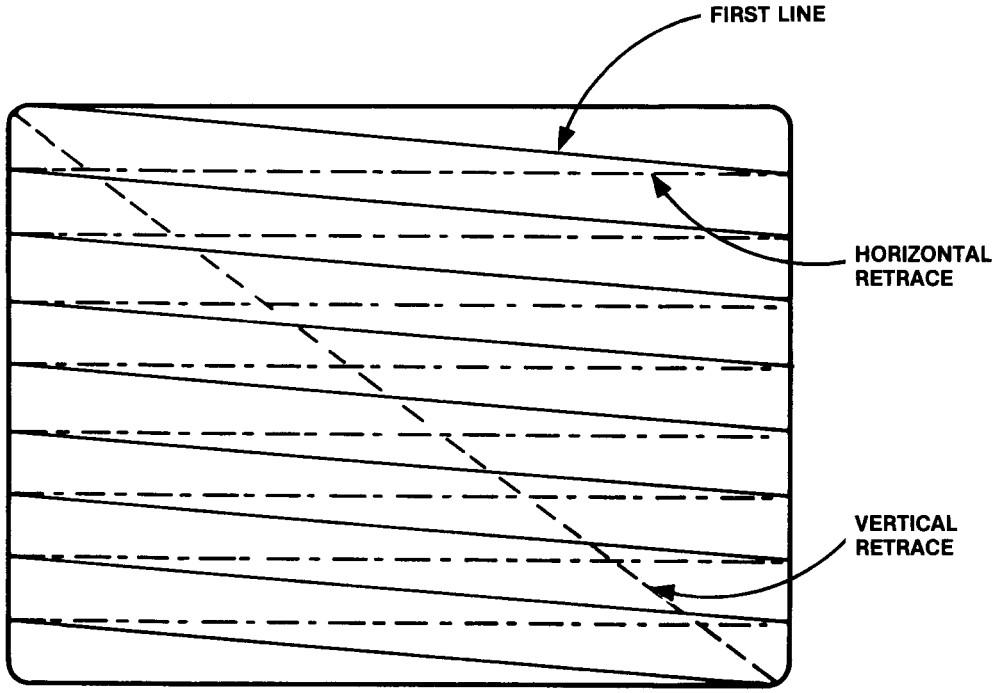

Figure 1 Non-Interlaced Raster Scan

both occur simultaneously. The computer signals H BLANKING and V BLANKING are used in developing sync signals; they also load new information into the motion-circuit counters.

After the electron beam has been reset to the left side again, it sweeps the second horizontal line, as shown in Figure 1. Since the beam is deflected vertically as well as horizontally, the second line appears beneath the first. The beam continues to scan in this fashion until the end of the last line, located in the lower right corner of the CRT.

At this point, both a horizontal and vertical sync pulse occur, and the electron beam is reset back to the left top corner of the CRT—where the beam began. This reset process is called ***vertical retrace***, and the electron beam is blanked out during this time.

Each time the electron beam has scanned the entire CRT, it has completed one full ***field*** which contains 256 horizontal lines. In the non-interlaced raster, successive fields are laid out almost on top of each other. Two complete fields constitute one ***frame***, and 30 frames are created per second.

When a monitor is not receiving incoming sync signals from the game PCB, it operates in the ***free-running mode.*** In this case, it simply generates a raster not timed with the operation of any other device. When connected to a video-game computer, it locks onto the sync signals and is therefore ***synchronized*** with the operation of that computer.

The PCB sync signals are precisely timed, so that the electron beam in the monitor begins each ***line*** when an H SYNC pulse occurs. The ***frame*** begins with a V SYNC pulse.

Defining CRT Locations: A monitor generates a raster that contains 256 horizontal lines, and the game-PCB signals can illuminate up to 320 separate points to form an image. In order to illuminate a desired point, that point must be described so the electron beam is intensified exactly as it reaches the desired horizontal and vertical position. This is done by assigning a set of coordinates to each separate point.

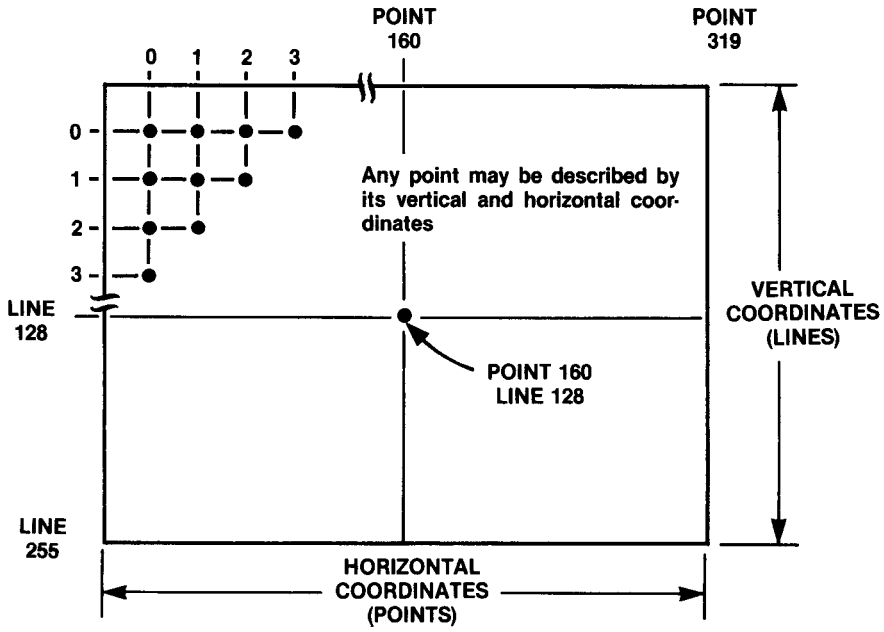

Figure 2 CRT Locations

The terminology used in this coordinate system is shown in Figure 2. Notice that each raster line has a ***vertical*** position on the screen. The first line (where the beam starts) is called line 0. Moving to the bottom, each line increases by one digit, with the last line numbered as 255.

Each horizontal coordinate also is assigned a number. The first point occurs in the upper left corner of the CRT and is called point 0. The point to its right is point 1, the third is point 2, etc., until the end of the line at point 319.

Thus, any location on the CRT can be described as the intersection of some line and point (refer again to Figure 2). The combination of the vertical and horizontal address produces a set of coordinates to identify every point on the raster. For example, to illuminate a point approximately in the middle of the CRT, you would need to intensify the electron beam as it reaches the intersection of line 128 and point 160.

You can visualize the CRT as a rectangle bounded on the top and bottom by lines 0 and 255; the sides are bounded by points 0 and 319. Since points and lines are spaced approximately equidistant, a shape 4 by 4 will be about square.

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2. Quadrascan™ X-Y Monitors

The new generation of games uses a video display monitor commonly know as the ***X-Y monitor.*** Instead of scanning across many raster lines, this type of monitor uses ***vector generation*** to create images on the screen. Atari uses 15- and 19-inch black-and-white X-Y monitors, depending on the size of the game cabinet.

The advantages of X-Y monitors over raster-scan are several: they allow game designers to produce a more detailed picture, draw lines at any angle, and display more moving objects on the screen. Also, the monitor has greater contrast.

The only disadvantage (and a minor one, at that) is the inability to "fill in" areas with a solid color, as raster-scan monitors can do. Only outlines can be drawn.

Vector generation works on a simple geometric principle. The X and Y coordinate system (two-dimensional grid pattern) is "laid out" on the screen, and the dot at the center of the grid becomes the center of the screen. From this center point the dot moves outwards, drawing lines at any angle, including horizontally and vertically. These lines are called ***vectors.***

With the X-Y monitor comes some new terminology. You may be familiar with raster-scan terms such as ***vertical, horizontal*** and ***video***. You can set up loose relationships between both types of monitors as follows:

Horizontal—X axis
Vertical—Y axis
Video—Z

These relationships are shown in Figure 3. Note that all movements of the dot start at the center of the screen. This is the "zero" condition, when both input voltages to the X and Y amplifiers are zero.

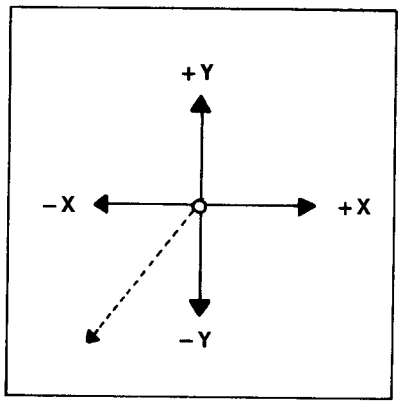

Figure 3 X-Y System of Display

If the Y input voltage to the Y amplifier is gradually increased from zero volts to +7, the dot will move straight towards the top of the screen as indicated by the +Y arrow.

Conversely, if the Y input voltage is gradually increased from 0 volts to -7 volts, the dot will gradually move straight towards the bottom of the screen, as indicated by the -Y arrow.

The movement of the dot in the X axis is to the right for positive voltage, and to the left for a negative voltage input. If ***both X and Y input voltages*** are increased from 0 to -7 volts, the dot will move in the direction indicated by the dashed line.

B. Adjustments

The raster monitor is adjusted like any normal TV set. The adjustable controls are listed below.

1. Brightness

Brightness is adjusted ***before*** contrast. Adjust so that the CRT background is the desired intensity.

2. Contrast

Adjust so that the images are as bright and clear as possible against the pre-adjusted background.

3. Vertical Hold

Adjust only if the picture appears to be rolling up or down on the CRT. Adjust for a stable, centered picture.

4. Vertical Height

The vertical height and vertical linearity adjustments (below) are interactive. The vertical height adjustment changes the vertical dimension of the picture. Adjust for optimum picture size.

5. Vertical Linearity

Change this adjustment only if the top of the picture seems compressed. If the game is a paddle game, adjust the linearity so the paddle remains the same size throughout its vertical travel.

If the game does not use paddles, use some other image to establish if the top of picture is being compresssed. If adjusting the linearity adversely affects vertical size, repeat Steps 4 and 5.

6. Yoke

Generally speaking, do not touch the yoke adjustment unless you are a **qualified TV repair technician!** The yoke should never require adjustment unless the monitor has been installed in a different type of game or the adjustment magnets have been tampered with.

In either case, the entire picture appears to be offset, and normal adjusting does not restore it to its proper position. The two yoke adjusters are located on neck of the monitor, and they affect the vertical and horizontal deflection of the electron beam.

If yoke adjustment is necessary, follow the instructions given in the appropriate monitor manual.

7. Brightness and Contrast on X-Y Monitors

Turn brightness and contrast all the way down. Then increase brightness until the images are barely visible. Adjust ***contrast*** for proper illumination.

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C. Monitor Repair

Troubleshooting a monitor is ***not*** a matter of thorough knowledge of the monitor circuitry. The big step in the troubleshooting process is to be able to identify the problem and then to proceed to the proper malfunctioning circuit.

In some cases, such as a black screen, the malfunctioning circuit is unknown. Then the procedure is to start with the most common circuit. By process of elimination, you can locate the defective circuit.

The purpose of this section is to help you identify the symptom, guide you to the malfunctioning circuit, and then list the probable faulty components. This should eliminate most of the guessing and reduce troubleshooting time.

1. Raster-Scan

Each picture will have its own failure symptoms. We define the most common symptoms as follows:

Vertical collapse looks like a narrow (horizontal) raster line running from left to right. This is caused by no vertical motion.

Vertical roll is an unstable picture that moves up or down the screen, somewhat like a filmstrip.

Horizontal tear looks like a picture that is diagonally torn in several places.

Horizontal collapse appears as a narrow (vertical) raster line running from top to bottom of the screen.

Retrace lines are four to eight thin white video lines running diagonally across the screen.

The long table that follows in Figure 4 covers symptoms seen on the picture tube, lists probable faulty circuits, and shows suspected faulty components.

When two symptoms appear at the same time on the screen, you can use the tables to pinpoint the circuit. For example, a monitor may show both a horizontal tear and a vertical roll. Looking at the tables, the only circuit listed under both problems is the ***sync separator.***

Figure 4 Black-and-White Raster-Scan Monitor Troubleshooting

Symptom/Problem:	Check this Component			
	Motorola XM501/701	Motorola XM5000/7000	TEC Videoelectronics	Wells-Gardner
Horizontal Tear				
A. Sync Separator Circuit				
1. Separator transistor	Q5	Q10	Q301	Q206
2. Amplifier transistor	Q1	Q11	Q400	Q201
3. Shorted diode	D23		D201	
4. Phase diodes open or shorted	D7	D5, 6	D401, 402	D205
5. Shorted capacitors	C2			C201
B. Feedback Separator Circuit				
1. Capacitors open or shorted	C15, 32	C12, 14	C402, 415	C207, 210
2. Resistor open	R45	R24	R408	R216
Black Screen—Fuse Blown				
A. Horizontal Output Stage				
1. Output transistor shorted	Q9	Q9	Q403	Q103
2. Damper diode shorted	D1	D7	D403	D106
3. Limiter diode shorted	D2	D8	D801	D206
4. High-voltage diode defective	D4	D11	D404	D105
5. High-voltage transformer defective	T2	T2	T403	T102

Symptom/Problem:	Check this Component Motorola XM501/701	Motorola XM5000/7000	TEC Videoelectronics	Wells-Gardner
B. Low-Voltage Power Supply				
1. Bridge diode(s) shorted	D9-12	D16-19	D901-904	D101-104
2. Power transformer internal short	T4	T3	T901	T101
Black Screen—Fuse OK				
A. Horizontal Output Circuit				
1. Output transistor open	Q9	Q9	Q403	Q103
2. High-voltage transformer open	T2	T2	T403	T102
3. High-voltage diode open	D4	D11	D404	D105
4. Open B+ resistor		R43	R420	
B. Horizontal Driver Circuit				
1. Transformer open	T1	T1	T402	T201
2. Driver transistor open or shorted	Q8	Q8	Q402	Q209
C. Pulse Shaper Circuit				
1. Shaper transistor open or shorted	Q7	Q7		Q208
D. Horizontal Oscillator Circuit				
1. Oscillator transistor open or shorted	Q6	Q6	Q401	Q207
2. Transformer defective	L1	L1	T401	L201
3. Capacitors open	C18, 19	C18, 19	C408, 409	C213, 214
E. CRT and Socket				
1. Spark gap shorted	Pin 2	Pin 2	Pin 6	Pin 2
2. Socket wire open	Pin 2	Pin 2	Pin 6	Pin 2
Low-Voltage Power Supply Too Low				
A. Reference Amplifier				
1. Reference zener low	D6	D20	D906	ZD201
2. Reference transistor shorted	Q15	IC1, Q19	Q903	Q204
B. Series Pass Amplifier				
1. Driver transistor open	Q14	Q18	Q902	Q102
2. Series pass transistor open	Q16	Q17	Q901	Q101
Low-Voltage Power Supply Too High				
A. Reference Amplifier				
1. Reference zener open	D6	D20	D906	ZD201
2. Reference transistor open or leaky	Q15	IC1, Q19	Q903	Q204
B. Series Pass Amplifier				
1. Driver transistor shorted	Q14	Q18	Q902	Q102
2. Series pass transistor shorted	Q16	Q17	Q901	Q101
Raster Cannot be Turned Off, Retrace Lines				
A. Low Video Output Stage Power-Supply Voltage				
1. Diode breakdown too low	D5	D10	D207	D107
2. Capacitor open	C43D	C23D	C220	C101D
B. Video Output Circuit				
1. Video output transistor leaky	Q3	Q5	Q202	Q203
2. Video driver transistor leaky	Q4	Q4	—	Q205
3. Blanking diode leaky	—	—	D204	—
C. CRT Socket				
1. Spark gap shorted	Pin 7 in socket	Pin 7 in socket	Pin 7 Z801	Pin 7 in socket
2. Open brightness control	R21			R121
3. No voltage to brightness control	R21			R121
D. Spot Killer				
1. Transistor short	Q21			

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Symptom/Problem:	Check this Component Motorola XM501/701	Motorola XM5000/7000	TEC Videoelectronics	Wells-Gardner
No Video or Distorted Video, Raster OK				
A. Video Output Circuit				
1. Video output transistor has low gain	Q3	Q5	Q202	Q203
2. Video driver transistor has low gain	Q4	Q4	—	Q205
3. Coupling capacitor shorted or open	—	—	C208	—
4. Bypass capacitor open or shorted	C6	C5	C207	C204
5. Zener diode open or shorted	—	C1, D3	—	—
B. Amplifier Circuit				
1. Video transistor defective	Q2	Q2, 3	Q201	Q202
2. Compensation diodes shorted or open	D8, 13	—	—	D202, 203
3. Coupling capacitors open or shorted	C4	C3, 4	C203, 205	C221
4. Contrast pot open	R5	R6	R211	R116
C. Video Input Circuit				
1. Video input transistor defective	Q1	Q1	Q200	Q201
2. Input coupling capacitor open or shorted	C1	C1	C201	C202
No Raster—Video Visible				
CRT Circuit				
1. Brightness control open		R73	R803	
2. Spark gap shorted or open lead		Pin 2	Z802	
3. No voltage to the brightness control		R73	R803	
Vertical Roll				
A. Sync Integrator Circuit				
1. Sync integrator transistor(s)		Q12, 13		
2. Integrator capacitors short or open	C34, 35	C34, 35	C306, 307	C226, 227
B. Sync Separator Circuit				
1. Sync separator transistor(s)	Q5	Q10, 11	Q301	Q206
C. Input Video Circuit				
1. Voltage transient diode shorted	D23			D201
2. Bypass capacitor shorted or open	C2			C201
D. Vertical Oscillator Circuit				
1. Vertical oscillator transistor(s)	Q10, 11	D12	Q302	Q210, 217
2. Ramp capacitors	C37, 38	C37, 38	C313, 314	C231
Horizontal Collapse				
Horizontal Yoke Circuit				
1. Coupling capacitor open	C29	C25	C418	C105
2. Linearity coil open	L3	L3	L406	L202
3. Width coil open	L4	L2	L405	L101
4. Yoke open	L5	L4A	L401	Not designated on schematic
Vertical Collapse				
A. Vertical Output Circuit				
1. Vertical output transistor(s)	Q13	Q15	Q304, 305	Q215, 216
2. Coupling capacitor open		C40	C317	C234
3. Output transformer open	T3	—	—	—
4. Choke open	—	L5	—	—
5. Yoke open	L5	L4B	L401	Not designated on schematic
B. Vertical Driver Circuit				
1. Driver transistor(s) open or leaky	Q12	Q14	Q303	Q211, 212, 213, 214

Symptom/Problem:	Check this Component Motorola XM501/701	Motorola XM5000/7000	TEC Videoelectronics	Wells-Gardner
C. Vertical Oscillator Circuit				
1. Oscillator transistor(s) open or leaky	Q10, 11	D12	Q302	Q210, 217
2. Ramp capacitor(s) open or shorted	C37, 38	C37, 38	C313	C231
3. Height control open	R65	R60	R321	R256
4. Vertical hold control open	R82	None	R319	R108
D. Vertical Power Supply is Low or High				
1. Shorted capacitor(s)	C33, 36	—	C419	—
2. Zener open or shorted	—	D21	—	—
3. Diode open or shorted	—	D23	D203	—
4. Resistor(s) open	R50, 55, 56	R95	R421	—

2. Quadrascan™ X-Y

Figure 3 (shown earlier in this chapter) shows the X-Y display system with its two axes. To simplify troubleshooting, you can divide the monitor screen into four quadrants, divided exactly along the axes (see Figure 5).

Figure 6 shows examples of four separate symptoms. To determine where the problem lies, first determine what is present, then what is missing. Use Figure 5 as a guide.

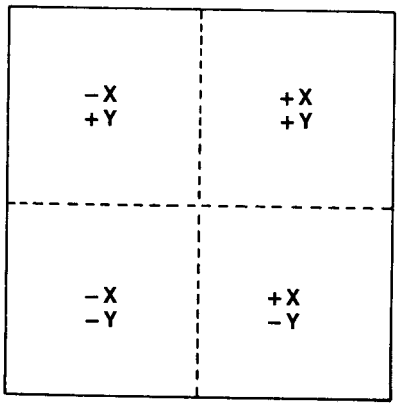
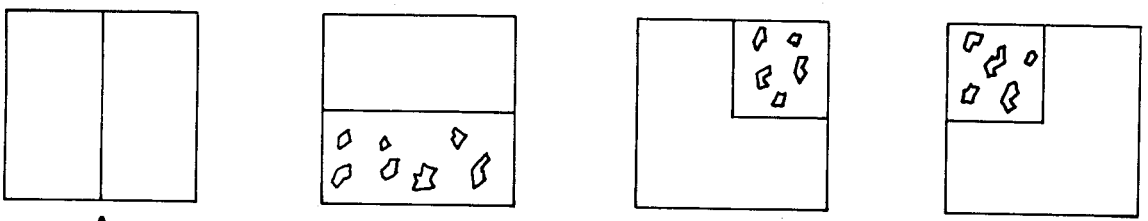


Figure 5 Quadrants in X-Y Display System



Symptom	Present	Missing	Probable Cause
A Thin line	+Y, −Y	+X, −X	X amplifier
B One-half picture	+X, −X, −Y	+Y	Y amplifier
C One-quarter picture	+Y, +X	−X, −Y	X or Y amplifier or −25V power supply
D One-quarter picture	*(You figure out this one)*		

Figure 6 Examples of Four Problems in X-Y Monitors

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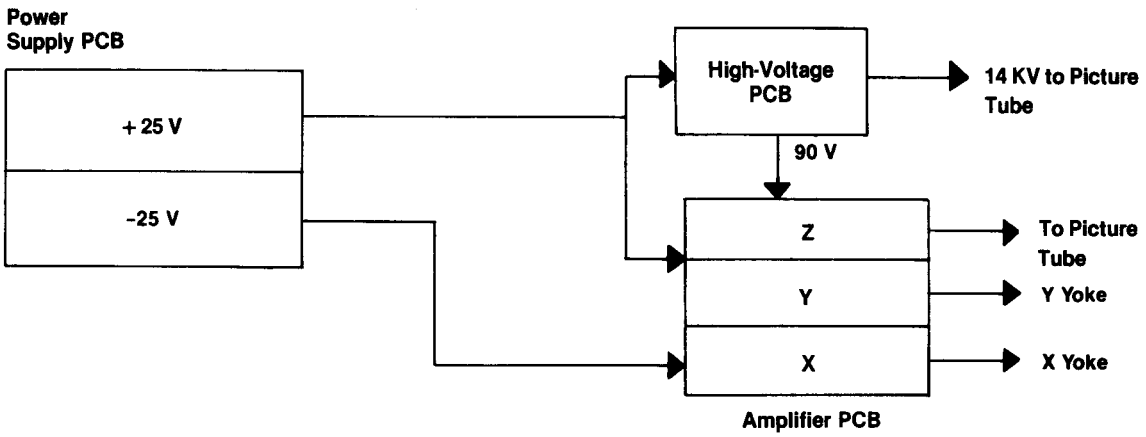

Figure 7 X-Y Monitor Circuit Boards

The Quadrascan monitor consists of three circuit boards (see Figure 7). The ***power supply board***, located on the bottom of the frame, supplies the ±25 V for the other two boards. The ***high-voltage board***, located inside the cage on the left panel, supplies all the high voltages needed for picture-tube operation. In addition, this board generates 90 V for the Z amplifier.

The ***amplifier board*** consists of three separate amplifiers. The X amplifier drives the X yoke windings, the Y amplifier drives the Y yoke, and the Z amplifier supplies blanking and brightness for the picture tube.

At the top of the amplifier board are four power transistors mounted on a large heat sink. The upper transistor closest to the picture tube is the −Y driver (2N3792). The transistor below it (2N3716) is the +Y driver.

The transistors closest to you are the X drivers. The top one is −X and the bottom transistor is the +X. You now have all the basic information necessary to begin repairing a Quadrascan monitor.

Voltages on X-Y Monitor: Ninety percent of the problems in an X-Y monitor can be diagnosed with three key voltage measurements. They are as follows:

1. +25 volts—Measure this voltage on the case of the +X driver transistor (type 2N3716).

2. −25 volts—Measure this voltage on the case of the −X driver transistor (type 2N3792). If one or both of these voltages are too low or high, proceed to the power-supply section.

3. +90 volts—Measure this voltage on the amplifier board, as follows. Locate the Z amplifier transistor (Q504) right above the brightness control. Place the meter lead on the tab (or nut holding down the tab) of the transistor. If the voltage is lower or higher than 90V, proceed to the high-voltage board section. If all voltage measurements are correct, proceed to the XYZ amplifier board.

Remember, always make these three measurements first! Troubleshooting the three boards down to the faulty component is explained in detail in Figure 8.

Figure 8 Black-and-White X-Y Monitor Troubleshooting

Power Supply Board

The following procedure is for the +25 volt power supply. Components in parentheses are for the −25 volt power supply. All voltage measurements are to the chassis.

Problem	Solution
Fuse 100 (101) open	• Check bridge rectifier DB100 for shorted diodes. • Check capacitor C100 (101) for short.
25V measures 40V	• Zener diode ZD100 (101) open.
25V is too low	• Measure the voltage on the emitter of the transistor Q100 (101). Should read 40V. If this voltage is 30V or less, capacitor C100 (101) is open or one diode in DB100 bridge rectifier is open. • Remove the two screws holding the transistor Q100 (101) to the heat sink. Measure the base voltage. If 27V, replace Q100 (101). If less than 27V, Zener diode ZD100 (101) is defective or capacitor C102 (103) is leaky.

High-Voltage Board

Remove the cover by removing the two screws on top of the cage.

Problem	Solution
Fuse open (F900)	• This may be a matter of adjustment. Locate the high-voltage adjustment pot R912 (next to Q901). Rotate it completely clockwise. Replace fuse and apply power. Place positive lead of meter on pin 5 (grey wire) of the harness input connector P900. Slowly turn the high-voltage adjustment until the meter reads 90V. If the fuse opens again, check the following components. Opens: ZD900, ZD901, and Q901. Shorts: Q900, Q902, Q903, and ZD903.
90V measures less than 80V	• Measure the voltage on the anode of the Zener diode ZD900 or the emitter of Q901. Should read 9V. If less, replace diode. • Locate resistor R901 near the top edge of the board between Q900 and Q901. This 1.2K ohm resistor stands up about a half inch off the board. Place positive voltmeter lead on the resistor lead closest to the edge of the board.

Voltage Reading	Probable Cause
9V	Q901 shorted
Less than 15V	ZD901 shorted, or Q900 or Q902 has low gain
25V	Open Q900, Q902, Q903, R906 or T900

• If all components are OK, the oscillator circuit (Q903) may be loaded down by a defective component in the secondary of T900. With an ohmmeter, check the following components for leakage: D903, C909, C906 and C907.
The other components D901, D902 and the doubler cannot be checked with an ohmmeter. Use the following procedure instead. **Note:** When working with the doubler, ***always*** make certain that the CRT anode is discharged to ground!
Unsolder the wire going from the high-voltage transformer to the terminal of the doubler. Apply power and measure the 90V (pin 5 of R900). If the 90V comes up, replace the doubler. To determine if D901 or D902 are loading down the oscillator, unsolder one end of the diode and note if the 90V actually measures 90V.

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"XYZ" Amplifier Board

Missing information can either be caused by the logic (game) PCB or the X-Y amplifier. The easiest approach is with an oscilloscope. However, a scope is generally not available on location. Follow the steps listed below to determine which is the faulty board. The Y measuring points are in parentheses.

Missing X (Y) Information

1. Set your voltmeter on "AC" and on the 10-volt scale.

2. Measure the voltage at pin 1 (2) of P703. The meter should read 4.5V ± 1V. If less than 3.5V or even zero, the game PCB is defective and the monitor is probably OK.

3. Measure the voltage at pin 2 (3) of P702. The meter should read 4.5V ± 1V. If zero, check for open fuse F700 (F600). This is a small pico fuse located near the side of P702. Replace with a 2-amp. fast-blow fuse.

If the fuse is OK and the voltage is low, check Q705, 706, 707 and 708 (Q605, 606, 607 and 608). You could swap the +X driver transistor Q708 with the +Y driver transistor Q608 to see if the problem follows the transistor. Similarly, the −X (Q707) and −Y (Q607) can be swapped.

Z Amplifier

Proper adjustment of the brightness and contrast controls is the same as for the raster-scan monitor.

1. Turn both brightness and contrast controls to minimum.

2. Turn up brightness until picture is barely visible.

3. Turn up contrast for desired picture.

Problems related to the Z amplifier are few. Remember! Make sure all power supplies are operating and that the filaments in the picture tube are glowing.

Problem	Solution
Black screen	• Turn up the brightness control. One of three symptoms will appear: no picture, a dot in the middle of picture, or interconnecting lines between objects. Proceed to troubleshoot, based on what appears:
No picture	• R515 or brightness control (R516) is open.
A dot	• If the red LED (D507) is on, proceed to X-Y amplifier procedure.
Interconnecting lines	• If the red LED (D507) is on, check the following components for shorts or open circuits: D504, D505, D506 and C510. • If the red LED is off: Q504 is open, Q503 is shorted, contrast control R526 is open or there is no Z input from the game PCB.

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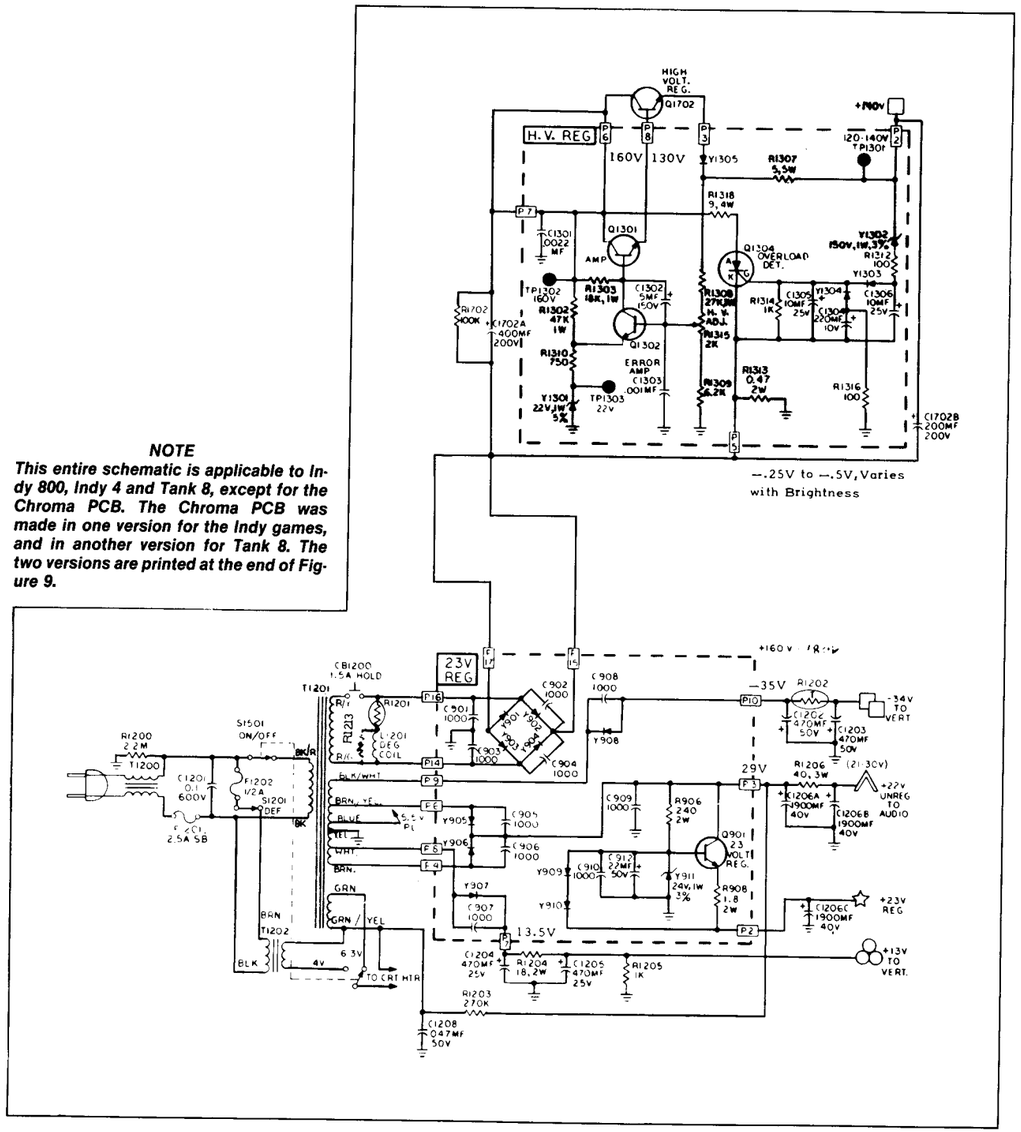
NOTE

This entire schematic is applicable to Indy 800, Indy 4 and Tank 8, except for the Chroma PCB. The Chroma PCB was made in one version for the Indy games, and in another version for Tank 8. The two versions are printed at the end of Figure 9.



Chroma PCB for Indy 800™ and Indy 4™ Game

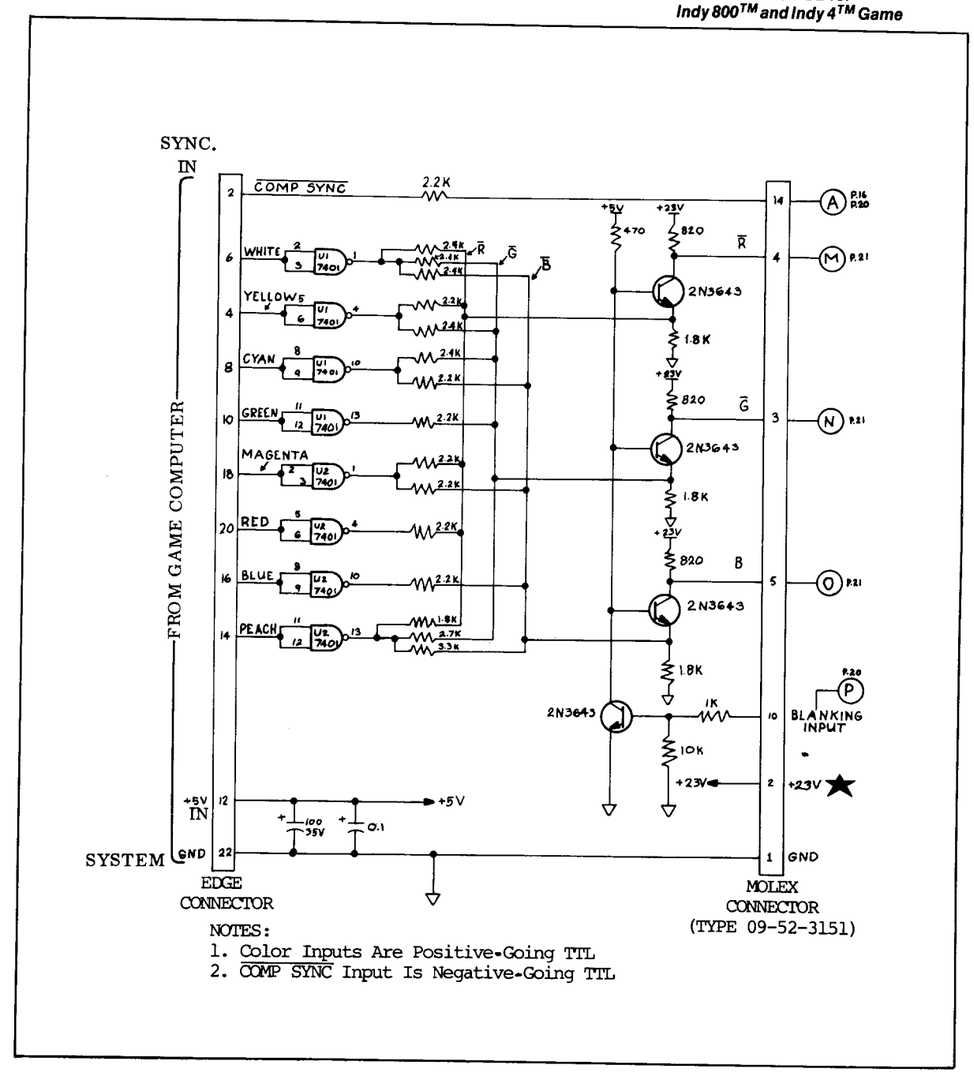


Figure 9 Schematic of G.E. Model 25MB 25-Inch Color Monitor, (as used in Indy 800™, Indy 4™ and Tank® 8)

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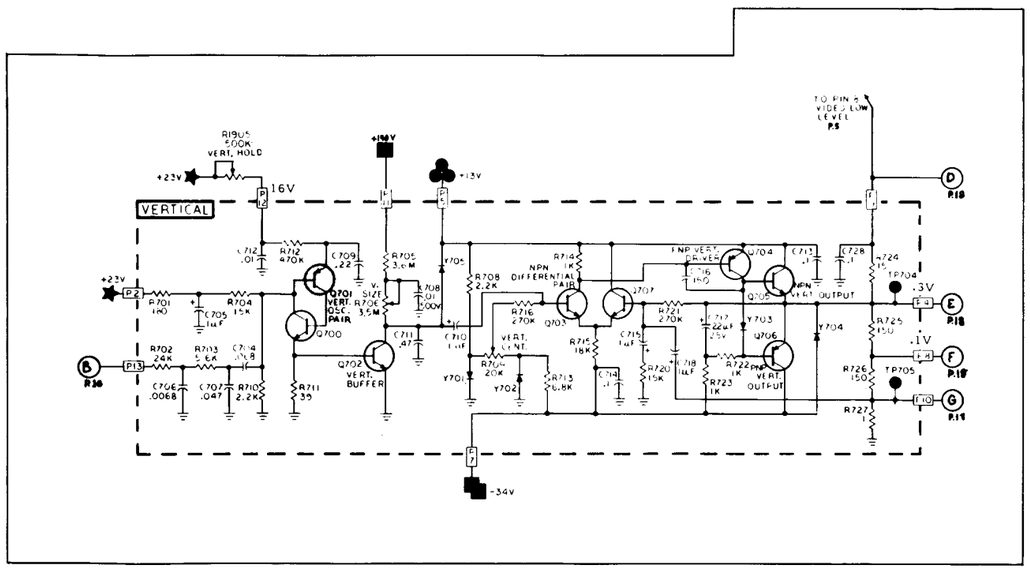
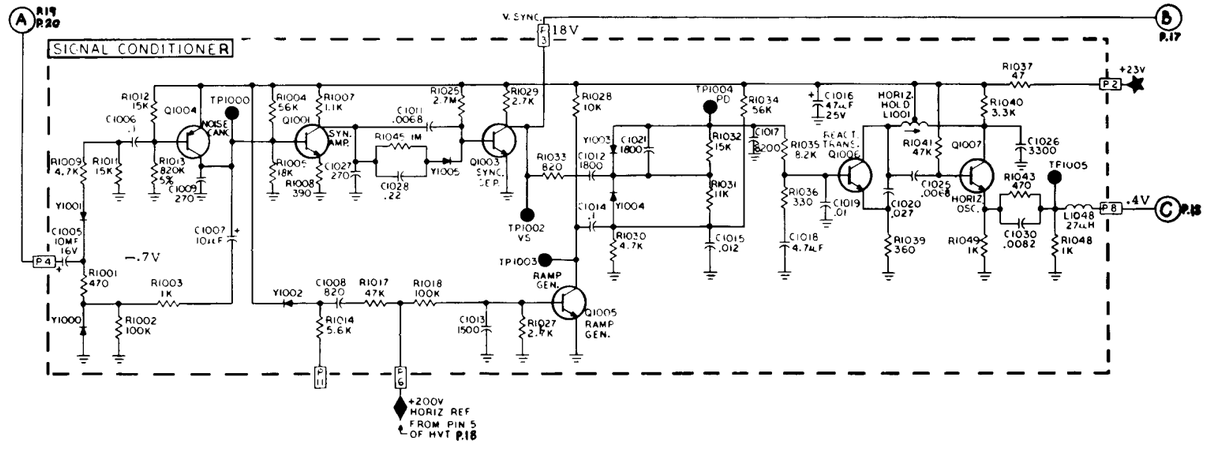
Figure 9, continued
Schematic of G.E. Model 25MB
25-Inch Color Monitor
(as used in Indy 800™, Indy 4™ and Tank® 8)





