Mark-8

Hints and Tips

December 2000

1. Introduction

1.1 Purpose of this Document

The purpose of this CD disc is to provide a single complete source of information concerning the construction of the Mark-8 computer. The original 47-page construction article for the Mark-8 computer serves as the main reference. The original article contains circuit theory, assembly instructions, schematics and board artwork. The main body of this document helps clarify some of the shortcomings of the original construction article and hopefully provide the builder with enough information to build a working Mark-8 computer.

In addition, Hal Singers Mark-8 newsletters are included on this CD. The newsletters are a valuable source of information and describe many of the construction problems and solutions discovered by a large number of hobbyists who attempted to construct this computer. If you construct the Mark-8 computer you will understand everything they are talking about. Careful reading of these newsletters will also reveal comments and references to now famous computer personalities. The 1975 January issue is especially interesting reading, as that was the month the Altair was introduced.

1.2 History of the Mark-8 Computer

The Mark-8 computer is considered by some to be the microcomputer that ignited the personal computer industry that is continuing on today. During the early 70's access to computers was very limited. A large corporation could purchase or leased a multimillion-dollar IBM 360 mainframe. Smaller corporations or universities could spend 10 or 20 thousand on a Digital PDP minicomputer or three thousand for an Intel Intellec. Finally, the cheapest method to access a computer was time-sharing, which basically meant the company rented computer time. A company would purchase a Teletype and modem then dial into a remotely located computer owned by someone else. Typically, you could only dial in at certain times of the day and were charged for the usage by the minute. This is how Bill Gates first started using computers when he was in 8th grade. A few computer clubs did exist at this point whose main focus was the PDP series of computers, but the price severely restricted membership.

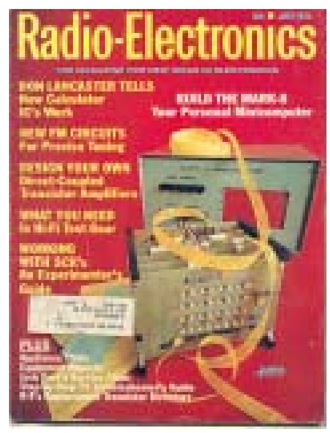


Figure 1 Cover Page July 74 Radio Electronics

This change in 1974 when Jon Titus published complete plans for the Mark-8 computer in the July 1974 issue of Radio Electronics. This article aroused enormous interest among electronic hobbyist since the computer could be built for under $500. This was the first time complete plans for a microcomputer were published in a popular magazine. Even if you didn't want to build the computer, the article itself was groundbreaking since it described the computer in detail and provided complete schematics for the entire computer. Now with the plans in the magazine almost anyone with a decent job could afford to build a real computer using the newly minted Intel 8008 microprocessor. The intense interest in the Mark-8 gave birth to many newsletters and clubs, mainly to exchange hints and tips about the construction and operation of the Mark-8 computer. Unfortunately, the construction of the Mark-8 computer was difficult for a variety of reasons. This eventually led to its downfall and the subsequent honor of the "First Successful Personal Computer" awarded to the later 8080 based Altair 8800 described in the January issue of Popular Electronics. Initially Popular Electronics was looking for a Mark-8 type of computer to feature in its magazine, but after evaluating the Mark-8 shortcomings they decided on a more upscale type of computer to beat out its competitor. The computer designed by Ed

Roberts, a contributing writer for Popular Electronics, was selected and name Altair, and that was the beginning of the end of the Mark-8.

1.3 The Mark-8 Computer

The Mark-8 computer is based on the Intel 8008 microprocessor. The standard configuration Mark-8 has 1 Kbytes RAM, four 8 bit output ports and two 8 bit input ports. Unique to this computer are the bare wire motherboard, non-plated through holes PCBs, extremely low-density -9V powered 1101 RAM's, and wooden card cage. Later on, hobbyist built the Mark-8 using more standardize methods to ease in the construction since most people could not get their original Mark-8 to work. The Mark-8 computer is based on the typical high cost minicomputer "multi-card, common backplane" design of that era. The backplane (motherboard) is simply a set of 41 bare wires interconnecting all the boards together. Eight of the bus wires have different signals on them depending on the specific card, because of this the cards had to be arranged in a specific order. Some cards also had interconnections on the top of the card in addition to the backplane connections on the bottom. The board's vias are not plated through, meaning when you constructed the card you had to solder each pad on both sides. The frame holding the cards together is made out of pine wood. The front panel of the Mark-8 is also loosely based on the minicomputer designs (like the PDP) of that era. You toggle data into the computer via paddle switches and read/verify data via LEDs. The Mark-8 uses one of Intels earliest chips, the 256 x 1 bit static 1101 RAMs for memory. The Mark-8 can access a total of 4 Kbytes of memory (four boards at 1K each). It is powered by a linear power supply (5V@ 8amp,-12V@2.5 amp trimmed to-9V). The original Mark-8 that is shown on the cover of July 74 issue of Radio Electronics now resides in Smithsonian Institution's "Information Age" display.

Figure 2 Mark-8 Card Cage

2. Basic Parts

The first job in building this computer is to find all the parts. Only the printed circuit boards could be purchased from Jon Titus (through a contracted PCB house) back in 1974, everything else needed to be purchased from an electronic parts distributor or built at home. The original article contains a fairly complete part lists, however, a lot of the details are left up to the reader. Table 1 is a more comprehensive parts lists that includes all the parts necessary to construct a Mark-8 computer that looks exactly like the Mark-8 pictured in the article.

2.1 Printed Circuit Boards

The Mark-8 printed circuit boards are the most difficult parts to find or make. The original sets of boards are double sided non-plated-thru holes printed circuit boards. They are made this way to save money. Unfortunately they require a tremendous amount of additional work to assemble. Using non-plated-thru holes PCBs means that you have to manually solder a small jumper wire through any run that is routed from the top of the board to the bottom. It also means that you have to solder both the top and bottom leads of every resistor, capacitor, or IC installed on the board. If you read the old Mark-8 newsletters you will notice many people talking about this problem. This problem was the main reason that many people failed to complete the Mark-8. Section 4.1 contains detail instructions concerning the proper methods to deal with non-plated-thru holes. If you follow the instructions contained in that section you will have little trouble assembling a reliable Mark-8 with non-plated-thru hole boards.

Acquiring the boards is another problem. Some of the original sets of boards are still around, usually only partly assembled as the original owner probably gave up a long time ago. Lacking that, making a set from the artwork is another option. However, an original copy of the construction article is needed for this task as the reprint contained in this document is not accurate enough to make films. Toner transfer methods are not reliable for such large double side boards, don't even think about doing that. A third option is to wire wrap the boards. This is a viable option if a set of the original boards cannot be located or made. A forth option is to redraw all the artwork using a modern CAD PCB layout program and generate industry standard Gerber files. Any PCB house can make the boards directly from the Gerber files. However, this is time intensive task and prone to many errors if you lack experience.

Tips

1. *No outline for the boards is given in the original artwork, make the boards 6.5 X 9.5 inches.*
2. *Watch when cutting the boards that the 41 pin wire bus is aligned in all the boards.*
3. *The Data Input MPX Board has 42 pins, ignore the 42nd pin, line up the 1 pin of this board with the first pin of the other boards.*
4. *If you use Molex connectors as described in the parts list, make sure that when cutting the boards that the mounting holes are 7.87 mm from the edge, otherwise the Molex connectors won't fit.*
5. *Make all the holes .025 inches wide, except the Molex connector holes, which should be .062.*

