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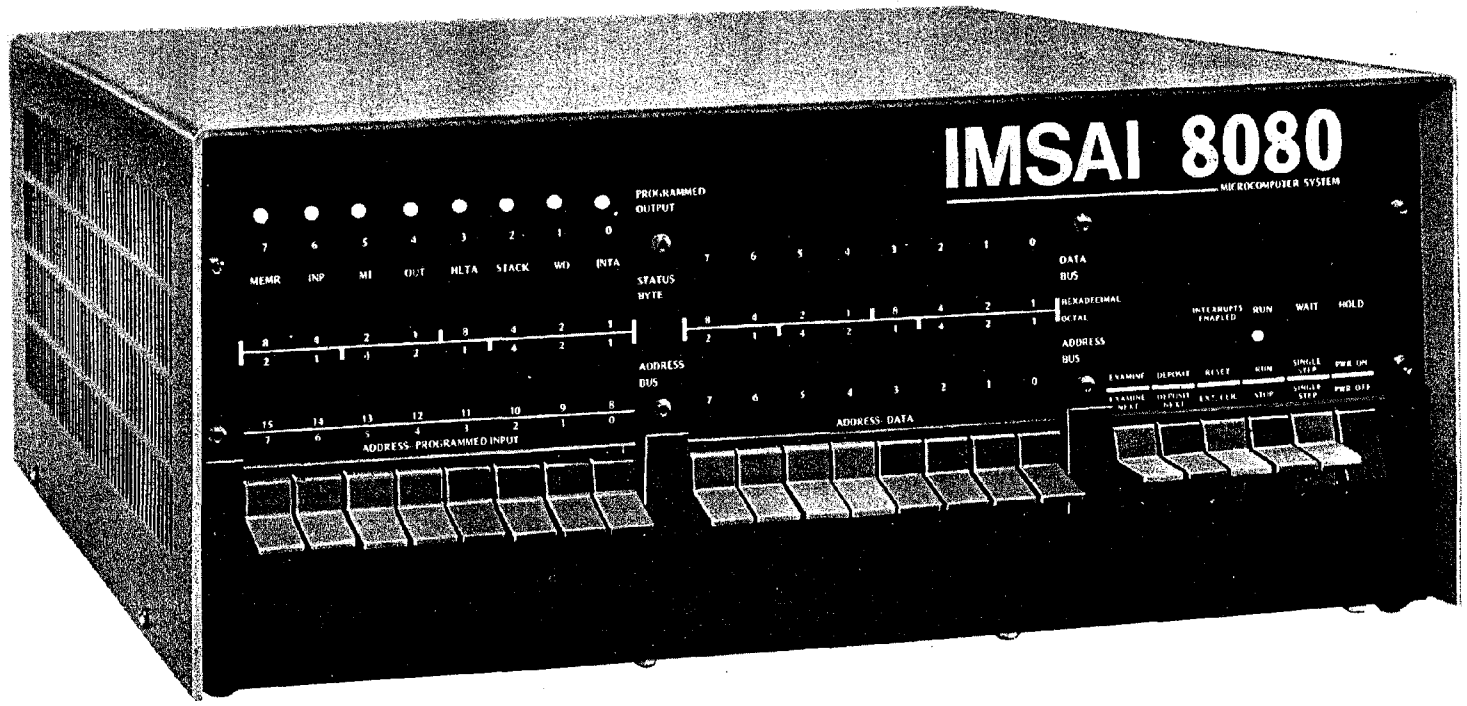
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IMSAI 8080
MICROCOMPUTER SYSTEM
PROGRAMMED OUTPUT
MEMR
INP
MI
OUT
HLTA
STACK
WO
INTA
STATUS BYTE
DATA BUS
HEXADECIMAL OCTAL
ADDRESS BUS
INTERRUPTS ENABLED
RUN
WAIT
HOLD
EXAMINE
DEPOSIT
RESET
RUN
SINGLE STEP
PWR ON
PWR OFF
ADDRESS-PROGRAMMED INPUT
ADDRESS-DATA

INTRODUCTION

The documentation for the IMSAI 8080 Microcomputer System consists of several books. This volume, the IMSAI 8080 Microcomputer System User Manual, contains a detailed description of the features and configuration of the computer as a complete system. It also describes the printed circuit boards that form the system building blocks. The chapter format begins with a functional description of the system or board, including brief notes about all the features. The actual operation of the system or board is then described in a theory of operations section. The physical and electronic arrangement of the system or board are next shown with a photograph and a schematic. Assembly of the board from a kit is described by assembly drawings or photos, a complete parts list, and assembly instructions in each chapter. Finally, the information that tells the user how to use the design features of the board to implement various functional options is contained in a user guide section for each board.

Operation of the computer as a system is documented in the IMSAI 8080 Microcomputer System User Manual in the chapter General Assembly and Test Instructions and also in the chapter on the CP-A (Front Panel Control Board). The software supplied with the basic unit, consisting of a resident monitor, assembler and text editor is described in the last chapter of the IMSAI 8080 Microcomputer System User Manual. This chapter includes both a description of the software and a complete object listing.

Supporting documentation is provided by a copy of the Intel 8080 Microcomputer System Users Manual, supplied in every system kit to give IMSAI users the primary source of detailed information about the function and instruction set of the logic implemented by the intergrated circuit chip set used in the IMSAI 8080. A handy reference card, the Intel 8080 Assembly Language Reference Card, is supplied to summarize much useful information from this manual.