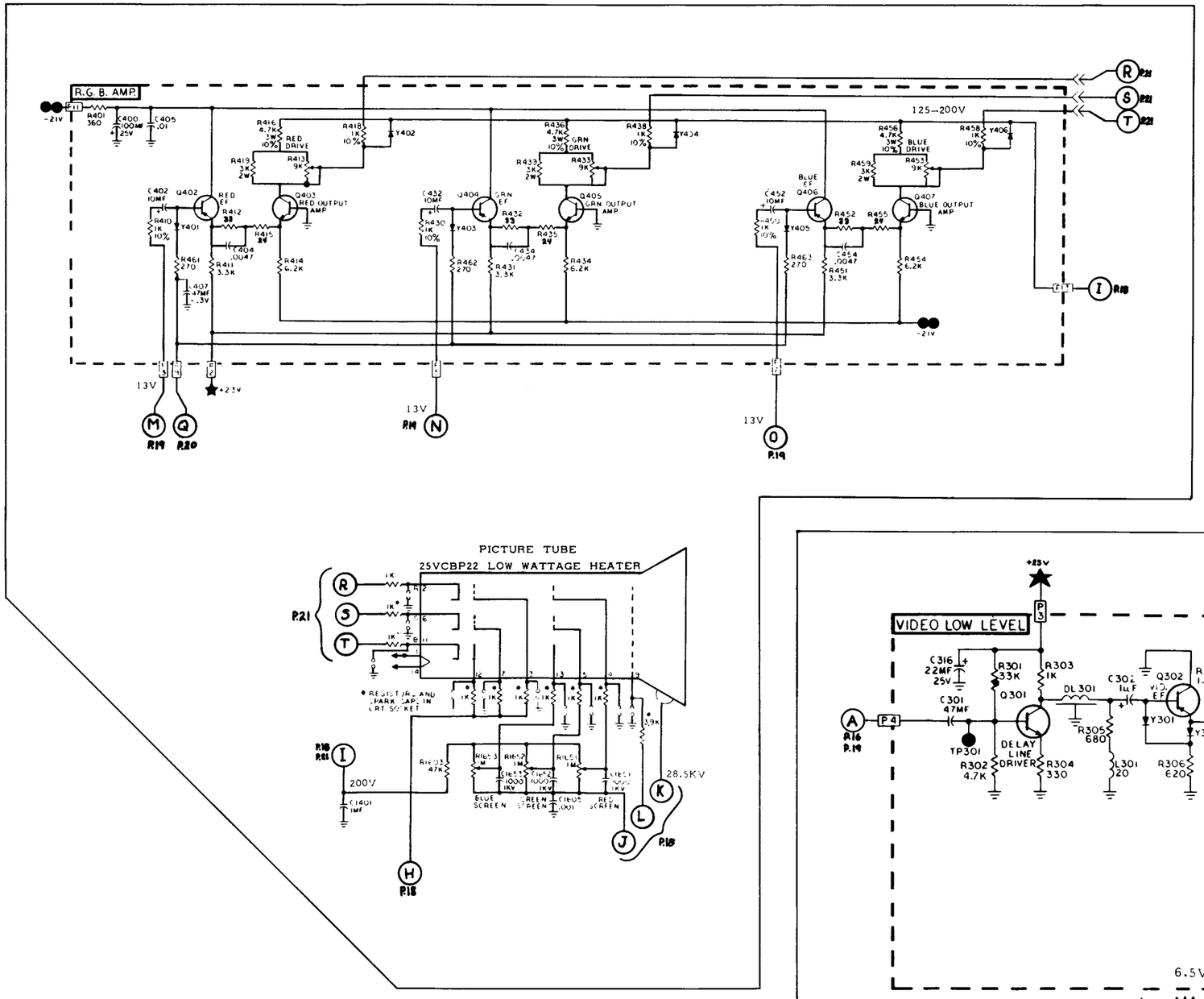
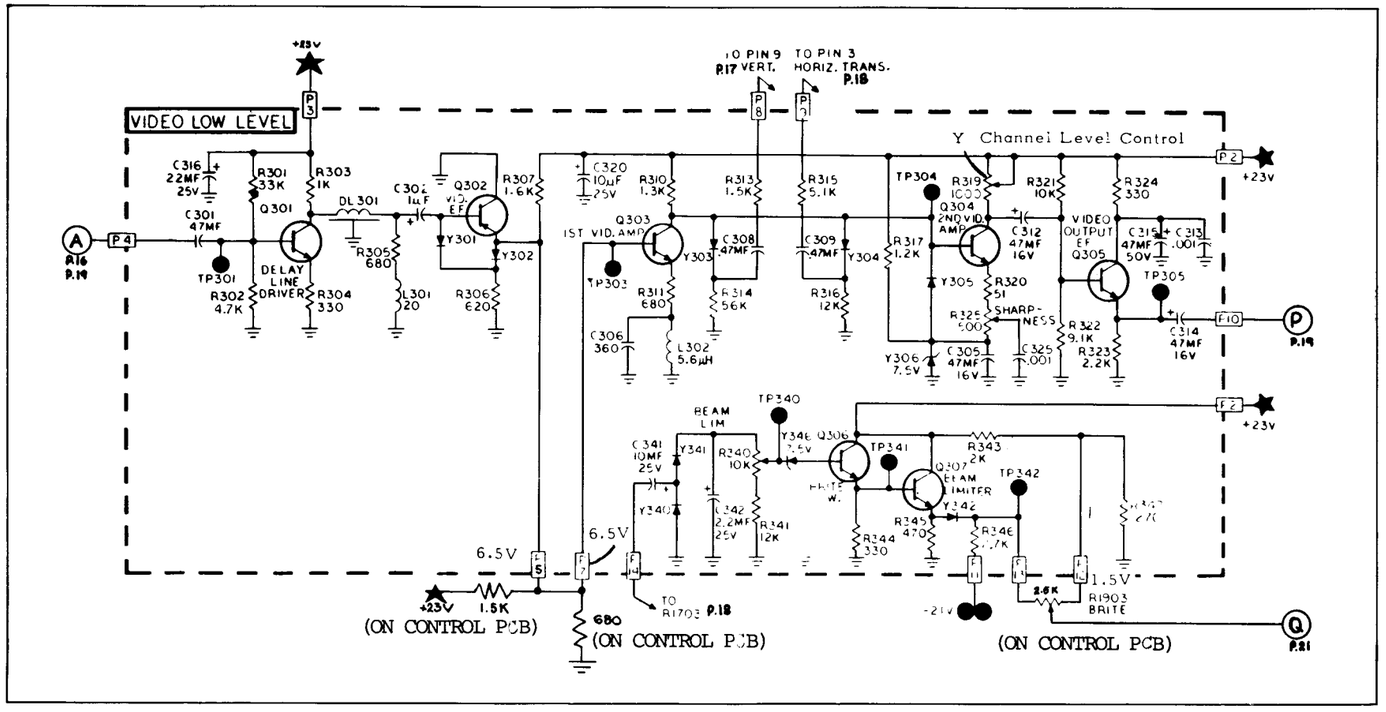


Figure 9, continued
Schematic of G.E. Model 25MB
25-Inch Color Monitor
(as used in Indy 800™, Indy 4™ and Tank® 8)



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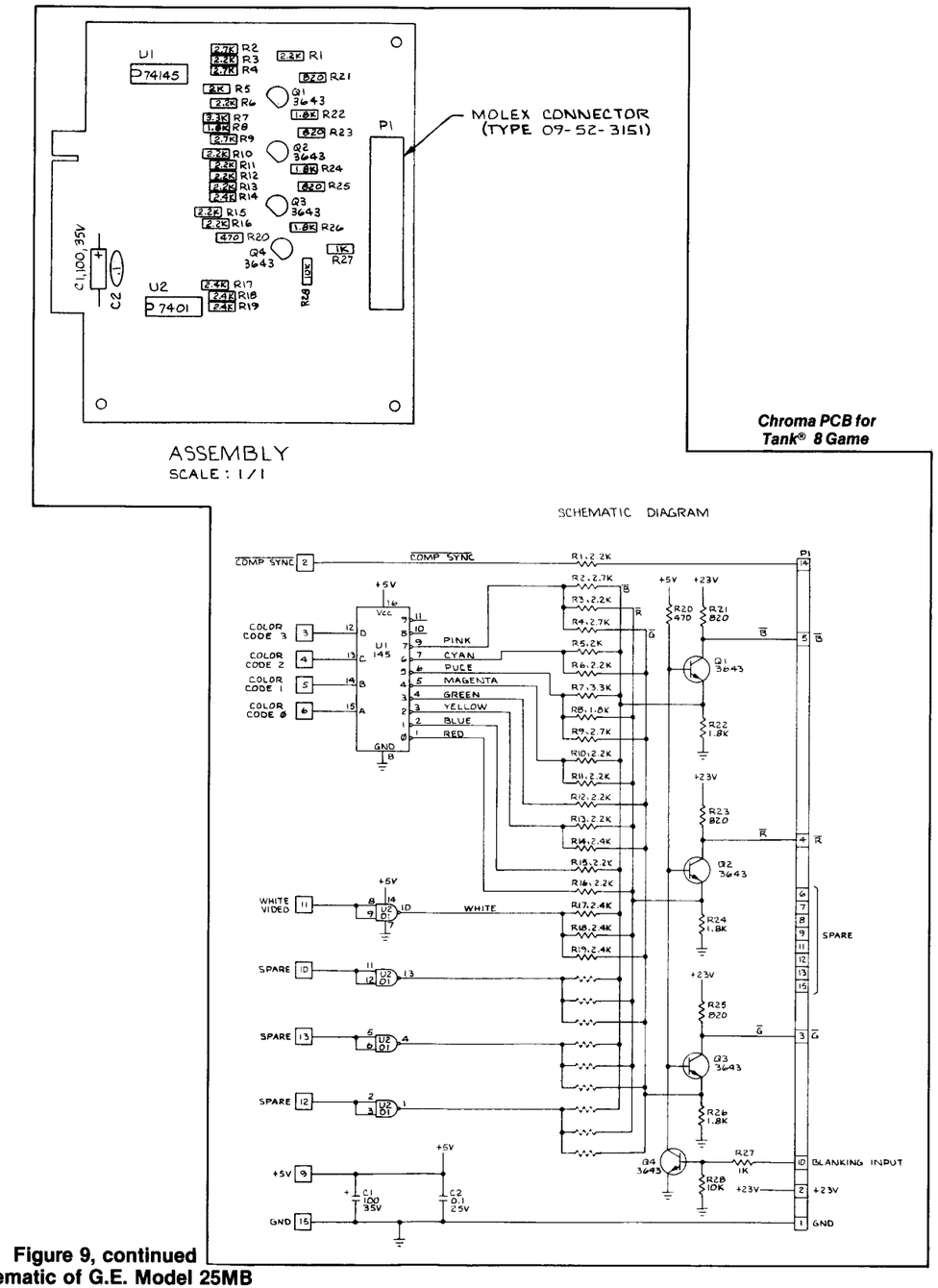

Chroma PCB for Tank® 8 Game

Figure 9, continued
Schematic of G.E. Model 25MB
25-Inch Color Monitor
(as used in Indy 800™, Indy 4™ and Tank® 8)

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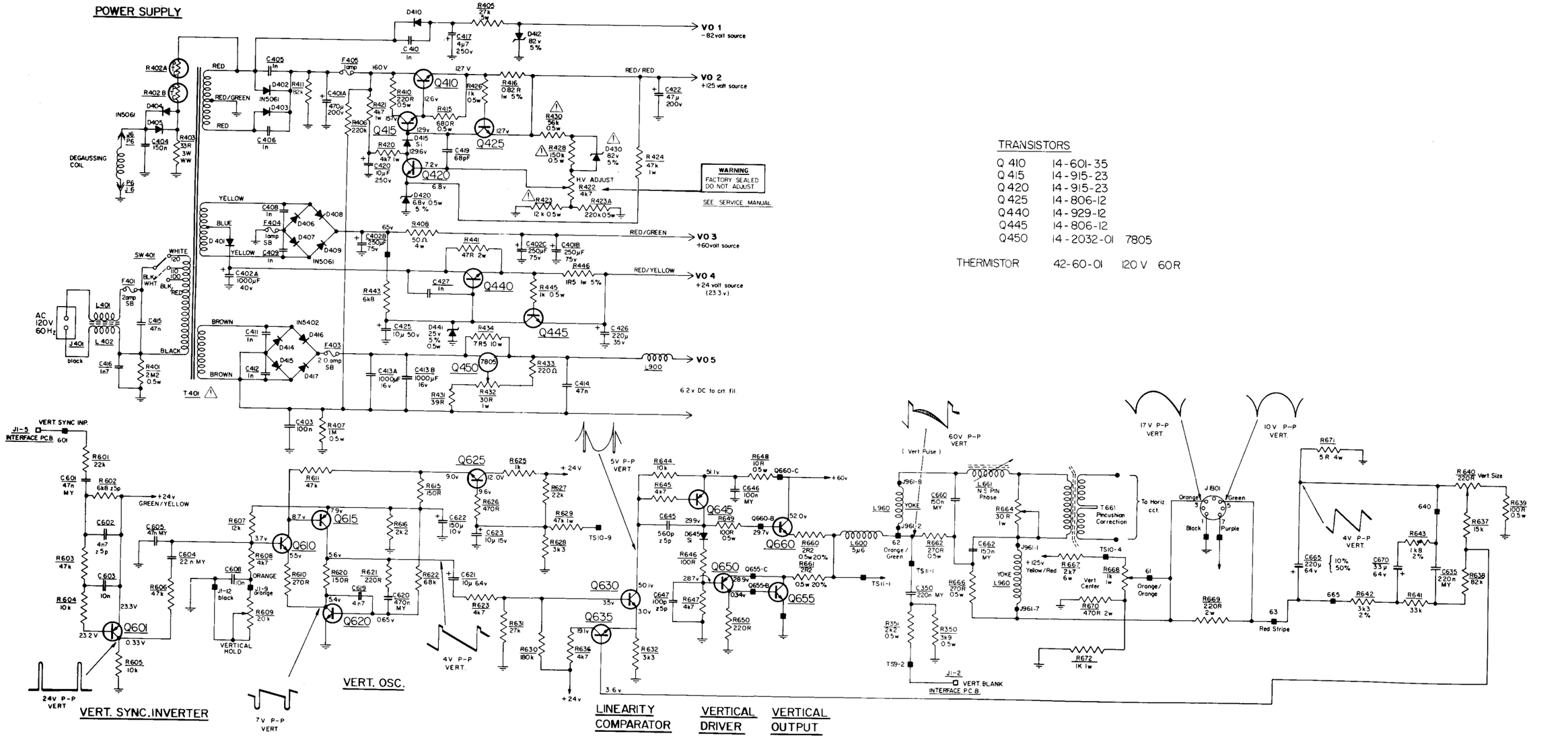

TRANSISTORS

Q 410	14-601-35
Q 415	14-915-23
Q 420	14-915-23
Q 425	14-806-12
Q 440	14-929-12
Q 445	14-806-12
Q 450	14-2032-01 7805

THERMISTOR 42-60-01 120 V 60R

Figure 10 Schematic of Electrohome Model GO2 25-Inch Color Raster-Scan Monitor (as used in Tank® 8 and Sprint™ 4)

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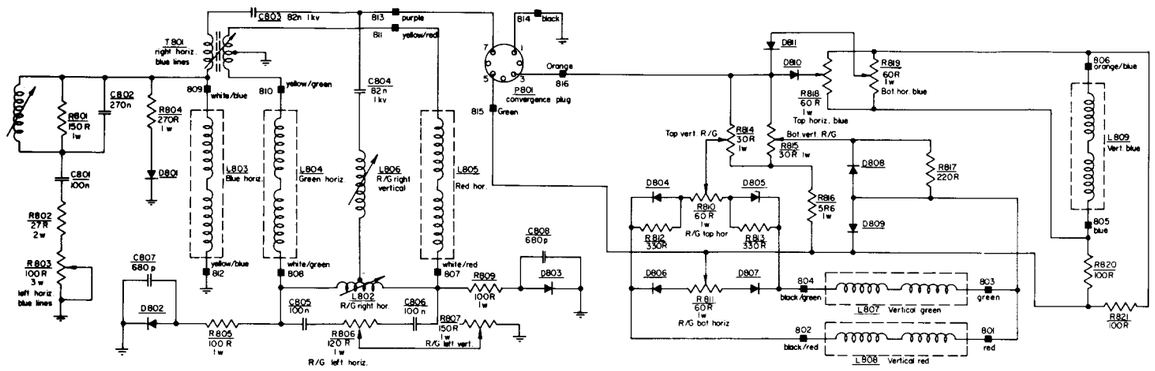
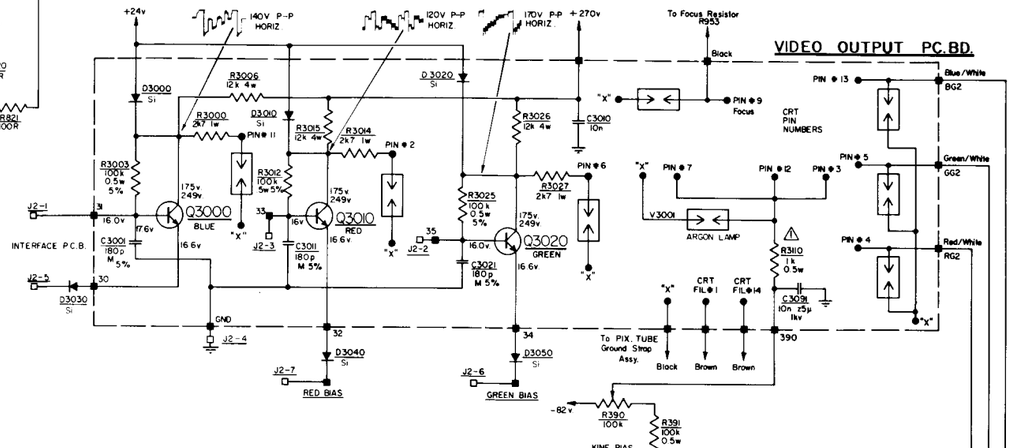
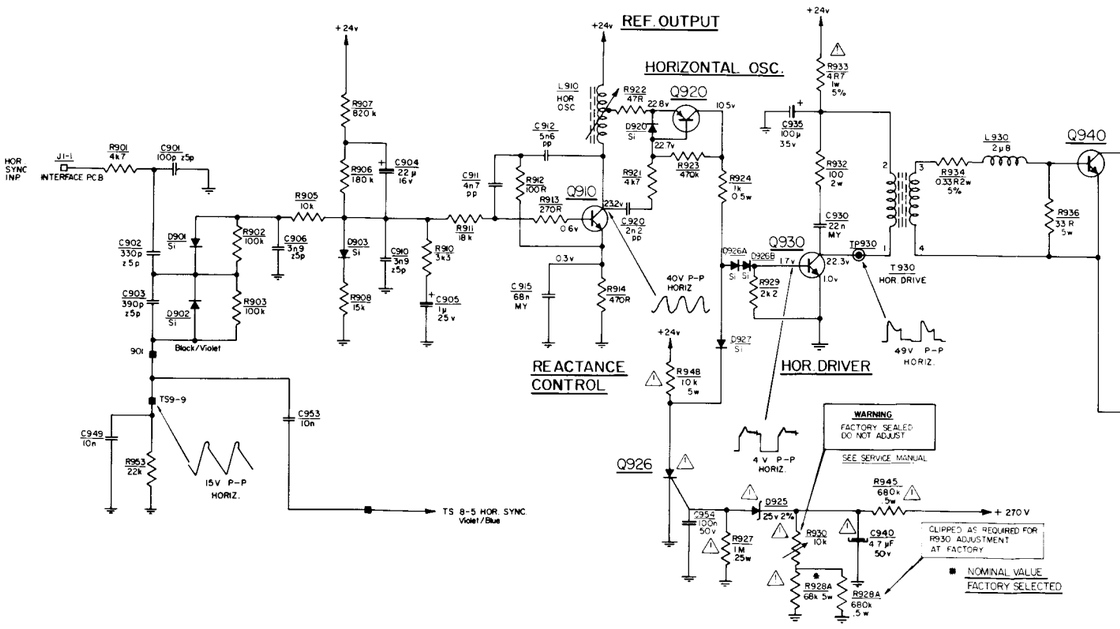
Figure 10, continued
Schematic of Electrohome Model G02
25-Inch Color Raster-Scan Monitor
(as used in Tank® 8 and Sprint™ 4)







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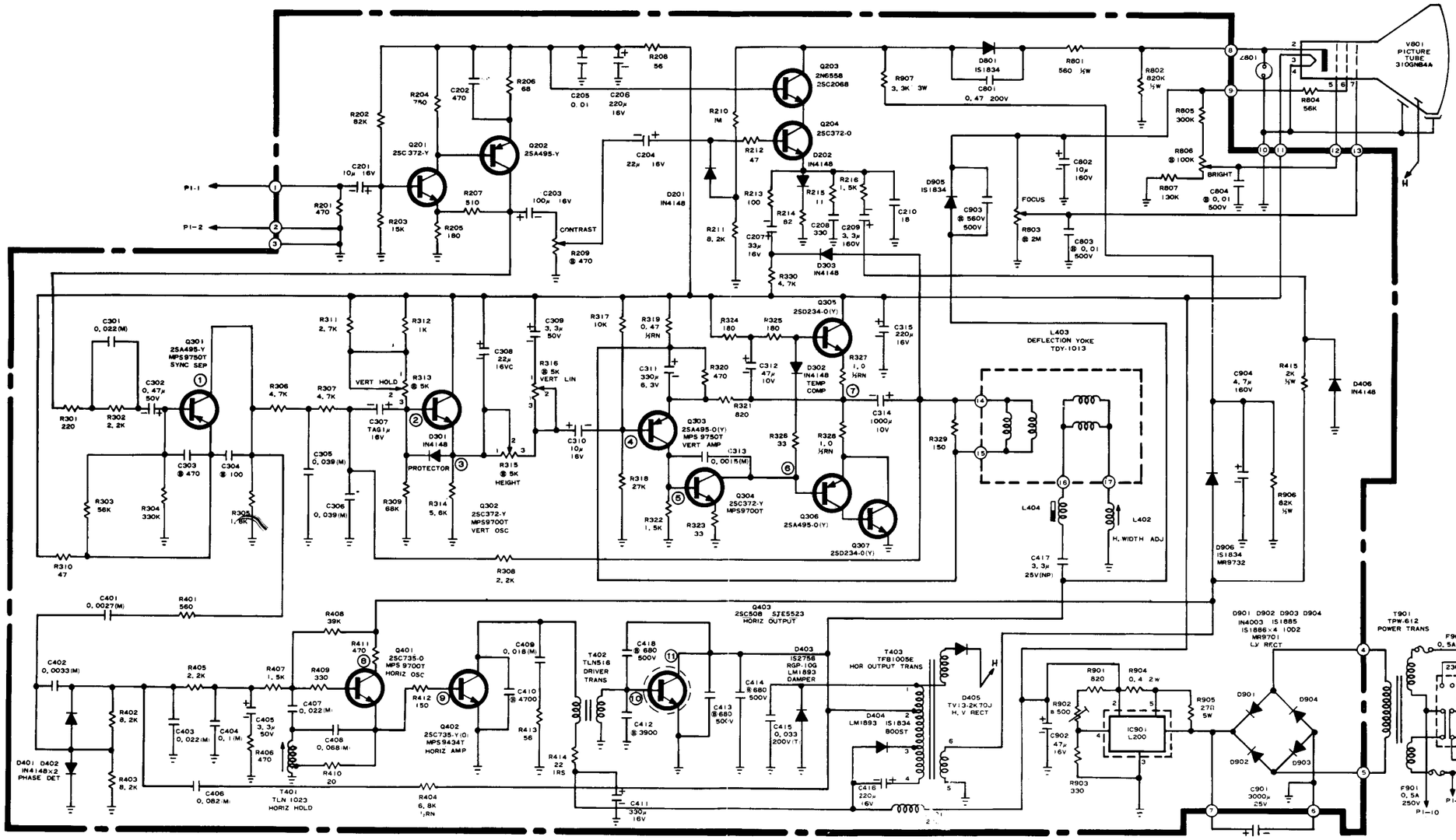

1. 9·1V	2. 1·82V	3. 1·5V	4. 0·68V	5. 1·4V

6. 12·5V	7. 11V	8. 3·2V	9. 1·5V	10. 8·4V	11. 120V

Figure 11 Schematic of TEC Videoelectronics Inc. Model TM-612 12-Inch Monochrome Monitors

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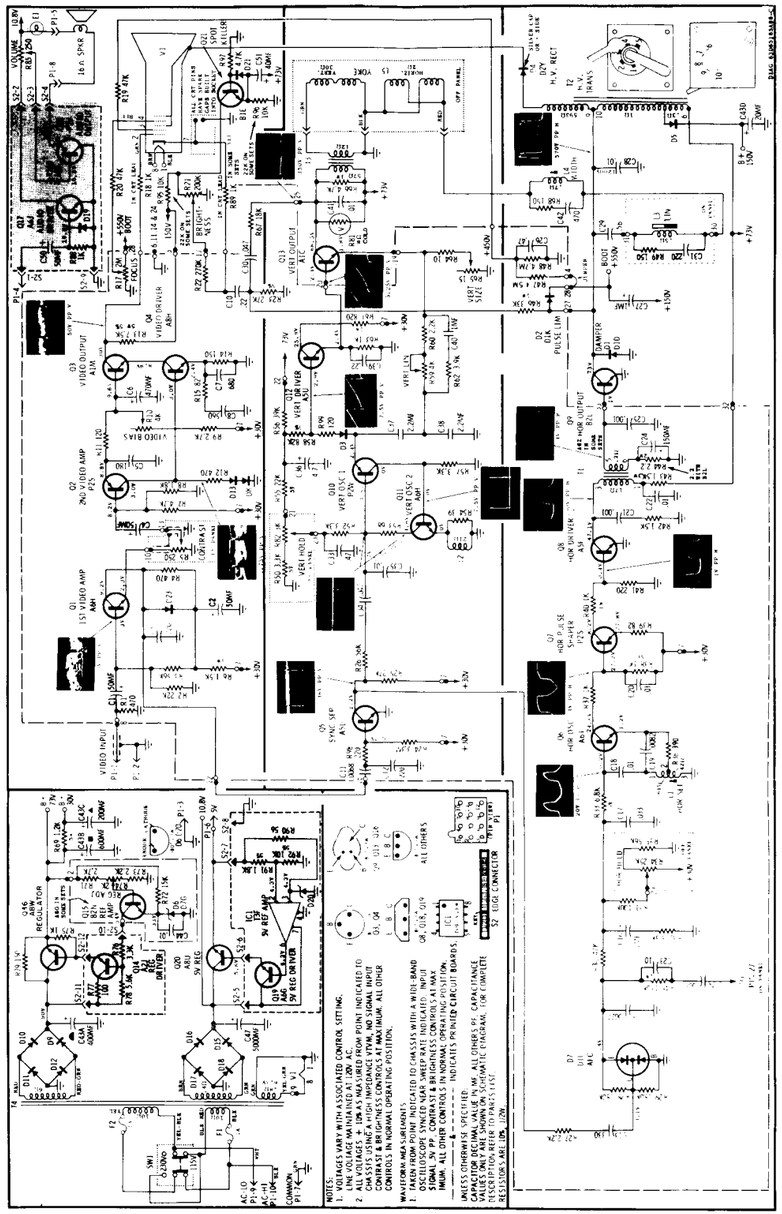

Figure 12 Schematic of Motorola
Models XM501/701
19- and 23-Inch Monochrome Monitors

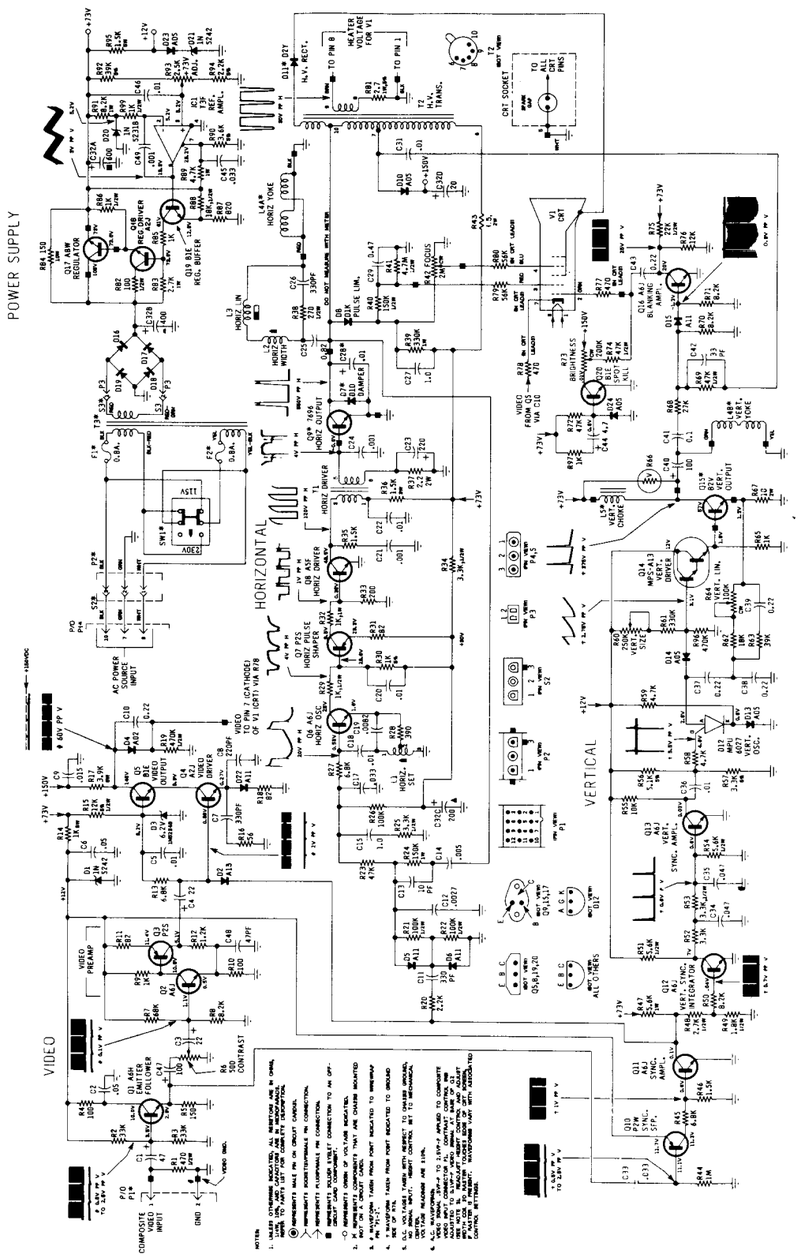

Figure 13 Schematic of Motorola
Models M5000/7000
19- and 23-Inch Monochrome Monitors

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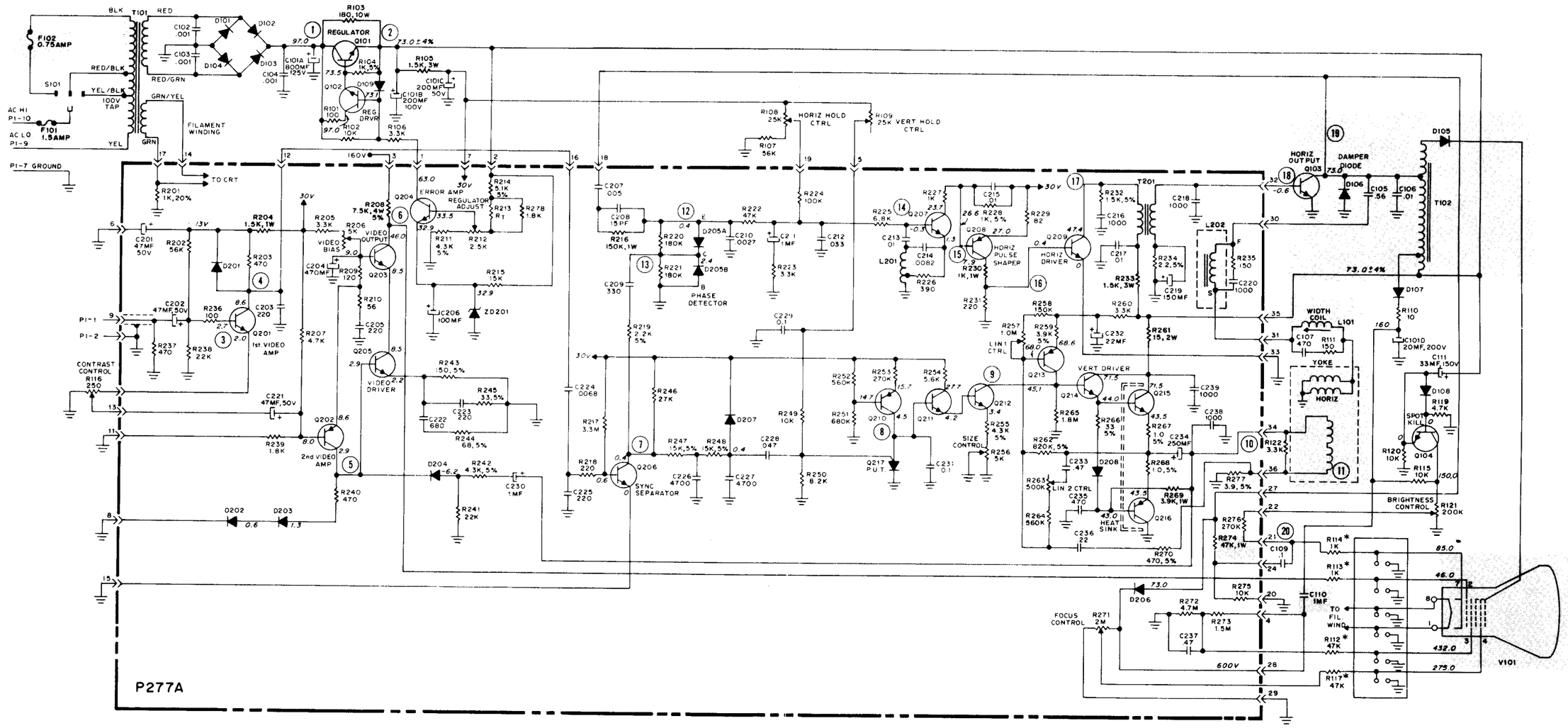

Figure 14 Schematic of Wells-Gardner Models 19V1001/22V1001 19- and 23-Inch Monochrome Monitors

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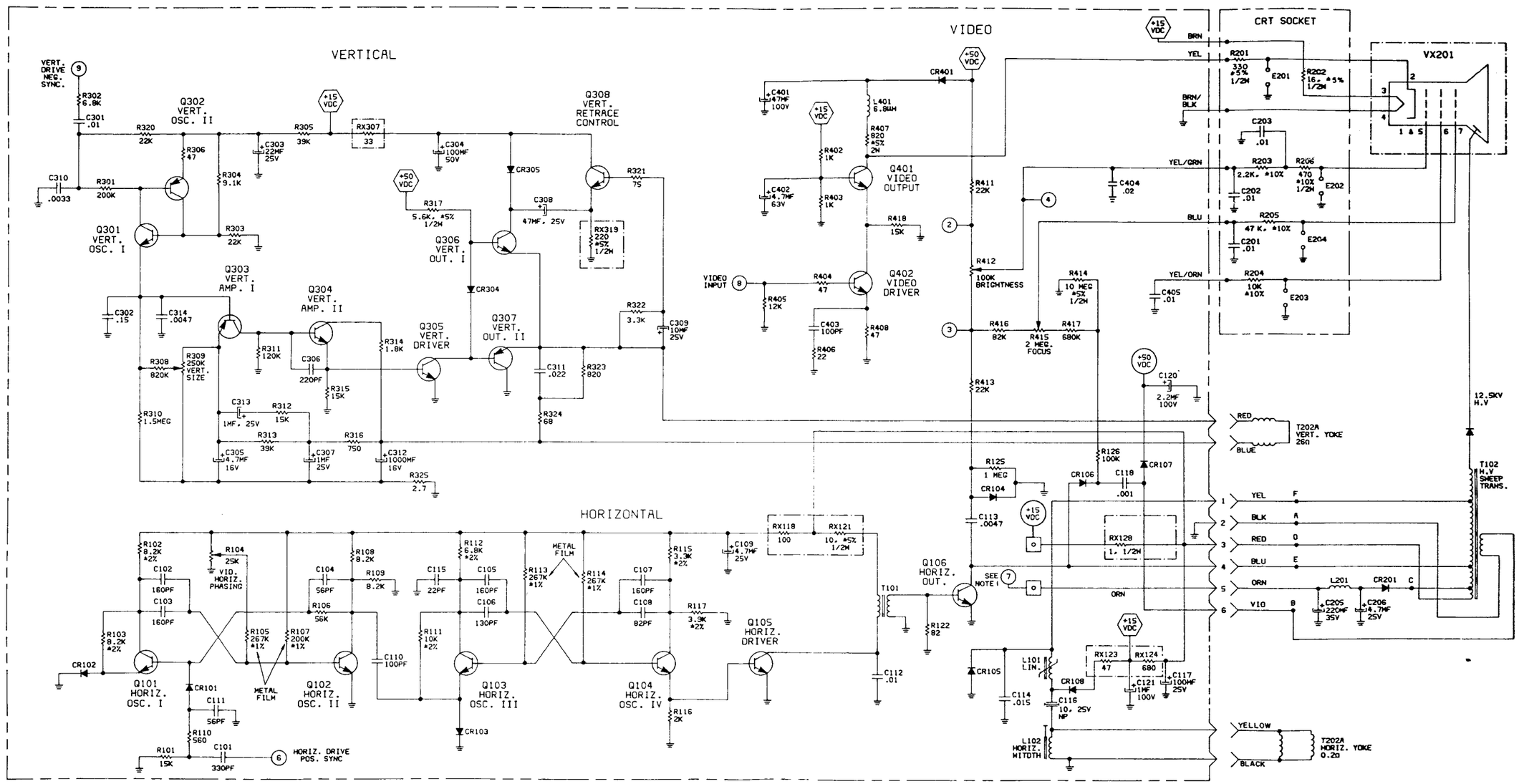
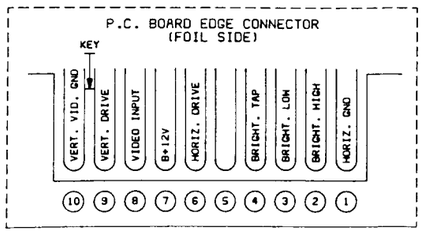




= DC VOLTAGE SOURCE

= DC VOLTAGE APPLIED

NOTE: 1. CUSTOMER SUPPLIED EXTERNAL DC SOURCE ON PIN 7 EDGE CONNECTOR

Figure 15 Schematic of Zenith Model D12 12-Inch Monochrome Monitor

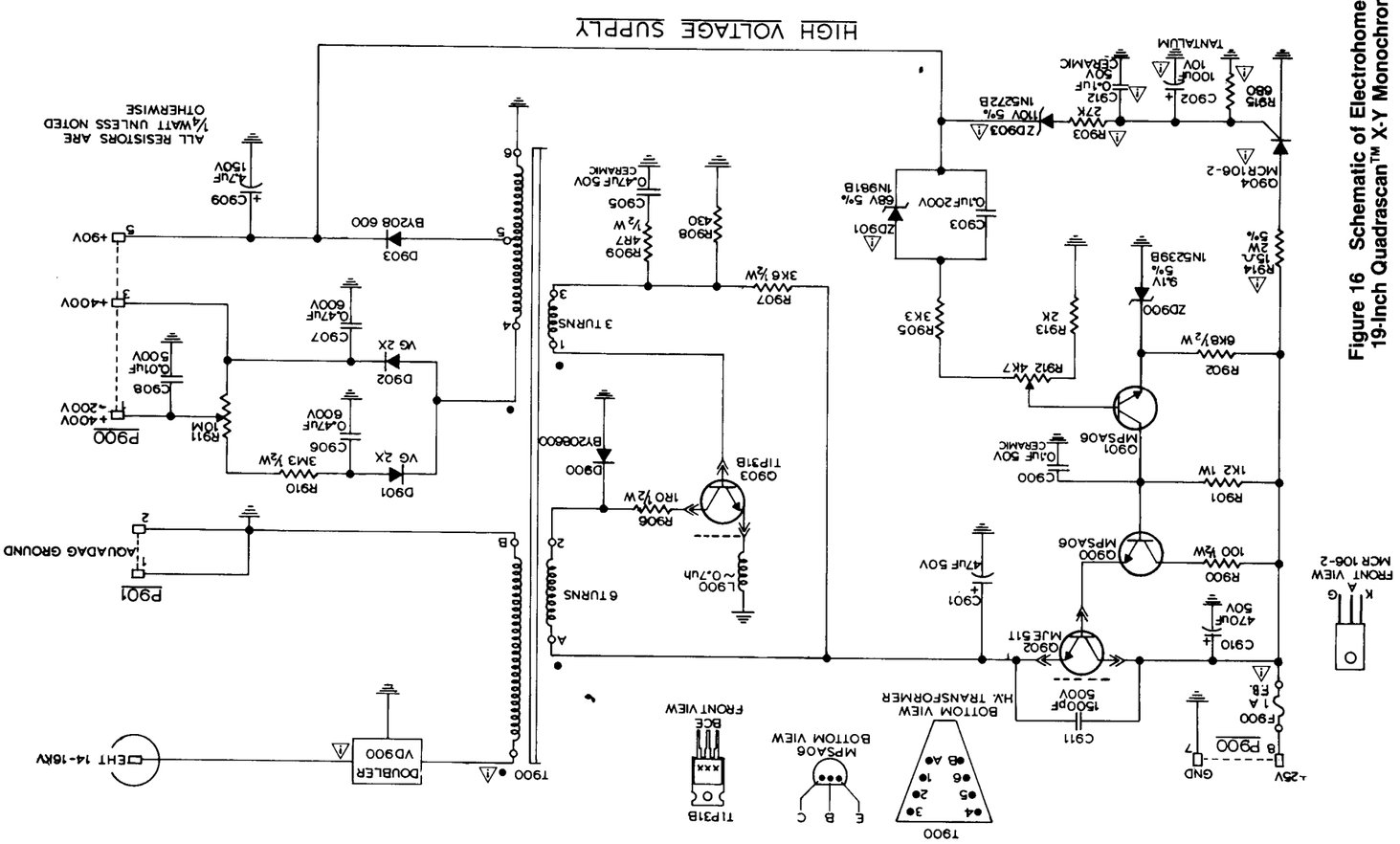
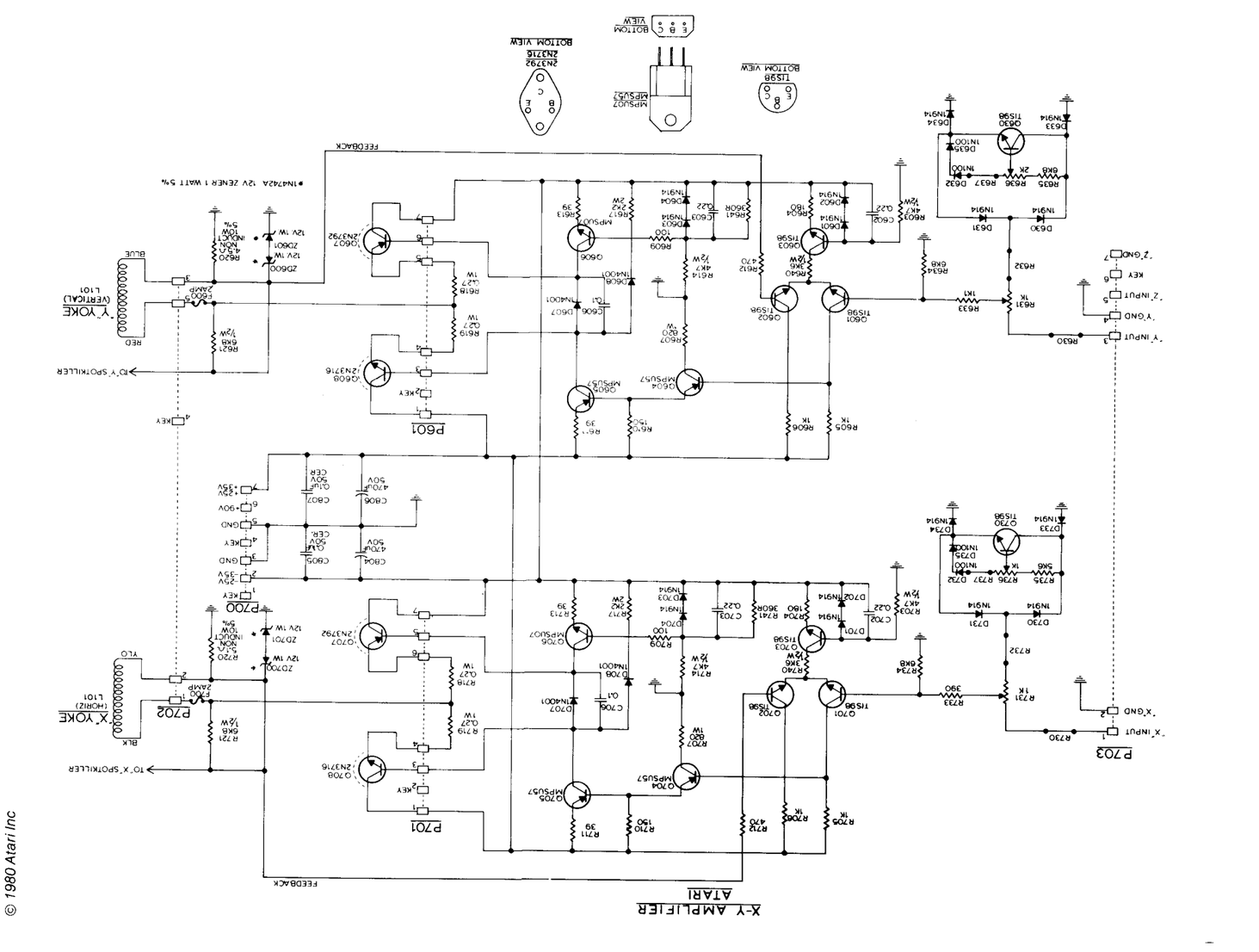