Item	Component	Type	Value	Quantity
1	Cable	Hook up Wire	Insulated 24 gauge solid, 25 feet	1
2	Cable	Hook up Wire (high power)	Insulated 18 gauge stranded, 4 feet	1
3	Cable	Power Cord	IEC Type, 6 foot 3 conductor	1
4	Cable	Wire Bus/Jumper Wire	22 Gauge, soft annealed, copper, tinned bus bar wire 40 feet	1
5	Cable	Ribbon	Rainbow, 16 conductor 28 gauge, 1 foot	1
6	Capacitor	Disc	Ceramic, .01uF, 100 Volt Radial Leads	6
7	Capacitor	Disc	Ceramic, .1uF, 100 Volt Radial Leads	17
8	Capacitor	Disc	Ceramic, 33pF, 1000 Volt Radial Leads	1
9	Capacitor	Disc	Ceramic, 680pF, 100 Volt Radial Leads	1
10	Capacitor	Electrolytic	Electrolytic, 100uF, 10 Volt Axial Leads	2
11	Case (optional)	Steel Rectangular	Bud SB2142	1
12	Connector	Board Edge	Molex, 09-52-3081	14
13	Connector	Board Edge	Molex, 09-52-3081 male plug	14
14	Crystal	Ex	4 Mhz	1
15	Diode	LED	5mm Red, Clear Lens T1-3/4 LED	32
16	Diode	LED	5mm Red, Red Lens T1-3/4 LED	1
17	Hardware	Card Cage Brackets	steel 1.013 x.487 inch mounting brackets	8
18	Hardware	Card Cage Frame	Pine 1/2x3/8x8 inch, painted black	4
19	Hardware (optional)	Card Cage Nuts/bolts	8-32 x 3/8 inch machine bolts/nuts	8
20	Hardware	Card Cage Screws	Sheet Metal #6 x 1/2 inch screws	8
21	Hardware (optional)	Front Panel	18 gauge steel, Hole punched, painted green/blue, black silk	1
22	Hardware (optional)	Front Panel Diode Mount	Plastic Clip and Ring, T1-3/4 LED mount	1
23	Hardware (optional)	Front Panel Filter	Plastic, Transparent red, 1/8 inch, 6x4.5 inches	1
24	Hardware (optional)	Front Panel Filter Bolts/nuts	6-32 x 1/2 Bolt/nuts	4
25	Hardware	Wire Ties	4 inch, white plastic	10
26	IC	7400 series	7400	14
27	IC	7400 series	7402	3
28	IC	7400 series	7404	13
29	IC	7400 series	7410	2
30	IC	7400 series	7420	1
31	IC	7400 series	7442	5
32	IC	7400 series	7474	2
33	IC	7400 series	7475	10
34	IC	7400 series	7476	3
35	IC	7400 series	74123	2
36	IC	7400 series	74193	4
37	IC	74L00 series	74L04N	3
38	IC	8000 series	8263	2
39	IC	8000 series	8267	2
40	IC	80XX series	Ceramic D8008-1	1
41	IC	LSI	MM1101A1 Static Memory	8
42	PCB	Address Latch Board	FR-4, .063, drilled, 1 ounce copper tinned	1
43	PCB	CPU Board	FR-4, .063, drilled, 1 ounce copper tinned	1
44	PCB	Input Multiplexer Board	FR-4, .063, drilled, 1 ounce copper tinned	1
45	PCB	LED Register Display Board	FR-4, .063, drilled, 1 ounce copper tinned	1
46	PCB	Memory Board	FR-4, .063, drilled, 1 ounce copper tinned	1
47	PCB	Output Latch Board	FR-4, .063, drilled, 1 ounce copper tinned	1
48	Power Supply	+5V,-9V DC	Collins Triple Output Linear Supply or similar	1
49	Resistor	Carbon	1/4 watt, 5%, 10,000 ohms	11
50	Resistor	Carbon	1/4 watt, 5%, 1000 ohms	31
51	Resistor	Carbon	1/4 watt, 5%, 1800 ohms	1
52	Resistor	Carbon	1/4 watt, 5%, 22,000 ohms	9
53	Resistor	Carbon	1/4 watt, 5%, 220 ohms	35
54	Resistor	Carbon	1/4 watt, 5%, 560 ohms	1
55	Sockets (optional)	Extended Lead DIP Sockets	Mill Max 111-93-XXX-41-001, xxx defines number of socket pins	100
56	Switch	Front Panel Power Switch	C&K Mini Toggle SPDT	1
57	Switch	Front Panel Paddle	C&K 7101J4	10
58	Switch	Front Panel Momentary Paddle	C&K 7108J4	6

Table I – Mark-8 Suggested Parts List

2.2 Obsolete IC's

The Mark-8 parts list included four obsolete parts, the Signetics 8267, Signetics 8263, 256 x1 bit 1101 memory, and the Intel 8008. Obsolete means that the manufacturer doesn't make the part anymore, however, these parts can frequently be found from electronic surplus dealers, in old computer boards or EBAY. The Intel 8008 is easiest to find, the D8008, D8008-1, C8008 or C8008-1 will work. The Signetics parts are harder to find but can be easily simulated with modern parts. Look at the truth tables in Appendix A for more information.

2.3 Power Supply

The Mark-8 requires a +5V 3 Amp and –9V 1.5 Amp power supply. A linear supply is most realistic and used by all hobbyist in the 1970's. A modern surplus switching power supply could also be used, however, it is difficult to find a modern switching supply with a –9 Volt output. One option is to add linear regulator to a –12V output to obtain the desired –9-volt output, however, providing regulated power at a few amps is not trivial. If you can find a linear power supply with a +5V and +9 Volt output and the returns are isolated (floating) you can tie the +9 voltage output to the 5V ground to obtain a –9V output. The simplest method is to use a standard variable dual output lab power supply.

Tips

1. *If you have a variable bench top power supply, use that, you can always buy a permanent supply for the Mark-8 later.*
2. *The original surplus linear power supply for the Mark-8 didn't fit in the case. If you ever visit the Smithsonian look at the back of the Mark-8, you will find an open back with no power supply, it didn't fit so it was omitted from the display.*

2.4 Case and Front Panel (optional)

The approximate size of the original Mark-8 case is 17 inches wide, by 9.5 inches high by 11 inches deep. BUD makes a case of this size today, see Table 1 for more details. The front panel has to be cut and labeled. Use a metal panel of about 16 or 18-gauge thickness if you are not using the panel from a commercial case. Jon Titus applying stick-on lettering and sealed the panel with a few coats of clear coat (polyethylene or similar). See Figure 3 for detail dimensions of the front panel.

Tips

1. *You really don't need a case or front panel to construct a Mark-8 computer. Making or buying either is expensive and time consuming. Alternatively, simply attach the switches to a single strip of pinewood to keep them organized. Many Mark-8's were originally built this way.*

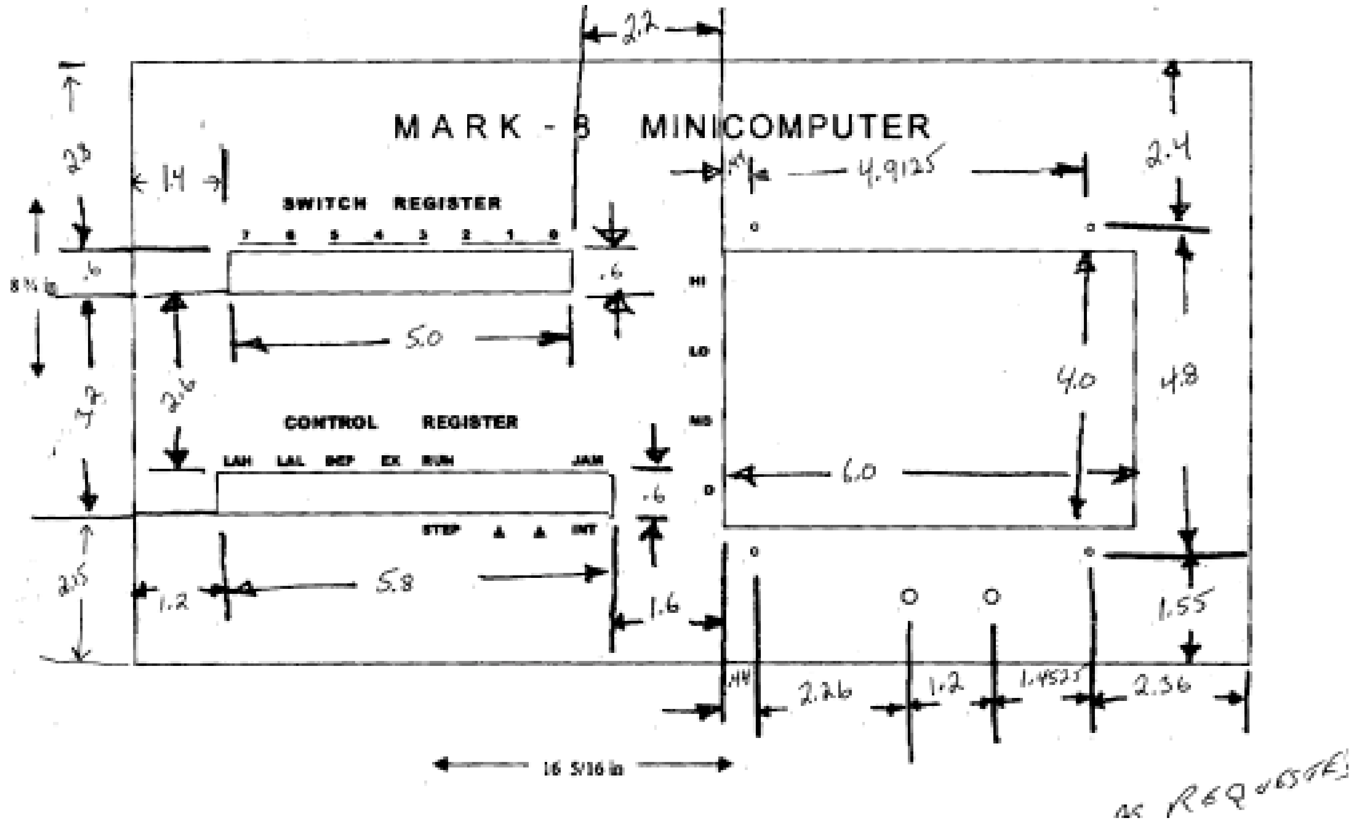


Figure 3 Mark-8 Front Panel Dimensions

3. Unique Tools and Parts

The Mark-8 is a home built computer, both electrically and mechanically. A wide variety of tools including a soldering iron, electric drill and even a table saw are necessary to construct a good looking and functional computer. The more unique tools and parts are described below.