Figure 16 Schematic of Electrohome Model GO5 19-Inch Quadrascan™ X-Y Monochrome Monitor



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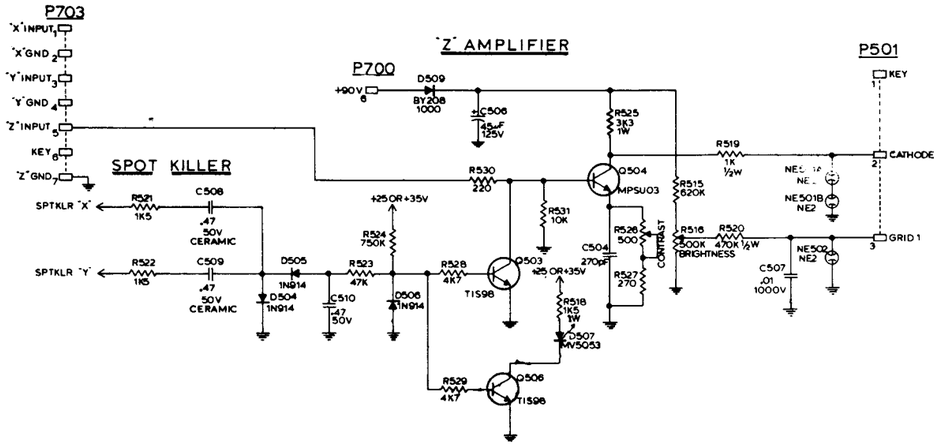
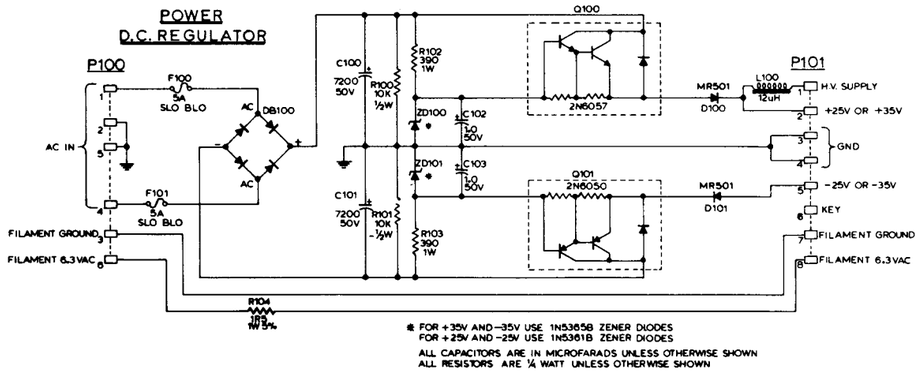
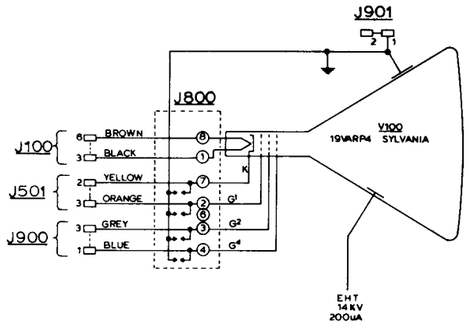
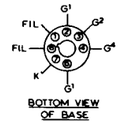
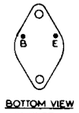
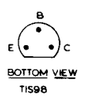












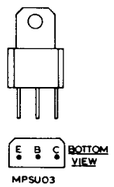
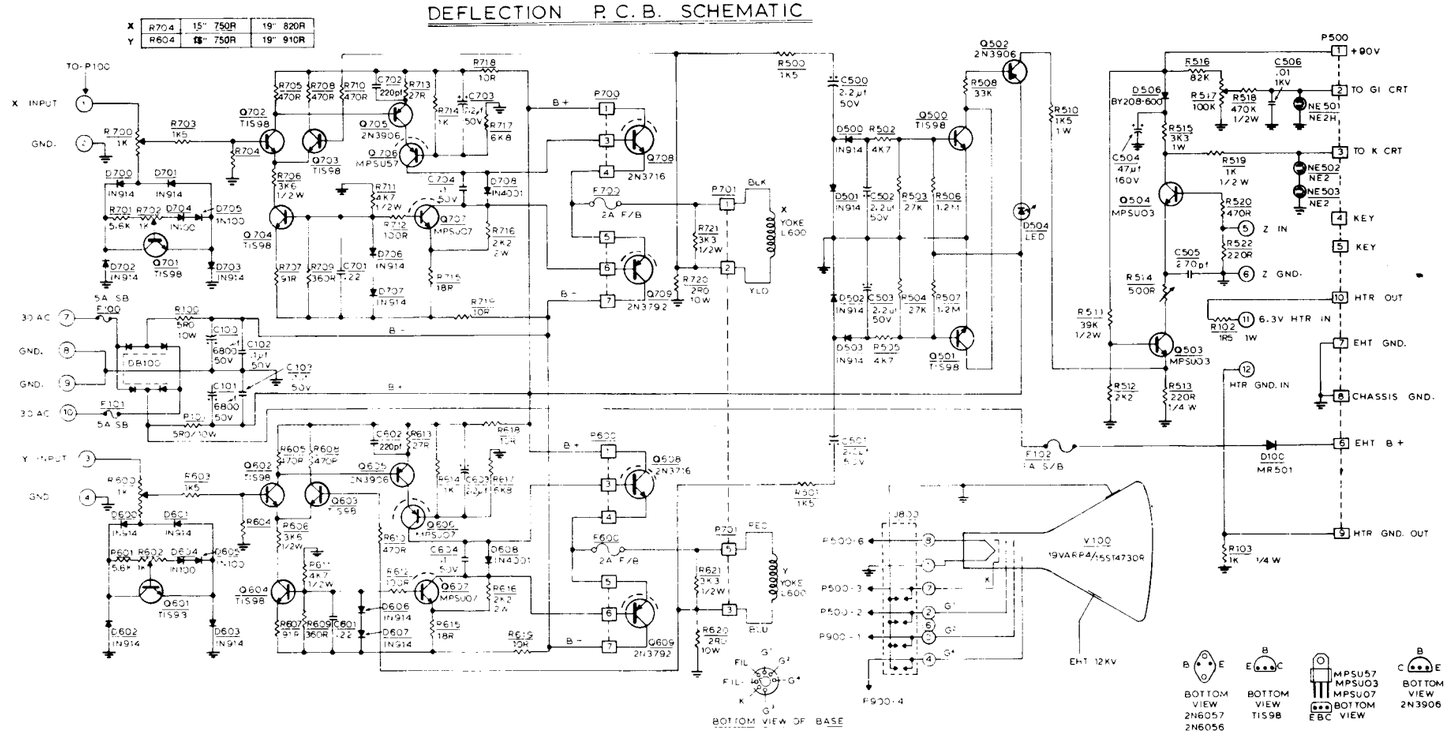


Figure 17 Schematic of Electrohome Model GO5-802/805 19- and 15-Inch X-Y Monochrome Monitors



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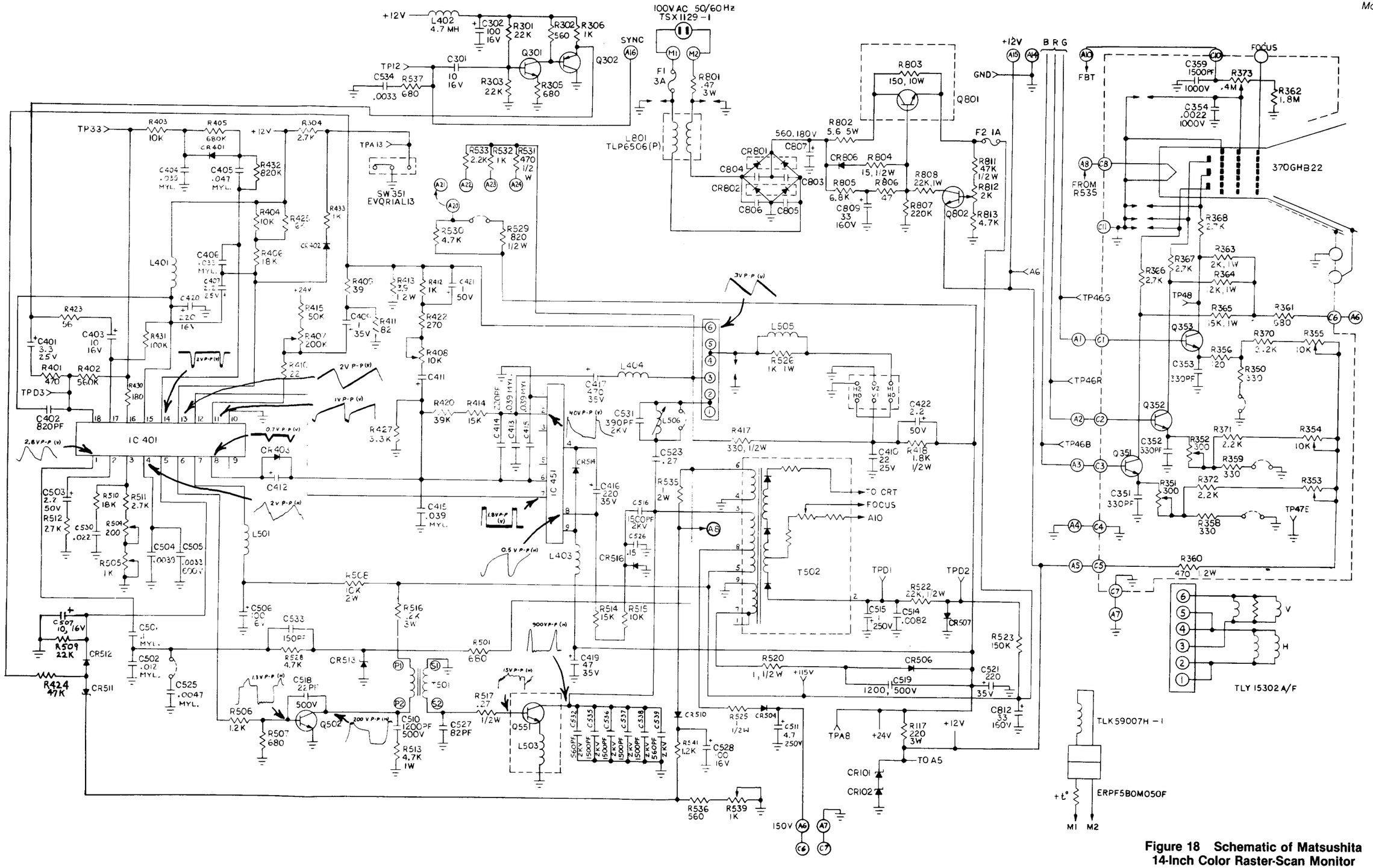

Figure 18 Schematic of Matsushita 14-Inch Color Raster-Scan Monitor

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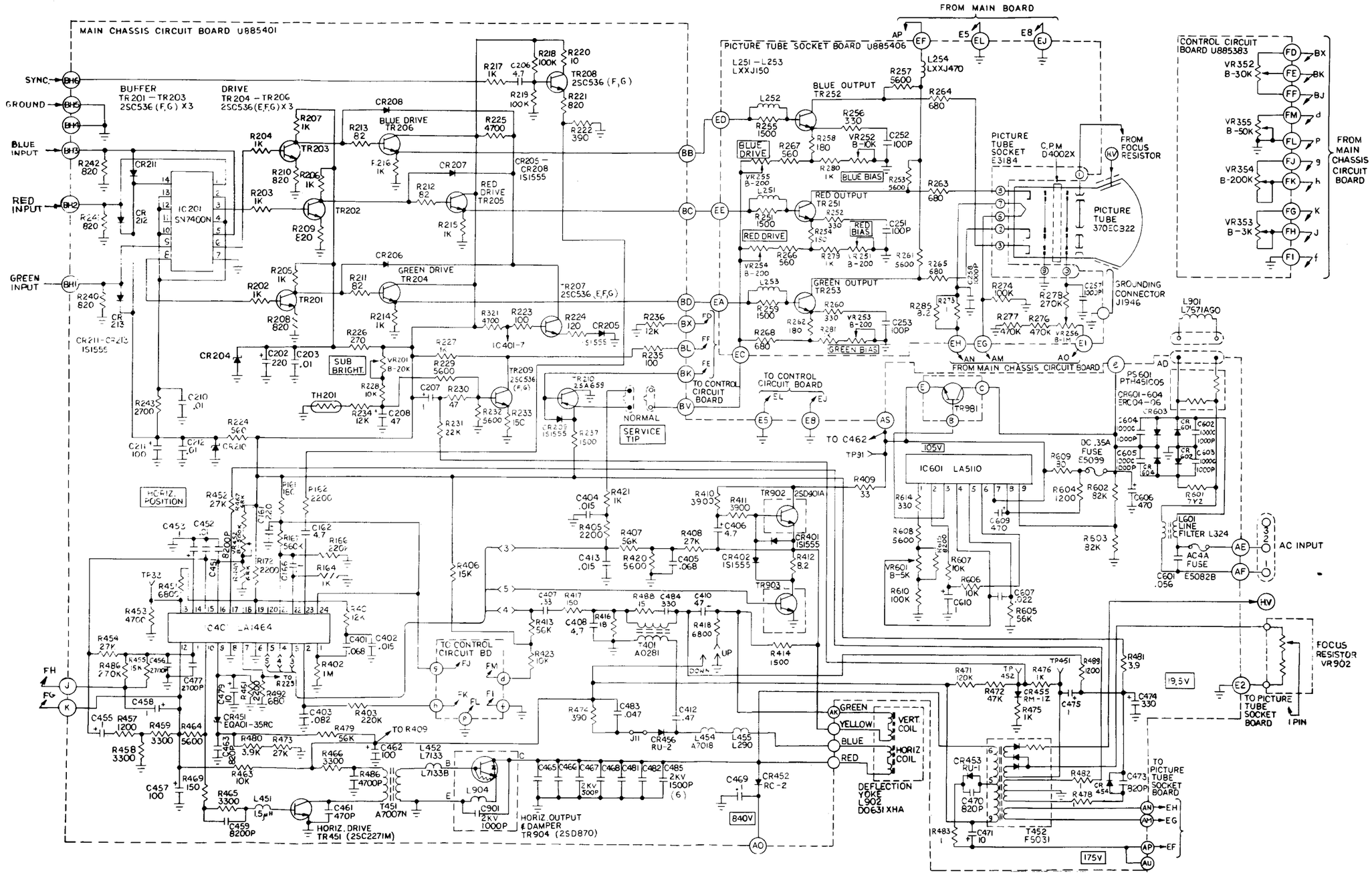

Figure 19 Schematic of Sanyo 14-Inch Color Raster-Scan Monitor

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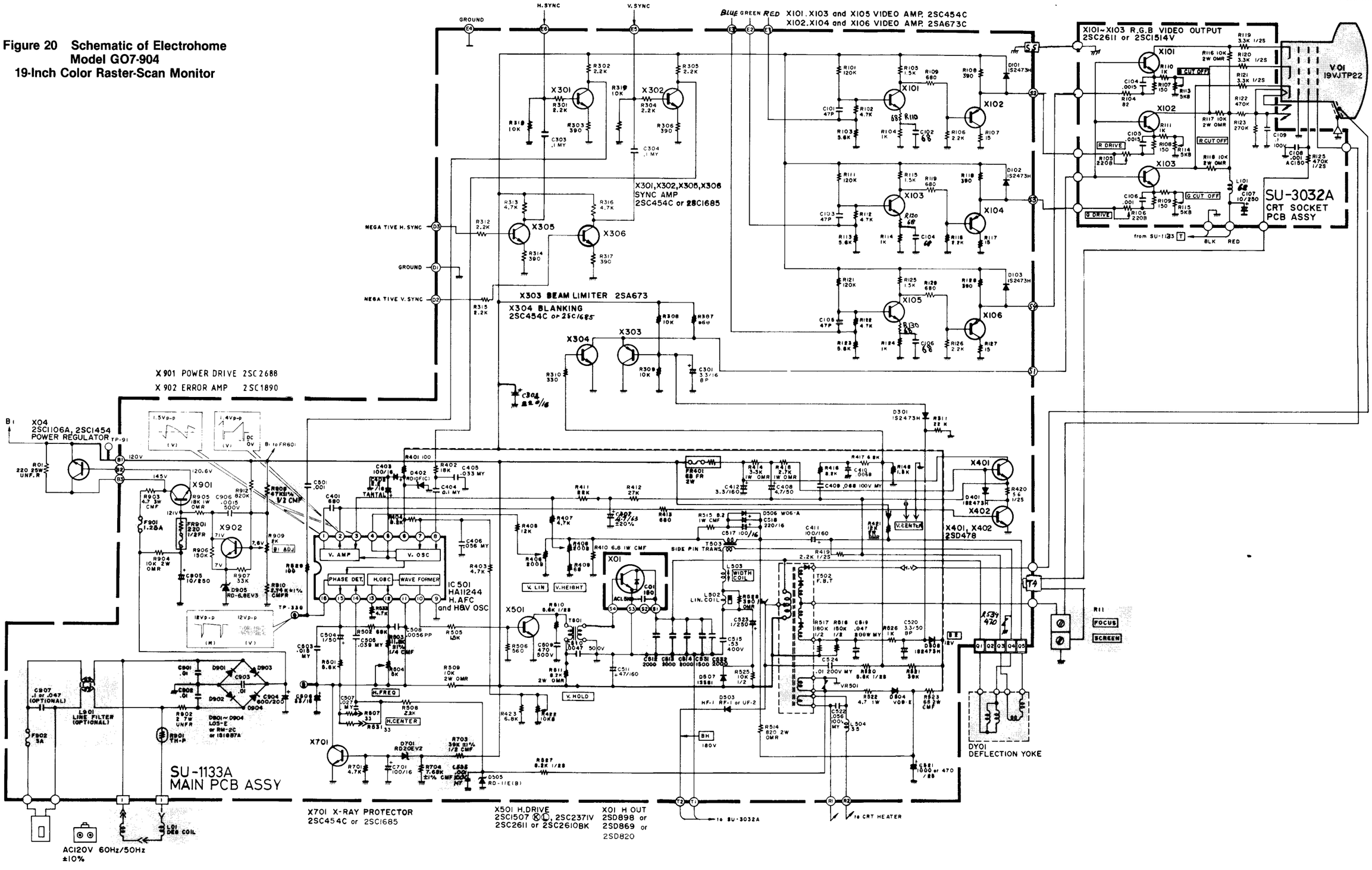
Figure 20 Schematic of Electrohome Model GO7-904 19-Inch Color Raster-Scan Monitor



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WARNING

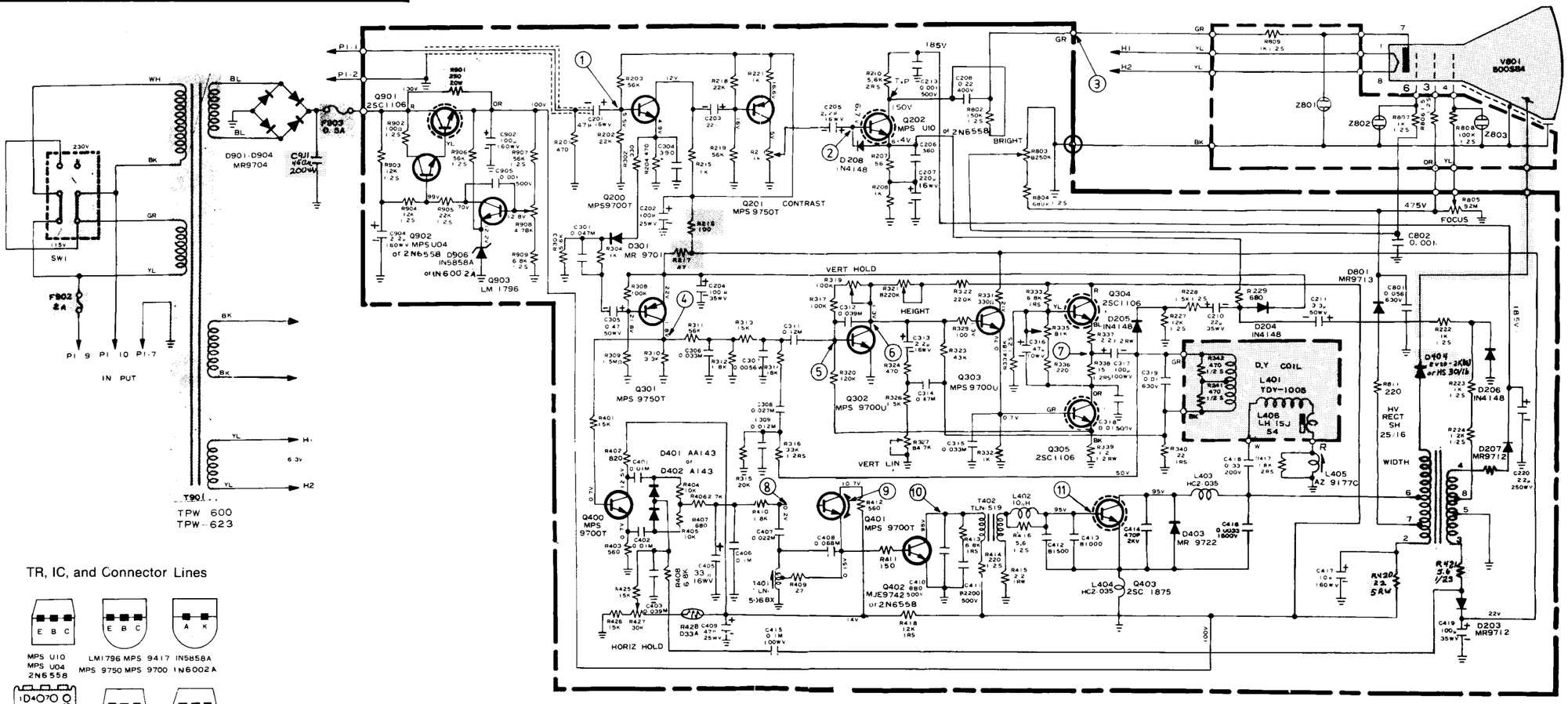
Safety-Critical Components

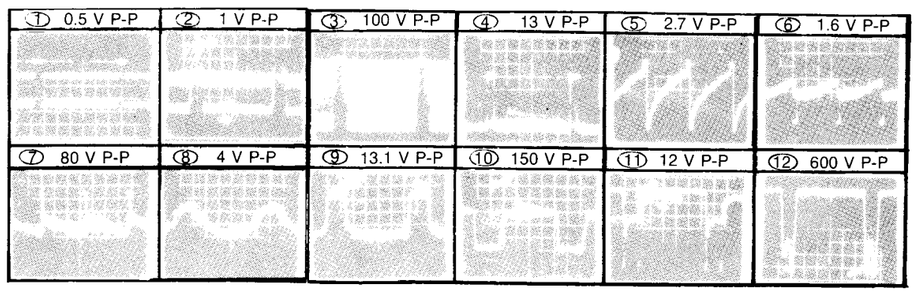
Components marked with an asterisk (*) on the parts list and with gray shading in the schematic have special characteristics important for safety.

You may create shock, fire, or other hazards by using a replacement that does not have the same characteristics as the recommended part.

NOTES

1. Unless otherwise specified, all resistance values are in ohms.
2. Unless otherwise specified, in the schematic diagram all capacitor values less than 1 are expressed in mfd, and values more than 1 are in pfd.
3. Voltage readings are taken with VTVM from point indicated on chassis to ground.
4. All waveforms are measured with strong signal input and contrast set to give normal picture.
5. This schematic diagram covers basic or representative chassis only. There *may* be some differences between actual components on chassis and the schematic diagram.





TR, IC, and Connector Lines

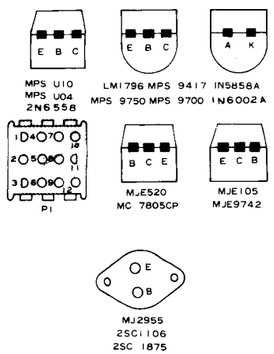


Figure 21 Schematic of TEC Videoelectronics Inc. Models TM-600/623 19- and 23-Inch Monochrome Monitors

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Chapter 4

Printed-Circuit Board Components

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A. Introduction to Solid-State Electronics

Electricity is the flow of electrons or current through a material, usually metal. This current flow is caused by a difference in potential between the two ends of the material. This potential difference is called ***voltage.***

Any material that allows current to flow through it is a ***conductor.*** Some materials allow current to flow through them more easily than others. For example, current flows through a wire more readily than wood. Therefore, wood is said to have more ***resistance*** than wire. The amount of resistance in electronic circuits is measured in ***ohms***, which is abbreviated as Ω .

B. Resistors

Certain amounts of resistance are often desirable in circuits. To permit circuits to have pre-determined resistances in various places, manufacturers make components called ***resistors.*** These are available in many sizes and shapes. In addition, they have a fixed or variable amount of resistance.

Power is measured in watts and abbreviated ***W.*** The larger the power rating of a resistor, the more voltage and current it can handle.

1. Fixed-Value Resistors

One type of fixed-value resistor is made of wire, since even wire has some resistance. These are known as ***wire-wound resistors.*** This type is usually found in power-supply circuits of many video games.

The wire-wound resistors are large enough to have their value and power rating written on them, without any cryptic codes. Typical values you might see are ***4 OHM 10W***, or ***2 OHM 20W.*** (The Greek Ω symbol might be used, instead of ***OHM***.)

The other type of smaller resistor, due to lack of space, has its resistance value coded in the form of four or five color bands. You should be concerned with only the first four bands. To determine how to read these bands, hold the 4-banded resistor with the empty non-banded area at your right. (If the resistor has five color bands that fill up its entire length, then hold it with what is most likely the yellow band at the right.)

Counting from the left, Bands 1 and 2 are the significant digits of resistance value. Band 3 is the multiplier; and Band 4 is the ***tolerance,*** or how much percentage the resistance in ohms may vary.

Atari's game boards use resistors mostly with a tolerance of ±5%. For example, the value of a typical resistor might be 10,000 ohms, plus or minus 5%. The means it would provide 9,500 to 10,500 ohms of resistance.

The yellow fifth band mentioned previously does not always appear on resistors; it represents a reliability rating. Yellow (or three other possible colors) means a certain percent of change in value will occur after every 1000 hours of operation.

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The chart in Figure 1 will let you quickly identify values of resistors.

Color	Bands 1 & 2 Significant Digits	Band 3 Decimal Multiplier	Band 4 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	10,000,000	
Grey	8	100,000,000	
White	9	1,000,000,000	
Gold	—	0.1	±5%
Silver	—	0.01	±10%
No color	—	—	±20%

Figure 1 Color Codes for Fixed-Value Resistors

To illustrate the color coding system, assume a resistor has the color bands shown in Figure 2. The first two bands (significant digits) show "10", which is multiplied by the third band's value of 1,000—meaning 10,000 ohms resistance. Band 4 is gold, meaning a tolerance of ±5%.

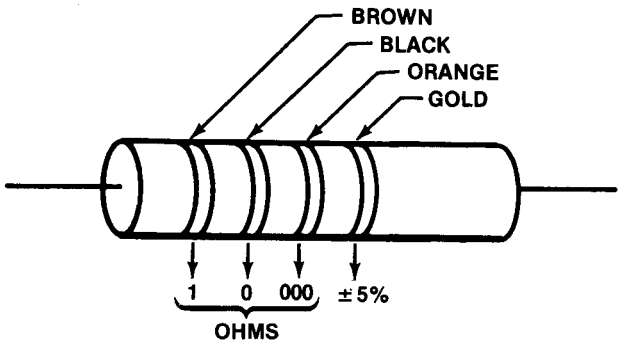


Figure 2 Example of a Resistor's Color Codes

The schematic symbol for fixed resistors is:

On some schematics, a resistor is shown by using the letter ***P.*** This means that the digital circuit is using a ***pull-up resistor.*** A pull-up usually has a value of around 2200 ohms and is used to force an IC pin to a logic 1 (high).

As you can see in Figure 1, most of the multipliers have a lot of zeroes. If you are writing the resistance values this way, you could easily make a mistake. Therefore, values are often abbreviated to eliminate most of the zeroes.

The most common abbreviations used are ***K*** for 1000, and ***M*** for 1,000,000. The 2200-ohm pull-up resistor is then shown as 2.2K, while the resistor in Figure 2 is shown as 10K ohms. The values of all resistors are usually shown on Atari's schematics, right under the reference designation Rxxx.

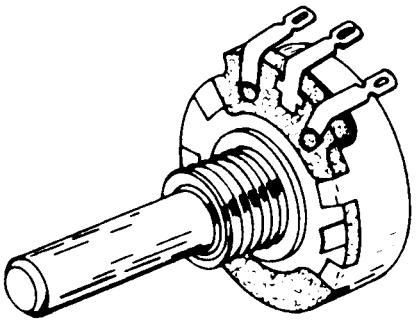


Figure 3 A Typical Potentiometer

2. Variable Resistors

Another type of resistor is the ***variable*** one, sometimes called a potentiometer, or a "pot" for short. See the accompanying Figure 3. The pot has an overall resistance with an adjustable tap which allows the resistor value to be changed.

Ohm's Law:

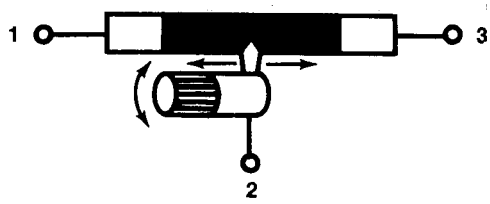
Resistance is related to voltage and current by Ohm's Law, which is a simple formula:

$$E = I \times R$$

R is the resistance value, ***E*** is the voltage, and ***I*** is the current value. If you vary the amount of resistance between two terminals of a pot, you are also varying the ***voltage*** across those terminals. Thus, a pot allows you to set different voltage levels.

Suppose the overall resistance of the pot is 5K ohms. This will be read between terminals 1 and 3:

A tap called a ***wiper arm*** is mounted inside the potentiometer's housing, and it makes contact with the resistance material. The wiper arm is connected both to terminal 2 as well as a shaft that you can rotate:



The rotation causes the wiper arm to travel from one end of the resistance material to the other.

As you turn the shaft, the amount of resistance between terminals 1 and 2, and terminals 2 and 3 will change. Going in one direction, the resistance between the first two terminals will ***increase***, while the resistance between the second two will ***decrease.*** Turning the shaft in the opposite direction will cause the opposite to happen.

The resistance in most pots used in video games is linear. That means the resistance material is spread evenly along the path that the wiper arm covers.

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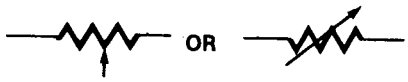
The schematic symbol for a pot is slightly different from a resistor. In the example below the wiper arm is represented by the arrow.



Pots usually have their resistance values plainly marked on them. However, sometimes the values may be in the form of a code. The code is very simple to learn: the first two numbers are the significant digits, and the third number is the multiplier or number of zeroes that follow.

For example, a marking of ***502*** (50 + 2 zeroes) means 5000 or 5K ohms. Another marking of ***104*** equals 100K ohms, or 10 + 4 zeroes.

A pot that's used as a player control is usually wirewound and is sealed to keep out dirt and moisture (which would affect the pot's life).

Any dirt or particles that get into the pot may cause a momentary loss of contact, or a very large resistance at one spot in the range. If the pot is used as a paddle control, this damage will show up as jerky paddle motion (the paddle suddenly hops very far, even though the pot was turned just a small amount), or the paddle will not move at all when the pot is turned.

Pots cannot usually be repaired—because they're sealed at the factory. You should replace them since the time and effort required to clean them usually costs more than a replacement.

3. Uses of Potentiometers

Pots are used as controls in various places in video games. As a player control, a potentiometer will change voltage levels that correspond to certain spots where a paddle appears on the screen. This type of control is found on games like Breakout® and Avalanche™.

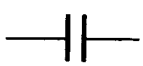
Potentiometers are also used in joysticks where they control two voltages. Examples of games that use the joystick principle are Sky Raider™ and Flyball® .

Using a pot, you can fine-tune some input to operational amplifier circuits, such as those in Flyball and Starship 1™. You can also control a voltage amplifier output, such as the X and Y amplifiers found on games like Asteroids™.

In addition, pots are used to set audio levels on all Atari video and pinball games. They are also needed to fine-tune many different circuits in monitors. You are probably familiar with the pots used as brightness and contrast controls on televisions.

C. Capacitors

A commonly used component in electronic circuits is the capacitor. The schematic symbol for a capacitor is as follows:



This component usually has two metal plates inside that are separated by an insulator. Because the plates are made of metal, electrons readily flow to them.

Although capacitors also contain wire inside, the electrons accumulate on the plates, because these have a larger surface area than the wire. When electrons accumulate in one area, the capacitor stores a charge.

The plates are not directly connected; therefore, DC current flow is blocked. Alternating current (AC) ***can*** pass through a capacitor due to the stored charges. Therefore, one of the capacitor's functions is to block DC voltages, while allowing AC to pass.

1. DC-Voltage Blocking

An AC voltage may be a signal of a specific frequency, or it could be quick transients. Since the voltage change on the capacitor's plates will be gradual (it takes time to charge and discharge a capacitor), the capacitor tends to smooth out transients or voltage changes.

In the case of a varying voltage, engineers use a capacitor to filter or smooth out a waveform in the power supply. In digital circuits, most of the signals you will find are switching between 0 and 5 volts. This fast switching of signals causes some voltage spikes to get onto the power supply buses on PC boards (due to the composition of the ICs).

Capacitors can be placed across 5-volt and ground buses to filter out the switching signals. These signals or transients will pass easily through the capacitor to ground, whereas the capacitor will block DC voltage. When used in this way, these components are called ***de-spiking capacitors.*** Usually their value is .1 μF (see Subsection 3 that follows for an explanation of capacitor values).

2. AC-Voltage Resistance

Capacitors also have varying amounts of resistance to AC currents, and this resistance is called ***reactance.*** The resistance of a capacitor depends on its value and the AC frequency of the voltage.

Capacitors of different values block different AC signals, and allow others to pass. When capacitors are used this way, they are called ***filters.*** Examples of this type of filter are the tone controls on an audio amplifier.

A capacitive filter can also be made to allow a certain frequency to pass through it. When a capacitor charges and discharges at a certain rate into a resistor, the charge will appear as an oscillation at a certain frequency. This is a ***tuned circuit*** or a ***tank circuit***. (The word ***tank*** has no relation to Atari's Tank® video game.)

3. Characteristics of Capacitors

Capacitors are made in a wide range of sizes, plus several shapes (most are cylindrical). Different types of insulating materials are used inside to withstand various voltages before the capacitor fails. This voltage is known as the ***breakdown voltage***, and is usually printed on the capacitor. If you are replacing a capacitor, use one with the same voltage rating or higher.

Capacitance is measured in ***Farads***—named for Michael Faraday, an important 19th-century English chemist and physicist. A Farad is a very large value, and most capacitors are measured in microFarads or picoFarads. This value is usually stamped on the capacitor.

As with resistors, we use abbreviations in a capacitor value to avoid writing and reading many zeroes. The ***micro*** prefix is abbreviated as μ, ***u***, or ***m***. It means multiply times .000001 or one-millionth, shortened to 1×10^{-6}. The ***pico*** prefix is abbreviated as ***p*** and means multiply times 10^{-12} or one-trillionth.

Some of the larger capacitors have an electrolytic material in them for an insulator. An example of an electrolytic capacitor is an 8000 μF cap used in the power-supply circuit of many video games. For your safety, and so they operate properly, ***you must install these capacitors in a circuit a certain way because they have polarity.***

Just as you observe polarity when replacing batteries, if you replace a polarized capacitor, ***make sure the + side of the capacitor goes towards the correct end of the board.***

WARNING

If you insert a polarized capacitor the wrong way, it will break down and explode!

The polarity of capacitors is always marked on Atari's PCB assembly drawings. On the boards themselves, you'll find that the etched-metal pad at the positive end of the capacitor is square, instead of the usual round shape. In addition, Atari marks the polarity on recent boards with yellow silk-screening.

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4. Value Codes of Capacitors

Capacitors with color-coded values, rather than written-out values, are made of tantalum and are sometimes found in monitors. The color code is similar to that for resistors, mentioned previously in this chapter. See the table in Figure 4 for capacitor color codes and their meanings.

Color	Significant Digits 1st	2nd	Multiplier	Voltage at 85° C. or 184° F.
Black	0	0	—	—
Brown	1	1	—	6
Red	2	2	100	10
Orange	3	3	1,000	15
Yellow	4	4	10,000	20
Green	5	5	100,000	25
Blue	6	6	1,000,000	35
Violet	7	7	10,000,000	50
Grey	8	8	100,000,000	—
White	9	—	—	4

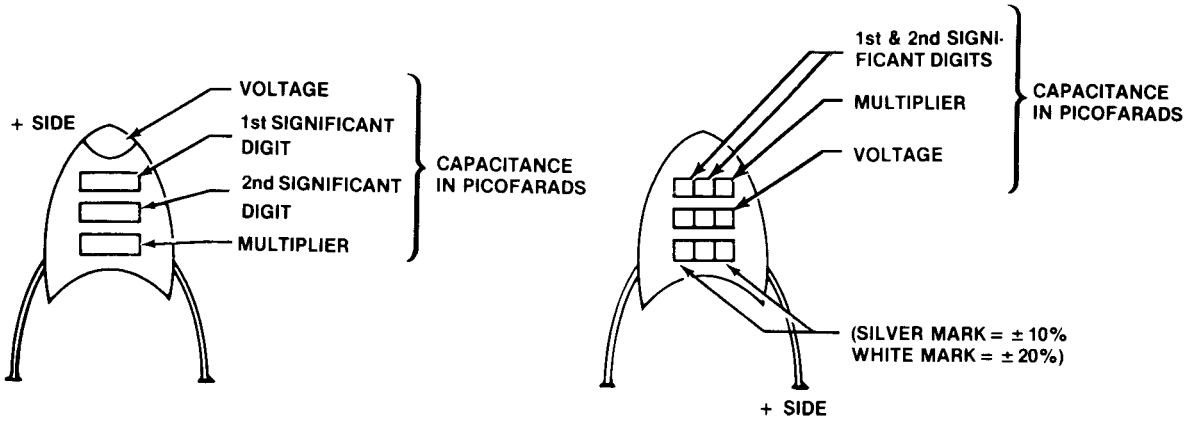


Figure 4 Color Codes for Capacitors

The other coding system for capacitors is similar to the number code mentioned for variable resistors. An example is the code 104P. Such a code is used on some mylar caps, or on radial caps applied as de-spiking capacitors on boards such as Asteroids™.

In this number code, the first two places (1 and 0) are the significant digits, and the third place is the multiplier or number of zeroes that follow. The letter *P* stands for picoFarads.

Therefore, this example of ***104P*** equals 10 x 10,000 or 100,000 pF. This value is then further reduced to eliminate the five zeroes: you move the decimal point six places to the left to convert to μF, and the result is .1 μF.

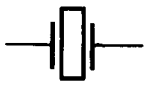
D. Crystals

Certain materials are sensitive to voltage. When a voltage is applied to such a material, it will be under stress and vibrate. By choosing the correct material, size, and shape, you can control the frequency of the vibration.

An electronic component made with such a material is called a ***crystal.*** Made most often of quartz, crystals are available in different sizes and frequencies. The frequencies are always stamped on the crystals, and typical frequencies you might encounter are 10 to 14 mega-Hertz.

A frequency of 1 Hertz is one cycle or vibration per second. Since ***mega*** means times one million, crystals typically vibrate at the incredible speed of 10-14 million times per second. In addition, they do so with great accuracy—namely at the rated speed ± .005%.

The schematic symbol of a crystal is:



Crystals are used in clock circuits on all video game boards, and in oscillator circuits of monitors. A crystal cannot be repaired; when it is bad you must replace it.

E. Coils

When a current flows through a wire, a magnetic field is created around the wire. The field from one strand of wire is very weak, but if many strands or coils of wire are placed close together, the separate magnetic fields will interact with each other and become strong. An example is a simple electromagnet.

If the current is constant, it will create a strong magnetic field, as well as a voltage. If the voltage suddenly changes polarity, the strong field will try to oppose the sudden change. In other words, the "induced" voltage from the first field will oppose the new voltage.

1. Inductors

A component with a coil of wire inside is known as an ***inductor*** or a ***choke.*** Its schematic symbol is:

With alternating current (AC), the polarity changes constantly, and an inductor will oppose the changing current, or try to block AC. Direct current, because it is constant in polarity, will flow through these components easily. The ability of a coil to oppose AC is known as ***inductance.***

Inductance is measured in Henrys. Just like capacitors, inductors have a certain amount of resistance (called ***reactance***) to AC voltages of different frequencies.

Since inductors block sudden changes in voltages or AC, they can be used to filter out AC or transient spikes that are on a DC signal line. Small transients are created whenever a switch closure happens (due to the mechanical composition of switches).

Engineers can eliminate this switch "bounce" by using inductors to prevent transients from reaching the digital circuitry. Inductors are used for this purpose on games such as Lunar Lander™, Asteroids™, and Missile Command™.

Inductors also offer resistance to frequency-sensitive circuits, so they are used in monitor filter and oscillator circuits. Similar to resistors and capacitors, inductors are often marked with their values in Henrys.

2. Transformers

If you place two coils close together, their magnetic fields will interact. Their induced voltages will also interact and be transferred from one coil to the other. The amount of voltage transferred depends on the size of the coils or number of windings.

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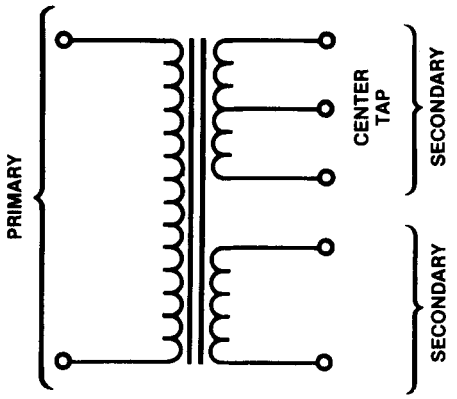
If you apply 117 VAC to one coil, then you'll also find a voltage on the other winding. The 117 VAC side is called the ***primary,*** and the second winding is the ***secondary.*** In addition, the secondary may have a wire connected to its center, which is called a ***center tap.*** All of these parts collected together are called a ***transformer.*** The schematic symbol for a transformer is shown below:



A transformer may have several secondary windings. Some of the most common secondary winding voltages found in video games are 6.3, 16.5, 25, 30, 65, and 80 VAC.

Sometimes the secondary voltages are printed directly on the transformer. Others have numbered terminals or color-coded wires. To find out what voltage is on each lead, look at the schematic.

You should check transformers for the presence of all secondary voltages. If they are not present, then check the primary to make sure it has the correct voltage going to it. Transformers that are bad cannot be repaired; you must replace them.

Uses of Transformers: Transformers are used in the power-supply section of video games. They may also be used to convert one voltage to a higher one. An example of this is the ***flyback transformer*** in a television or monitor that "steps up" the primary voltage to a much higher one (for example, 24,000 volts).

Transformers can also be used to transfer voltage signals from one circuit to another. This type is called a ***coupling transformer*** and is found in television monitor circuits.

F. Diodes

1. The "Charge" Principle

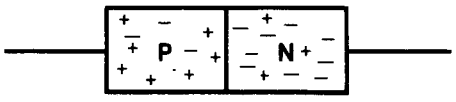
All material in the universe is made up of atoms. The main subatomic parts that carry an electrical charge are protons (+) and electrons (−). Opposite charges are attracted together, and identical charges repel each other. You have probably seen this principle work with two magnets.

Because of these characteristics, an electron will be attracted to a positively charged particle, the proton. In addition, two electrons will repel each other, as will two protons. Keep this in mind as you remember the statement mentioned at the beginning of this chapter: ***electricity is the flow of electrons.***

2. How Diodes Are Made

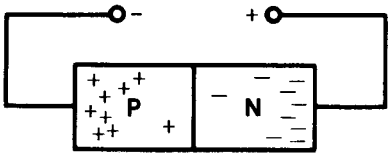
Chemists can put an excess of protons or electrons in a certain material. Let's assume that the material with the excess protons is called ***P***, while that with an excess of electrons is called ***N***.

To simplify this abstract idea, imagine doing the following. You glue some P material to some N material; then you glue a wire to each end of this "assembly." Refer to the illustration below:



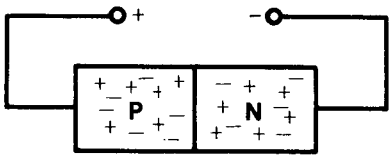
Remember that a power supply has two terminals. The ***ground*** end is the side with an excess of electrons, while the positive side has an excess of protons.

Suppose you connected the N material to the + of the power supply, and the P material to the ground side. Refer to the picture below:



The N electrons will flow to the + supply, shown at the top of the picture, and the P protons will flow to ground (shown with – sign). The result is that no current flows through the P/N junction.

If you reverse the leads to the power supply, the electrons from the N material will flow ***through the P material*** to the + end of the power supply. Now you have current flowing through the P/N junction, as shown below:



3. Properties of Diodes

The P/N material and its wires are known as a ***diode***. The wire connected to the P side is called the ***anode***; the wire at the N side is the ***cathode***. Supplying voltage to a diode is called ***biasing*** it. The schematic symbol for a diode is:

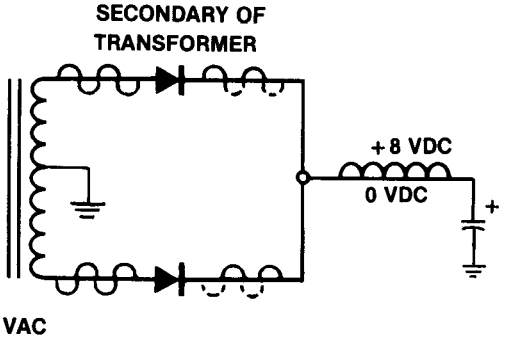
When you first connected the diode so no current flowed through it, it was ***reverse-biased.*** When you later turned around the leads, it was ***forward-biased***, and current went through. Therefore, diodes have the property of conducting voltage in one direction, but not the other.

If you supply AC to it, the diode will only conduct when it's forward-biased, and will be off when it's reverse-biased.

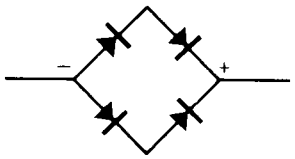
Suppose the diode conducts when the AC signal has a positive voltage, and then it's non-conducting during the negative part of the waveform. The diode is now being used to obtain only a positive voltage from the AC. This is called ***rectifying*** the AC voltage to a positive DC-type voltage.

More specifically, when a diode conducts only half the time, it is called a ***half-wave rectifier***, since you have only half the waveform. This application of diodes is commonly used in power-supply circuits.

If you add another diode so it conducts during the negative half of the waveform, plus you add the two signals together, your waveform will be much closer to DC. This is called a ***full-wave rectifier***, and is commonly found in the power supply of most video games. The schematic symbol for it is:



By connecting four diodes together, you create a ***bridge rectifier***. This type of rectifier is usually found on video-game PCBs; its schematic symbol is:



The most common types of diodes are made of germanium and silicon, two chemical elements. A diode must have a certain voltage applied to it before it will conduct current. Silicon diodes require about .7 volt before conducting current, whereas germanium ones need about .3 volt.

Diodes can be used in circuits as switches. They do this by turning on or conducting current when they are given the proper conducting or ***threshold voltage***. In this case, they are known as ***switching diodes*** and are used on video-game PCBs.

As mentioned earlier, chemists can put an excess of protons in a material: this is called ***doping*** the material. It is possible to dope the P/N material of a diode so it has certain characteristics when it is reverse-biased.

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One trait it will have is maintaining a certain voltage. This type of device is known as a ***Zener diode***, and it regulates voltages in power supplies. Its schematic symbol is:

4. Light-Emitting Diodes

Certain materials give off light when electrons strike them. An example of this is the phosphor on the face of a television picture tube. The tube lights up when the electron beam inside hits it.

By mixing some phosphoresent material with the normal P and N materials in a diode, the diode will light up when electrons pass through it. This type of diode is known as a ***light-emitting diode***, abbreviated as ***LED***. Its threshold voltage is higher than for normal diodes—usually between 1.8 and 2.5 volts. Its schematic symbol is:

The light it emits depends on the phosphor used. The radiation may be visible to humans: in this case, the LED is used as an indicator light. Engineers use LED indicators on video-game PCBs to show that power is on the board, or to show that the steering circuitry is working on some of the video driving games. LEDs are also part of the playfields of some video games, such as Video Pinball™.

LEDs can also emit light that is invisible to humans (it radiates only in the infrared frequencies). Such a light-emitting diode is commonly used on steering boards in both driving and Trak Ball™ type of games.

G. Transistors

A device known as a ***transistor*** results from connecting two diodes back to back. The two types of transistors, then, have PNP or NPN material.

A transistor has three leads: the emitter, the base and the collector. You can turn on an NPN transistor by applying forward-biased current to the emitter/base junctions (see Figure 5). Turn on a PNP transistor by applying reverse-biased current to the emitter base.

A POSITIVE OR LOGIC HIGH ON THE BASE WILL TURN ON AN NPN TRANSISTOR.

COLLECTOR	N	L
BASE	P	H
EMITTER	N	L

COLLECTOR	P	H
BASE	N	L
EMITTER	P	H

NEGATIVE OR A LOGIC LOW ON THE BASE OF A PNP TRANSISTOR WILL TURN IT ON.

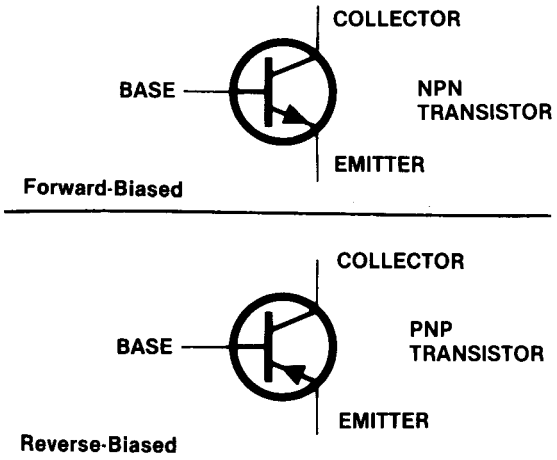

Figure 5 Current Flow in a Transistor

1. How Transistors Work

The base of the transistor is like a valve on a water pipe. When the valve of the pipe is closed, no water flows through, and the pipe is turned ***off***. And when the valve is fully open, all the water available flows through the pipe—the pipe is turned ***on***. The pipe can be compared to the transistor, where the water droplets are electrons.

The ***fully-open*** water valve compares to electrons flowing through the semiconductor material. In this instance, we say the material is ***saturated***, since all the available electrons are flowing through the device. In the transistor this occurs when both the emitter/base and base/collector junctions are ***forward-biased***.

The ***fully-closed*** valve compares to electron flow through the semiconductor material being shut off. In this second instance, we say the material is ***turned off***. In the transistor this occurs when both the emitter/base and base/collector junctions are ***reverse-biased***.

These two conditions are similar to a switching diode. Such a transistor is called, logically, a ***switching transistor***. The voltage on the transistor's base is one of the factors controlling whether the transistor is switched on or off (supplying current flow to a circuit or not).

If you set the water valve to various positions in the middle region (not fully on or off), you can control the amount of water passing through the pipe.

The corollary in electronics is a transistor in its ***active state***. This occurs when the emitter/base junction is forward-biased and the base/collector is reverse-biased. The amount of electrons (current) that will flow depends on how far the junctions are forward- and reverse-biased. An active-state transistor is used in circuits as an amplifier.

2. Uses of Transistors

Transistors can be connected in various in circuits. They can match the resistance or reactance of other circuits, can allow for voltage or current gain (which is why they are used as amplifiers), or they can invert the input signal.

By connecting one transistor amplifier to another, you can greatly increase the voltage or current. This is called ***cascading*** different stages of transistor amplifiers. Such a circuit is often found in monitors.

When you increase the voltage or current by cascading, you increase the power output. You can also buy a readily available device with several transistors put into a single housing or "package." This device is called a ***Darlington transistor***. It's used to handle lamps and other things in video games that require greater power than can be handled by a single transistor.

Chemists can also dope a transistor with material sensitive to light. The amount of light reaching the transistor's lens determines the threshold voltage on the base of the transistor. This device is called a ***phototransistor***.

Similar to an LED, the phototransistor can be made sensitive to certain frequencies of the light spectrum. Games commonly use infrared-sensitive transistors. An example of this is a phototransistor that picks up light signals radiated by infrared-emitting LEDs.

Engineers frequently use such a combination of components on steering PCBs to determine direction and speed of a steering wheel or Trak Ball™ being turned. When the photo LED and phototransistor are molded together into one plastic package, they are known as an ***opto-coupler.***

You will find the opto-coupler used on newer steering boards. The phototransistors used without LEDs (for detecting light intensity) were designed into the older games such as Outlaw® and Qwak®.

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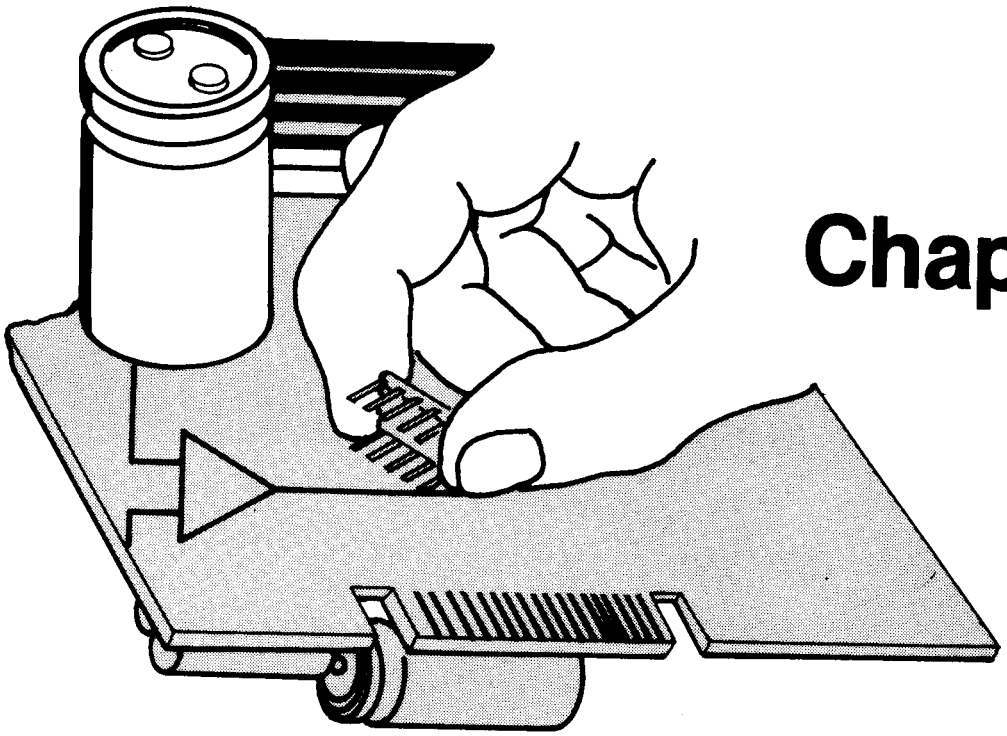

Chapter 5

Introduction to Integrated Circuits

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A. IC Pin Configurations

Integrated circuit "packages" come in many sizes, from the simpler small ones with 8 pins (or legs), to the large microprocessor chips with 40 pins. ICs are always marked with index notches or indentations to show proper orientation when inserting them into the PCB. Look at any Atari video game board, and you'll see that the notches (except for the microprocessor) face towards the edge connector. ***Never insert an IC backwards, as you will probably destroy it, the moment you apply power!***

Pins are identified by number; counting starts with the first pin to the left or counterclockwise from the index notch (as viewed from the top). The illustrations in Figure 1 show three typical ICs and how their pins are numbered.

B. How to Find ICs on a Printed-Circuit Board

Integrated circuits are arranged on boards in a grid pattern. Hold an Atari video-game PCB with the component side facing you and the edge connector at the right. The horizontal ***rows*** are numbered from 1 to about 12 (depending on the board's length), starting at the left. The vertical ***columns*** are lettered from A to about R, starting at the bottom. ***Important: Note that the grid system never uses G, I, O, or Q: these letters are too easily confused with the numbers 6, 1, or 0.***

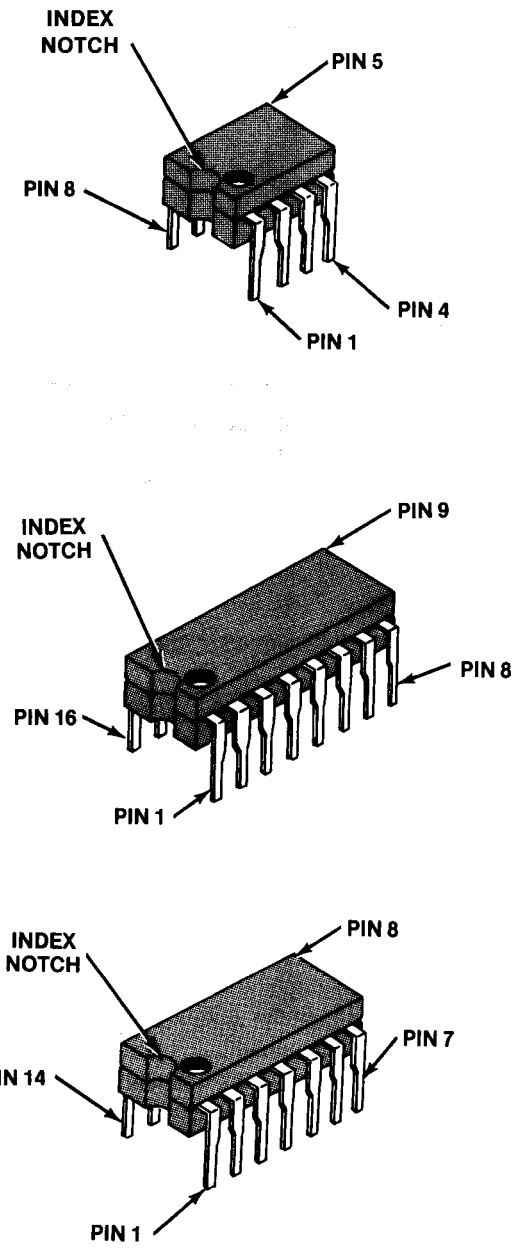

Figure 1 IC Pin Configurations

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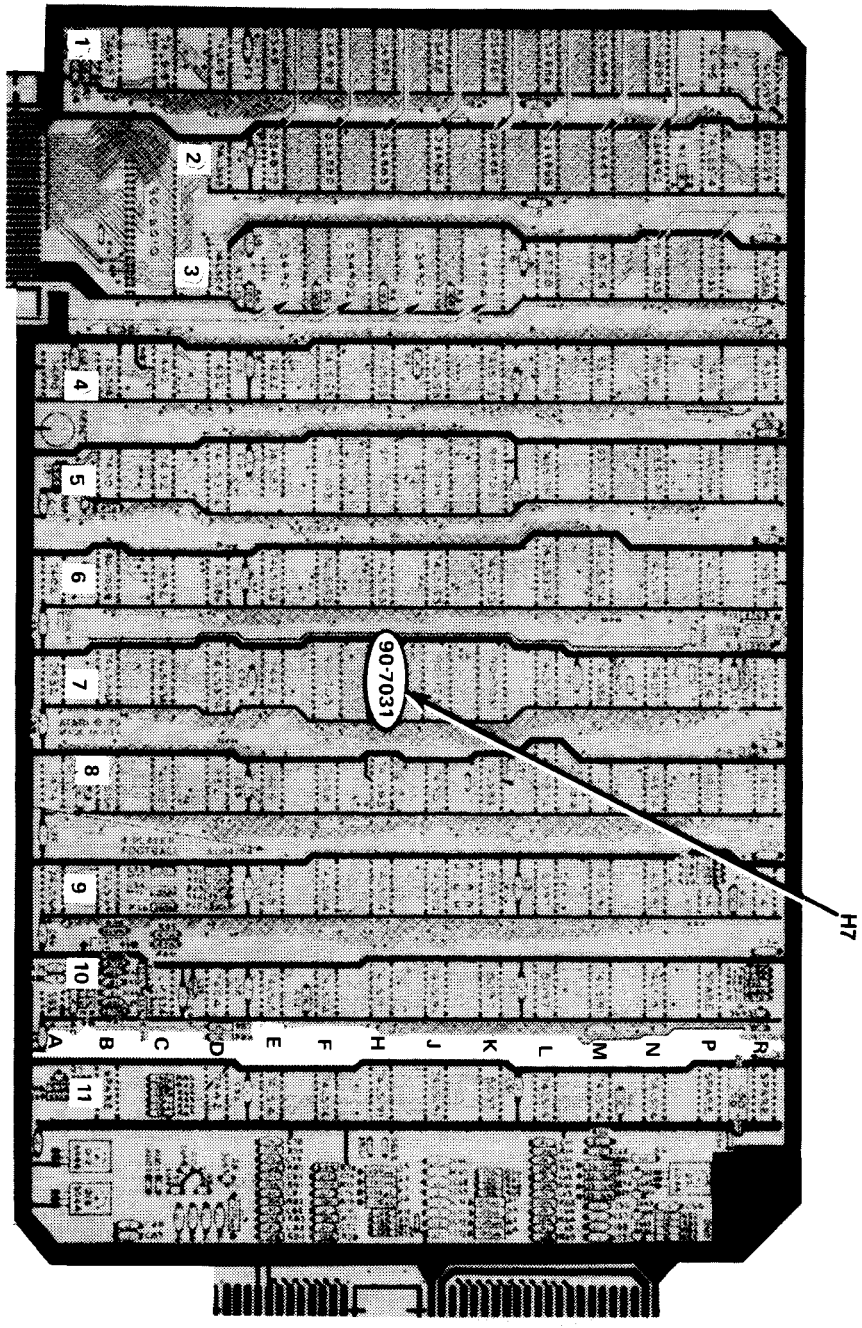

Figure 2 Typical PCB Grid Pattern

On all coin-op game boards made by Atari up through spring 1980, you will find the grid system identified in metal, wherever space permits. Sometimes several numbers or letters have to be eliminated or shown elsewhere, because the components don't provide enough space.

Since spring 1980, all new Atari PCBs are silk-screened in yellow ink to show the grid system and all resistor, capacitor, diode, etc. reference designations. The grid system is easier to use, since every IC will have its grid location silk-screened right next to it.

For example, at the intersection of row H and column 7 you will find chip H7 (see Figure). And if you want to talk about this chip's pin 1 specifically, then you would call it H7-1.

Sometimes the PCB design requires a chip to straddle two rows: this often happens with ROMs and PROMs. In such a case, the chip would be identified as H/J7, for example.

Generally speaking, chips used in the same circuit are located near each other. This is necessary because the designer must keep traces as short as possible to avoid picking up noise and other undesired signals.

C. How to Identify Device Types

Each chip is identified in the PCB assembly drawing and on its body by a 7400- or 9300-series part number. This is the number you use when looking up that chip in the manufacturer's data book.

Actual chips may sometimes have two or more manufacturer's type numbers. In addition, they may also have a batch number printed on them.

D. Date Codes

Chip manufacturers also imprint date codes on their integrated circuits. These codes sometimes cause confusion: chips made in 1974 have date codes that resemble 7400-series part numbers. If in doubt, cross-check the IC against the PCB assembly drawing and parts list printed in each game manual or parts catalog.

E. IC Manufacturers' Logos

All chips are marked in some manner to indicate manufacturer. Many symbols are fairly easy to recognize, but some show only an abstract symbol or logo of the company. The accompanying Figure 3 identifies all major chip manufacturers from whom Atari has bought or currently buys integrated circuits.

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Figure 3 Identification of Major Chip Manufacturers' Logos

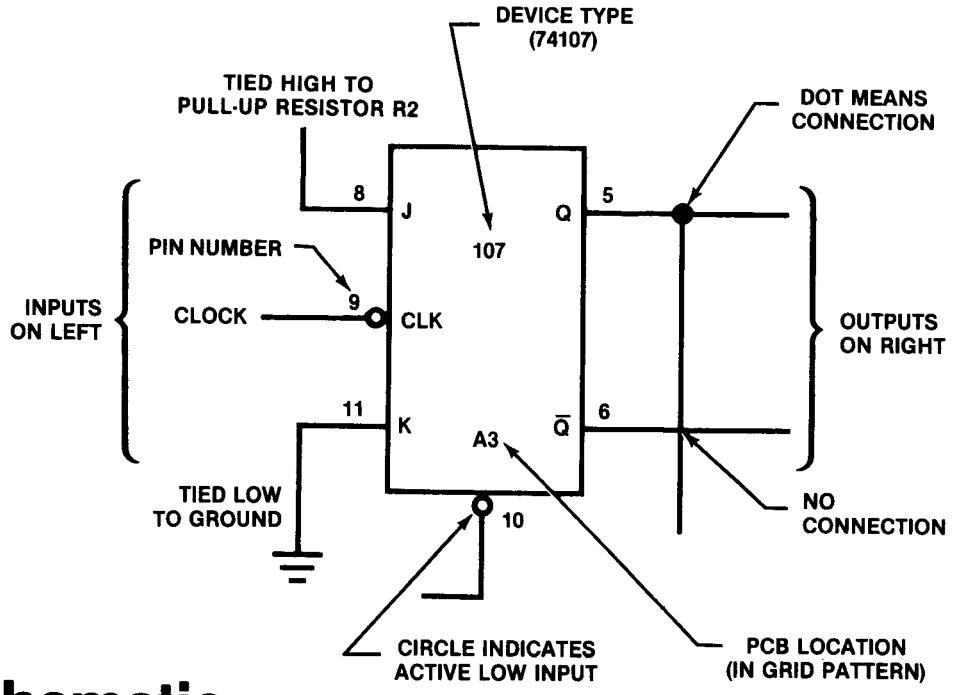

Figure 4 Schematic Symbol Conventions

F. Schematic Symbol Conventions

Figure 4 shows most of the integrated-circuit symbol conventions used on Atari schematics. Note that not all pins are shown in this figure, nor are they in the "correct" order. If any pins aren't shown, then they are unused.

Pins are depicted in "mixed-up" order, because schematic drafters try to keep inputs on the left or top side of the ICs and outputs on the right or bottom for clarity. If the pins were arranged in their physically realistic order, the lines would run everywhere, and the schematic would be incredibly hard to read. Schematics are ***symbolic*** representations—they are not intended to be physically realistic.

Schematics include many signals. No standards exist for naming signals, so game designers generally make up their own names. The result is a diversity of names from game to game, even if their function is the same.

Some signals such as CLOCK, H RESET, and V SYNC remain the same among different games. On the other hand, the signal that enables or disables the game's play-mode functions is variously known as ATTRACT, ATTACT, ATTRC, etc.

To save space on schematics, signal names are often abbreviated. Examples are H SYNC (horizontal synchronization), VLd (vertical load), UNMDACX (X-axis unmultiplexed digital-to-analog converter), and SHCON (sample and hold control).

Signals not easily given meaningful or characteristic names are simply identified by letters or numbers. For example, sync chain outputs are known as 1V, 2V, 4V, etc. You should also know that the letter *Q* always indicates an output, no matter how used.

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G. Binary Counting System

Everyone is familiar with the decimal counting system, because we normally use it every day. Moreover, this system (called "base 10") was developed because we humans have ten fingers or ***digits***.

Logic circuits, however, have only two "fingers": on and off. Therefore, all logic devices count by twos or in base 2, instead of tens. This counting method takes a bit of practice getting used to, but it's certainly not difficult.

A quick review: In the decimal system, each ***place*** contains successively higher multiples of ten. The first place is the "ones" place or 10^0 (any number raised to the zero power is 1). The second place over towards the left is the "tens" place or 10^1 (1 x 10). The third is called the hundreds place or 10^2 (10 x 10).

As an example, the number 256 consists of 2 in the hundreds place (or 200), 5 in the tens place (or 50), and 6 in the ones place (or 6). Adding these numbers results in 256. See Figure 5 to illustrate this example.

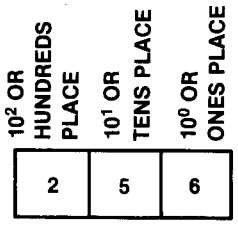

Figure 5 Decimal System Example

The binary system is similar, except that each place contains multiples of ***two*** instead of ten. The first position is the ones place or 2^0. The second is the twos place or 2^1 (1 x 2). The third is the fours place or 2^2 (2 x 2), and the fourth is the eights place or 2^3 (2 x 2 x 2).

DECIMAL EQUIVALENTS	BINARY PLACES 2^3(8)	2^2(4)	2^1(2)	2^0(1)	HEXADECIMAL EQUIVALENTS
0	0	0	0	0	0
1	0	0	0	1	1
2	0	0	1	0	2
3	0	0	1	1	3
4	0	1	0	0	4
5	0	1	0	1	5
6	0	1	1	0	6
7	0	1	1	1	7
8	1	0	0	0	8
9	1	0	0	1	9
10	1	0	1	0	A
11	1	0	1	1	B
12	1	1	0	0	C
13	1	1	0	1	D
14	1	1	1	0	E
15	1	1	1	1	F

Figure 6 Decimal, Binary and Hexadecimal Equivalents

Figure 6 illustrates the binary counting system up to the decimal number 15. The first decimal (zero) has no value, so "0" appears in the top row. The figure shows that the decimal number 1 is expressed in binary as 0001, and the decimal 2 is 0010 in binary. Three is the addition of 1 plus 2, or binary 0011.

When dealing with digital devices, each individual numeral is called a ***bit*** The entire number is known as a ***word***. Looking at Figure 6, you can see that it takes only one bit to express the decimal number 1, two bits for 2 and

3, three bits for numbers 4 through 7, and four bits for 8 through 15. A fifth bit is required to express the number 16. (Each bit is a higher power of 2.)

Atari rarely uses numbers greater than nine bits in electronic video and pinball games because, generally speaking, 454 is the highest number needed. If nine bits are used, we can express numbers as large as 111111111 (or decimal 511).

Although we can count and express numbers by using numerals, computers use low voltage for "0" and high voltage for "1". In *Section I, Basic Digital Laws* you will see how a binary counter chip can count from 0000 to 1111 at its four output pins—by sequentially producing highs and lows.

H. Hexadecimal Counting System

As we saw earlier, to express the number 16 in binary, for example, requires 5 bits. Furthermore, binary numbers are cumbersome and can easily be mis-written with their long strings of zeros and ones.

In the early 1960s a system for computers was devised to reduce the number of bits required for expressing numbers—it was base 16, or the hexadecimal system—often called "hex". The term comes from combining ***hex*** (six) and ***decimal*** (ten).

Hexadecimal digits consist of the usual ten digits we're accustomed to, plus the first six letters of the alphabet. Therefore, the base 10 and base 16 counting systems are equated as follows:

Decimal Numbers

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

0 1 2 3 4 5 6 7 8 9 A B C D E F

Hexadecimal Digits

The only conversion between counting systems that you might have to do in electronic game repair is from hex to binary. To do such a conversion, simply find the equivalent binary number for each hex digit and write it underneath that hex digit. Then read the binary number directly as you wrote it out.

For example, hexadecimal 3DF4 is converted into binary as follows:

3	D	F	4
0011	1101	1111	0100

I. Basic Digital Laws

1. High, Low and Pulsing

The function and operation of logic circuits is described using standard symbols and notations. All logic functions are described using the ***positive logic convention.***

This is a system of notation where the more positive of two levels is called the high or 1 state, and the more negative is called the low or 0 state. Remember the introduction to binary counting mentioned earlier? We said a logic circuit can be only on or off. That's the same as these two states. Specifically, the high state means the existence of +2.4 to +5 VDC. If a signal is low, then the voltage will be 0 to +0.8 VDC.

In addition to being either high or low, a signal could also be pulsing. This means it's changing states. The logic probe illustrates this very graphically when the pulse indicator turns on, after the probe is applied to a circuit.

2. Active Low Signals

Signal names are often written on schematics with overscoring, such as $\overline{\text{HALT}}$-$\overline{\text{STROBE}}$—pronounced "haltstrobe not". These signals go low to initiate events (an ***active low***). Those not overscored go high when active. Overscored signals are ***always*** at the logic level opposite their non-overscored counterparts.

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3. Three Laws of Logic

All logic devices and circuits are constructed from three basic building blocks or laws: ***and,*** ***or*** and ***negation.***

The AND law states that when two signals are input together, the output is high only when ***both*** inputs are high.

The second law, the OR principle, states that the output will be high when ***either*** or ***both*** inputs are high. A variation of the OR theme is the Exclusive OR: in this case, the output is high when ***either, but not both***, input signals are high (i.e., both inputs must be in opposite states).

Negation, the third law, simply means that the output is always ***inverted*** from the logic level of the input.

J. Truth Tables

As you saw earlier, an IC can have either high or low inputs; the various combinations of inputs result in different outputs.

A ***truth table*** is simply a list of all the possible input/output combinations. Usually the table contains zeroes and ones to represent the lows and highs on all the IC pins (refer to Figure 7).

AND GATE TRUTH TABLE

INPUT		OUTPUT	
1	2	3	← PIN NUMBERS
0	0	0	
0	1	0	← LOGIC-LEVEL COMBINATIONS
1	0	0	
1	1	1	

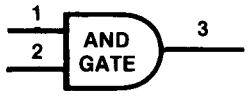


Figure 7 Explanation of Binary-System Truth Table

K. H, L, S and LS Device Types

Technicians who are new to electronics sometimes have difficulty properly identifying ICs. This is due to the fact that not all identification letters are marked on most ICs.

One series of parts uses transistor-to-transistor logic (shortened to *TTL*). Standard TTL logic typically can toggle or switch on and off as fast as 35 MHz, meaning 35 million times per second. However, this may be too slow for some applications.

Part numbers on ICs that start with ***74*** indicate a commercial-temperature-range TTL integrated circuit. ***54***- series parts work in temperature ranges given in military specifications. The ***54***- series withstands the much wider temperature range that occurs in satellites and missiles.

1. "H" Devices

When you add an *H* after the series number, you are indicating the part is a ***high-speed*** TTL device. It typically can toggle at 50 MHz, but it also draws more power than other types of devices.

2. "L" Devices

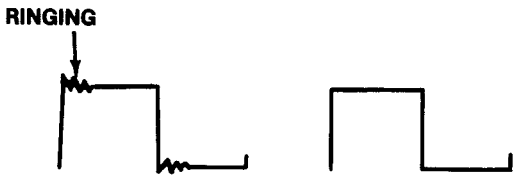
An *L* added after the series number means the part is a ***low-power*** device—using less current than a standard TTL device. Specifically, we mean the power to provide necessary current to activate the input pin. A low-power IC is usually slower than a standard TTL device.

3. "S" Devices

Adding an *S* to a part number indicates that it's a ***Schottky type***. This term evolves from the German scientist W. Schottky, who discovered an effect that produces a much "cleaner" output than standard TTL devices.

Specifically, the characteristics of this effect are an output that is more sharply defined than with standard TTL. This improvement to standard TTL greatly increases the usable speed of a device because of its cleaner waveform. Schottky-type devices can switch off in less than 1 nanosecond, or 1 billionth of a second. (This is about 3,000 times faster than standard TTL.)

You can see the difference of the cleaner output from Schottky-type devices by comparing these two illustrations:



TTL OUTPUT SCHOTTKY OUTPUT

4. "LS" Devices

As technology progressed, scientists took another step to improve IC performance. They combined low power consumption and the Schottky effect to build a part with a series suffix of *LS* (for ***low-power Schottky***).

This process allows flip-flops to toggle at up to 45 MHz, without an increase in the current needed to operate the device.

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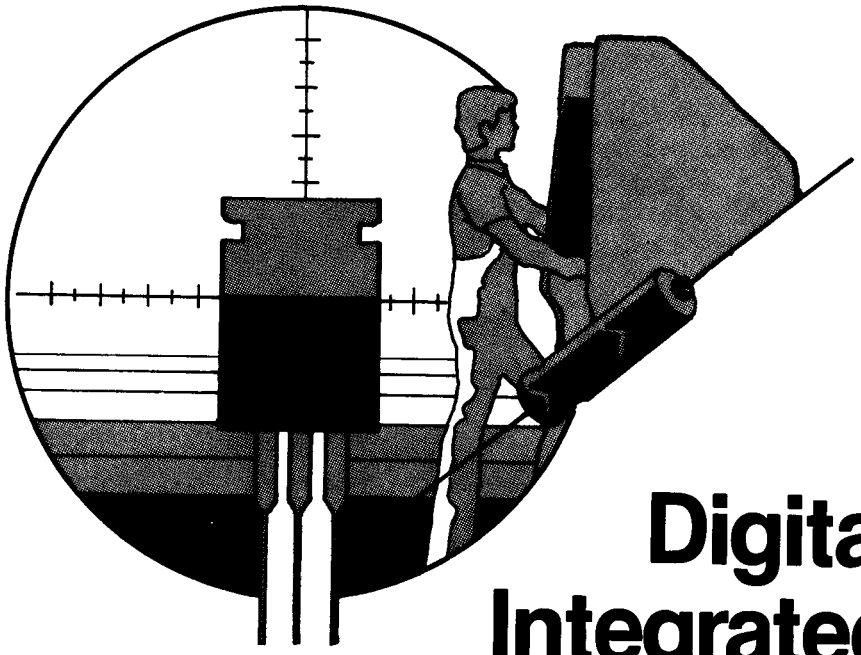
Chapter 6



Digital Integrated Circuits

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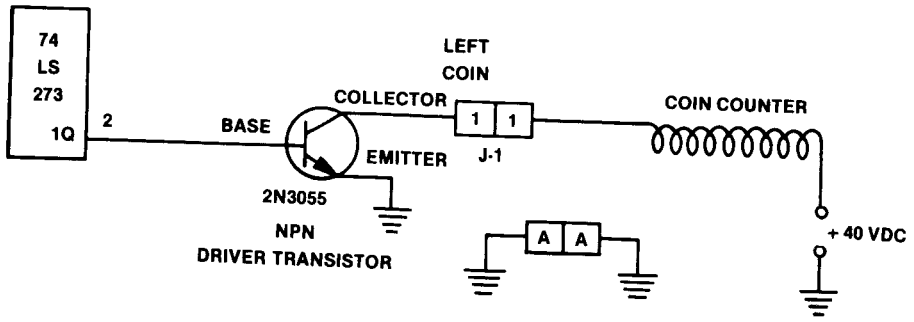
A. Transistors as Switches

The most common application of transistors in games is as a switch. They are used to turn on coils, lamps, motors and even audio circuits. In this type of application a few simple checks will verify the proper operation of a transistor.



The figure above represents an NPN driver transistor, as used in a typical game. When the base of this transistor goes positive or to a logic 1, the transistor is saturated. The collector voltage should be just above 0 VDC. It reacts like a switch supplying ground to the coin counter coil.

When this transistor is turned off, the collector voltage should be close to whatever the power supply is, in this case 40 VDC.

Generally speaking, transistor failures are caused by excessive current, temperature or a combination of both. You can use several instruments to check the characteristics of transistors. Some simple tests can be performed with an ohmmeter. Basically, an ohmmeter can check for opens or shorts in a suspected component.

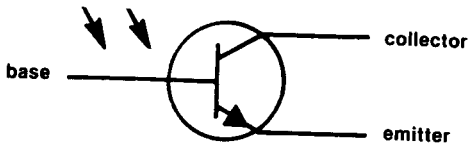
A word of caution. Some ohmmeters use a test voltage that on the highest resistance ranges could damage the component you are testing. Therefore, you should start testing with your meter set at R $\times$ 100 scale.

Note: The following tests are done using a Simpson 260 or equivalent.