3.1 Soldering Iron (non plated thru holes only)

One critical tool used to construct the Mark-8 is a fine tip soldering iron (1/64 inch). A very good soldering iron is the Weller WM120 soldering iron. The WM120 is a specialized soldering iron for fine detailed work. It's a pencil thin, lightweight, low power soldering iron with an extremely narrow soldering tip. This tip makes short work of the most difficult part of the Mark-8 construction, soldering the DIP sockets into the non-plated-thru holes of the PC board. If you are using plated-thru-boards or wire wrapping the boards then a regular soldering iron will be fine.

Figure 4 Weller WM120 Soldering Iron

3.2 Extended Lead Sockets (non plated thru hole only)

One unique part that is very helpful in the construction of non-plated-thru boards is and extended lead socket. Its also helpful if you purchase an open frame socket, as it will help in finding solder bridges. The extended lead socket is pushed half way through the printed circuit board. The socket leads are then soldered on both top and bottom. This is necessary since the PC boards don't have plated thru holes. Wire wrap sockets can also be used, however, the PCB holes have to be re-drilled to a larger diameter. However, this reduces the clearance between adjacent pads, thus making solder bridges more likely.

Figure 5 Extended Lead Socket

4. Board Assembly

The methods and techniques used to construct the boards varies greatly depending if the PCB's have plated-thru-holes or not. Section 4.1 can be ignored if you are using standard plated boards or are wire wrappi3ng the Mark-8.

4.1 General Non-Plated-Thru-Holes Assembly Techniques

There are many ways to assemble the Mark-8 non-plated-thru boards. One method is to simply solder the sockets directly onto the boards, both top and bottom. The method described in the subsequent paragraphs is one of the best and assumes the use of the Weller soldering iron and extended leaded sockets. If you haven't done any major soldering in the past 20 years, here are some general tips:

1. The secret to soldering is a clean and properly heated joint.
2. Clean means that the board should be sanded and then wiped with isopropyl alcohol. Sand with a fine sandpaper (400 grit) and wipe clean with a paper towel soaked in alcohol.
3. Solder the boards immediately after cleaning; otherwise an oxidation layer will build up on the copper traces. Flux helps clean the solder joint of oxidation, but you shouldn't depend on it.
4. Additional liquid flux may be used to aid in the soldering process. The pros always use it. You simple paint the joint with flux before soldering. Although solder has flux added to it, it is generally not enough. Flux reduces the melting point of solder, cleans the joint (the flux is vaporized by the heat of the iron and the vapors will clean the surfaces of any oxidation) and in general helps the solder flow around the joint, resulting in the nice professional looking joint.
5. The disadvantage of flux is it takes time and makes the board sticky afterwards. If you do flux buy a can of flux remover and simply dip the entire board in the flux remover after you completed the entire board. Flux remover only removes recently applied flux, so you must do it soon after you completed the board.
6. Use a wet sponge to clean your solder tip. Clean the tip every forth solder joint, if you don't the heat transfer capability of the solder iron will be reduced and the iron will not be able to properly heat the joint.
7. Heat the joint to be soldered and then apply the solder to the joint, not the soldering iron tip. The solder should melt as soon as it touches the joint, if it doesn't then either your soldering iron is too weak or you haven't heated the joint long enough. It takes two to four seconds (depending on joint size and soldering iron wattage) to heat a joint properly; most people don't wait long enough. Apply the soldering iron to the joint, count to 3 and then apply the solder to the joint, it should melt instantly and surround the joint. If the joint is too cold, the solder will flow and surround your soldering iron tip! Which is what you don't want.
8. Use 60/40 (60% tin, 40% lead) rosin core solder and the smallest diameter you can find.
9. Use a solder wick to remove solder, it works best as compared to the more expensive solder "suckers".

4.1.1 Inserting The Sockets :Step 1

The first step in assembling all the boards is to properly place the socket into the boards at the correct depth. If you don't do this correctly you won't be able to correctly solder both sides of the pin. This is easily accomplished by using 4 dimes. First place the sockets all the way through the boards as shown. The picture shows only 3 sockets being assembled, do all of them at the same time.

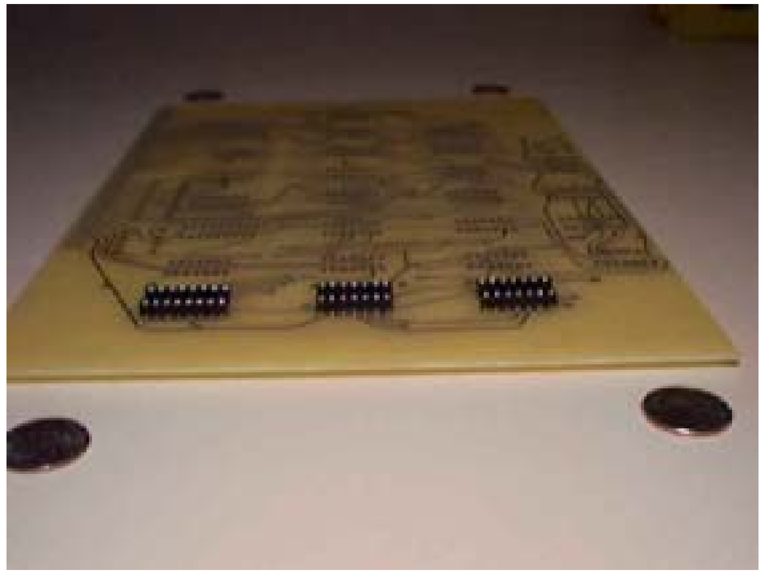


Figure 6 Initial Socket Setup

4.1.2 Inserting The Sockets :Step 2

Next slide the dimes underneath the four sides of the board.

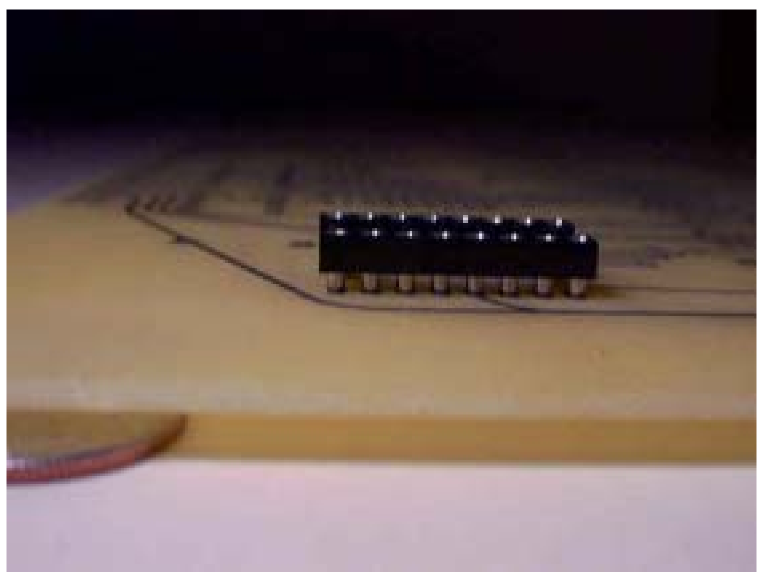


Figure 7 Socket Position, Fully Pushed Thru

4.1.3 Inserting The Sockets: Step 3

Next, with your fingers, push the PCB down until it hits the dimes. The sockets will be pushed up at just the right depth for proper soldering. As a bonus all the sockets will be at the exactly the same height, so your boards will look good too.

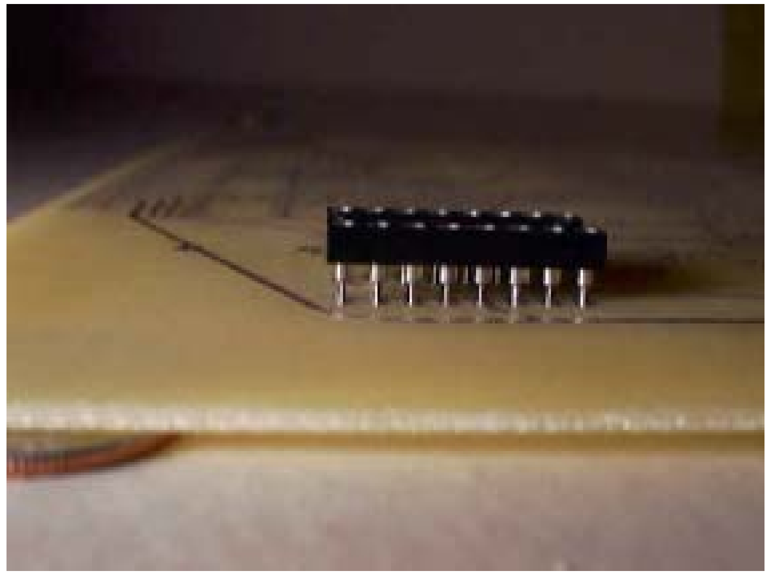


Figure 8 Socket Position After Board Lowered

4.1.4 Inserting The Sockets: Step 4

This is the same socket, bottom view. At this point you are ready to solder the socket.

Figure 9 Bottom View of Properly Installed Socket

4.1.5 Inserting The Sockets: Step 5

This shows the socket soldered onto one of the boards. Noticed how it's soldered on top of the board. The bottom of the socket is also soldered as normal. Solder bridges occur easily, take your time.

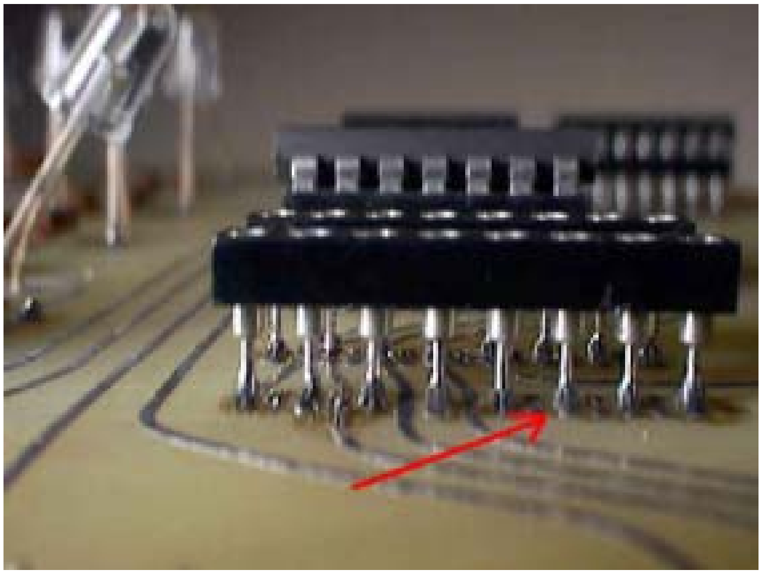


Figure 10 Properly Soldered Socket

4.1.6 Inserting The Sockets: Step 6

Verify all solder joints by backlighting the printed circuit board and inspect for solder bridges. The use of an 2x-illuminated magnifying glass makes this a simple task. Solder bridges will stand out like a sore thumb. The open frame sockets also help. Find all the solder bridges now. Each solder bridge will take about 2 hours to locate and fix after the Mark-8 is assembled.

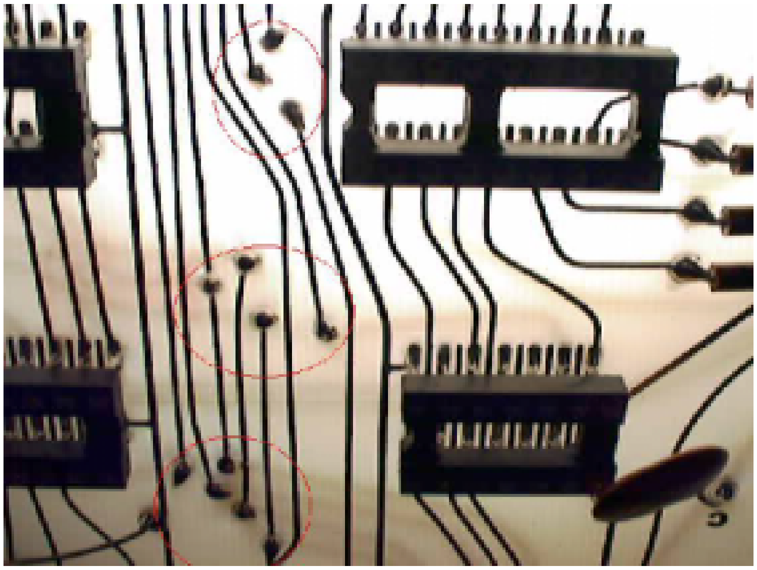


Figure 11 Backlite Board (with Vias in circled area)

4.1.7 Vias

Another difficulty of assembling non-plated thru hole boards is the vias (see circled items on Figure 11). Vias make connections from the top of the board to the bottom. Place a spare piece of bare wire through them and solder both sides to complete the connection. Make sure you get them all, this is a very time consuming task on some of the boards.

4.2 Board Assembly Debugging

In order to increase the probability that the Mark-8 computer will actually work it is best to start debugging the boards as they are assembled. It is very difficult to fix certain problems if they are found after the boards are assembled and soldered together. The following are some general debug guidelines:

1. After soldering the sockets on the boards, verify that you did not short any of the pins together by doing a continuity test between each adjacent pin. This is a common bug in Mark-8 computers. It may seem like a waste of time, but you will have much more confidence in the completed Mark-8 if you do this. Notice that some of the pins are intentionally shorted together; use the layout diagrams as a guide to determine if the short is intentional or not.
2. The pads on the molex connectors are barely wide enough to form a good solder joint. Perform a continuity test between the molex connectors and the trace it supposed to be connected to.
3. Verify that all the thru holes are wired, there should be no empty holes in any of the boards except for the memory board.
4. Check orientation of the IC's after they are all inserted in the sockets. The Mark-8 boards do not use any standard for orientation, so this is another common problem.
5. Check that none of the power rails are shorted (-9V, +5V and GND). Since there are many power rail traces on each board shorts between power rails are common. It is very difficult to locate a short in the power rails after the boards have been soldered together.

4.3 CPU Board Assembly

CPU artwork is error free in the original article; however, this is the second hardest board to construct, next to the memory board. There are about 50 feed thrus on this board; you will most likely miss one, especially the feed thru behind the gang of resistors on the bottom of the board. In addition, watch the jumpers as they are easily missed. Also noticed the orientations of the IC's, the outer two rows are different then the inner two rows.