The ohmmeter's power supply can be used to bias (turn on) the transistor under test. When testing a suspected bad transistor, place the meter leads between the emitter and collector. Note the meter reading, and reverse the meter leads. If this junction is good, both readings will be open or infinity.

Emitter-to-base readings will have one high reading, something less than infinity, and one low reading (not zero). Collector-to-base readings will be about the same. Silicon transistor readings will be higher than germanium types. Power transistors will usually have lower readings in both directions than the smaller types.

Photo transistors change emitter-to-collector current in proportion to the amount of light applied to the base.



The figure above shows a schematic symbol of a phototransistor. When not exposed to light, this part has a high emitter-to-collector resistance. When light strikes the base, the emitter/collector resistance is low and causes the transistor to conduct.

Some phototransistors have a base bias resistor to aid in low-light conditions. Phototransistors are used in switching applications. When pulsed by a light-emitting diode, a typical phototransistor will turn on and off in less than 10 microseconds.

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B. Logic Gates

To minimize repair time on solid-state systems, it is important to be able to understand and interpret the information given in the schematics. This section is primarily for the person who understands what's going on with the board but still gets a little confused with logic gates. The confusion may be in regard to when outputs should be high or low, and if what you see with a scope or a logic probe is correct.

If you have memorized truth tables for all gates, congratulations to you. If you always match the right table with the right gate—wonderful. If you don't, or if you have never memorized gate names, symbols, and truth tables, take heart—there is an easier way.

Logic gates are electronic switching circuits. To avoid confusion remember:

1.) is the symbol for AND.

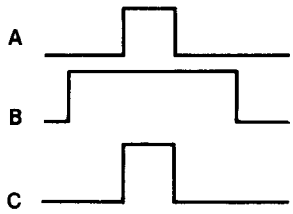
2.) is the symbol for OR.

If you get these mixed up, remember that looks like the letter "D" in AND.

1. AND Gate

The output C is high when inputs A ***and*** B are high.

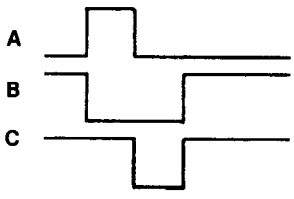
SCOPE PICTURE:



2. OR Gate

Output C is high when either input A ***or*** input B, or both A and B are high.

SCOPE PICTURE:



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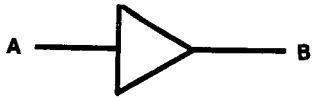
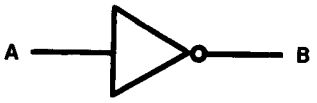
3. Buffer



This simple device does not change the level of a signal. A high input results in a high output, and a low input results in a low output.

SCOPE PICTURE:

4. Inverter



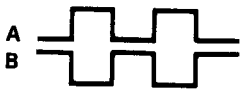
The inverter, as the name implies, ***inverts*** the logic state of a signal. When input is high, output is low. On simple AND or OR gates the small circle (without the buffer) represents the inverter.

As we look at more complicated devices (such as integrated circuits), there is a key to logic levels:

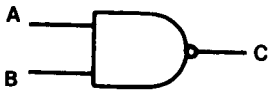
- A small circle indicates the active state of that signal is a logic low (0VDC to .8VDC).
- No circle indicates the active state of that signal is a logic high (2.4VDC to 5VDC).

A small circle on an input pin means that input is active low. A small circle on an output device means the output is active low.

SCOPE PICTURE:

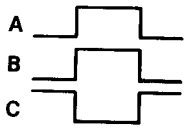


5. NAND Gate



The NAND gate consists of an AND gate and an inverter (represented by the small circle). If input A and input B are high, output C will be low (inverted).

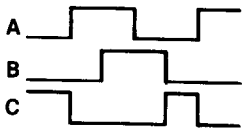
SCOPE PICTURE:



6. NOR Gate

The NOR gate combines the OR gate and an inverter. Output C is high only when inputs A and B are low.

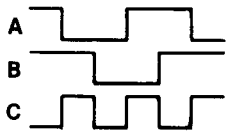
SCOPE PICTURE:



7. Exclusive OR Gate

The extra line on the input to the OR gate could be called "only." The output is high (no circle) ***only*** when A or B is high, but not when both A and B are high.

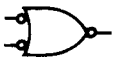
SCOPE PICTURE:



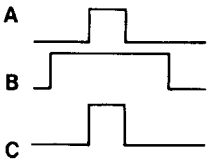
Simply stated, the output of an ***Exclusive OR*** gate is high only when the inputs are at opposite logic levels.

Here's another one you see used. Just read it like any other. Output C is low, when input A is ? and B is ? . If you said low, low, you are right.

Now is there a functional difference between

 and ?

SCOPE PICTURE:



Besides logic gate symbology, the actual signal name will also tell you what that signal should be doing. There are two ways you will see a signal—with a line over it or not.

For example:

START

$\overline{\text{START}}$ (Start not)

A signal without a line over it is normally low (about 0 volts) and goes high to do its job. In other words, START would be low until you start the game; then it would go high (almost 5 volts).

$\overline{\text{START}}$ would be high and go low when the game is started.

Another way of looking at it is that a "not" or negated signal (line over it) goes low when it is performing its function (true).

Now you have several keys that will tell you what you should see at any given point on a schematic:

- Read a gate (regardless of number of inputs) starting from the output—high or low. Note that the output will be in the correct state ***only*** when the inputs are satisfied.
- Note the logic symbol (AND gate or OR gate).
- Look at the inputs to determine if that signal should be going low (circle) or going high (no circle).
- Look at the signal name:
  Does it have a line over it? If so, it is normally high and goes low to be true or to perform its function.
  If it doesn't have a line over it, then it is normally low and goes high to be true or to perform its function.

By learning to use these few simple keys, you will soon find that reading schematics will become easier. In addition, your ability to understand and troubleshoot solid-state equipment will improve greatly.

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C. Flip-Flops

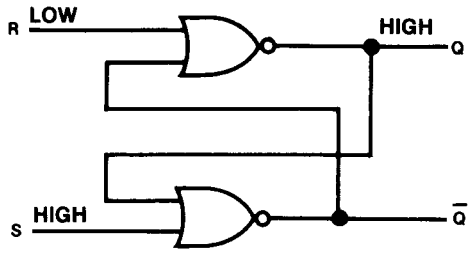
1. RS-Type Flip Flops

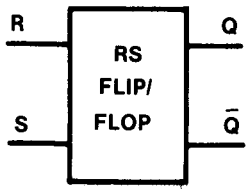
Flip-flops are devices that have complimentary outputs. When Q is low, $\overline{Q}$ is high. In other words, outputs are always in opposite states.

A flip-flop normally stays in a steady state until an input signal causes it to switch to the opposite state. The figure at the right is an example of a simple flip-flop made from single gates.

INPUTS		OUTPUTS	
R	S	Q	$\overline{Q}$
L	L	Previous State	
L	H	H	L
H	L	L	H
H	H	Not Allowed	

Assume that R is low and S is high. The high on S causes $\overline{Q}$ to go low along with a low R, making Q high.





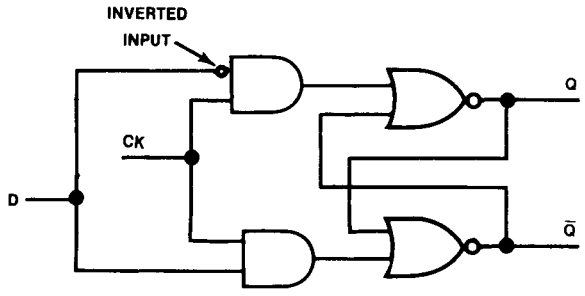
RS-Type Flip-Flop Schematic Symbol

2. D-Type Flip-Flops

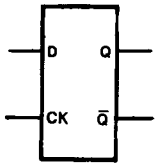
Another type of flip-flop is a D-type. It has one data input and a clock pulse input to trigger the data flow. A D-type flip-flop using gates and an inverter is illustrated below.

INPUTS		OUTPUTS	
D	CK	Q	$\overline{Q}$
H		L	H
L		H	L

Whatever is on D will be on the output Q on the next rising edge of the next clock pulse.

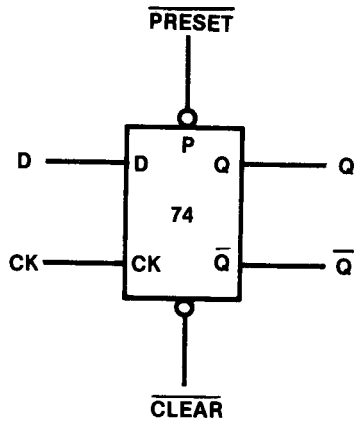


D-Type Flip-Flop Schematic Diagram



D-Type Flip-Flop Schematic Symbol

As shown below, two pins are added to our D-Type flip-flop; preset and clear. Both are active low.



Information at the input is transferred to the outputs on the positon edge of the clock pulse (if PRESET and CLEAR are both high).

INPUTS			OUTPUTS	
PRESET	CLEAR	D	Q	Q̄
L	L	L	H	H
L	L	H	H	H
L	H	L	H	L
L	H	H	H	L
H	L	L	L	H
H	L	H	L	L
H	H	L	L	H
H	H	H	H	L

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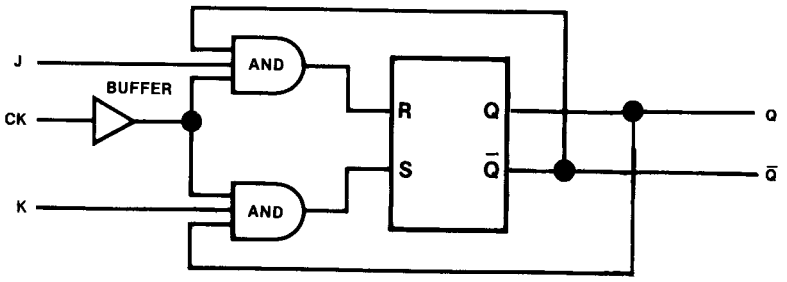
D. JK-Type Flip-Flops

A JK flip-flop is made by modifing the RS flip-flop, with the addition of a couple of gates for latching and clock trigger, as shown in the figure below.

1. If J and K are both low, there will be no change on the output.
2. If J is low and K is high, then the next incoming clock pulse will make the Q output low and make the $\overline{Q}$ output high.
3. If J is high and K is low, the next clock pulse will put Q high, and the $\overline{Q}$ will be low.

INPUTS		OUTPUTS	
J	K	Q	$\overline{Q}$
L	L	NO CHANGE	
L	H	L	H
H	L	H	L
H	H	Toggle	



JK-Type Flip-Flop Schematic Diagram

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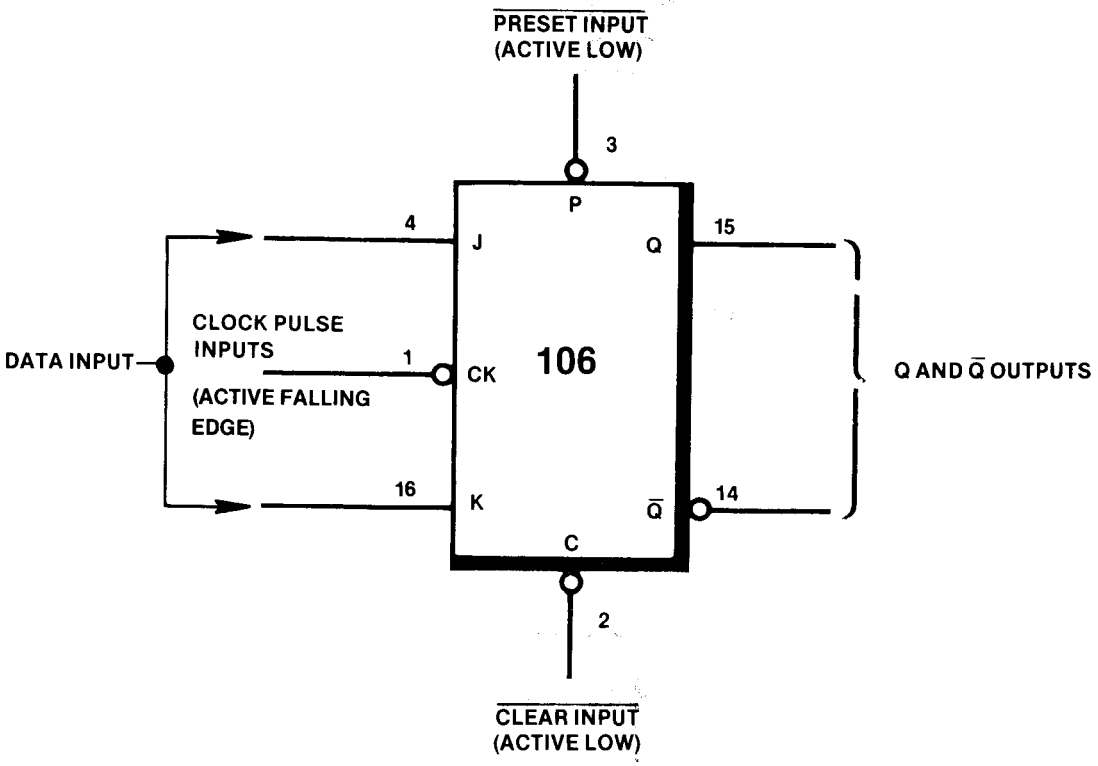
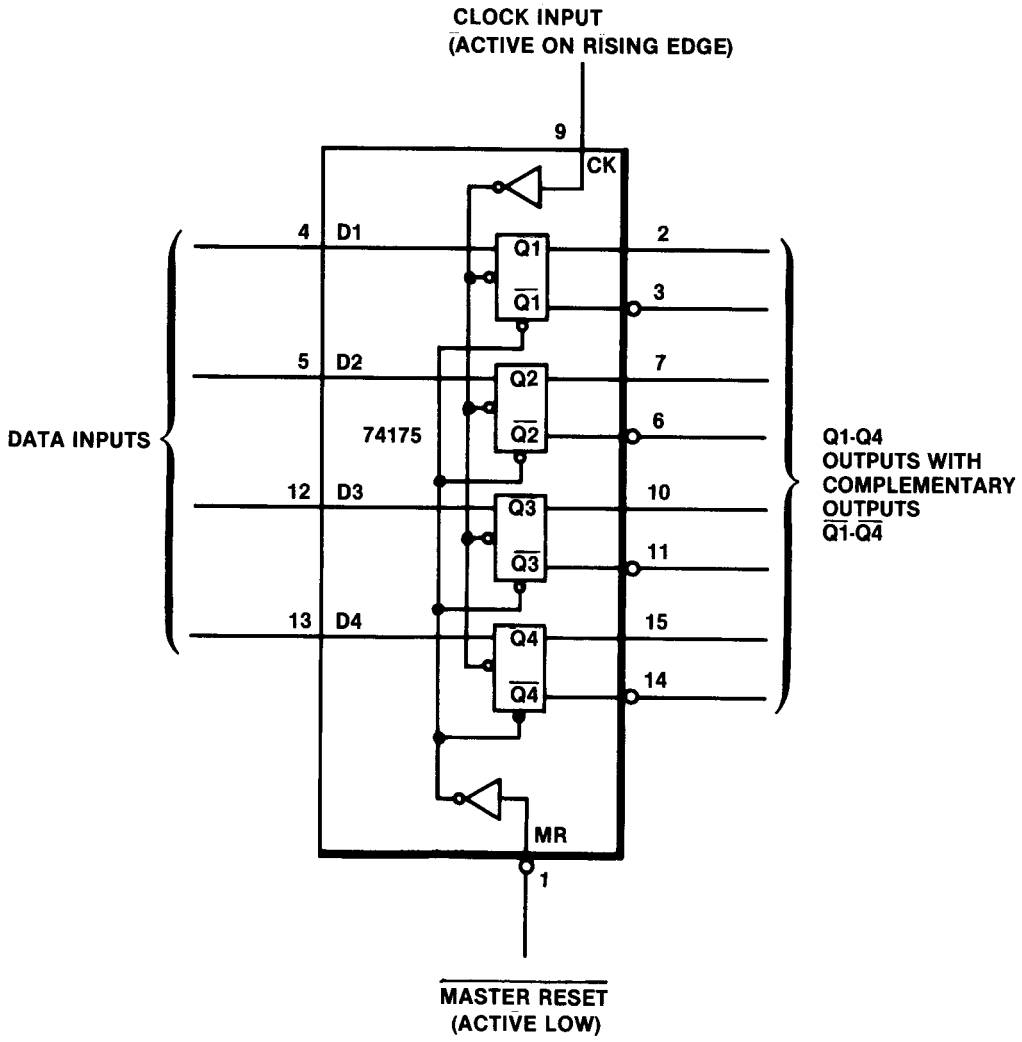


E. Quad Latch

The four flip-flops in a quad latch store the state of their individual D inputs during the low-to-high change of the clock (_┘‾). This loads individual Q and $\overline{Q}$ outputs.

$\overline{MR}$ (active low) resets all Q1-Q4 outputs low and $\overline{Q1}$-$\overline{Q4}$ high, independent of clock or data inputs.



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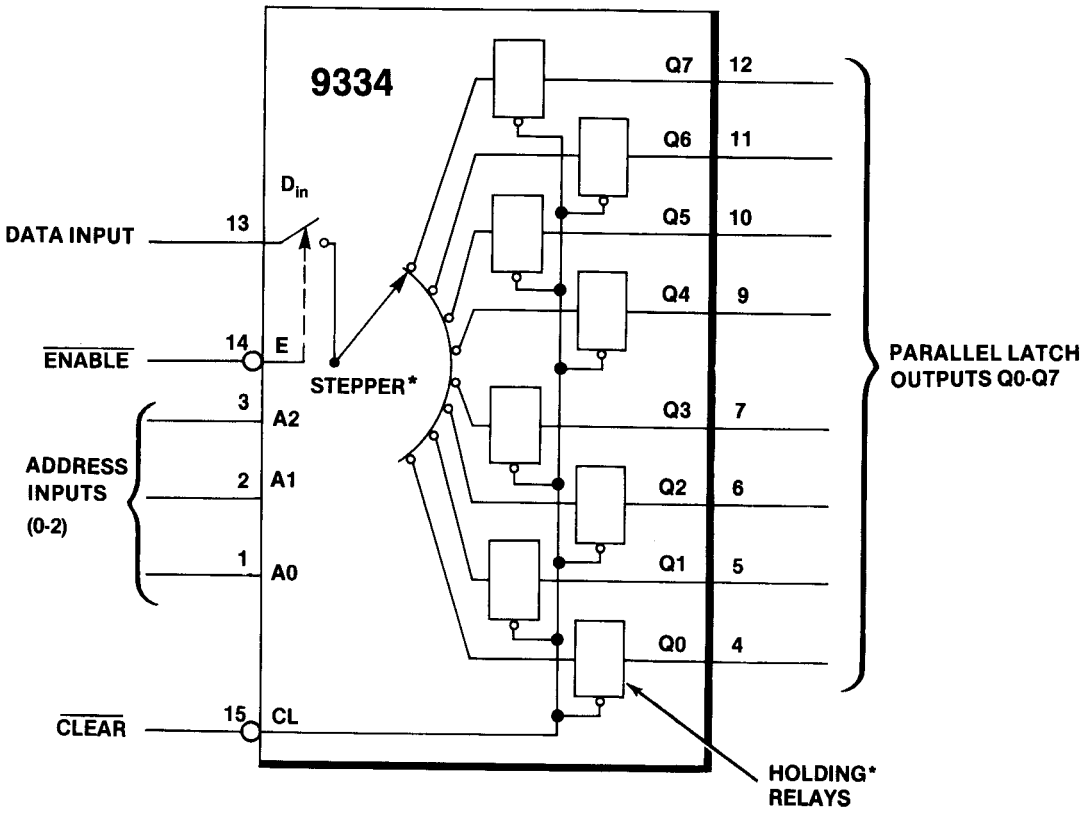
F. Addressable Latch

Address inputs select which output (Q0-Q7) will receive and latch data input. $\overline{\text{ENABLE}}$ should be held high while the address lines are changing. When the address lines stabilize and $\overline{\text{ENABLE}}$ is made low, DATA INPUT is transferred to the selected output.

The 9334 is capable of storing single-line data in eight addressable latches. It is also used as a 1-of-8 decoder with active-high output.



*For illustration, these terms refer to electromechanical devices.

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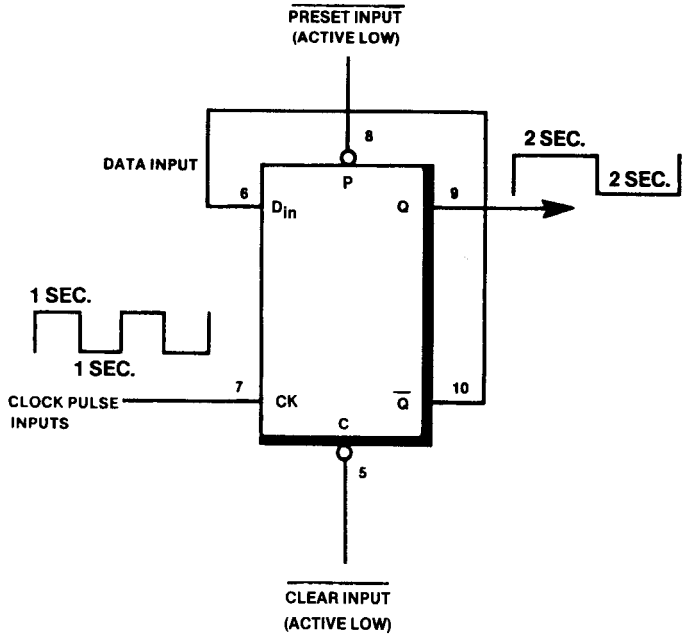
G. Counters

1. Divide-by-2 Counter

On the second clock pulse, the outputs will toggle. Since the Q output supplies new data to the input, it takes two complete clock cycles in, to provide one complete cycle out. Thus, we have a divide-by-2 counter.



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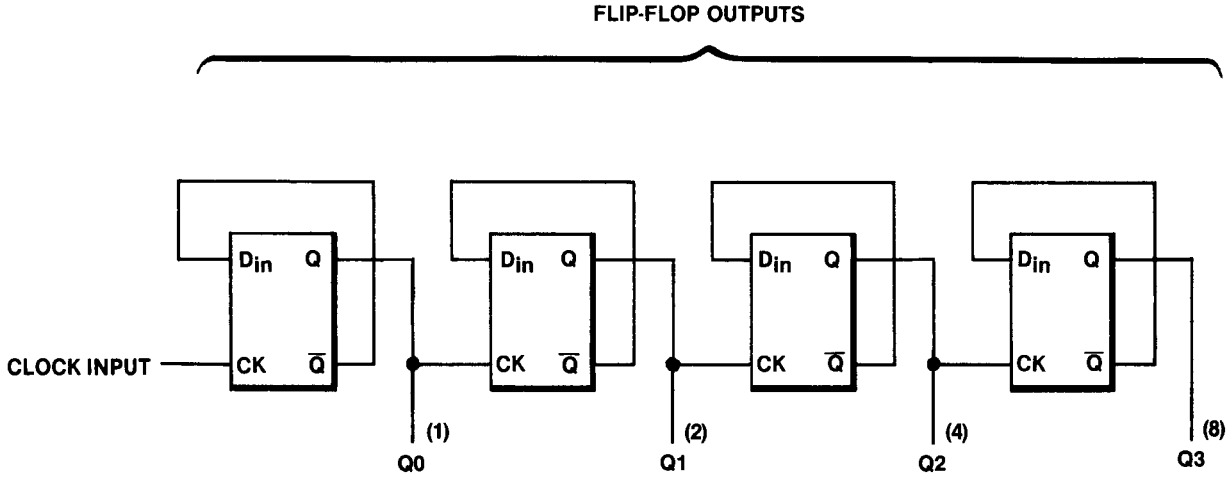
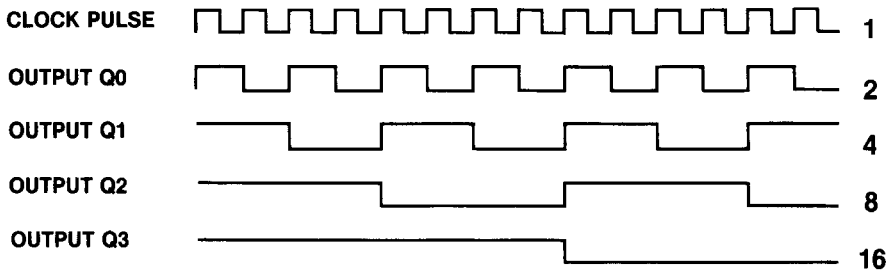
2. Counter Chain

By *cascading* (or connecting in series), you have a binary counter. There are two distinct states in a binary counter.

A *ripple counter* is one that uses the output of one flip-flop to trigger the input of the next flip-flop.



Example of Divide-by-2 D-Type Flip-Flops in a Divide-by-16 Counting Chain.



Timing Chart of a Divide-by-16 Counter

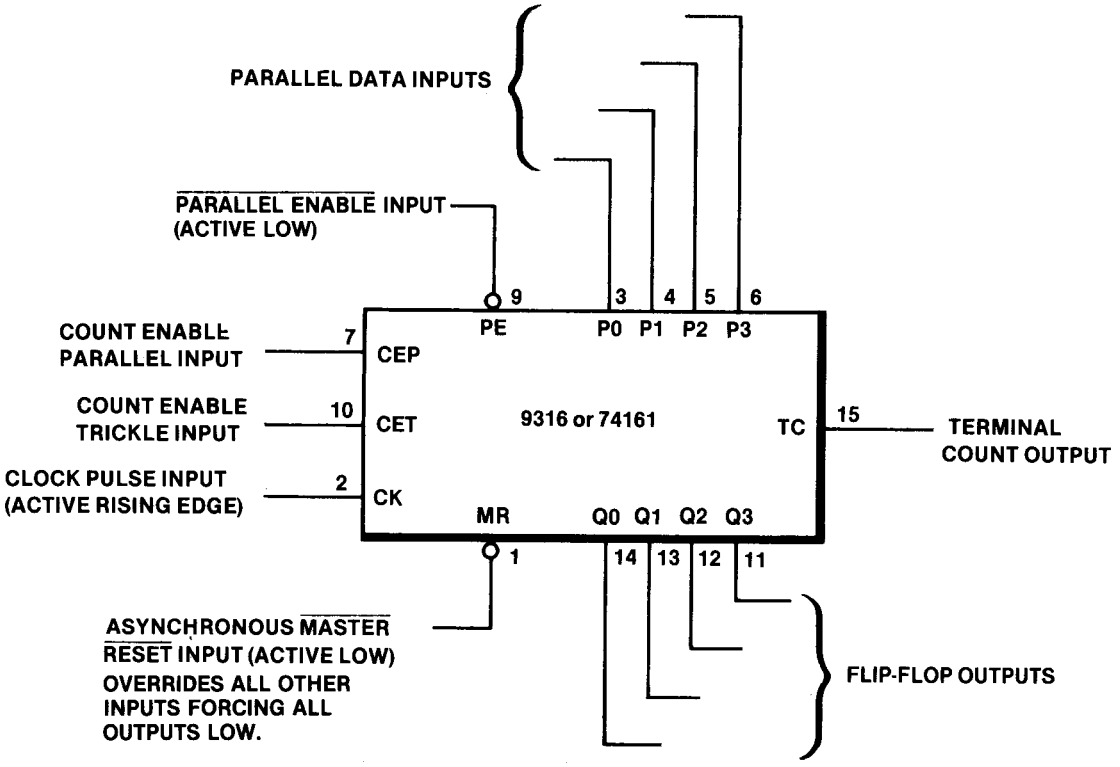
3. Presettable Binary Counter

The $\overline{PE}$ input (active low) overrides counting, allowing information on the parallel data inputs to be loaded into the counter on the next rising edge of CLOCK INPUT.

CEP (count enable parallel input) and CET (count enable trickle input) permit counting when both are high, if $\overline{PE}$ and $\overline{MR}$ are high. CEP or CET inhibits counting if either are low.

Parallel-load capability permits the counter to be preset to any desired number (in other words, the starting number from which this device will count).

Terminal count (TC) output is high when CET is high, and the counter is at its maximum count.



Changes of the Q outputs occur as a result of the low-to-high change of clock (CP).

Terminal Count is used in multistaging counters (by connecting TC to either CEP or CET of the next counter in a chain).

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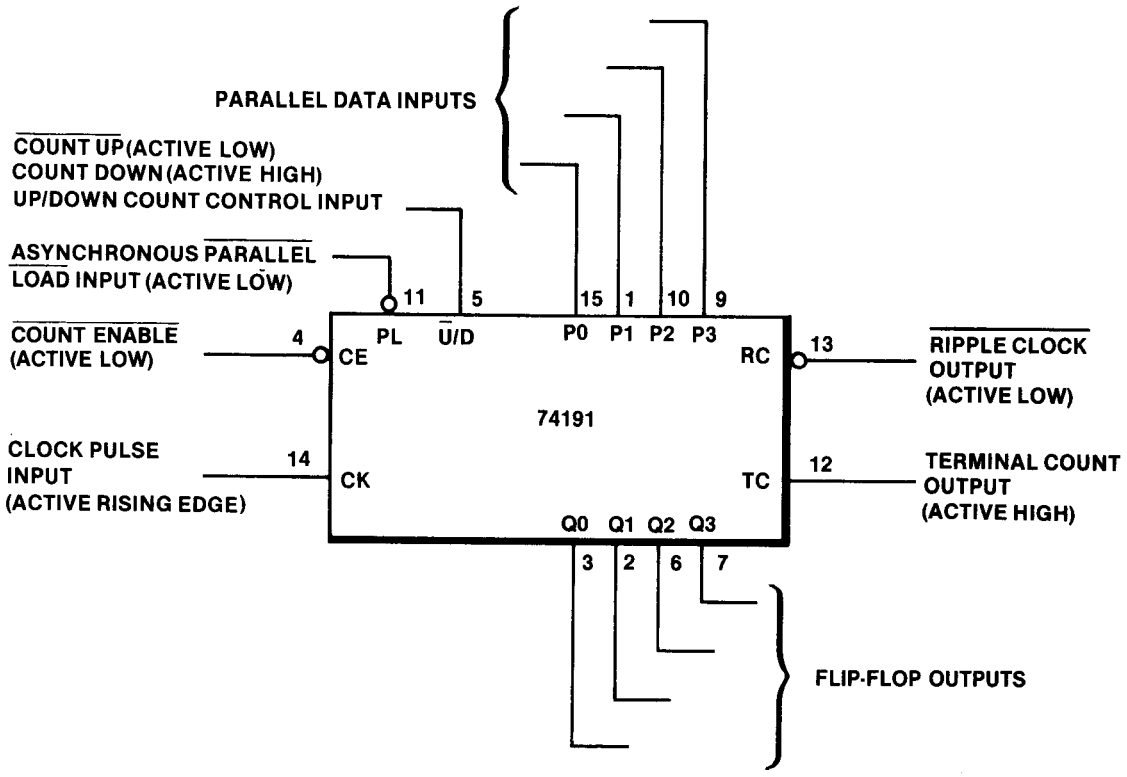
4. Up/Down Counter

If the parallel-load ($\overline{PL}$) input is low, information on the parallel data inputs (P0-P3) is loaded into the counter and appears on the Q outputs.

Parallel-load capability permits the counter to be preset to any desired starting number. $\overline{RC}$ output is normally high when $\overline{CE}$ (count enable) is low and TC (terminal count) is high. The $\overline{RC}$ output goes low during the clock cycle and stays low for one full clock cycle. When used for multistaging, TC output is used as the clock input for the next counter in a chain.

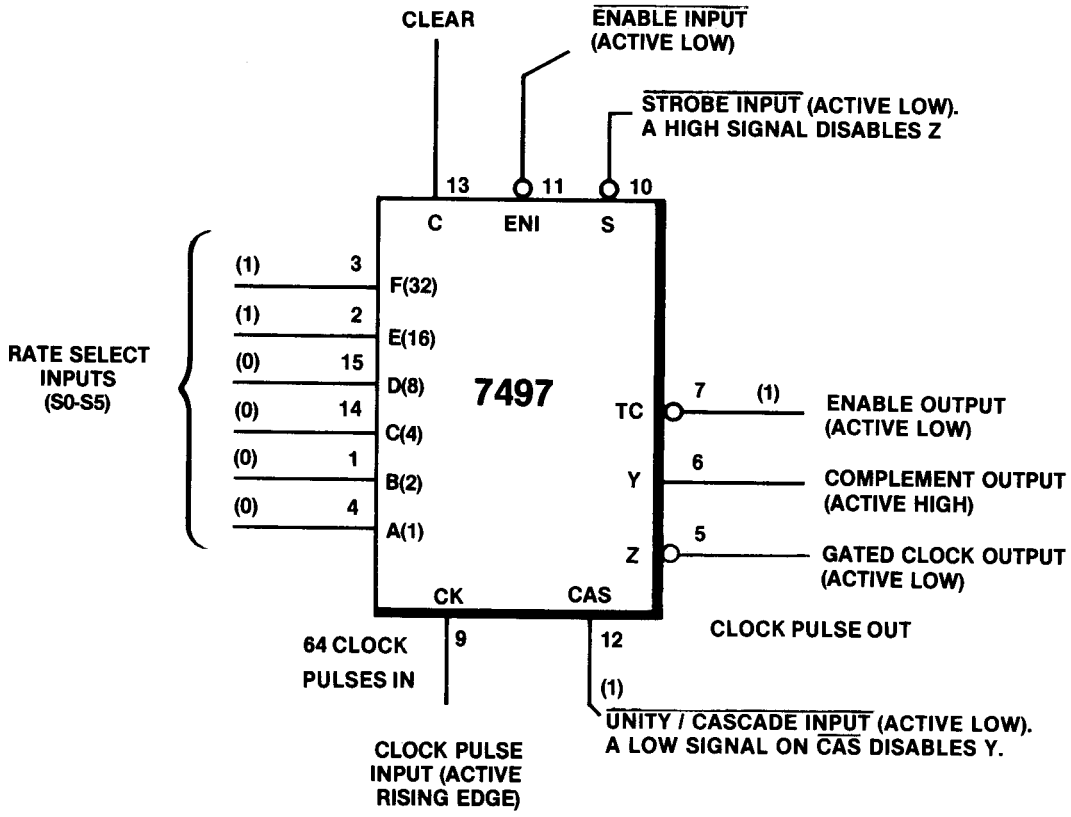
Terminal count (TC) output is normally low, and goes high when the counter reaches zero in the count-down mode or reaches maximum in the count-up mode.



H. Rate Multipliers

The master reset input (active high) prevents counting and resets the counter.

The output pulse rate relative to the clock frequency is determined by signals applied to the select (S0-S5) inputs.



The Z output is normally high and goes low when CK and STROBE INPUT are low and any of the inputs (S0-S5) are high. The Y output is the complement of output A and is thus normally low.

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MODE AND RATE SELECT TABLE (See Note 1)

INPUTS									CLOCK PULSES	OUTPUTS				NOTES
C	$\overline{ENI}$	$\overline{S}$	A	B	C	D	E	F		$\overline{CAS}$	Y	Z	$\overline{TC}$	
H	X	H	X	X	X	X	X	X	X	H	L	H	H	2
L	L	L	L	L	L	L	L	L	64	H	L	H	1	3
L	L	L	L	L	L	L	L	H	64	H	1	1	1	3
L	L	L	L	L	L	L	H	L	64	H	2	2	1	3
L	L	L	L	L	L	H	L	L	64	H	4	4	1	3
L	L	L	L	L	H	L	L	L	64	H	8	8	1	3
L	L	L	L	H	L	L	L	L	64	H	16	16	1	3
L	L	L	H	L	L	L	L	L	64	H	32	32	1	3
L	L	L	H	H	H	H	H	H	64	H	63	63	1	3
L	L	L	H	H	H	H	H	H	64	L	H	63	1	4
L	L	L	H	L	H	L	L	L	64	H	40	40	1	

H = HIGH Voltage Level
L = LOW Voltage Level
X = Immaterial

NOTES:

1. **Numerals indicate number of pulses per cycle.**

2. **This is a simplified illustration of the clear function. CK and S also affect the logic level of outputs Y and Z. A LOW signal on S will cause output Y to remain HIGH.**

3. **Each rate illustrated assumes A-F are constant throughout the cycle.**

4. **CAS is used to inhibit output Y.**

m	PULSE PATTERN AT OUTPUT Y
1	11111111111111111111111111111111101111111111111111111111111111111
2	11111111111111101111111111111111111111111111111111101111111111111
3	11111111111111101111111111111111101111111111111111101111111111111
4	11111110111111111111111101111111111111111011111111111111101111111
5	11111110111111111111111101111111011111110111111111111111101111111
6	11111110111111101111111011111111111111110111111101111111011111111
8	11101111111011111110111111101111111011111110111111101111110111111
10	11101111111011101110111111101111111011111110111111101111110111111
12	11101110111011111110111011101111111011101110111111101110111011111
14	11101110111011101110111011101111111011101110111011101110111011111
16	10111011101110111011101110111011101110111011101110111011101110111
20	10111010101110111011101010111011101110101011101110111011101110111
24	10101011101010111010101110101011101010111010101110101011101010111
28	10101010101010111010101010101011101010101010101110101010101010111
32	0 1 0 1 0 1... ...0 1 0 1

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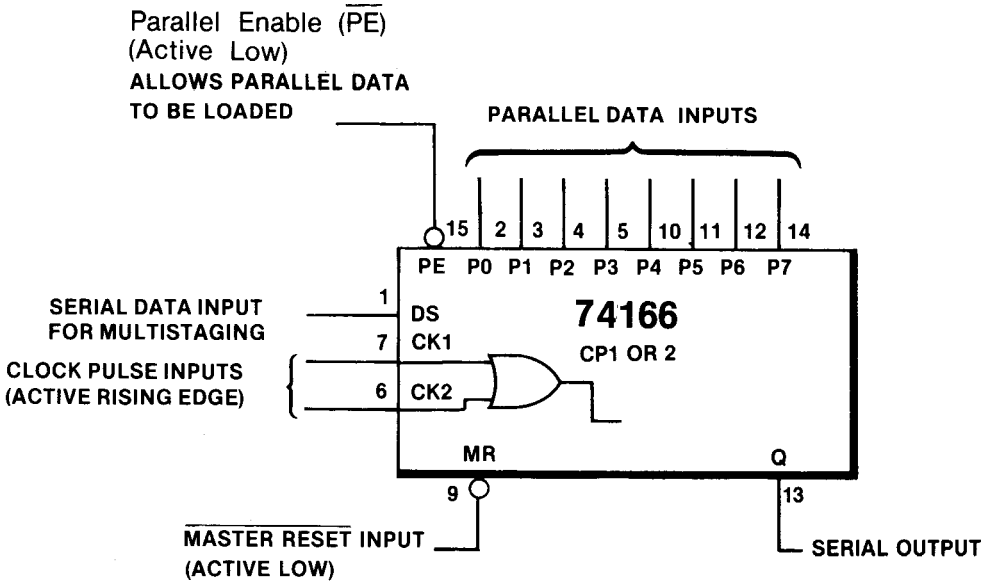
I. Shift Registers

A binary register is a group of flip-flops that are used for storing binary information. Information can be shifted in serial or parallel. Parallel is much faster but needs more hardware to maintain it.

Parallel-In/Serial-Out Shift Register



Information can be shifted left or right, and corresponds to multiplication or division. The number of flip-flops in the register determines its capacity—one flip-flop for each bit. Therefore, the register capacity is 2^n, where n is the number of flip-flops.

When $\overline{PE}$ is high, information is shifted from the serial data (DS) input to Q0. All data in the register is shifted one bit position—to Q0, Q1, Q2, etc. (it shifts one bit to the right). The first bit in is the last one out.

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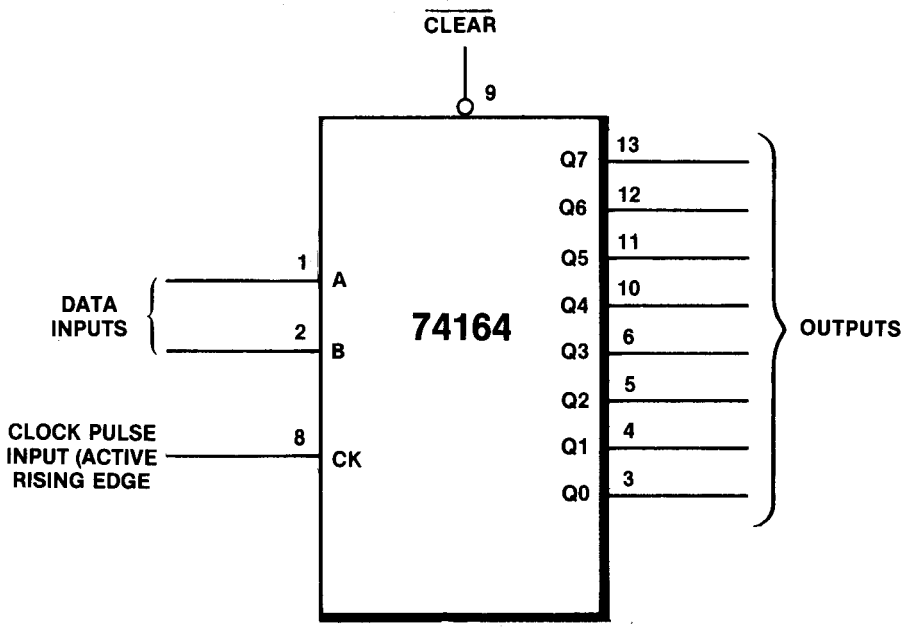
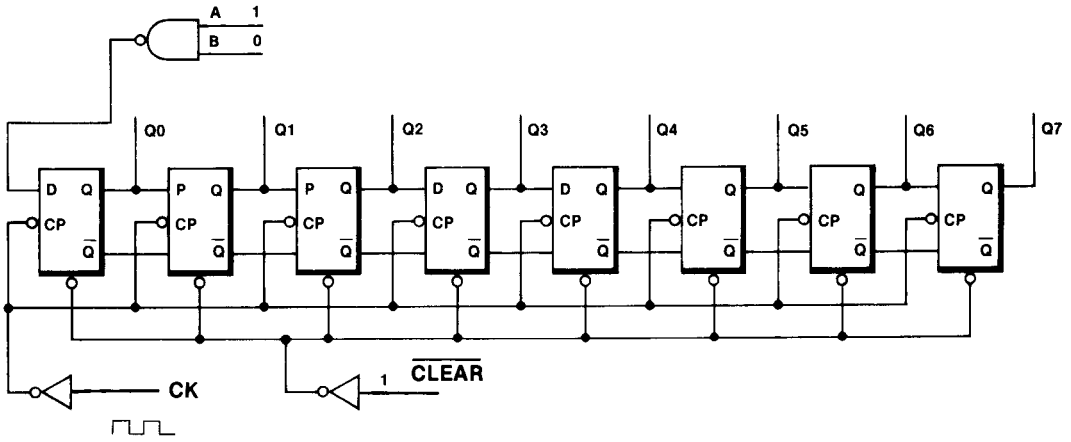
Parallel-Out/Serial-In Shift Register

The $\overline{\text{CLEAR}}$ (active low) overrides all other inputs and clears the register—forcing all Q outputs low.