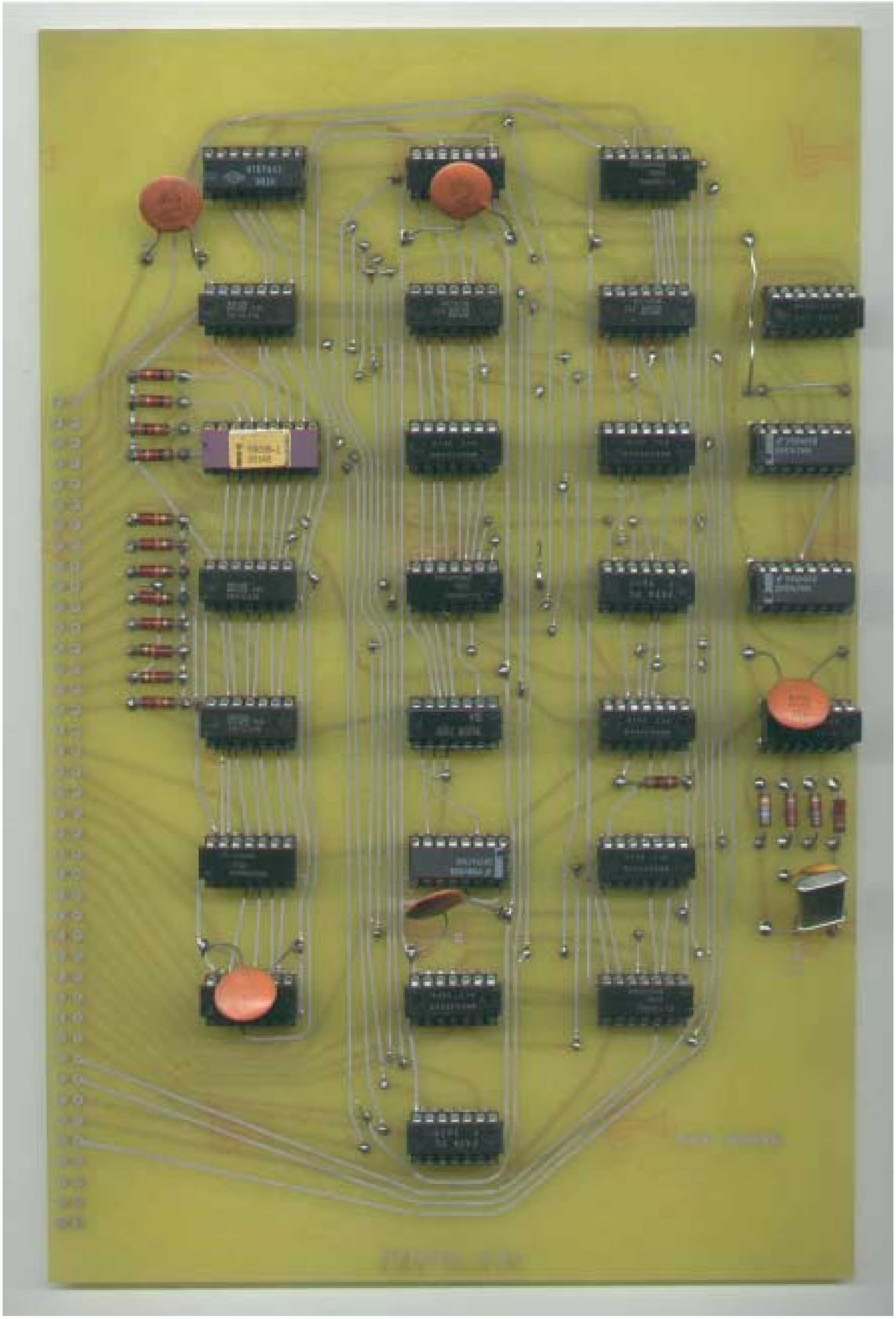


Figure 12 Assembled CPU Board

4.4 Address Latch Board Assembly

This is pretty easy board to build. Notice the large jumper on top of the board, it was not specified in the construction article, so make sure you add it.

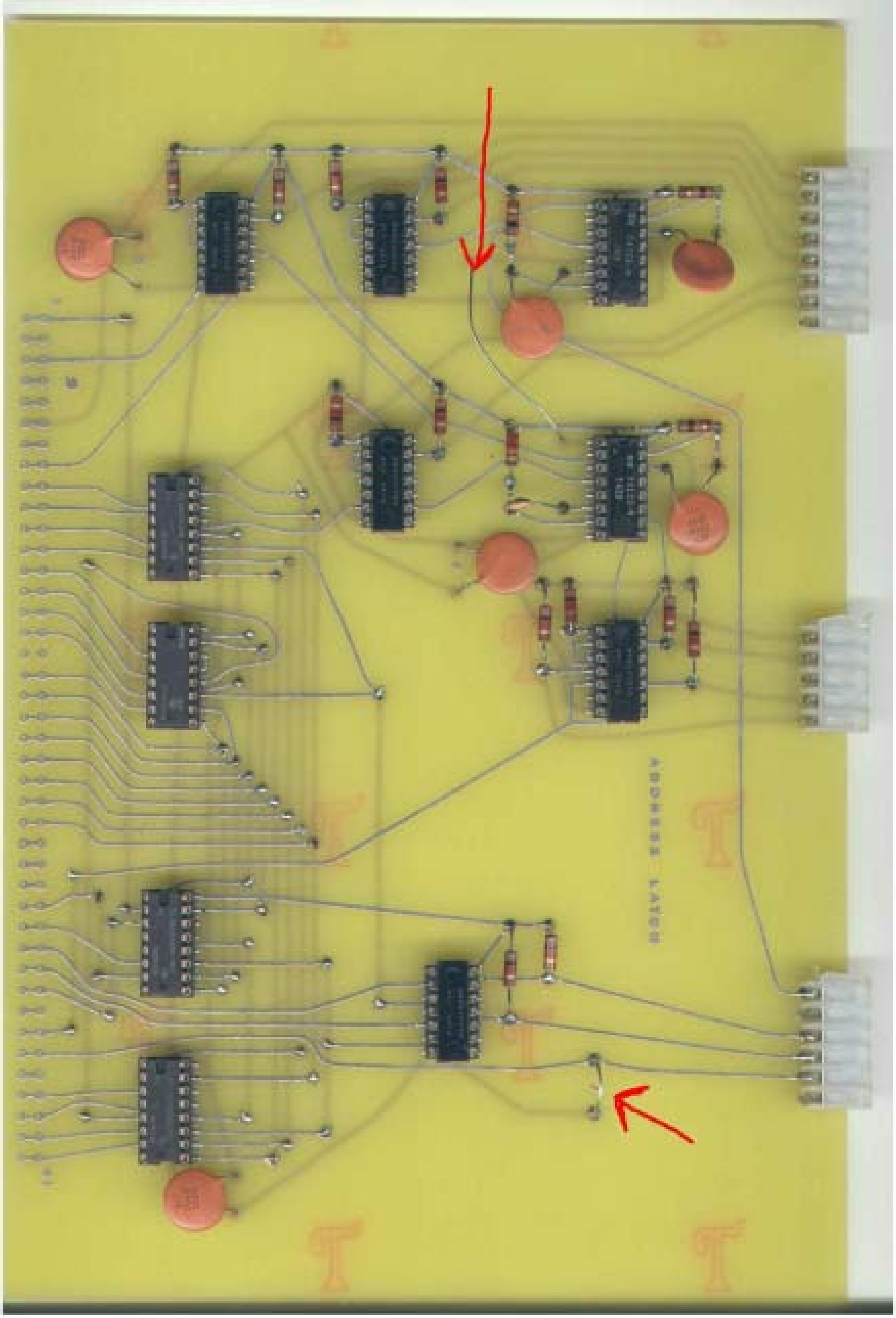


Figure 13 Assembled Address Latch Board

4.5 Input Multiplexer Board Assembly

The 1.0uF electrolytic capacitor stated in the plans is incorrect, it should be 100uF. Watch the jumpers again on this board.

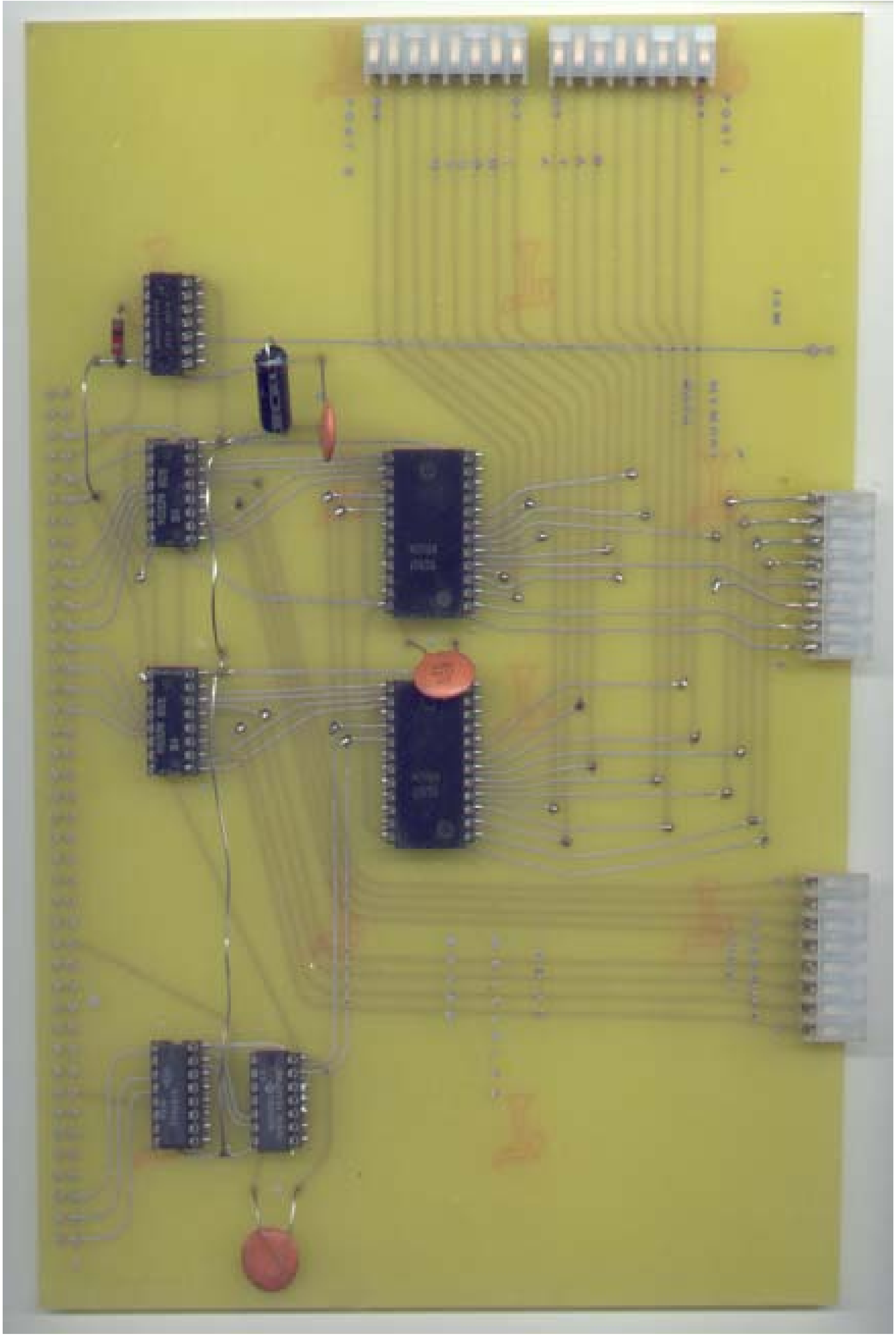


Figure 14 Assembled Input Mux Board

4.6 Memory Board Assembly

The Memory board is difficult to assemble. The artwork shorts the +5 volt rails to memory outputs if you install all the vias feed throughs, see the picture to see where they are, leave them alone (there are eight of them across the top of the board). If you have boards with plated thru holes then you must drill these out. The jumpers are set up for one memory board, if you are constructioning a Mark-8 with multiple memory boards you must change the jumper settings. See the original article for details about multiple memory board Mark-8's.

Also, after you soldered all the sockets you must verify that none of the memory traces that run across the board have shorted. Do this with a DVM **before** you solder the feed thrus. Take the DVM, set it up for resistance measurement and place one probe on a trace and the other probe on a trace adjacent to the first. This takes only 1 minute to do the entire board. You will be sorry if you have any shorts later so do it now.

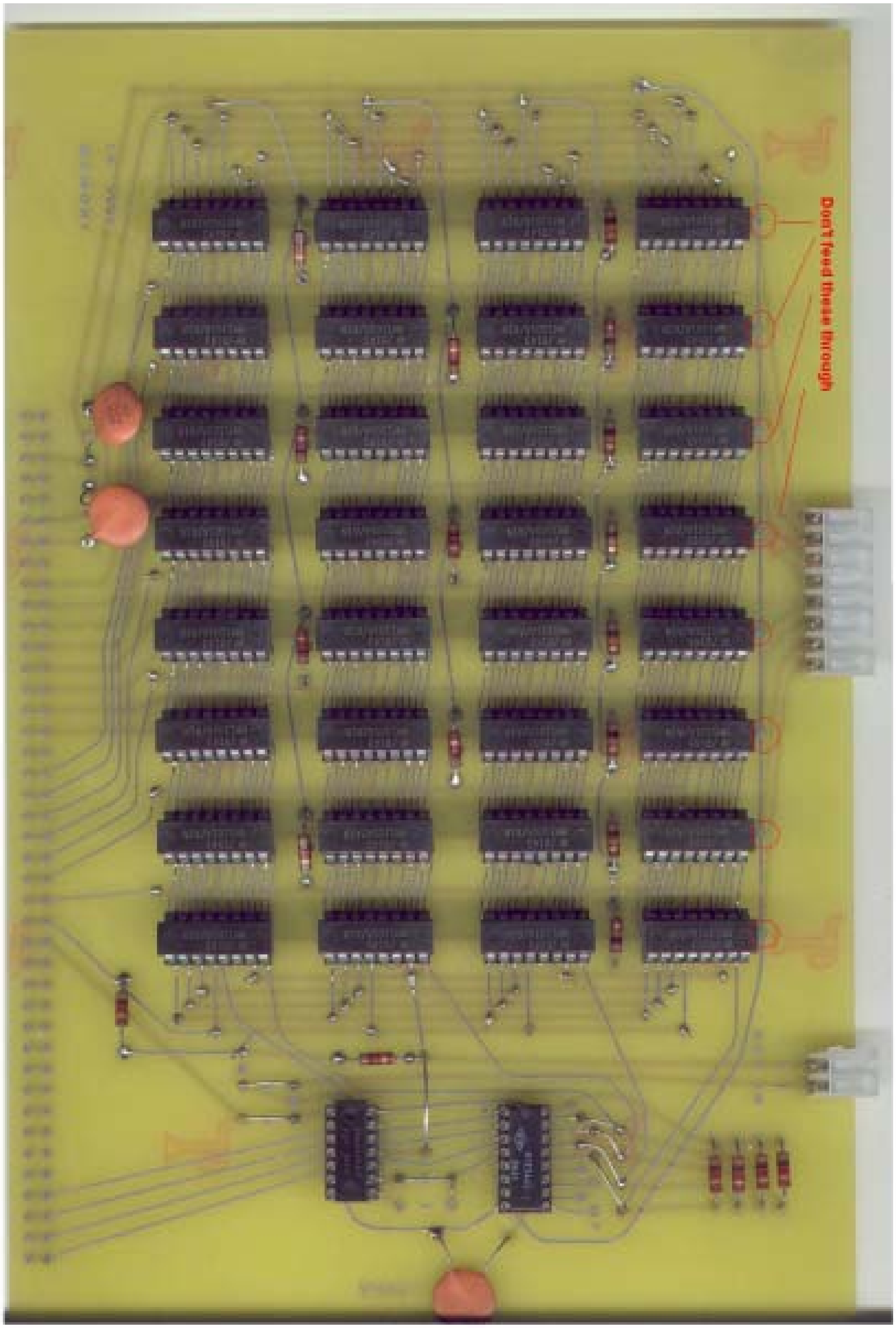


Figure 15 Assembled Memory Board

4.7 Display Board Assembly

The Display board has one error on the original Mark-8 artwork, the C2 cap is connected to +5 and +5V. See the photo for the fix. Make sure the LEDS are inserted correctly. Otherwise, this is an easy board to construct.