Each low-to-high change of the clock input shifts data one place to the right.

Data is entered serially through one of two inputs (A or B). Either input can be used as an active high enable for data entry through the other input.



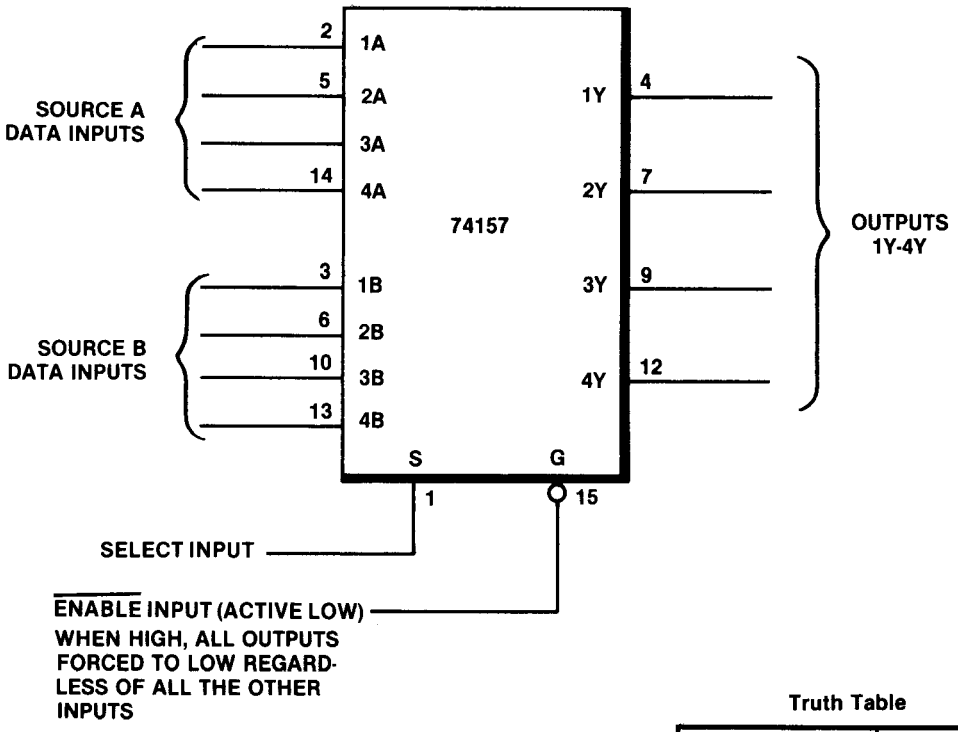


J. Multiplexers

A multiplexer is known as a ***data selector***—a circuit with a large number of inputs and only one output (the opposite of a decoder). The logic level on the output is determined by the logic level on only one input.

Four bits of data from two sources (0, 1) can be selected by using the common select (S) and enable (E) inputs.

1. Quad 2-Input Multiplexer (74157)

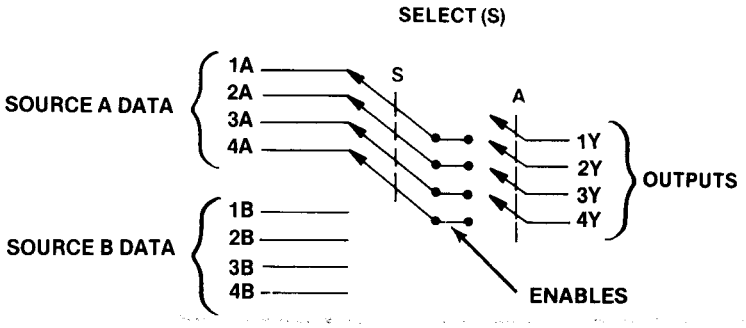


Truth Table

INPUTS				OUTPUT
$\overline{G}$	S	A	B	Y
H	X	X	X	L
L	H	X	L	L
L	H	X	H	H
L	L	L	X	L
L	L	H	X	H

H = High
L = Low
X = Immaterial

The example above shows a 4-pole, double-throw switch; position is determined by logic level on SELECT input.



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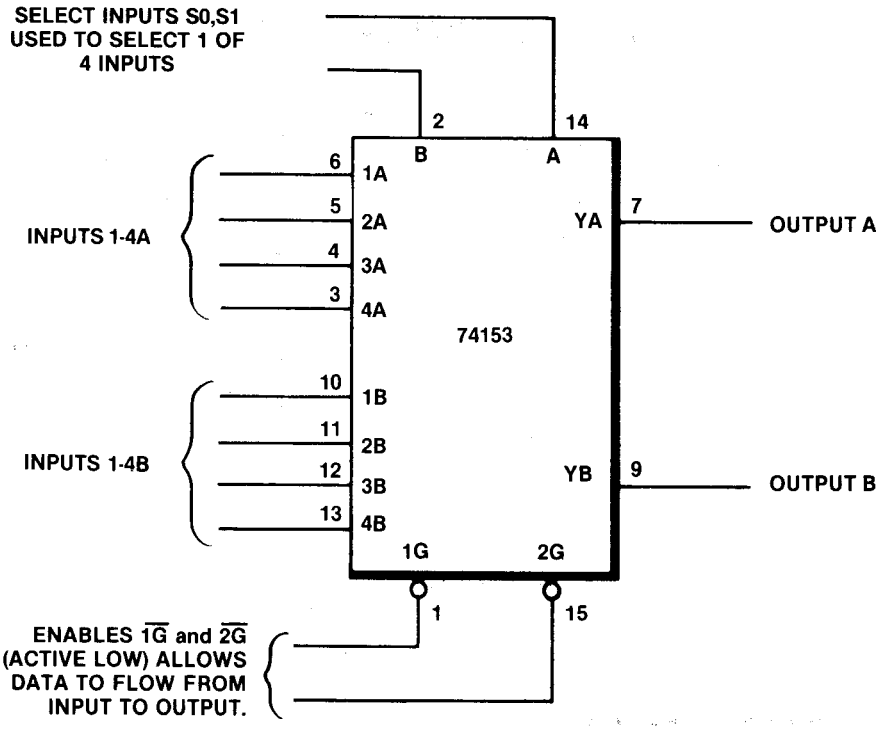
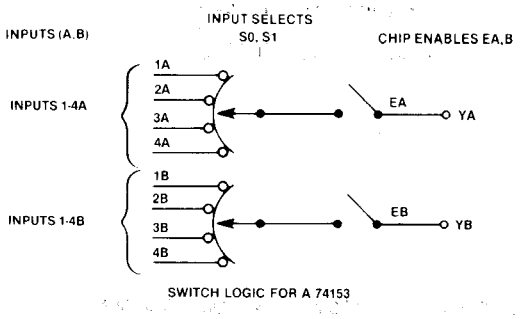
2. Dual 4-Input Multiplexer (74153)

The 74153 uses common select inputs and individual enables for each section. Each section, in turn, selects one bit of data from one of four sources.



L = Low
H = High
X = Immaterial



SWITCH LOGIC FOR A 74153

SELECT INPUTS		INPUTS (A or B)					OUTPUT
B	A	$\overline{G}$	1	2	3	4	Y
X	X	H	X	X	X	X	L
L	L	L	L	X	X	X	L
L	L	L	H	X	X	X	H
H	L	L	X	L	X	X	L
H	L	L	X	H	X	X	H
L	H	L	X	X	L	X	L
L	H	L	X	X	H	X	H
H	H	L	X	X	X	L	L
H	H	L	X	X	X	H	H

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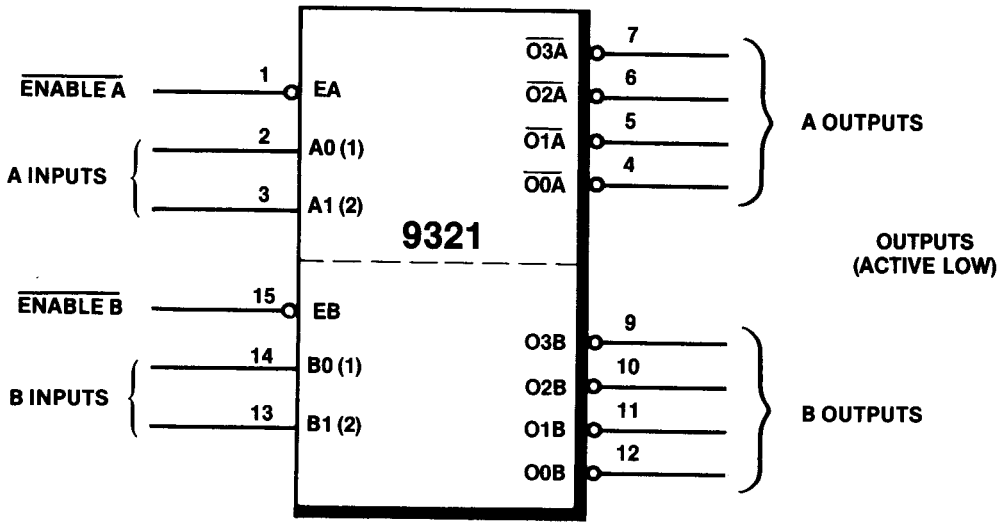
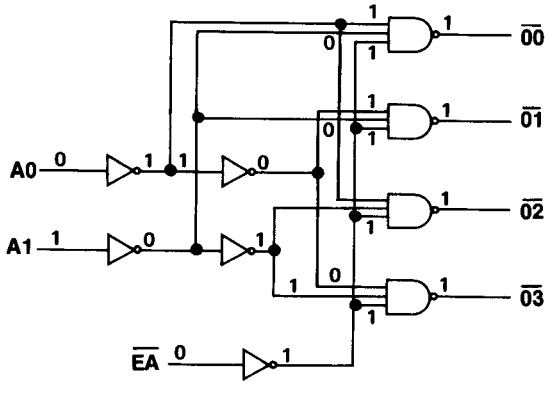
K. Decoders

A decoder converts information from one counting system to another, such as binary-coded decimal (BCD) to decimal.

1. Dual 1-of-4 Decoder

The $\overline{\text{ENABLE}}$ input (active low) when low allows output selection.





LOGIC DIAGRAM

TRUTH TABLE

INPUTS			OUTPUTS			
$\overline{E}$	A0	A1	$\overline{00}$	$\overline{01}$	$\overline{02}$	$\overline{03}$
L	L	L	L	H	H	H
L	H	L	H	L	H	H
L	L	H	H	H	L	H
L	H	H	H	H	H	L
H	X	X	H	H	H	H

H = High
L = Low
X = Immaterial

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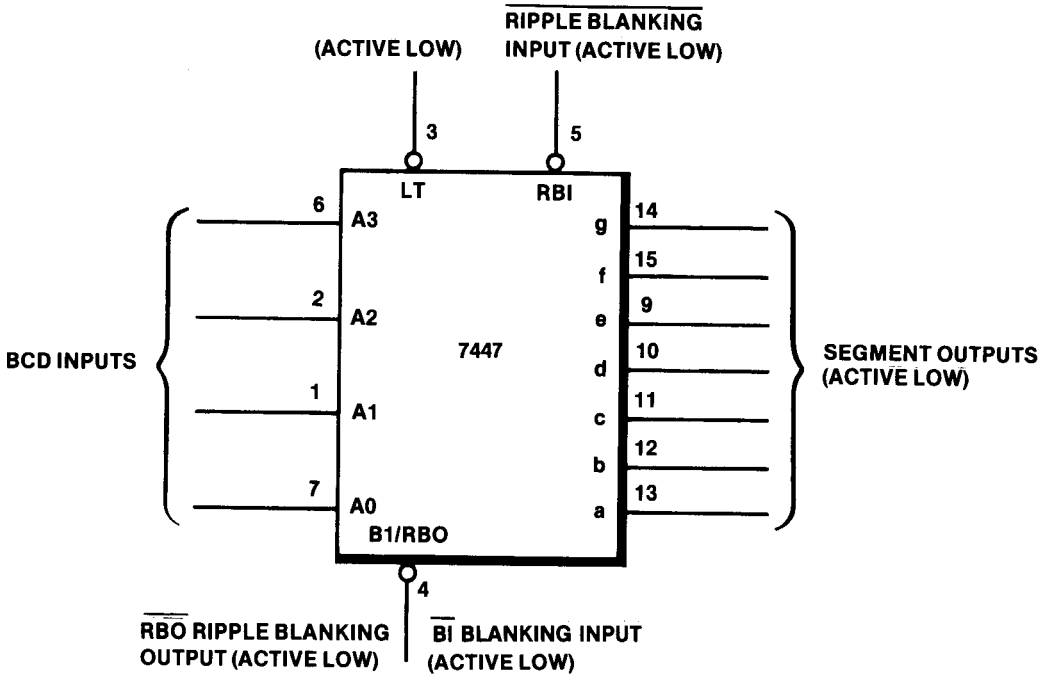
2. BCD-to-7-Segment Decoder Driver (7447)

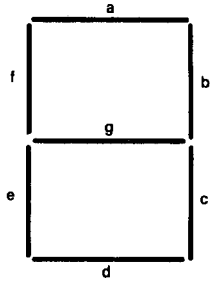
The $\overline{\text{LAMP TEST INPUT}}$ is a low signal applied to LT. It turns on all segment outputs—provided $\overline{\text{B1/RB0}}$ is not forced low.

A low signal applied to the $\overline{\text{RB1}}$ blanks the display and causes a multi-digit display.

A low signal to $\overline{\text{B1/RB0}}$ turns off all segment outputs. The blanking feature can be used to control display intensity by varying the duty cycle of the blanking signal.

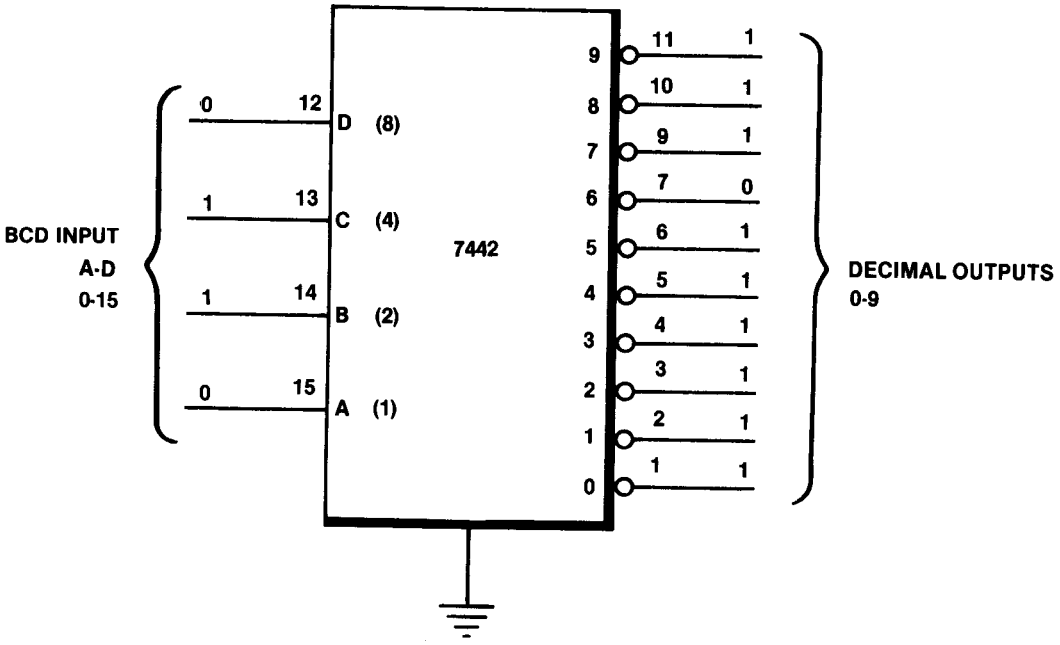
It may also be used as an output to blank leading zeroes in multi-segment displays by connecting to $\overline{\text{RBI}}$ in the next most significant digit.



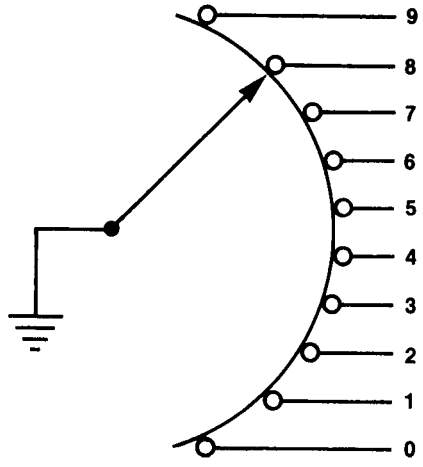


3. 1-of-10 Decoder (7442)

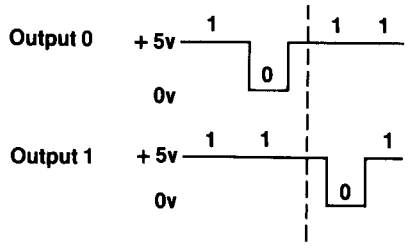
Any valid BCD input (0-9) forces one output low. Any invalid BCD input (10-15) causes *all* outputs to remain high.



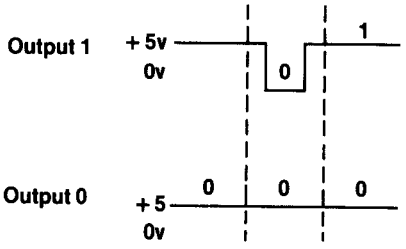
Example 1: Load Inputs (A-D) with binary number 0110_2 (6_{10}). Output 6 Pin 7 goes low. Remaining outputs high.



Example 2: A 7442 being displayed as a rotary switch.



Example 3: No two outputs are low at the same time.



Example 4: Output 0 is low all the time and Output 1 is high, going low. There are two lines low at the same time. Therefore, Output 0 is bad.

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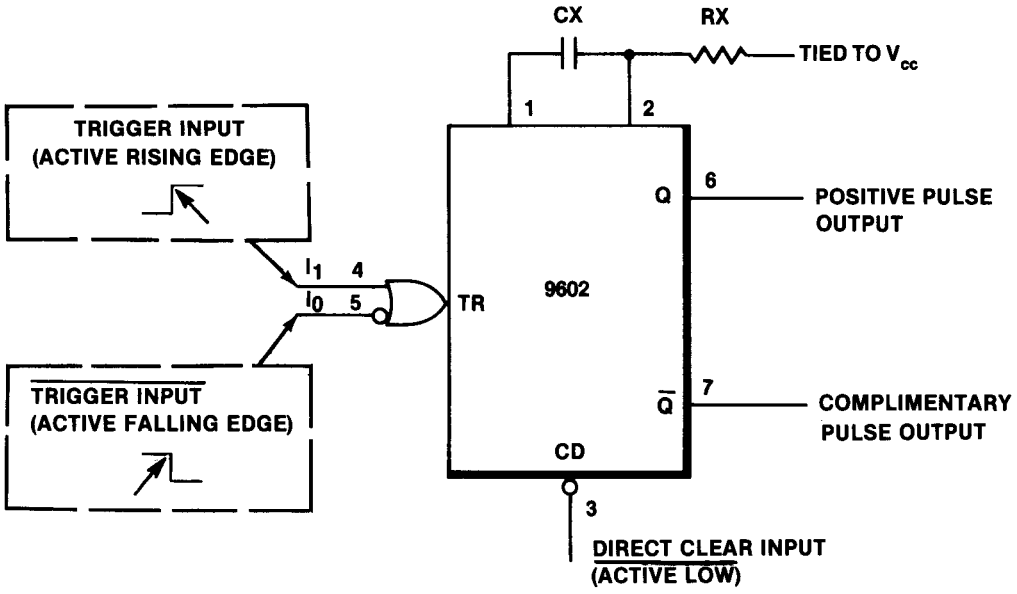
L. One-Shots or Multivibrators

A ***multivibrator*** is a regenerative circuit with two active devices. It is designed so that one device conducts, while the other cuts off. Monostable means it has one active state.

The ***one-shot*** type of multivibrator is stable in one state, but unstable in the other. When triggered, it goes from the stable state[1] into the unstable state[2]. It remains in the unstable state only temporarily, then returns to the stable state.

The ***monostable multivibrator***, also known as a one-shot multivibrator, delivers one output pulse for each input trigger.



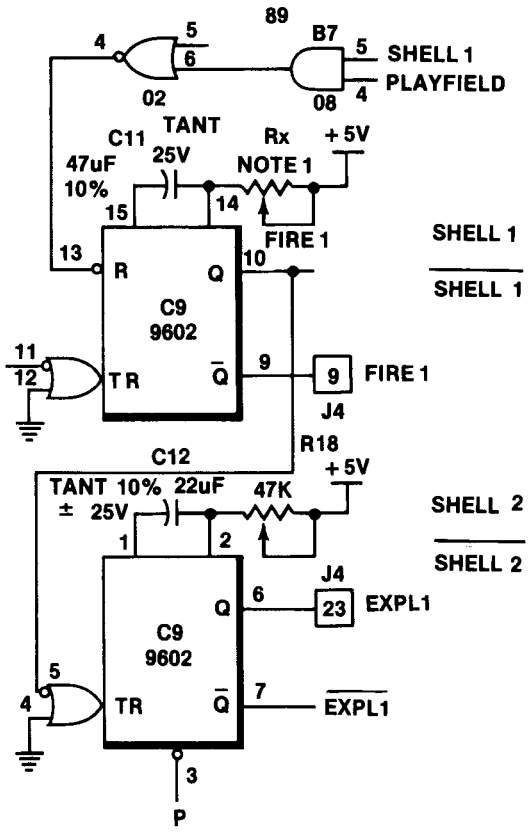
A low signal on CD terminates an output pulse, causing Q to go low and $\overline{Q}$ to go high.

[1]Stable State—Means it remains in one logic state (either 1 or 0).

[2]Unstable State—Is the logic condition immediately after the trigger pulse during which the output pulse is being generated.

A dual retriggerable resettable monostable multivibrator (one-shot):

1. Is a device triggered by a high or a low.
2. Has an output pulse width determined by RC circuit of pins 1 and 2, 14 and 15.



Note: In this example from Tank®, Rx is adjustable and controls the distance Tank 1 can fire a shell.

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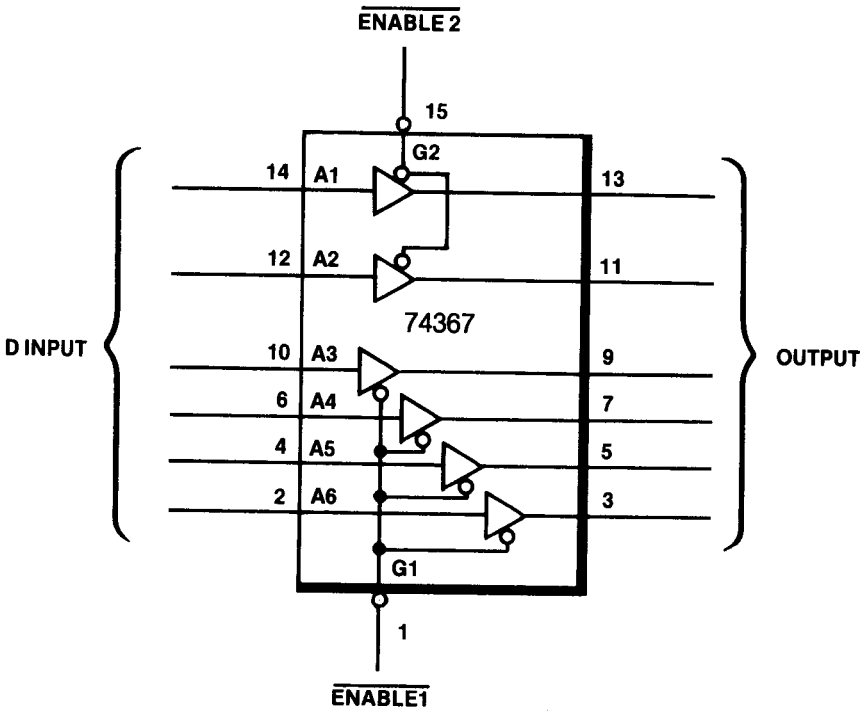
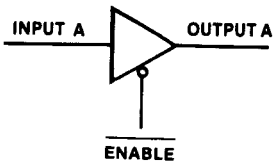
M. Buffers

1. Hex Tri-State Buffer

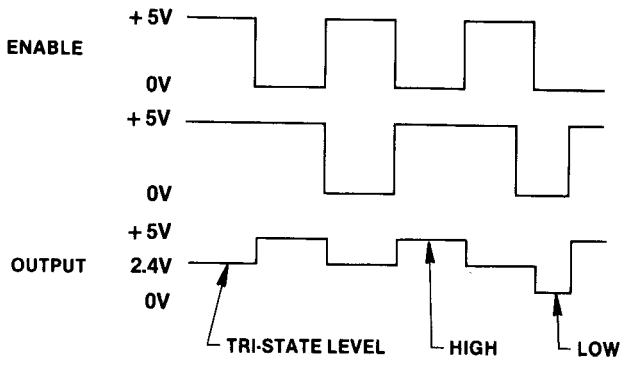
The hex tri-state buffer is used for controlling address flow and increasing fan-out. *Fan-out* is the number of inputs one output can drive, yet still maintain valid logic levels.





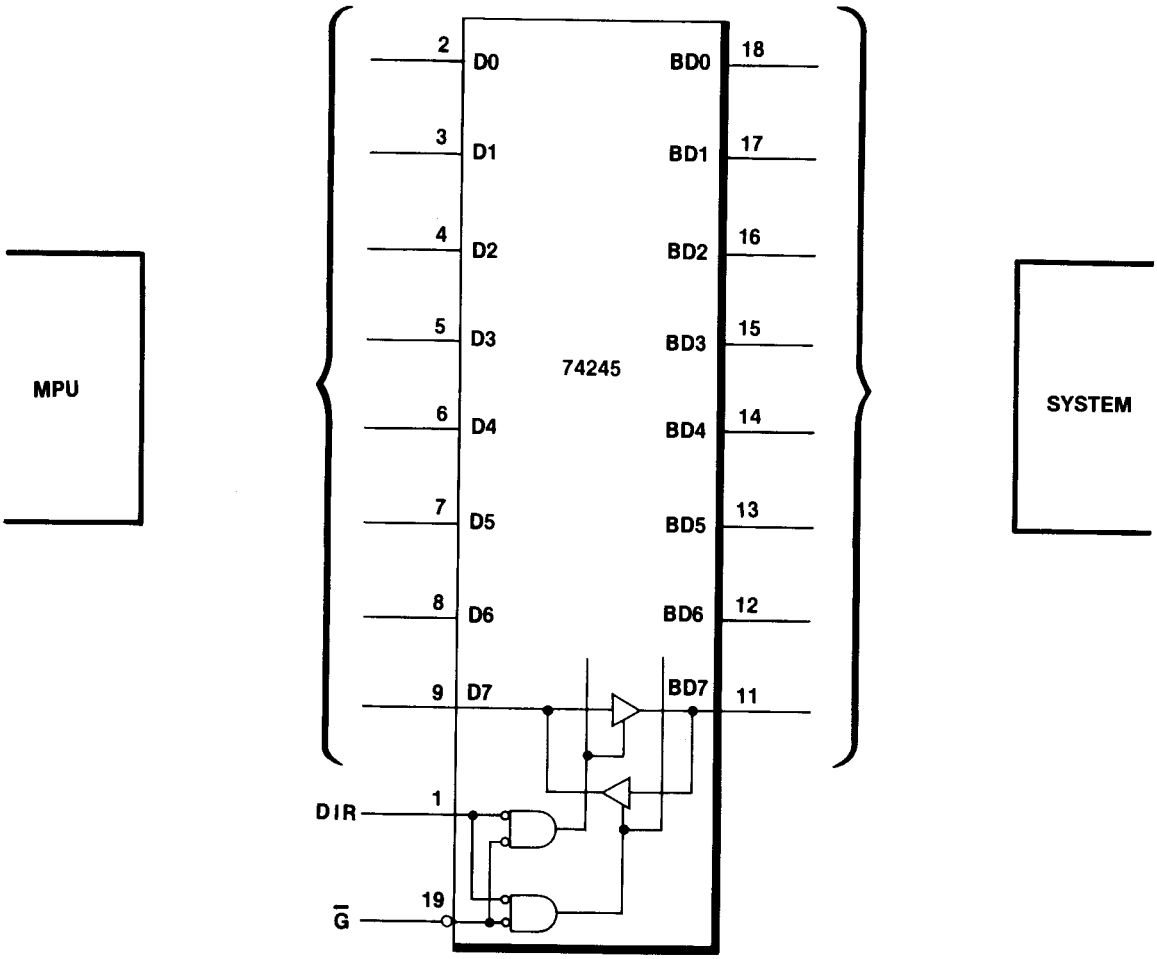
INPUTS		OUTPUT
$\overline{G}$	D	
L	L	L
L	H	H
H	X	Z

H = HIGH
L = LOW
X = IMMATERIAL
Z = HIGH IMPEDANCE (FLOATING)



2. Bidirectional Buffer

The bidirectional buffer controls the direction of data flow. Data can flow into the MPU or out of the MPU.



INPUTS		OUTPUT
$\overline{G}$	DIR	
L	L	BUS B DATA TO A
L	H	BUS A DATA TO B
H	X	ISOLATION

L = LOW
H = HIGH
X = IMMATERIAL

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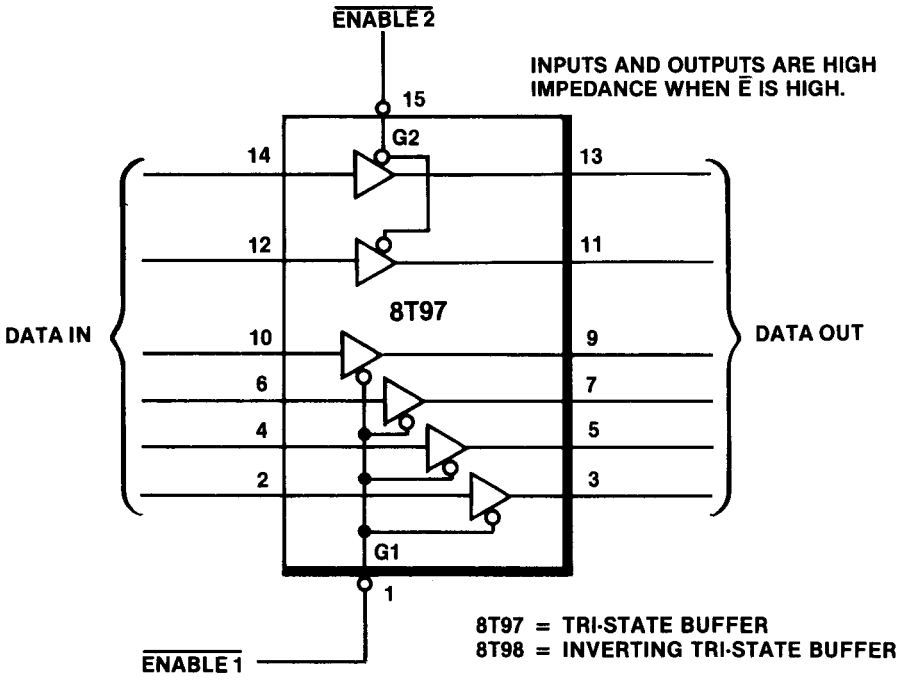
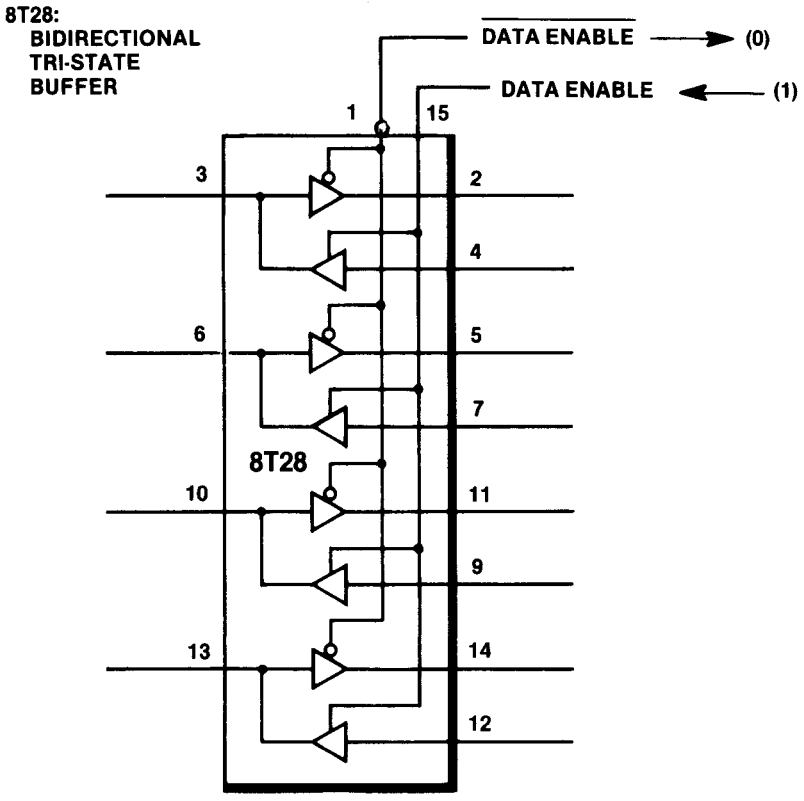
N. Buffer Drivers

ENABLE (0) = BUFFER
ENABLE (1) = HIGH Z (NOT IN CIRCUIT)





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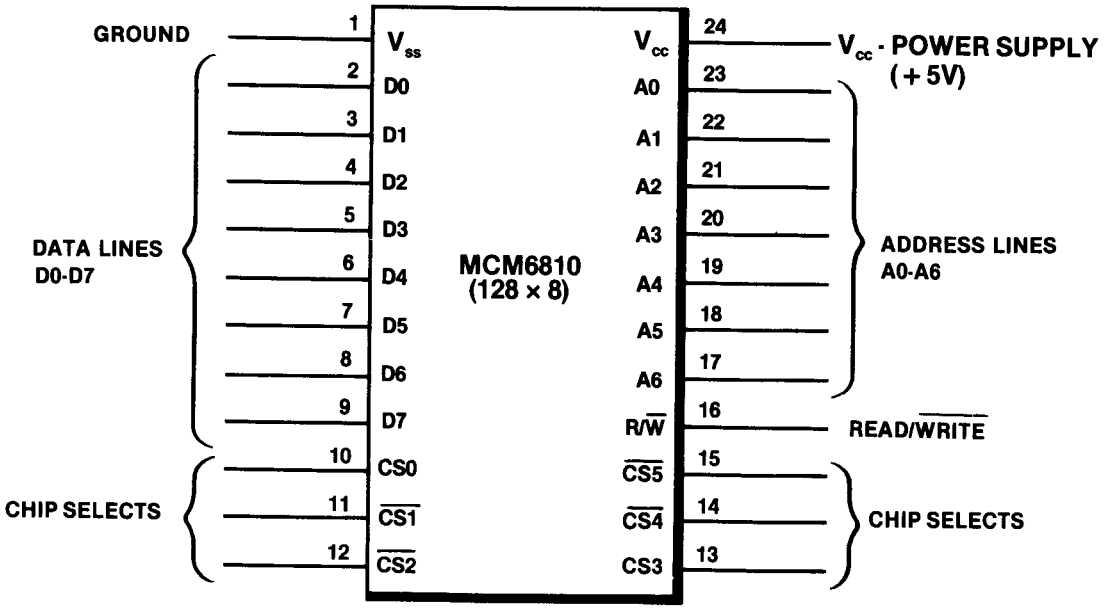
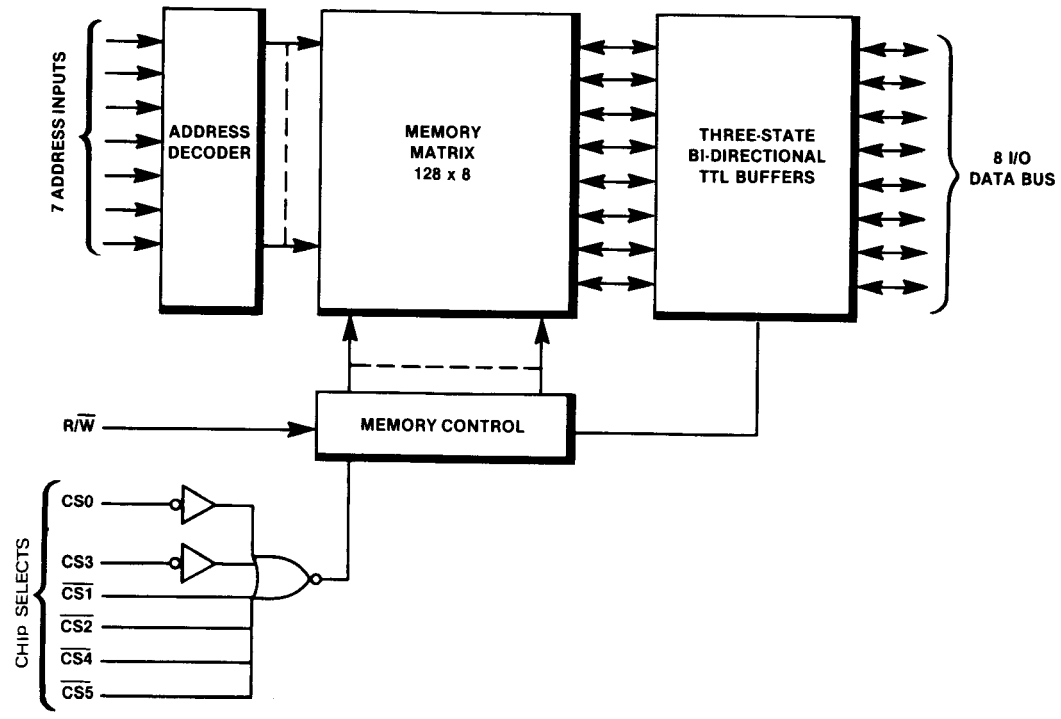
O. Random-Access Memories (RAMs)

The MCM6810 is a TTL-compatible random-access memory (RAM). It is a three-state NMOS chip containing 128 8-bit words (128 bytes)—all housed in a 24-pin package. It has 8 data-bus pins, 7 address pins, 6 chip-select pins (2 active level high, 4 active level low), 2 power pins (ground and +5 V), and a read/write pin.

To access the RAM, all six chip selects must be at their proper levels. The R/W pin must be in a high state to ***read from*** the RAM, and in a low state to ***write into*** the RAM.

When not being accessed, the RAM goes tri-state, in other words, high impedance to the data bus. A functional block diagram is shown in the lower illustration below.