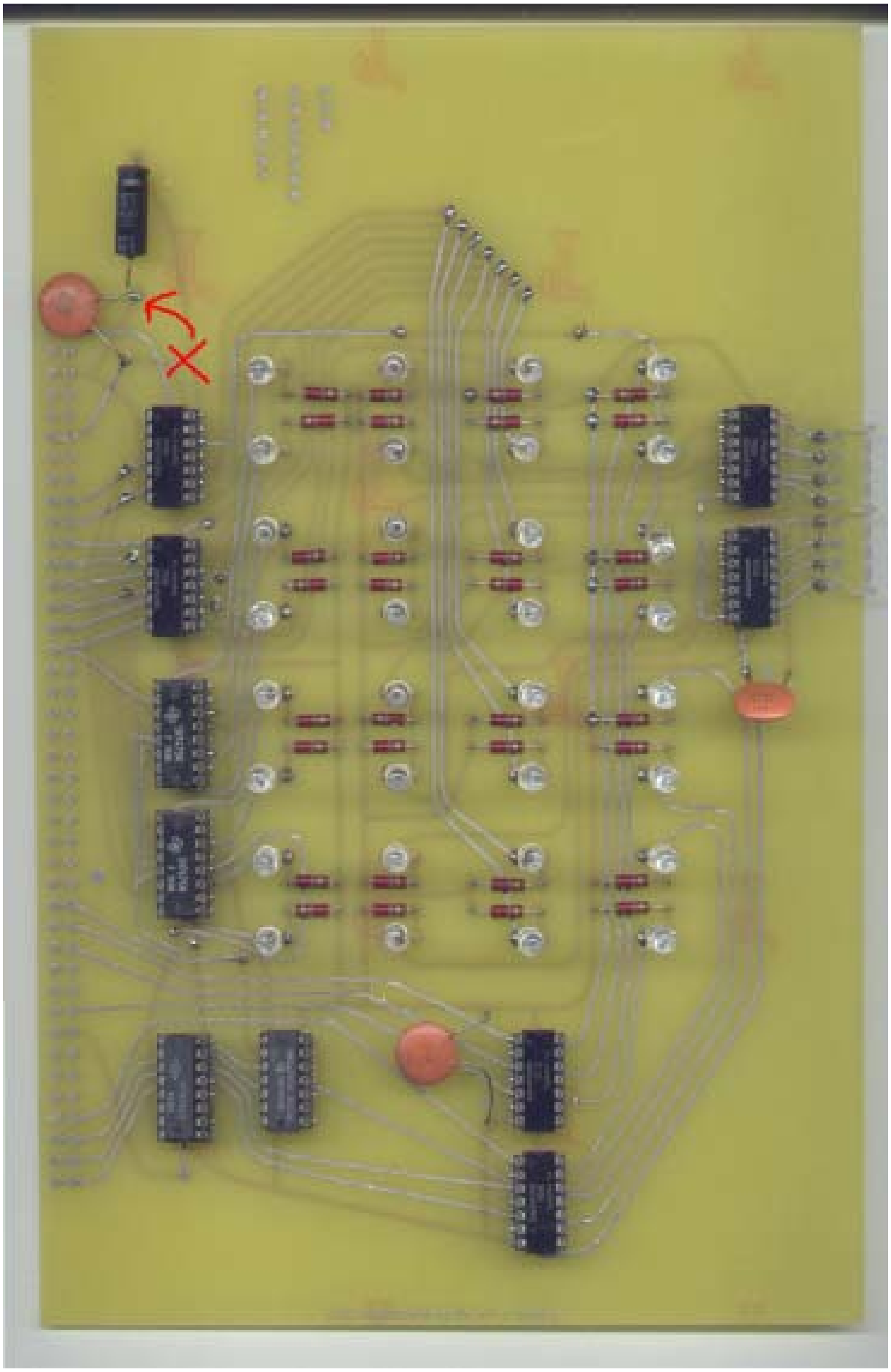


Figure 16 Assembled LED Display Board

4.8 Output Board Assembly

The Output Port board is error free in the original artwork. Easy board, but the jumpers could screw you up, take note of the jumpers on the picture.

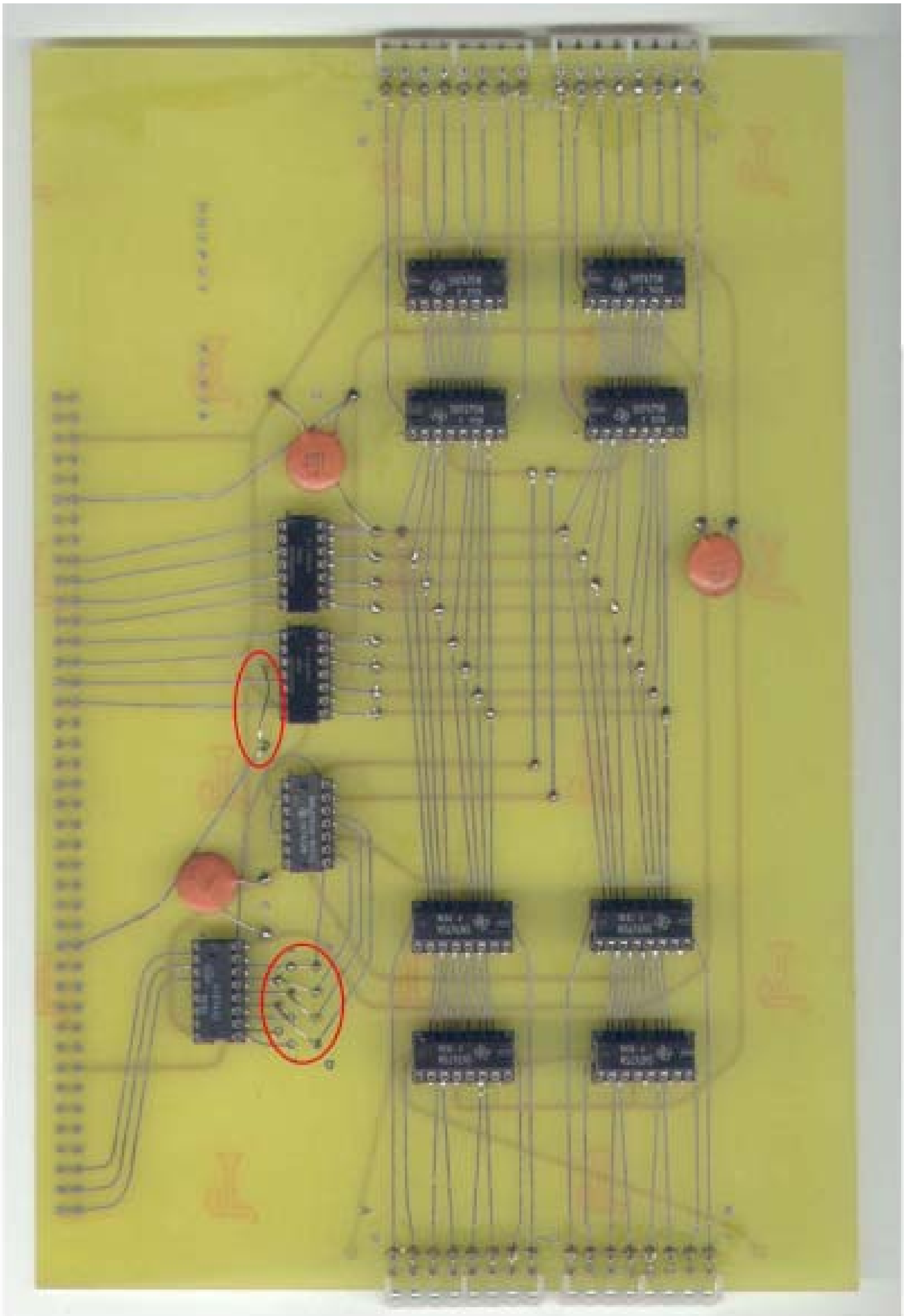


Figure 17 Assembled Output Port Board

4.9 Post-Board Assembly Debugging

5. Card Cage Assembly

The card cage is made out of four strips of 3/4 x 1/2 inch pine wood. Cut them to 8 inches long, paint it flat black and install L brackets on each end with a machine screw.

Figure 18 Wooden Card Cage Assemblies

With all the brackets installed on the wooden rails, line up the rails side by side and hold them together with a C clamp as shown below. Get a handsaw and cut six sets of slots across all four rails. A standard handsaw will cut the slots the correct width, about 1/16th of an inch.

Figure 19 Cutting the Slots for the Card

Now mount the CPU and LED boards by pushing the boards into the first and last slots as shown below.

Figure 20 Partially Assembled Card Cage

Drill four holes into the LED display board (the front board) and the CPU board (the rear board) to match up with the holes in the eight brackets. Fasten them with nuts and bolts. Install the rest of the boards (see **Figure 23** for order).

Figure 21 Fully Assembled Card Cage

6. Wire Bus Assembly

You are now ready to install the wire bus. Do this with the boards mounted in the frame, as the frame will provide a steady base. Install one 22-gauge bare bus wire (soft annealed copper, tinned) through each of the 41 bus holes. Push the wire into the first board and then pull it through the rest with needle nose pliers. After you installed all the wires pull each one taut with a plier to get rid of any slack. You can now solder both sides of the bus wire on each board.