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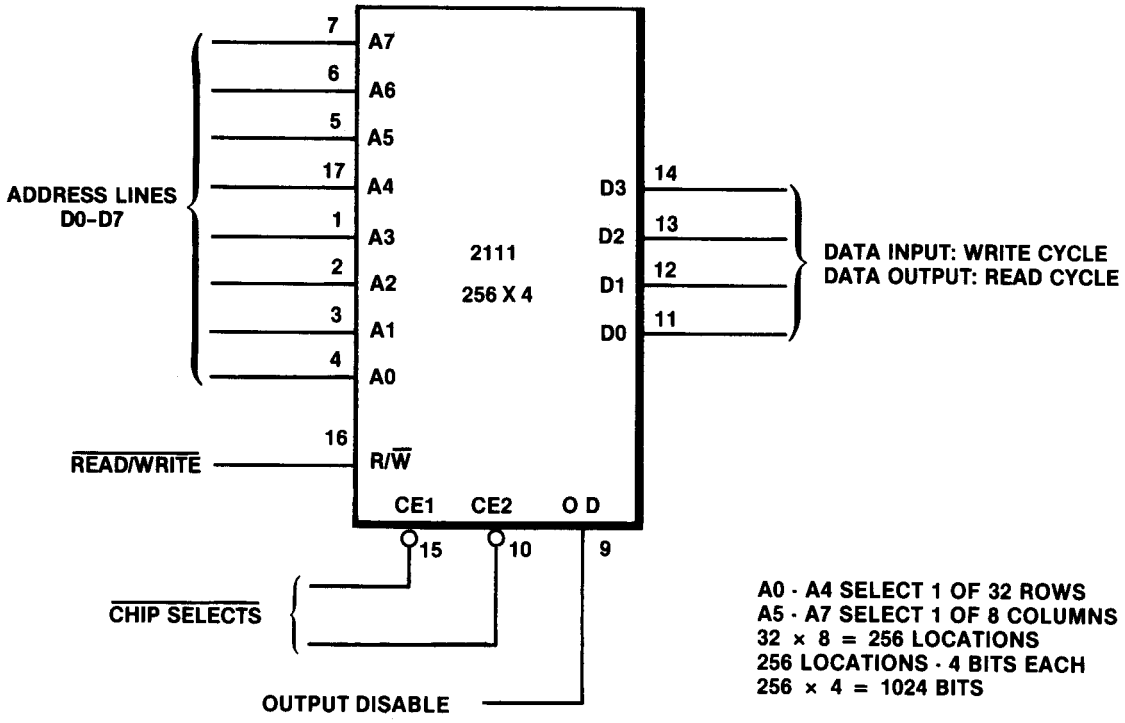
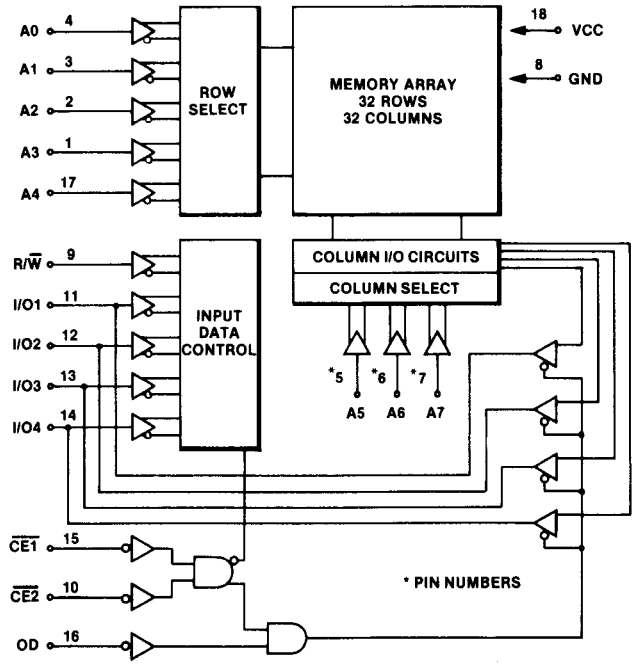
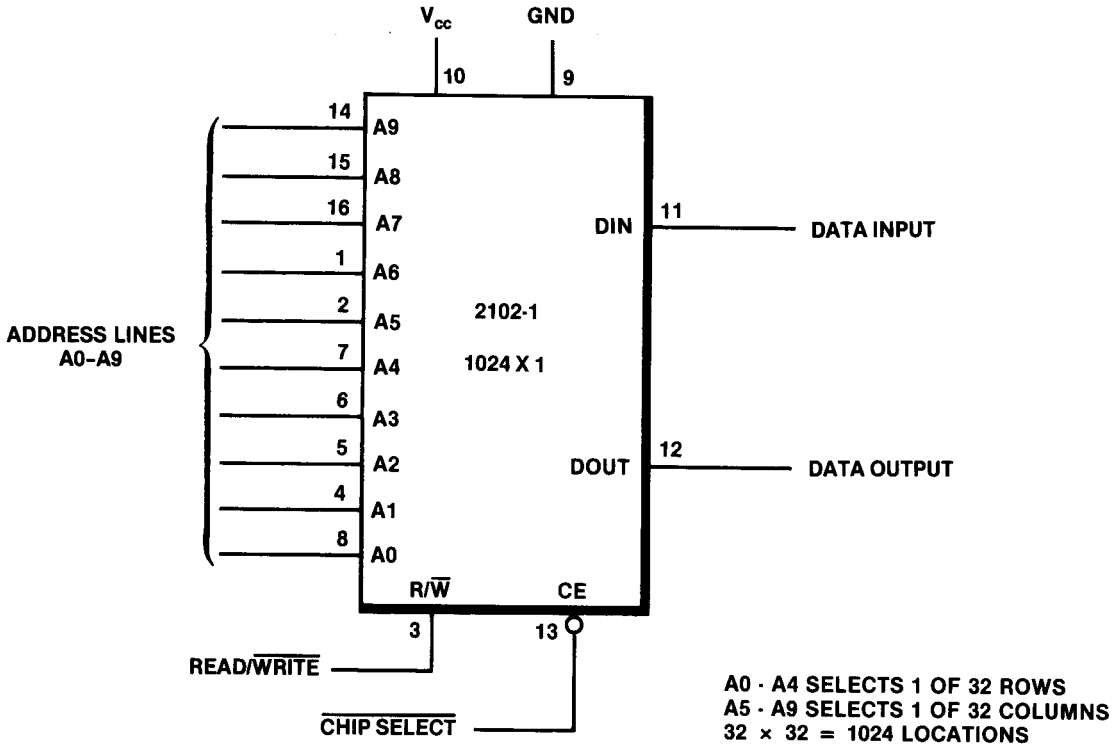
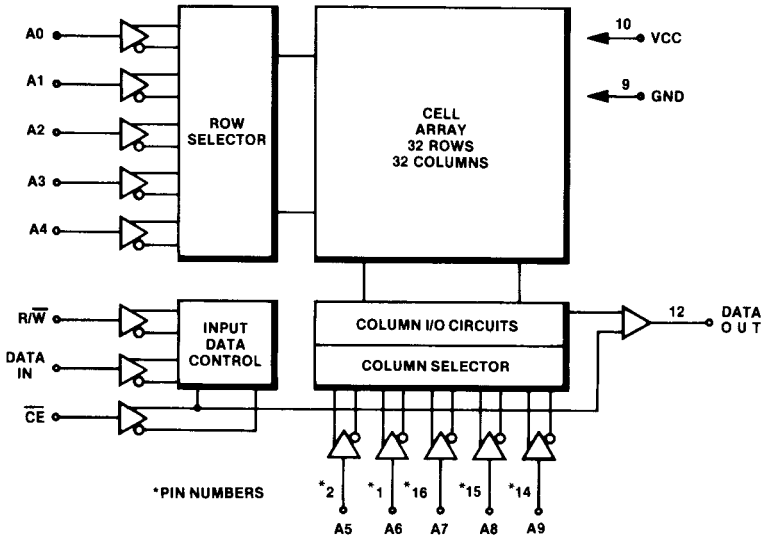
Type 2111 RAM





Type 2102-1 RAM





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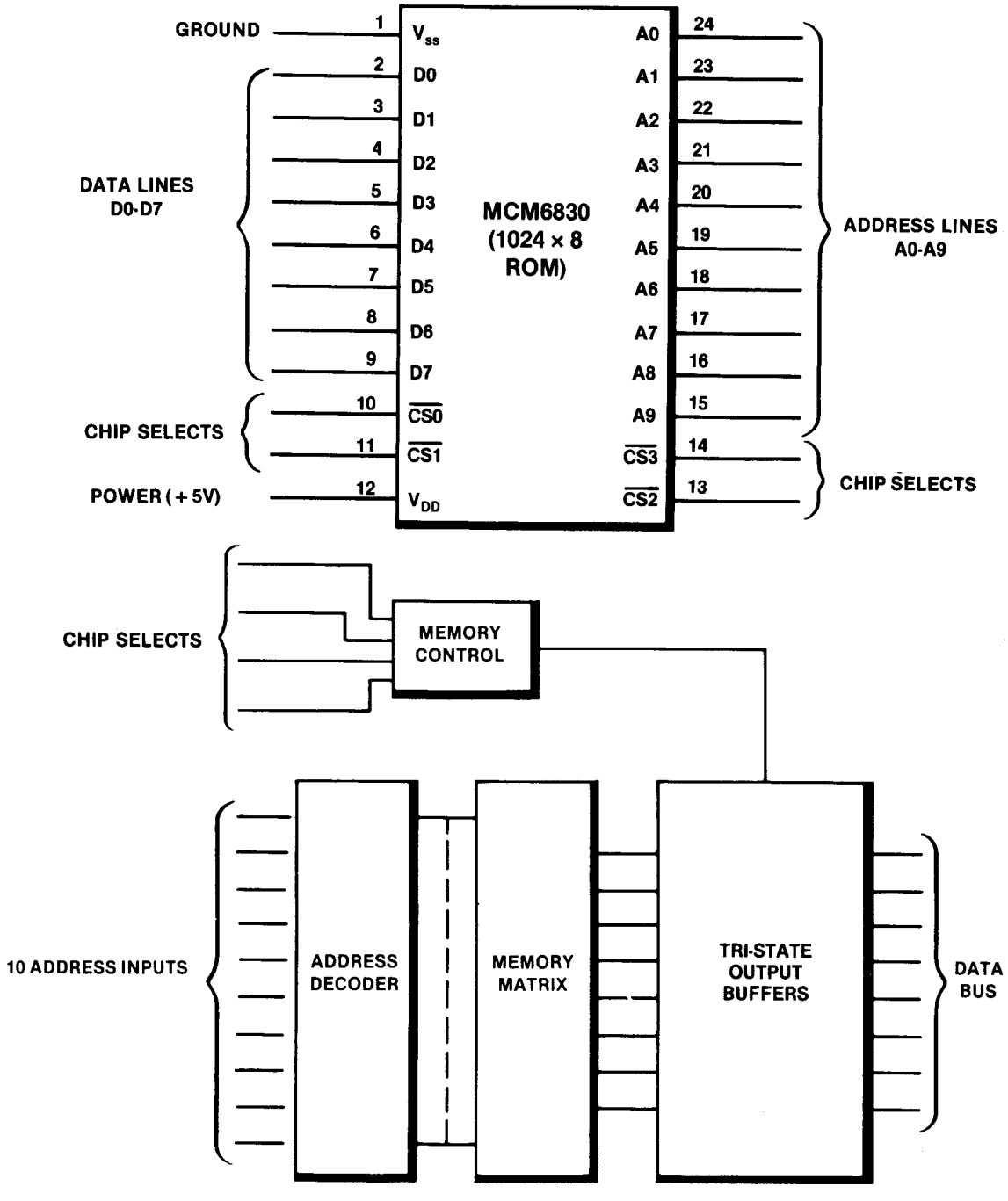
P. Read-Only Memories (ROMs, PROMs, EPROMs)

The MCM6830 is a static, TTL-compatible read-only memory (ROM). It is a single NMOS chip containing 1024 8-bit words (1024 bytes).

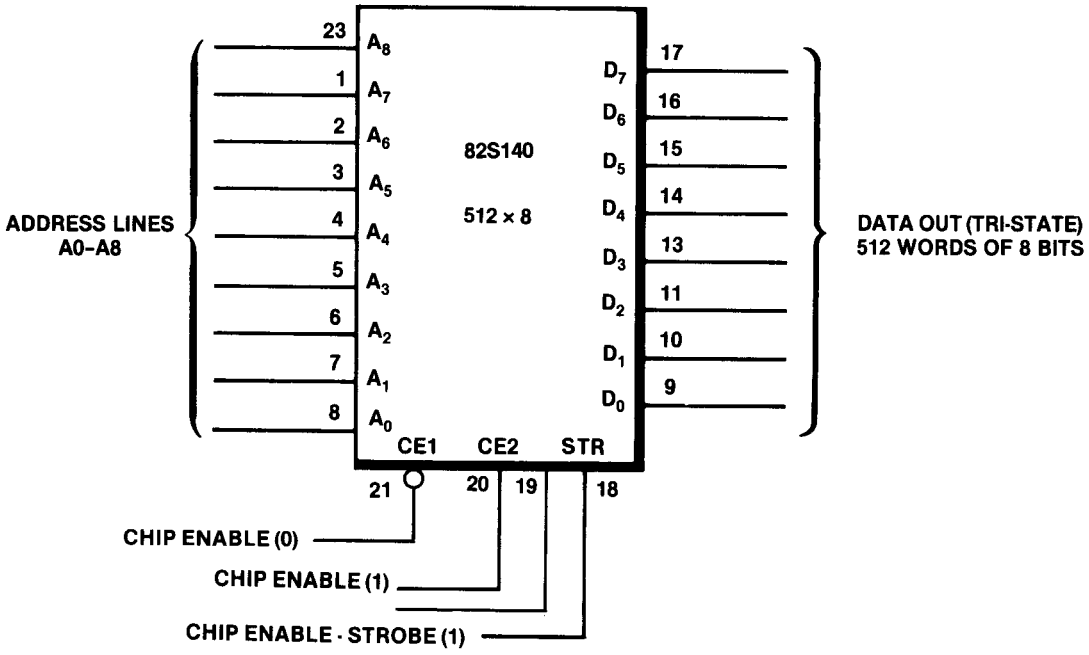
The ROM is a tri-state device housed in a 24-pin package. This package consists of 10 address pins, 8 data-bus pins, 4 chip-select pins, and 2 pins for power (+5 V and ground).

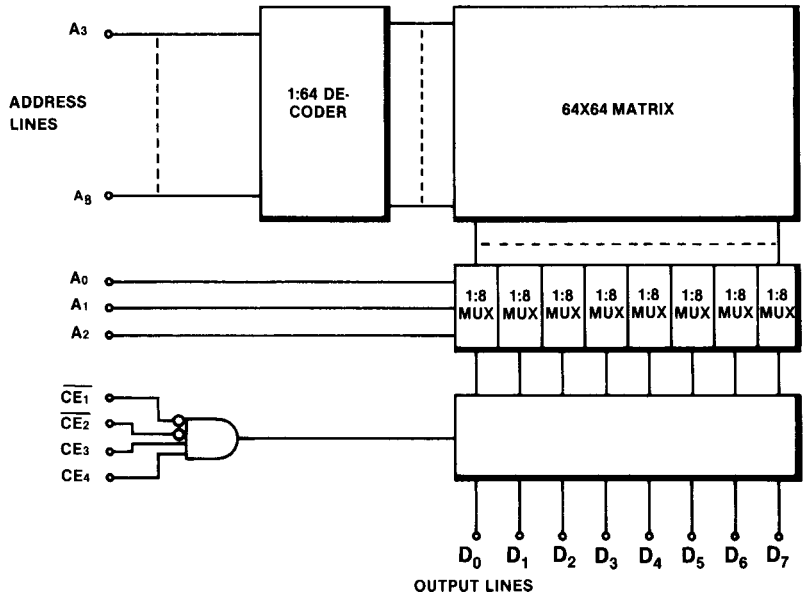
To access the ROM, all four chip selects must be at their proper levels. When not accessed, the device goes tri-state, in other words, goes to high-input impedance to the data bus.

READ ONLY MEMORY (ROM)



The 82S140 and 82S141 PROMs are programmable by Atari, which means that programs are immediately available for prototype or production games. These PROMs include on-chip decoding and 4 chip-enable inputs. These chips feature either open-collector or tri-state outputs for best word expansion in bused organizations.





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Q. Microprocessors (6800 and 6502)

1. Basic Operation

The ***microcomputer*** is a system that can be characterized as very simple in its detail and very complex in its overall operation. It carries out rather complex tasks by performing a large number of simple operations.

Control of the microcomputer system is primarily the responsibility of the ***microprocessor*** (for brevity referred to as ***processor, CPU,*** or ***MPU).*** By putting out addresses to program memory, it controls the sequence of operations performed; by interpreting and executing the instructions that it receives from the program memory, it controls the actual operations carried out by the system. The microprocessor is the most complex device in the system.

The processor causes the system to perform the desired operations by reading the first instruction in the program, and performing the very simple task dictated by the specific pattern of bits in this instruction (referred to as ***executing*** that instruction).

It then goes on to the next instruction in the program and executes it. This simple operation of ***fetching*** an instruction and executing it is performed over and over—each time on the next instruction in the sequence. In this way the program instructs the processor to bring about the desired system operation.

2. Addressing Terms and Concepts

Before starting a detailed discussion of the system operation, it will help to define a few terms and to introduce a few concepts concerning addressing. This should help you understand the more detailed discussion that follows.

3. Address Bus

The MPU address bus is capable of accessing 65,536 locations. The sole purpose of the address bus is to give each memory location its own unique address. This is accomplished by connecting the various chip selects on each part to be addressed to the address bus, in order to select that particular chip from the others.

The lower order address lines are used to select a particular location within the selected chip. You can think of this as selecting an individual page, and then selecting one word on that page, thus accessing only one word in the whole book!

Usually, RAM is located in lowest memory to take advantage of the direct memory addressing mode. ROM is always in high memory because we must access the eight highest memory locations in order to have the three fixed vectors or addresses (IRQ, NMI, Reset) available to the MPU. I/Os (inputs/outputs) are usually located in middle memory.

The rules for addressing are:

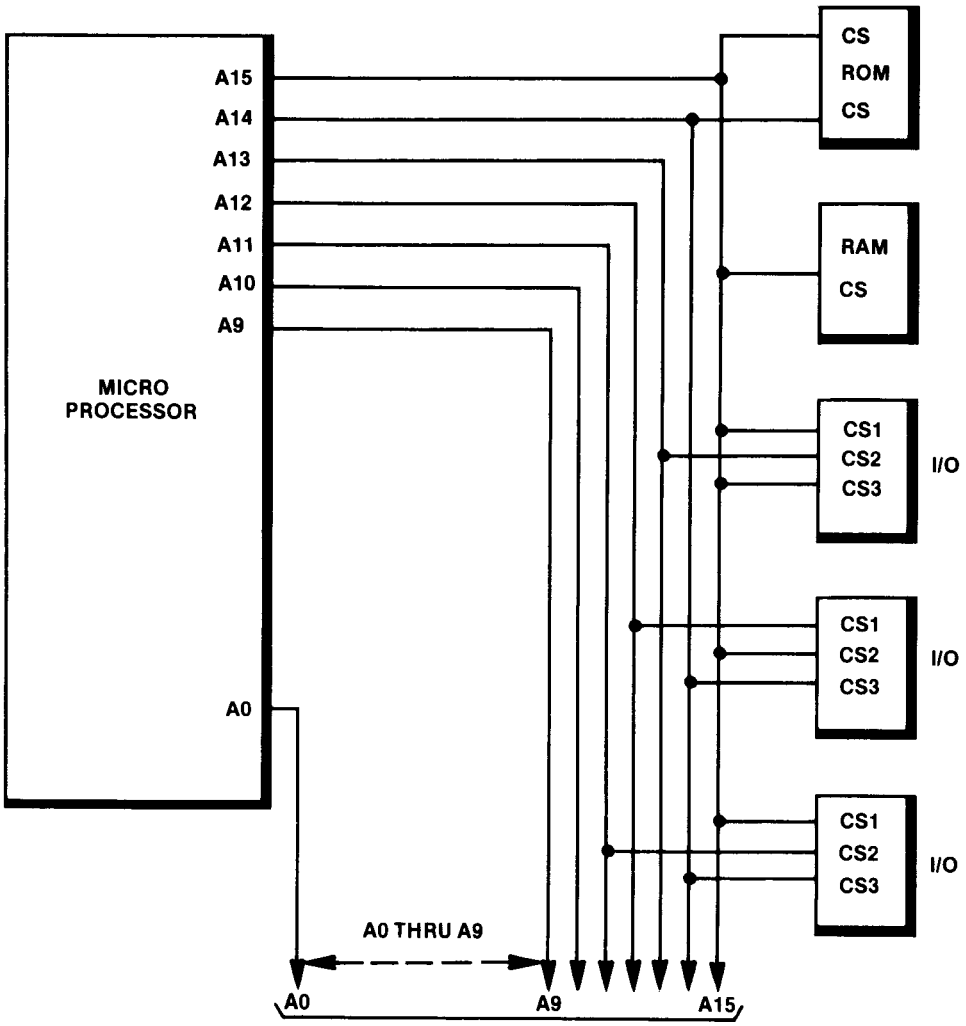
1. When ROM is addressed, RAM and I/O are disabled.
2. When RAM is addressed, ROM and I/O are disabled.
3. When I/O is addressed, ROM and RAM are disabled.

For simplicity, we refer in this book only to an 8-bit system. These typically use a Motorola 6800, MOS Technology 6502, Intel 8080 or Zilog Z80 microprocessor. These devices have eight lines (data buses) that send and receive information between the processor and the selected function—I/O, RAM or ROM.

4. Bit

The term ***bit*** is an acronym for binary digit, namely, anything that can be given a value of 0 or 1. Thus, an eight-bit data bus is a set of 8 lines that can each be assigned a value of logic 0 or logic 1. On these lines, the logic values are represented by two different levels—approximately 0 and 5 VDC. Similarly, a 16-bit binary display can be built with 16 individual lamps. The logic 1 is represented by the lamp being on.

In this book, we will refer often to an 8-bit data bus, a 16-bit address bus, 4 bits of data, 8-bit registers, etc. In all cases, the definition of a bit remains the same. A binary digit is either 1 or 0.



A0-A9: Address within selected function (I/O RAM/ROM)
A10-A15: Control (enable) Lines for I/O / RAM / ROM

Typical Address Assignments

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5. Address Space

The concept of an address space is very useful in understanding microcomputer systems. The term ***address space*** refers to the total set of addresses that the microprocessor can generate.

6. The Address Page

The concept of a ***page*** in memory is very important in 8-bit microcomputer systems. The internal organization of an 8-bit processor is centered around 8-bit registers, 8-bit parallel data paths, etc. Most arithmetic operations and logic operations, for example, take place on 8 bits of data at a time.

Likewise, the 16-bit counter that determines which instruction is being executed is actually divided into two 8-bit buses. One contains bits 0 to 7 (low-order address bits) and the other contains bits 8 to 15 (high-order address bits).

With this in mind, you can think of the address space as consisting of 256 blocks, each having 256 specific address locations. Each of these blocks is referred to as a ***page***.

7. Clock Generator

The clock generator produces a continuous waveform that is normally used to control all signal transitions within the system. It acts as the "heart" of the system.

In the typical microcomputer system the address bus will change during one half of the clock cycle and the data will be transferred during the second half. In addition to interpreting the address, data and control lines, the processor and support chips must also examine the system clock to know when to put out data or when to latch in data generated by another device.

8. Program Memory

The program memory stores the sequence of instructions that comprises the system program. Like any memory, this unit puts a pattern of 1s and 0s on the data bus in response to the address on the address bus input.

Each unique address selects a set of 8 binary bits and places this data on the data bus. Note that it does ***not*** matter where the address is generated or where the data is used. The memory simply obeys the rule that, given an address, it will put the corresponding 8 bits of data on the data bus.

A unique characteristic of most microprocessor-based systems is that the program is usually stored in ***read-only memories.*** The data is stored in a fixed pattern of bits in the memory.

Since the data is stored in the physical configuration of the device, the data will not be lost when power is disconnected from the chip. In addition, you only have to insert the device into its socket to provide the system program.

The term ***read-only memory*** refers to the fact that, in system operation, it's impossible for the processor to cause data to be stored in the device. The processor can only ***read*** the data that was stored in the device during the ROM manufacturing process. ***Reading*** a memory involves the simple process of supplying an address to the device to obtain the corresponding 8 bits of data on the data bus.

9. Data Memory

For temporary storage of input data, the results of arithmetic operations, etc., the microcomputer uses a read/write memory, commonly referred to as ***RAM (random-access memory).*** The processor can store data in the RAM (called ***writing*** the RAM), or it can read back the data it has stored.

As in the ROM, each address corresponds to eight memory cells. However, in a RAM the data must be placed into the memory by the processor and is stored in cross-coupled latches.

Turning off the power to the RAM will cause the loss of all data stored there. Because of this, the data is said to be ***volatile.*** Data in a ROM is not lost when power is disconnected from the device; ROM data is therefore referred to as ***non-volatile.***

Writing data into a RAM takes place when the write-enable signal goes to the write state. At this time the data on the data bus will be stored into the eight memory cells corresponding to the address on the address bus. The processor can ***read*** this same data by supplying the proper address and keeping the write-enable line in the read state.

10. Input/Output Devices

The ***input/output (I/O) devices*** are the circuits that interface the switches, solenoids, lamps, displays, etc. to the processor. This allows the processor to read data from the outside world, test the state of the switches, and perform the necessary operations.

No matter where data is generated, it must be in the form of 1s and 0s before the processor can work with it. Likewise, actions to be initiated by the processor must be triggered by 1s and 0s.

The transfer of data from the processor to an output device is usually accomplished by ***writing*** the data out in much the same way as the processor writes data into RAM. Each set of 8 input or output lines (referred to as ***ports***) is given an address, and the processor simply writes data to that address. For each 1 written out to the peripheral port, an output is set high. For each 0, the corresponding output is set low.

11. The Microprocessor

At first glance it may seem strange to discuss the support chips in the microprocessor-based system before mentioning the processor. However, we have used this approach because most of the inputs and outputs on the processor are aimed at properly controlling the support chips and peripheral devices discussed above.

The address bus, the bi-directional data bus and the write-enable line allow the processor to exercise direct control over the rest of the system. The address bus puts out addresses to control the source or destination of data transfers. These addresses are derived from various sources within the processor.

When the microprocessor fetches or gets the instructions from program memory, the addresses are usually derived from a counter that controls execution of sequential instructions. Addresses for RAM are usually derived directly from the program or are calculated from the data in the program and data in internal registers.

The bi-directional data bus serves as a path for transferring data into and out of the processor. The direction of the data transfer is determined by the write-enable line.

Another special function found in microcomputer systems is the interrupt. This function allows the I/O devices to directly affect the operation of the processor. When the interrupt signal is generated, the processor completes its current instruction; then under program control it will respond to the interrupt.

The importance of this function is that it allows the processor to execute the system program without requiring the latter to monitor the status of the I/O device. The software that handles the operation of each I/O will be executed only when required.

The remainder of this section is a list of terms associated with microprocessors and descriptions of their functions. Because of the similarities between the 6800 and 6502, we have listed them together.

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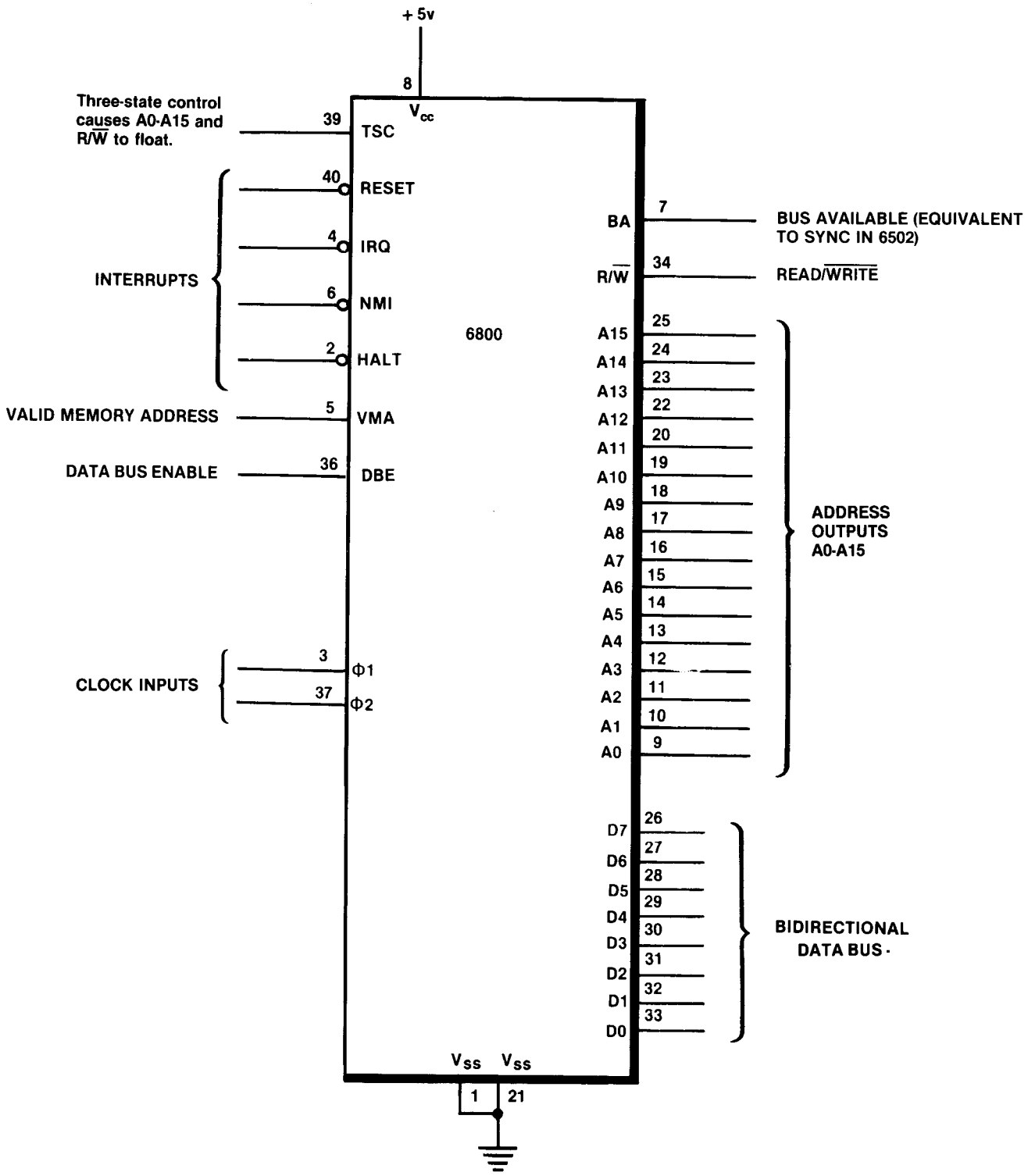

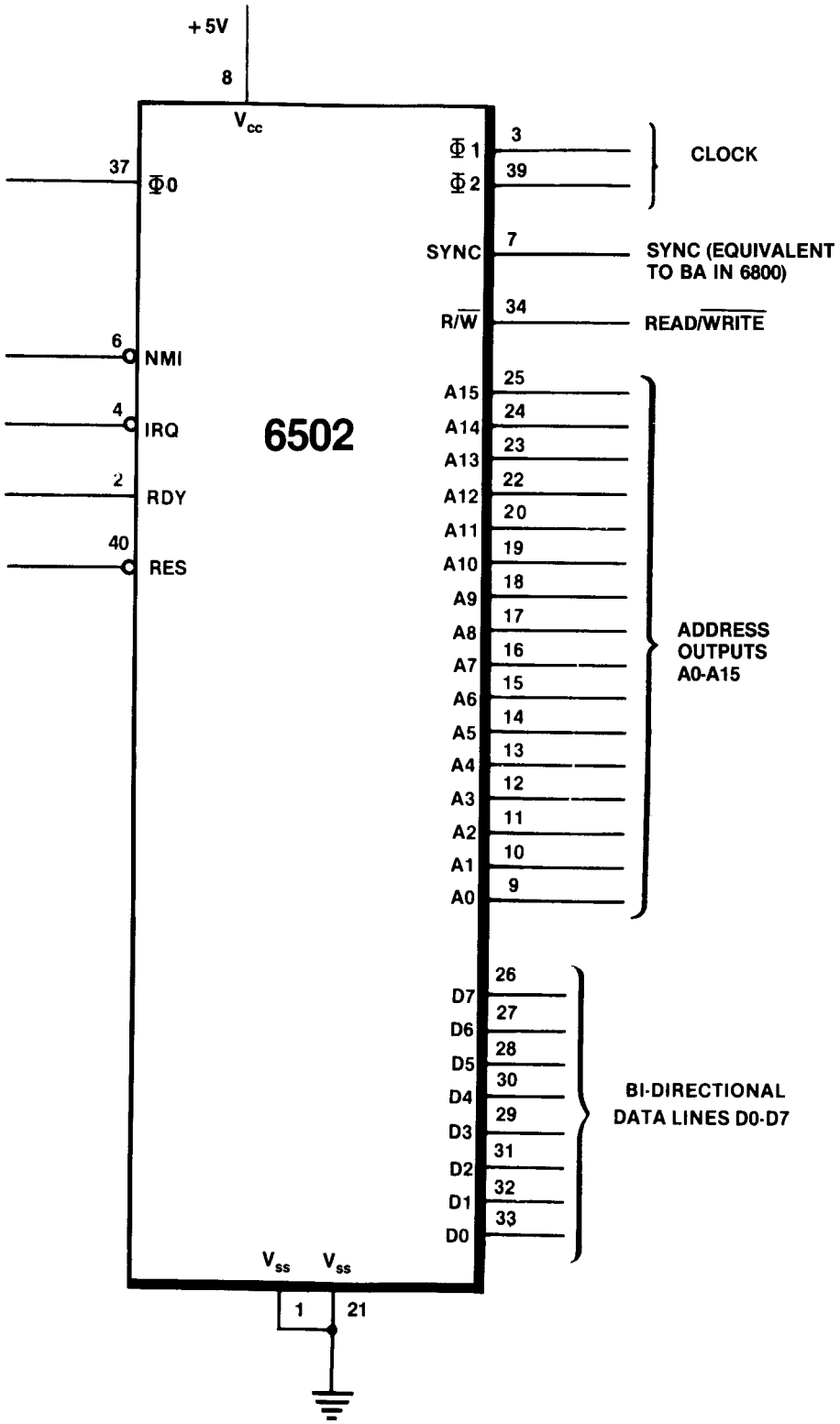
+5V
8
V_{cc}
6502
37
Φ0
6
NMI
4
IRQ
2
RDY
40
RES
Φ1
3
Φ2
39
CLOCK
SYNC
7
SYNC (EQUIVALENT TO BA IN 6800)
R/W
34
READ/WRITE
A15
25
A14
24
A13
23
A12
22
A11
20
A10
19
A9
18
A8
17
A7
16
A6
15
A5
14
A4
13
A3
12
A2
11
A1
10
A0
9
ADDRESS OUTPUTS A0-A15
D7
26
D6
27
D5
28
D4
30
D3
29
D2
31
D1
32
D0
33
BI-DIRECTIONAL DATA LINES D0-D7
V_{ss}
V_{ss}
1
21

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12. Bus Structure

A microcomputer system is organized around two primary buses. Each bus consists of a set of parallel paths that can be used to transfer binary information between the devices in a system.

The first bus, known as the ***address bus***, is used to transfer the address generated by the processor to the address inputs of the memory and I/O devices. The processor is the only source of addresses in a normal system, so this bus is called ***unidirectional***. The address bus consists of 16 lines. This allows the processor to access (***read*** or ***write***) up to a 65,536 memory words, registers, etc.

The data bus consists of an 8-bit bidirectional data path. These lines transfer data from the processor to the selected memory word. During a write operation and from memory into the processor during a read operation, all data and all instructions are transmitted on the data bus.

The direction of the data transfers is controlled by the ***read/write*** (R/$\overline{W}$) line on the processor. This line performs the write enable function. As long as the R/$\overline{W}$ line is high (greater than 2.4 VDC) all data transfers will take place from memory to the processor (read operation). This line will go low only when the processor is going to write data out to memory.

As in most microcomputer systems, the timing of all data transfers is controlled by the system clock. The clock itself is actually two non-overlapping square waves. This two-phase clock system can best be thought of as two alternating positive-going pulses. We call these clocks ***phase one (Φ1)*** and ***phase two (Φ2).***

A phase-one clock pulse is the positive pulse during which the address lines change. A phase-two clock pulse is the positive pulse during which the data is transferred.

All signal transitions are specified with respect to the phase-one and phase-two clock signals. In particular, the address lines and the R/$\overline{W}$ line will stabilize during phase one, and data transfers will take place during phase two.

13. Processor Interrupts

By generating processor interrupt signals, the peripheral devices, i.e., displays, player controls, etc. can request service from the processor. The microprocessor has two interrupt input lines going to it: $\overline{IRQ}$ (interrupt request) and $\overline{NMI}$ (non-maskable interrupt).

Since the requirements of the two interrupt inputs differ, we will discuss them separately.

14. Interrupt Request ($\overline{IRQ}$)

The two interrupt lines for the microprocessor are $\overline{IRQ}$ and $\overline{NMI}$. The requirements for proper operation of the interrupt request ($\overline{IRQ}$) input are more stringent than for the second interrupt input, $\overline{NMI}$. This is due primarily to the fact that $\overline{NMI}$ is edge-sensitive. With the $\overline{IRQ}$ input, the processor will be interrupted any time the signal on $\overline{IRQ}$ is grounded (less than 0.4 V).

The interrupt request ($\overline{IRQ}$) responds in much the same manner as $\overline{NMI}$. However, this function can be enabled or disabled (masked) by the interrupt inhibit bit in the processor status register. As long as the I flag (interrupt inhibit flag) is a logic 1, the signal on the $\overline{IRQ}$ pin will not affect the processor.

The $\overline{IRQ}$ pin is not edge-sensitive. Instead, the processor will be interrupted as long the I flag is a logic 0 and the signal on the $\overline{IRQ}$ input is at ground. Because of this, the $\overline{IRQ}$ signal must be held low until it is recognized, that is, until the processor completes the instruction currently being executed.

If I is set when $\overline{IRQ}$ goes low, the interrupt will not be recognized until I is cleared through software control. To assure that the processor will not recognize the interrupt more than once, the I flag is set automatically during the last cycle before the processor begins executing the interrupt software.

The final requirement is that the interrupt input must be cleared before the I flag is reset. If there is more than one active interrupt driving

these two lines (ORed together), the recommended procedure is to service and clear both interrupts before clearing the I flag.

However, if the interrupts are cleared one at a time and the I flag is reset after each, the processor will simply recognize any interrupts still active. It will also process them properly but more slowly—because of the time required to learn from one interrupt before recognizing the next.

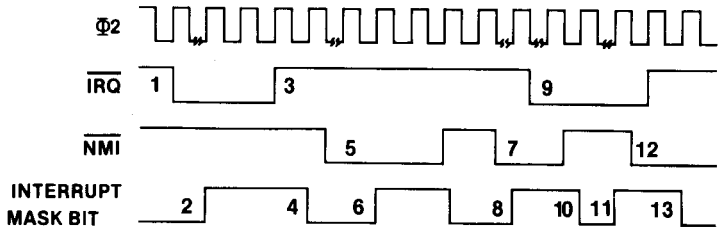
If the procedure recommended above is followed, each interrupt will be recognized and processed only once. The figure below gives several examples of interrupts, microprocessor recognition of each interrupt ($\overline{IRQ}$ and $\overline{NMI}$), and processor selection of interrupts during overlapping requests.

15. Non-Maskable Interrupt ($\overline{NMI}$)

The $\overline{NMI}$ input to the processor is edge-sensitive. To cause an interrupt to occur, there must be a negative transition of the signal on the $\overline{NMI}$ input. This negative transition will cause a single interrupt. The processor will ignore this input until the NMI signal goes high (greater than +2.4 V) and then back to ground.

Each major event affecting the microprocessor is explained below. The ***event numbers*** match the numbers in the figure on the next page.

Event Number	System Activity
1.	Processor is executing from main program and $\overline{IRQ}$ goes to low state.
2.	Processor recognizes the interrupt, stores the next address of its sequence, then sets I during the fetch of the interrupt vector.
3.	After servicing the interrupt, to avoid double interrupting the $\overline{IRQ}$ is reset before resetting the interrupt mask bit.
4.	Before the processor resumes normal program execution, the interrupt mask bit will be reset low.
5.	$\overline{NMI}$ goes low, signalling a non-maskable interrupt.
6.	$\overline{NMI}$ is recognized and serviced in the same manner as $\overline{IRQ}$.
7.	The processor has resumed normal operation when $\overline{NMI}$ again goes low requesting an interrupt.
8.	The interrupt mask bit is set high in response to the $\overline{NMI}$ request.
9.	Here $\overline{IRQ}$ has gone low to signal an interrupt request. This request is ignored, since the $\overline{NMI}$ interrupt is being serviced and the interrupt mask is set.
10.	The interrupt mask bit is reset after servicing $\overline{NMI}$.
11.	The processor is now able to recognize the $\overline{IRQ}$ signal, which is still low, and does so by setting the interrupt mask bit.
12.	During the servicing of $\overline{IRQ}$, $\overline{NMI}$ goes from high to low. The processor then completes the current instruction and abandons the $\overline{IRQ}$ interrupt to service $\overline{NMI}$. $\overline{NMI}$ is serviced regardless of the state of the interrupt mask bit.
13.	After completing the $\overline{NMI}$ interrupt routine, the processor will resume execution of the $\overline{IRQ}$ routine, even though $\overline{IRQ}$ has subsequently gone high.



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16. System Reset

One of the basic system-control functions is the system $\overline{\text{RESET}}$ signal. Whether this signal is generated automatically by external power-on circuitry or manually from a pushbutton switch, the system components must obey a fixed set of rules. This will assure proper system operation. (This is particularly true for the I/O devices.) System $\overline{\text{RESET}}$ occurs when a coin trips the coin switch.

In the MCS6502-based systems, designers assume that $\overline{\text{RESET}}$ pins on all I/O devices and the processor will be held low during power-on until the supply voltages and the clocks have stabilized.

This waiting period assures that the I/O pins will remain in a known state until the entire system is initialized and the processor is ready to assume control of the output lines. At this point, the processor is ready to run the system program.

The contents of latches, registers, and so forth is totally random after power is applied. On the I/O output pins, random data can be disastrous.

The only way to force these lines to a known condition is to apply the $\overline{\text{RESET}}$ signal. The designer can then make sure that the known condition will not cause spurious operations in the I/O devices. An example of a spurious operation is the firing of thumper bumpers when turning on the power.

In the processor, the single register that must be placed in a known state is the program counter. This is the register that selects the instructions to be executed. The $\overline{\text{RESET}}$ input causes the program counter to go to the first instruction in the system program.

The $\overline{\text{RESET}}$ input on the I/O devices performs one other very important function. Although the recognition of the processor interrupt signals is automatic and does not depend on software, the program determines the sequence of operations performed by the processor to totally service an interrupt.

Until the various internal registers in the processor have been initialized, the processor is not ready to respond properly to any external interrupts. For this reason, it's important that the system $\overline{\text{RESET}}$ disables all external interrupt signals until they are enabled by the processor. The programmer can then make sure the system has been properly initialized before the interrupts are enabled.

17. Ready (RDY)

The RDY input delays execution of any cycle during which the RDY line is pulled low. This line should change during the phase-one clock pulse. This change is then recognized during the next phase-two pulse to enable or disable the execution of the current internal machine cycle. This execution normally occurs during the next phase-one clock.

The primary purpose of the RDY line is to delay execution of a program fetch cycle until data is available from memory. This has direct application in prototype systems employing light-erasable PROMs or EAROMs. Both of these devices have relatively slow access times and require use of the RDY function if the processor is to operate at full speed. Without the RDY function, designers would have to reduce the frequency of the system clock.

The RDY function will ***not*** stop the processor in a cycle in which a write operation is being performed. If the RDY line goes from high to low during a write cycle, the processor will execute that cycle and will ***then*** stop in the next read cycle (R/W = 1).

18. SYNC Signal

In the MCS6502, a SYNC signal is provided to identify those cycles in which the processor is doing an OP CODE fetch. The SYNC line goes high during phase one of an OP CODE fetch, and stays high for the remainder of that cycle.

If the RDY line is pulled low during the phase-one clock pulse in which the SYNC line went high, the processor will stop in its current state. It remains in that state until the RDY line goes high. In this way, the SYNC signal can be used to control RDY to cause single-instruction execution.

19. Read/Write (R/$\overline{W}$)

This tri-state output line is used to signal all devices external to the MPU that the MPU is in a read state (R/$\overline{W}$ = high) or a write state (R/$\overline{W}$ = low). The normal standby state of this line when no external devices are being accessed is a high state.

20. Valid Memory Address (VMA)

This output line (when in the high state) tells all devices outside the MPU that there is a valid address on the address bus. This signal is ***not tri-state.***

21. Data Bus Enable (DBE)

This signal will enable bus drivers when they are in the high state. This input is normally the Phase 2 clock. During the high state, it will permit data to be output during a write cycle. During an MPU read cycle, the data bus drivers will be disabled internally.

22. Phase One (Φ 1) and Phase Two (Φ 2) Clocks

These two-phase non-overlapping clocks run at the V_{DD} voltage level. These clocks typically run at a rate of 1 MHz.

23. Restart ($\overline{RES}$)

This input on the 6502 is used to start the MPU from a power-down condition, resulting from a power failure or an initial start-up of the processor. If a positive edge is detected on the input, this will signal the MPU to begin the restart sequence. This will also start execution of a routine to initialize the processor.

All the higher-order address lines will be forced high. For the restart, the last two memory locations in the last ROM will be accessed. This means an address is stored to be loaded in the program counter. The program counter, in turn, tells the processor where program execution is to begin.

24. Go/Halt (G/$\overline{H}$)

When this 6800 input is high, the machine will fetch (get) the instruction addressed by the program counter and start execution. When low all activity in the machine will be halted.

This input is level-sensitive. In the halt mode, the machine will stop at the end of an instruction. Bus available will be at a logic 1 level. Valid memory address will be at logic 0, and all other tri-state lines will be in the tri-state mode.

The halt line must go low with the leading edge of phase one to insure single instruction operation. If the halt line does not go low with this leading edge, one or two instruction operations may result, depending on when the halt line goes low relative to the phasing of the clock.

25. Bus Available (BA)

The bus available signal will normally be low. When activated, it will go high, indicating that the MPU has stopped and that the address bus is available. This will occur if the GO/HALT line is in the halt (low) mode or the MPU is in a wait state as the result of some instruction.

26. Three-State Control (TSC)

This 6800 input causes all of the address lines and the read/write line to go into the tri-state or high-impedance state. The VMA and BA signals will be forced low. The data bus, having its own enable (DBE), is not affected by TSC.

27. Direct Memory Access (DMA)

In DMA applications, the tri-state control line should be brought high on the leading edge of the phase-one clock. The Φ1 clock must be held in the high state for this function to operate properly. The address bus will then be available for other devices to directly address memory. Since the MPU is a dynamic device, it must be refreshed periodically or destruction of data will occur.

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28. Data Bus (D0-D7)

Eight pins are used for the data bus. It is bi-directional, transferring data to and from the memory and peripheral devices. It also has tri-state output buffers capable of driving one standard TTL load and 130 pf at 1 MHz.

All inter-chip data transfers take place during the phase 2 clock pulse. During phase 1, the entire data bus is floating (tri-state).

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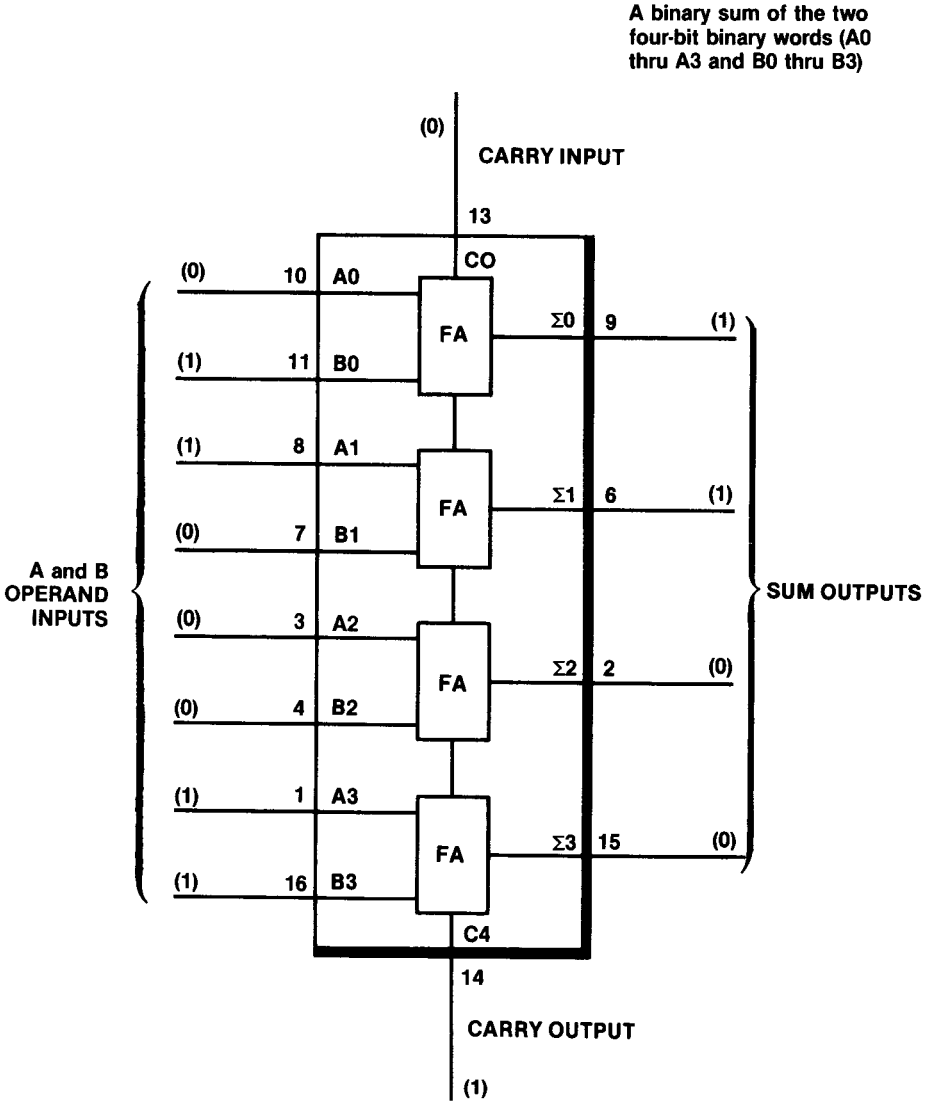
R. Binary Full Adder

Multistaging adders connect the carry output (C4) to the carry input (CO).



INPUTS									OUTPUTS				
CO	A3	A2	A1	A0	B3	B2	B1	B0	Σ3	Σ2	Σ1	Σ0	C4
L	H	L	H	L	H	L	L	H	H	H	L	L	H
	1	0	1	0	1	0	0	1	0	0	1	1	1
	0	1	0	1	0	1	1	0	1	1	0	0	0

H = High
L = Low

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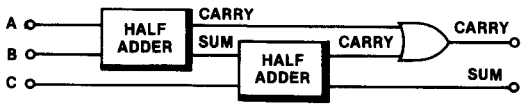
A ***full adder*** is a logic circuit with three inputs and two outputs. It adds 3 bits at a time, giving a sum and a carry output.

INPUTS			OUTPUTS	
C	B	A	CARRY	SUM
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

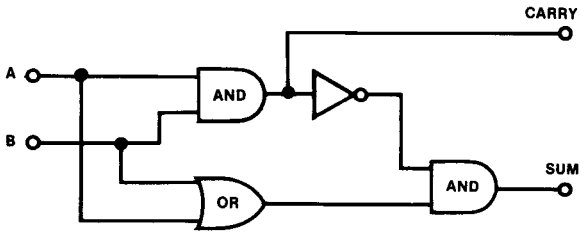
Full-Bit Adder



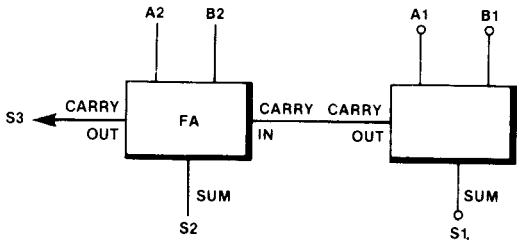
A ***half adder*** is a logic circuit with two inputs and two outputs. It adds 2 bits at a time, producing a sum and a carry output.

INPUTS		OUTPUTS	
B	A	CARRY	SUM
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

Half Adder



By connecting a half adder and a full adder, we make a ***parallel binary full adder.*** This is capable of adding numbers with many bits. The 7483 is one type of binary full adder that adds two 4-bit binary words.



A2 A1
+ B2 B1
S3 S2 S1

Binary addition is performed in the same manner as decimal addition. The example below shows simple binary arithmetic.

0 + 0 = 0
0 + 1 = 1
1 + 1 = 10 (0 plus a carry-over of 1)

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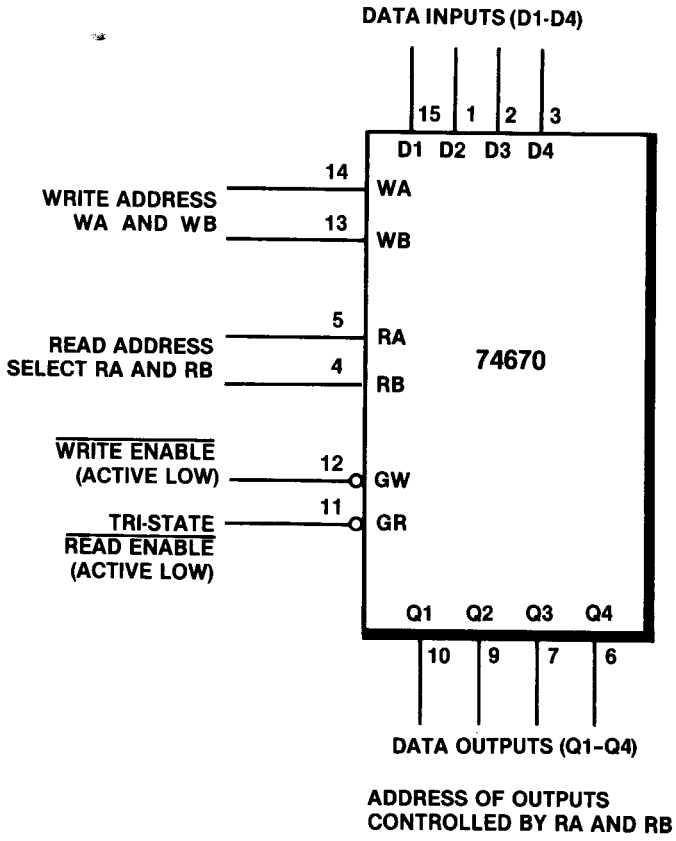
S. 4 x 4 Bus Register File

WA0 and WA1 select the word being ***written*** into. RA0 and RA1 select the word being ***read***.

The tri-state output (OE) active low makes it possible to add more stages—up to 128 outputs or 512 words.

Separate read and write inputs both address (RA0, RA1, WA0, WA1) and enable (WE and OE). This allows simultaneous read and write operation, by selecting one of four 4-bit words.



READ

READ INPUTS			
GR	RA	RB	OUTPUTS FROM
L	L	L	WORD 0
L	L	H	WORD 1
L	H	L	WORD 2
L	H	H	WORD 3
H	X	X	NONE (HIGH)

WRITE

WRITE INPUTS			
$\overline{GW}$	WA	WB	D INPUTS TO
L	L	L	WORD 0
L	L	H	WORD 1
L	H	L	WORD 2
L	H	H	WORD 3
H	X	X	NONE

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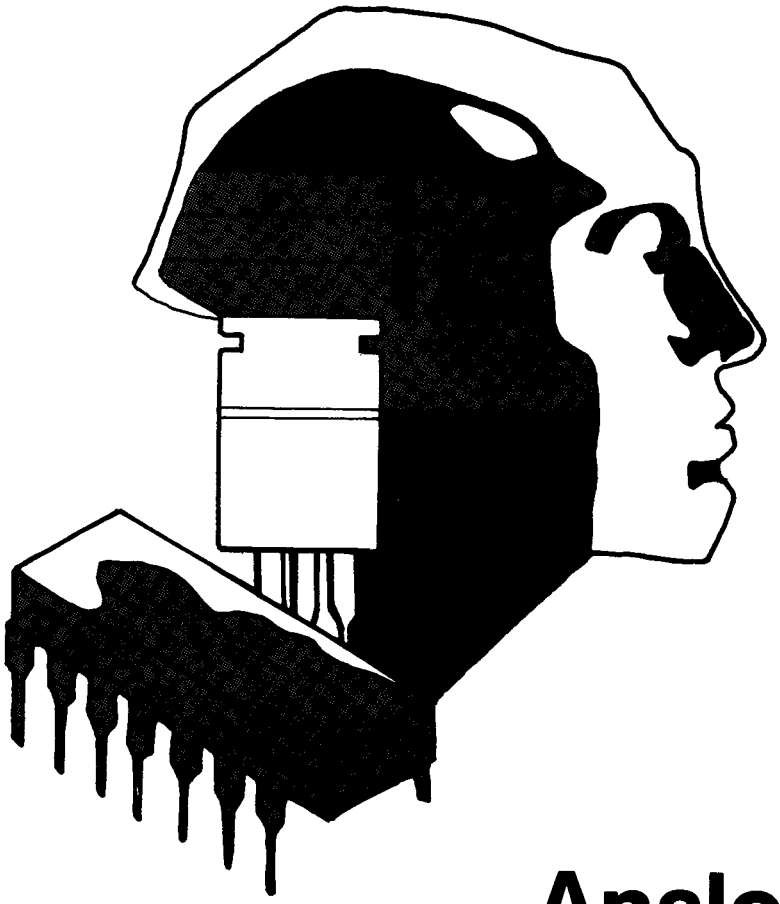
Chapter 7



Analog Devices

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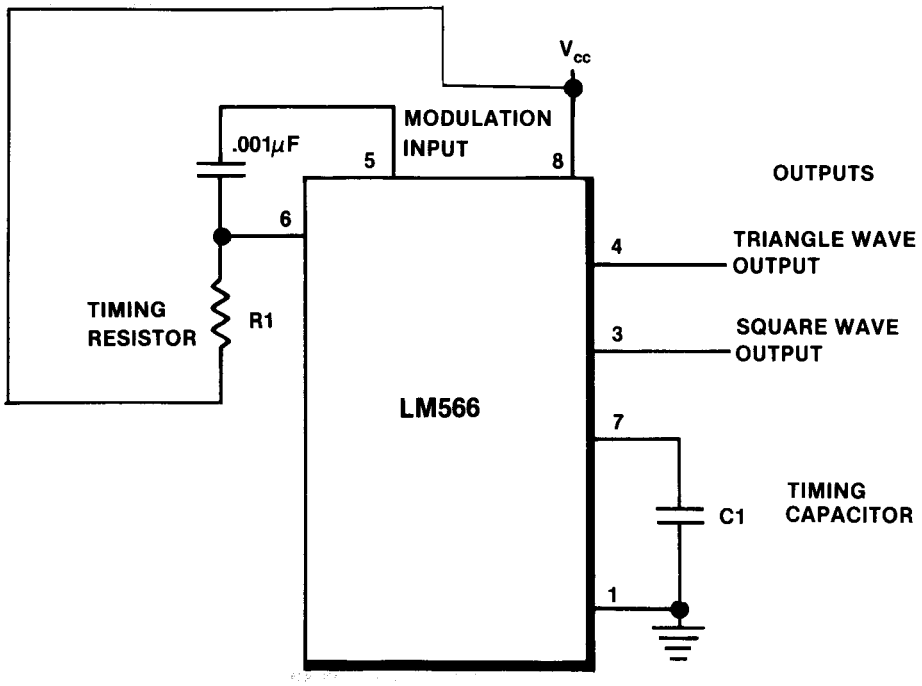
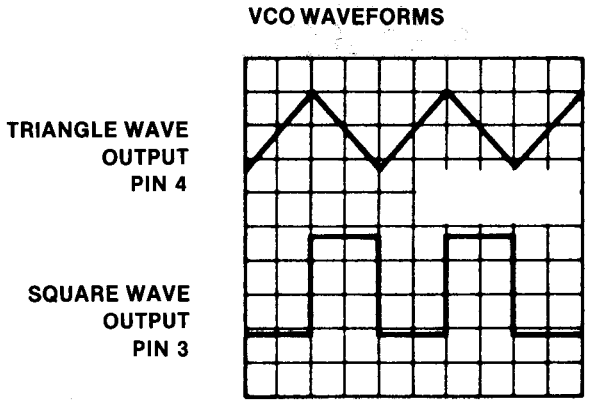
A. Oscillators

The LM566 provides a triangle wave and a square wave (see illustration at bottom of this page). The frequency of the outputs is determined by the values of R1, C1 and the control voltage on pin 5.

A .001 μF capacitor is connected between pins 5 and 6 to prevent oscillations that may occur during VCO (voltage-controlled oscillator) switching.





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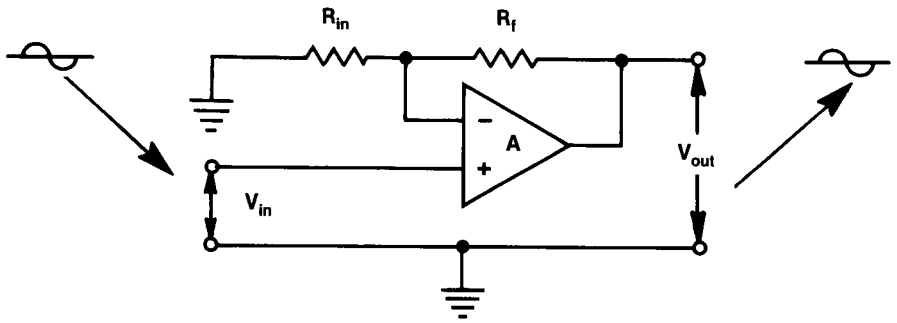
B. Operational Amplifiers

The ***operational amplifier*** or op amp, for short, is a high-performance amplifier. Due to its wide variety of applications, we will cover only a few of the more common uses of these versatile devices.

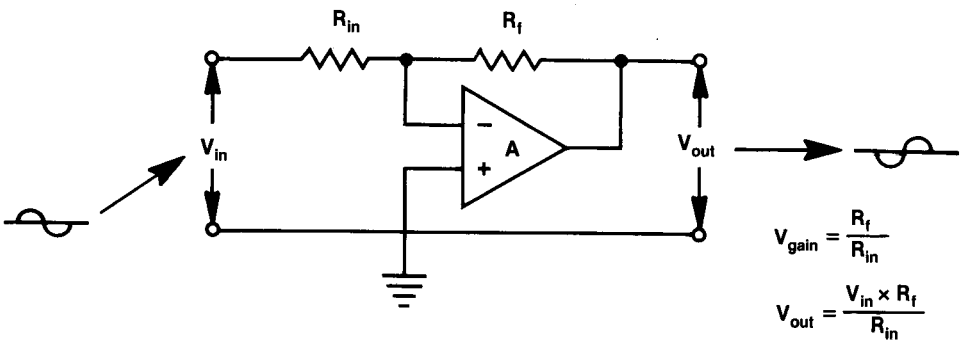
1. Non-Inverting Amplifier



The circuit shown above is connected as a ***non-inverting amplifier***. This is because the input signal is applied to the non-inverting input (+). Resistor R_f is called the ***feedback*** and R_{in} is called the ***input.***

The voltage gain of this circuit, or the ratio of the output voltage to the input voltage, is controlled by the values of R_{in} and R_f. In this configuration the output voltage is always in phase with the input voltage.

2. Inverting Amplifier



The op amp in the above illustration is connected as an ***inverting amplifier.*** This is because the input signal is connected to the op amp's inverting input (—) through R_{in}. R_{in} is called the ***input resistor.***

Resistor R_f is called the feedback. The voltage gain of this circuit is controlled by the values of R_{in} and R_f. In this configuration the input and output voltages are always 180° out of phase.

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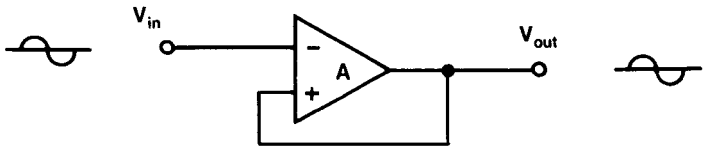
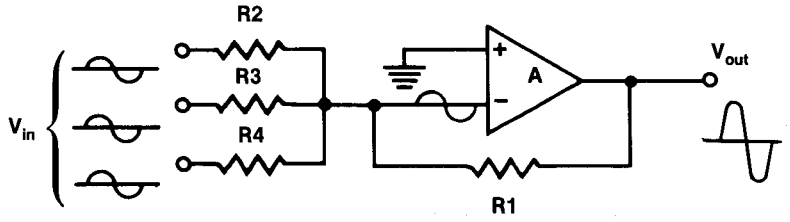
3. Voltage Follower



The ***voltage follower*** shown above is a unity-gain non-inverting amplifier; in other words, the input and output voltage ratio is 1 to 1. It has a very high input impedance, or resistance, and a low output impedance. It is used to buffer or isolate an input signal.

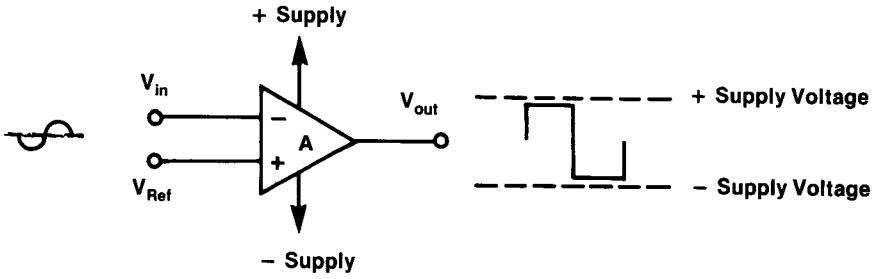
4. Summing Amplifier



The illustration above is using a resistive summing network (R2/R3/R4) fed into the inverting input of the op amp. The input voltages on all three inputs are added to give the actual V input.

The basic purpose of this circuit is to make a composite signal from several separate inputs. The ratio of values of R2, R3 and R4 will determine the shape and voltage of input signals. The ratio between R1 and the group of R2/R3/R4 will determine the gain of the circuit.

5. Comparator

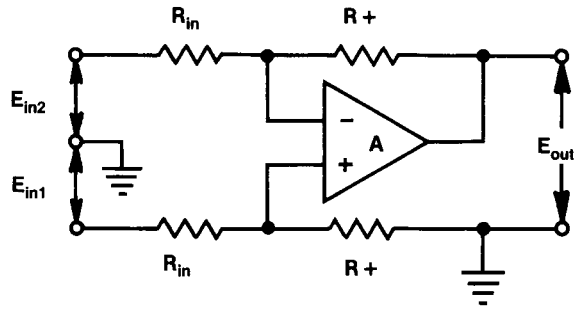


A comparator is a circuit that compares an input voltage with a reference voltage. The output reflects whether the input voltage is above or below the reference voltage.

When V_{in} is slightly greater than V_{Ref}, and V_{Ref} is negative, the output voltage will be close to the positive supply voltage. When V_{in} is slightly less than V_{Ref} the output will be very close to the negative supply voltage. This circuit is also known as a ***level detector.***

One application of this device would be to convert a paddle input from a potentiometer to a logic level that controls paddle movement.

6. Differential Amplifier



A ***differential amplifier*** is a combination of an inverting and non-inverting amplifier. If identical inputs are applied to E_{in1} and E_{in2}, E_{out} will be zero. If the inputs are not identical, the output will reflect the difference between the two. The circuit has a gain of $\frac{R+}{R_{in}}$.

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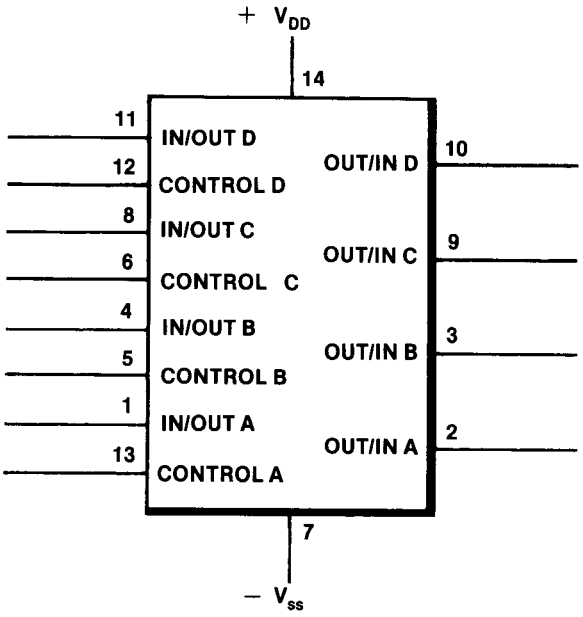
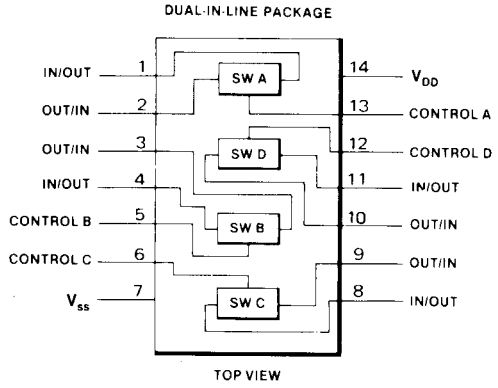
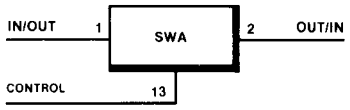
C. Quadbilateral Switches

The 4016 quadbilateral switch provides an extremely high "off" resistance and low "on" resistance. The switch will pass signals in either direction. It is used to control both analog and digital signals.







Normal Operation of Control Input

SW on = 1
SW off = 0
} **Logic levels**

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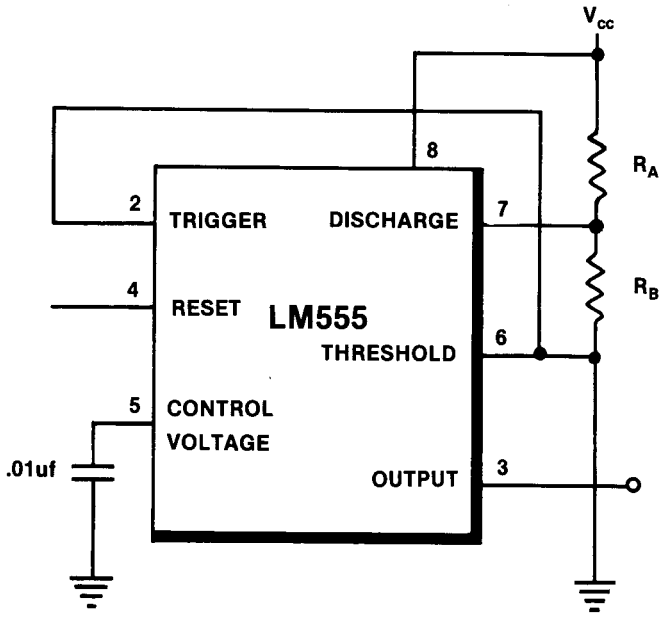
D. Timers (Voltage-Controlled Oscillators or VCOs)

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering and resetting, if desired for astable operation as an oscillator.

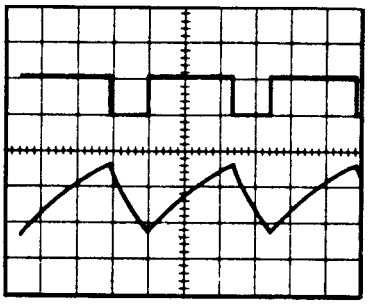
The free-running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms.



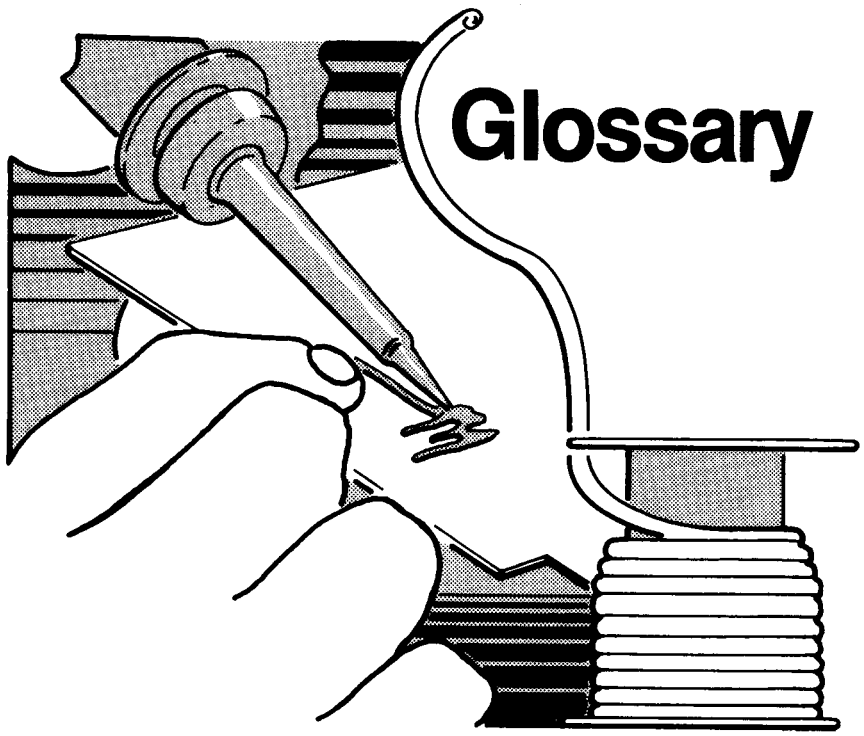
Astable Operation: If the circuit is connected as shown (pins 2 and 6 connected), it will trigger itself and free-run as a multivibrator. The external capacitor C1 charges through $R_A + R_B$ and discharges through R_B. Thus the duty cycle* may be precisely set by the ratio of these two resistors. As in the triggered mode, the charge and discharge times (and therefore the frequency) are independent of the supply voltage.

*The *duty cycle* is the percentage of time that a device is operating.

Astable waveforms generated in this mode of operation:



TOP TRACE—OUTPUT
BOTTOM TRACE—CONTROL VOLTAGE



Glossary

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Glossary

AC: Alternating current; from zero it rises to a maximum positive level, then passes through zero again to a maximum negative level.

ACCESS TIME: Time required to retrieve useable data from memory.

ACTIVE STATE: The logic state of a signal when it's true. Example: the active state for $\overline{\text{START}}$ (start not) is low.

ADDRESS: Specific location of data in memory; normally expressed in hexadecimal.

AMP: Short for ampere; measurement of electrical current equaling the flow of one coulomb per second.

ANALOG: Measurable in absolute quantity as opposed to on or off. Analog devices are volume controls, light dimmers, tachometers, etc.

ANODE: Positive (arrow) end of a diode.

AMPLIFIER: A device used to increase the strength of an applied signal.

AMPLITUDE: The maximum value from zero of a waveform.

ASTABLE: Having no normal state. An astable device will free-run or oscillate as long as operating voltage is applied. Oscillation frequency is usually controlled by external circuitry.

ASYNCHRONOUS: Not dependent on a system clock. Responds to random events such as a coin switch or fire button; it is unpredictable.

B+: Main power supply voltage of a monitor: derived directly from line voltage. In Quadrascan™ X-Y monitors it is 25V; in raster-scan monitors it is 73V.

BETA: Current gain of a transistor in the common emitter configuration. Mathematically expressed as the collector current (I_C) ÷ base current (I_B).

BEZEL:
1. A formed or machined retention device such as the conical piece used to mount a pushbutton switch to a control panel.
2. A cut or formed piece with graphics used to frame the monitor screen of a video game.
3. A vacuum-formed part mounted externally which frames the viewing area of a video game.

BIAS:
1. **Forward:** Conducting state of a diode or transistor.
2. **Reverse:** Non-conducting state of a diode or transistor.

BIDIRECTIONAL: Able to send or receive data on the same line. Example: a data bus of a microprocessor.

BINARY: Numbering system where all values are expressed using two digits (0 and 1).

BISTABLE: Having two normal states, as in a flip-flop, which switches from one normal state to the other when triggered by an external signal.

BIT: Binary digit; is either a 1 or a 0.

BLANKING: Turning off the beam on a CRT during retrace.

BLOCK DIAGRAM: A system drawing representing functional units by blocks. Very useful during initial troubleshooting for localizing a problem by function.

BOOLEAN ALGEBRA: Mathematical representation of logic used in the design and description of circuits. Its important symbols are: + (OR); • (AND); ⊕ (Exclusive OR); and $\overline{X}$ (X not, indicating a normally high signal that goes low to perform a function).

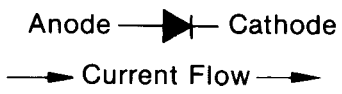
BUFFER: A device used to increase fan-out.

BUS: Set of parallel paths for transferring data.

BYTE: Smallest addressable unit of storage—typically 8 bits; synonymous with ***word*** in a 8-bit system such as 6800, 6502, and Z80.

CAPACITOR: A device capable of storing electrical energy. It blocks the flow of DC while allowing AC to pass.

CATHODE: Negative end of a diode.



CHARACTER: An alphanumeric or special symbol: A-Z, 0-9, @, *, #, etc.

CHIP: A single integrated circuit.

CLOCK: A repetitive signal for synchronizing all system functions.

COINCIDENCE: Occuring at the same time.

COMPLIMENTARY: Opposite states, such as the outputs of a flip-flop.

COMPOSITE SYNC: Horizontal and vertical sync bused together. Provides necessary timing to keep monitor in synchronization with the rest of the game system.

COMPOSITE VIDEO: Complete signal from system to monitor, comprised of H SYNC, V SYNC, and video.

COMPUTER: System capable of accepting and processing data and supplying results.

CONDENSER: See *CAPACITOR*.

CPU: Central Processing Unit; the 6800, 6502, Z80, etc.

CRT: Cathode-ray tube.

CROSS-TALK: Unwanted signal transfer between adjacent or parallel lines.

DATA: Information used by a computer for processing.

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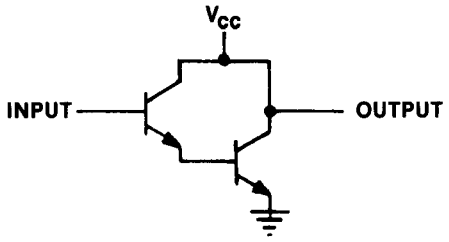
DARLINGTON: A two-transistor amplifier that provides extremely high gain.



DC: Direct current, meaning current flowing in one direction and of a fixed value.

DECIMAL: Numbering system using ten digits, namely 0 to 9.

DEFLECTION YOKE: Coils around the neck of a CRT. One set of coils deflect the electron beam horizontally and the other set deflects vertically.

DIAGNOSTICS: A programmed routine for checking out a system—for example, the self-test.

DIE: Silicon chip inside an integrated circuit package.

DIGITAL:
1. Data in numeric units; expressed in digits.
2. Logic system using a series of yes/no answers for computation.

DIODE: Semiconductor device with two terminals; it conducts in only one direction.

DISCRETE: Non-integrated components, such as resistors, capacitors, etc.

DMA: Direct memory access. A process of accessing memory directly that by-passes the CPU logic. Normally used for transferring data between the I/O ports and memory.

EHT: Extra-high tension.
1. A Canadian term for high voltage, OR,
2. The feeling you get when the phone rings at 1 a.m. Saturday morning and you're on call.

EAROM: Electrically alterable ROM; a memory that can be changed by the application of high voltage.

EEROM: Electrically erasable ROM; see ***EAROM.*** Note: The application of high voltage ***should not*** be practiced by the novice. Randomly applying high voltage may alter any number of components.

EROM: Eraseable ROM or PROM. Memory is erased by exposure to ultraviolet light. Also called a UV EROM.

FAT FINGER: Application of wrong tools or techniques when troubleshooting.

FAN-IN: Measurement of the load an input puts on a circuit. A standard fan-in draws 1.6 mA from the driving device.

FAN-OUT: Driving capacity of an output. The measurement of how many standard (1.6 mA) loads an output can drive.

FLYBACK: Step-up transformer used in a monitor to supply high voltage.

GATE: An IC with one output that responds only when some number of input conditions are satisfied.

GLITCH: Stray pulse.

I/O: Input/Output.

INTERLOCK: Safety switch that turns off system power when an access panel is opened.

IRQ: Interrupt request, a control signal to the CPU that is generated by external logic. This signal tells the CPU that external logic needs the attention of the CPU. Depending on the program, the processor may or may not respond.

HEXADECIMAL: Numbering system using 16 digits, namely 0-9 and A-F.

HORIZONTAL: Left-to-right motion on a monitor.

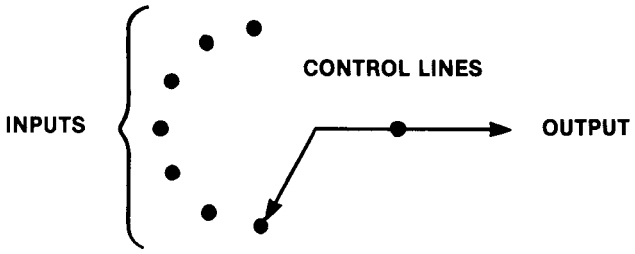
KLUDGE: A hodge-podge of parts assembled to perform a function, which none of them were probably originally intended to perform.

LEADING EDGE: The portion of a pulse going from an untrue to a true or active state.

LOGIC STATES: The conditions an IC input or output will be in, to be on or off (in other words, logic 1 or 0). The figure below shows logic levels (states) referenced to +5 VDC.

The above are voltage levels to look for in a TTL system.

MULTIPLEXER: A circuit with a large number of inputs and one output.



MSB: Most significant bit, or the highest bit of a binary number or device.

NMI: Non-maskable interrupt. A request for service from external logic. The CPU cannot ignore this interrupt request.

NYBBLE: 4 bits, or one-half of a byte.

OCTAL: Numbering system using 8 digits, namely 0-7.

OHM: Unit of resistance.

OHM'S LAW: Formula for showing relationship between voltage (E), current (I), and resistance (R). $E = I \times R$.

PAGE: A subsection of memory. A ROM has blocks of data. Each block has "x" number of bytes, and these blocks are called pages.

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PHOTO-TRANSISTOR: A transistor that is activated by an external light source.

POTENTIOMETER: A resistor with a moving tap that slides from one end of the resistive material (either carbon or wire) to the other. Usually abbreviated ***pot***.

RAM: Random-access memory. Temporary data storage.

RASTER-SCAN: A monitor system wherein images are displayed. The system controls the intensity of an electron gun that continuously scans along a horizontal and vertical axis.

RESET: Go to the beginning and start over.

RETRACE: In a raster-scan monitor, the time during which the electron beam is resetting either from right to left or from bottom of the CRT to the top.

ROM: Read-only memory. Permanent data storage.

STROBING:
1. Using one circuit to drive several display digits where each digit is turned on for 1/X of the time. X = number of display digits.
2. Repeated checking of asynchronous inputs to see if any have been activated.

SYNCHRONOUS: Controlled by a repetitive clock.

THRESHOLD: The point of conductance. In a silicon transistor, this point is about 600 millivolts.

TRAILING EDGE: The portion of a pulse changing from an active to an inactive (off) state.

TWEAK: Relatively small adjustment, usually made with a potentiometer.

TWIDDLE: Unguided or uneducated tweak.

V_{cc}: Voltage collector common; term used for the power-supply voltage applied to a circuit.

VCO: Voltage-controlled oscillator. An astable multivibrator where the output frequency is controlled by the level of control voltage.

VECTOR: The line segment drawn between X and Y coordinates in the Quadrascan™ monitor system.

WATCHDOG: A counter circuit designed to protect the processor from self-destruction if a program malfunction occurs. If a malfunction does occur, the counter applies continuous pulses to the reset line of the processor, which causes the processor to keep resetting. This continuous pulse is termed ***barking.***

WORD: The largest block of data that a computer typically processes at any one time. In the microcomputer world this is 8 bits (8 data lines = 1 byte.)

ZENER: A special diode used as a regulator: its main characteristic is breaking down at a specified reverse-bias (Zener) voltage.