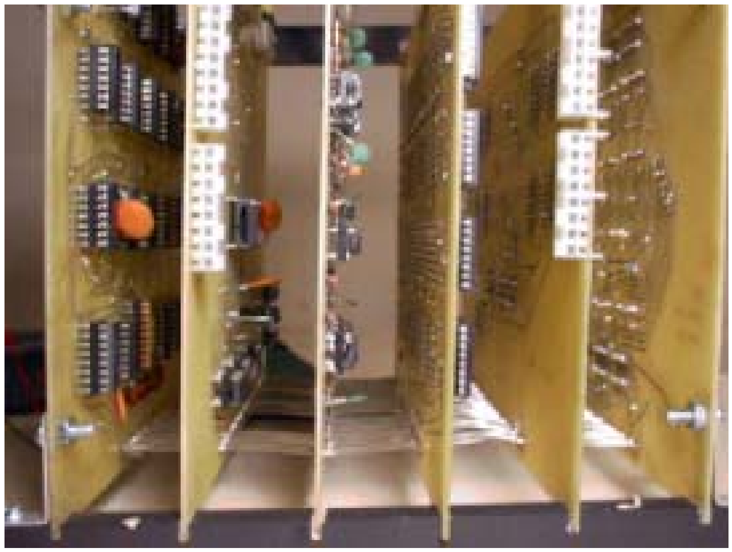


Figure 22 Wire Bus

After you solder all the wires you must cut the wires from pins 9 thru 16 between the Mux board and the address board as shown in Note 1 of **Figure 23**.

7. Top Bus Assembly

You are now ready to install the connectors on the bus on top of the cards. Using Molex plugs, a piece of ribbon cable and some yellow shrink wire make the cables as shown in the picture below. Below is the main cable connecting the data bus on the top of the cards. The other cables are described in the original article, make them the same way.

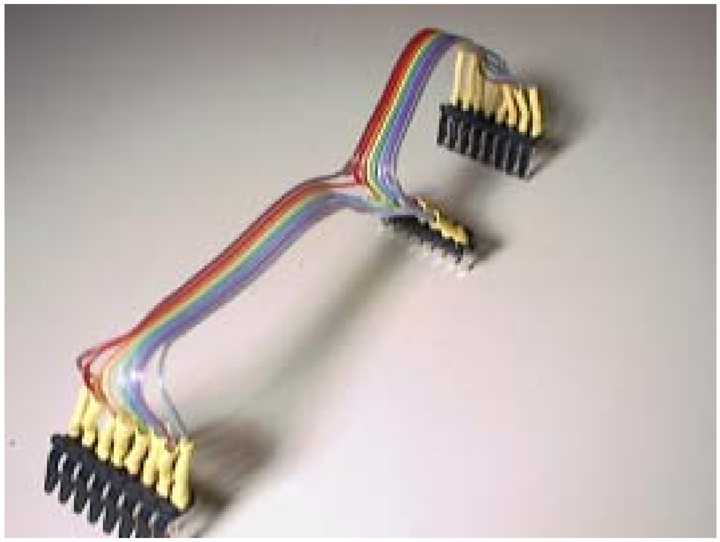


Figure 24 Assembled Top Bus Connector

8. Front Panel Assembly

The switches are attached to the front panel by screwing them into pine wood strips (same strips as the card cage frame, but painted white and cut shorter). First attach the pine strips to the front panel with epoxy. Make sure you roughen up both the pinewood and panel before gluing. Takes time to line up correctly. Draw a pencil line about 1/16 of an inch along both edges of the strips near the cutout of the panel. Use this as a guide to position the mounting holes in the switches. You will notice that the upper switch cutout is smaller then the lower, even though both cutouts accommodate 8 switches. This is because Jon Titus used double-poled switches in the lower cutout, which were wider. If you are using single pole switches you will have to space the lower switches further apart then the upper. Use stranded wire here to connect the switches to the card cage, otherwise you may get stress fractures with hookup wire if you open/close the front panel often. The filter is transparent acrylic, 1/8 inch. Take care to drill the holes in the acrylic, as it easily splits. You can also dye clear plastic window glass (available at Home Depot) with RIT dye if you can't find red acrylic. Just place the clear plastic in a hot bucket of water, add the dye and repeat as necessary to get the color you want. RIT dye will not color plastic unless the water is very warm. Switches are standard type used in the IMSAI computer.

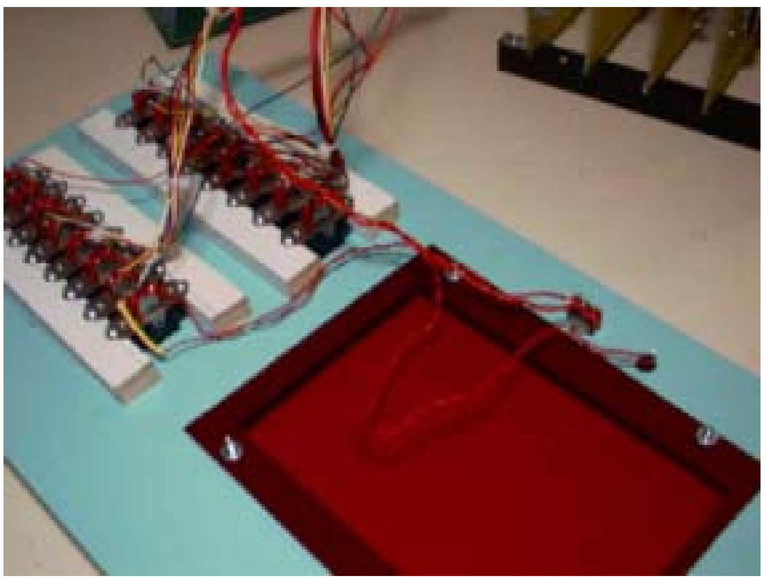


Figure 25 Front Panel Switch Assembly

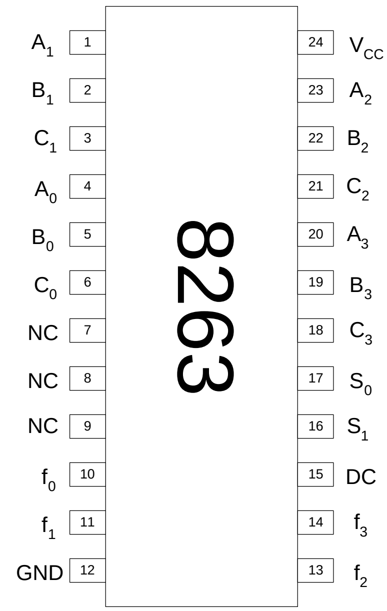
9. Post Assembly Debug

Here are several tips for debugging the completed Mark-8 computer:

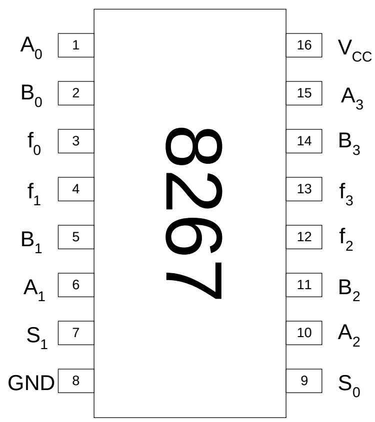
1. Before applying power to the Mark-8 computer verify that none of the power rails (+5V, -9V, GND) are shorted. Due to the number of power rail traces this is a common problem.
2. The LED's should light up to some random state after you power up.
3. Follow the debug instructions in the manual. The idea is to first test the address latch, memory, and LED boards before running the CPU.
4. As you are tracing down a faulty logic state and notice that the input to a logic gate is 1.6 volts (as opposed to 0 or 5.0 volts) it's probably due to the fact that the input is open. Trace backward from that point to find the open.
5. IC's don't fail often, if an IC is generating a output that is not consistent with the input then most likely the output is being pulled down or up by a faulty connection somewhere down the line. Pull the IC where the output is going to and see if the output goes to the correct value. If the output is going to a top level connector, pull the connector to see if the output goes to the correct value.
6. If you have a logic analyzer monitor the SYNC, S0, S1, and S2 outputs of the CPU as they will tell you what the CPU thinks it should be doing. Monitor the READY and INTERRUPT inputs to the CPU as will tell you what the CPU is told to do.

Appendix A- Signetics 8267 and 8263 Truth Tables

3-Input 4-BIT Digital Multiplexer



2-Input 4-BIT Digital Multiplexer



TRUTH TABLE

Select Lines		Outputs
S_0	S_1	$f_n(0,1,2,3)$
0	0	B_n
0	1	B_n
1	0	$\overline{A_n}$
1	1	1

TRUTH TABLE

DATA INPUT A_n B_n C_n	CHANNEL SELECT S_0	S_1	DATA COMPLEMENT	DATA OUTPUTS $f_n(0,1,2,3)$
A_n x x	1	1	0	A_n
x B_n x	0	1	0	B_n
x x C_n	1	0	0	C_n
x x x	0	0	0	0
A_n x x	1	1	1	$\overline{A_n}$
x B_n x	0	1	1	$\overline{B_n}$
x x C_n	1	0	1	$\overline{C_n}$
x x x	0	0	1	1
x x x	x	x	x	1