To assist users in gaining a full perspective on the design and use of microprocessor-based computer systems, IMSAI includes a basic text, An Introduction to Microcomputers.

IMSAI is currently working intensively on both additional hardware (more peripheral systems, the Shared Memory Facility, etc.) and system software. Full documentation of these additions will be made available to IMSAI owners as it is produced; the charge will be a nominal fee to cover the cost of reproduction.

IMSAI 8080 MICROCOMPUTER SYSTEM FEATURES

The IMSAI 8080 is a high quality microprocessor based computer system offering outstanding capability and flexibility at low cost.

Designed to facilitate simple modular expansion, the system has both the power and the versatility to handle a broad range of data processing needs.

The IMSAI 8080 is currently supported by a broad range of peripheral devices and interfaces, and comes with a basic resident monitor, assembler, and text editor, free of charge. A broad range of high level system software is now under development, and will be available soon in both source and object form to registered IMSAI 8080 owners at the cost of reproduction and handling.

The IMSAI 8080 is available in kit or assembled form. While primarily designed as a commercial computer, the unit is configured to facilitate construction by any careful assembler. High grade industrial quality design and components are used in both kits and assembled units.

Complete documentation is provided with each system, including:

IMSAI 8080 Microcomputer System User Manual (this book).

Intel 8080 Microcomputer Systems User's Manual, completely describing the integrated circuits used, and the instruction set.

An Introduction to Microcomputers, a fundamental textbook on the use of microcomputer systems.

a 90 day warranty on the system is provided. Full factory service is available at a cost commensurate with the work required.

SYSTEM FUNCTIONAL DESCRIPTION

The IMSAI 8080 Microcomputer System is a full-scale general purpose digital computer. Although small in size and low in cost, the system is exceedingly versatile and capable of data processing in the complete spectrum of practical applications.

The IMSAI 8080 used an 8080A microprocessor LSI chip to perform the central processing function. The instruction set provided by the 8080A is described fully in Chapter 4 of 8080 Microcomputer System User's Manual, provided as part of the IMSAI 8080 documentation package.

The IMSAI 8080 system is capable of unlimited expansion, due to the bus structure and IMSAI's exclusive shared memory facility, which permits parallel processing. The computing power that can be made available with the IMSAI 8080 system building blocks exceeds that of any currently available minicomputer.

The operation of the IMSAI 8080 is described in the manual chapters titled "General Assembly and Test Instructions" and in the CP-A Front Panel Control Board chapter. Input/output features are described in the I/O board chapters including SIO (Serial Input/Output board), PIO (Parallel Input/Output board) and UCRI (Cassette Recorder Interface board).

IMSAI 8080 SOFTWARE FEATURES

Basic system software (resident monitor, text editor and assembler) distributed in object form, with listing, and free of charge.

Future software releases are:

4K BASIC - upward compatible to DEC standard SUPER-BASIC

8K BASIC - Upward compatible to DEC standard SUPER-BASIC

12K BASIC - DEC standard SUPER-BASIC compatible

Floppy Disk Operating System

Linkage Editor
Macro-Assembler with relocatable code generation

12K FORTRAN compiler

IMSAI 8080 HARDWARE FEATURES

Flat cable interconnection used throughout.
Absolute minimum point-to-point wiring.
Front panel has programmed output port with LED indicators.
Front panel has large easy-to-use paddle handle switches.
Front panel legends are produced photographically and mounted behind acrylic panel for protection.
Front panel has filler to increase contrast of LED indicators.
Long-life LEDs used throughout.
Front panel circuit designed so that one-shot timing links are non-critical.
No point-to-point wiring to connect or disconnect front panel to or from system.
Attractive custom designed cabinet and panel.
Rackmount cabinet available as special option.
Cabinet designed to facilitate customizing front panel.
Sturdy card cage construction.
Room for 22 cards.
Power supply subchassis with high-current transformer and computer-grade electrolytic capacitors.
Heavy duty power supply supplies power sufficient for a full complement of cards (28 amps, up to 500 watts).
Straight-through back plane wiring. No special purpose slots.
Front panel plugs into any slot to operate machine.
Double-sided printed circuit boards with plated-through holes and solder mask.
All board contact fingers are gold-plated over nickel.
PC board material is glass-fiber-reinforced epoxy laminate.
On-board power regulation. Power is regulated by integrated circuit regulators with thermal current limits.
Tantalum board decoupling capacitors. Ample .luf disk ceramic power decoupling capacitors.
Designed with latest LSI and MSI components. Package count minimized.
Heavy current tri-state bus drivers used throughout the system.
System designed from initial concept for multi-processor, shared memory options.

MICROCOMPUTER SYSTEM SPECIFICATIONS

Processor: 8080A microcomputer chip

Directly Accessible Memory: 65,536 words
Word Size: 1 byte (8 bits)
Register Instruction Cycle Time: 2 microseconds
Basic Machine Cycle Time: 0.5 microseconds
Directly Accessible Input and Output Ports: 256
Machine Instruction Set Size: 78 basic instructions (181 instructions with variants)
Nested Subroutine Call Capability: Limited only by memory size
Interrupt Capability: 8 hardware levels
Registers: 6, plus stack pointer, program counter and accumulator

Memory Type: Semiconductor (1024x1 format chips)

Cabinet: Custom aluminum case with acrylic front panel

Dimensions: 19½" x 17" x 7"
Weight: 40 pounds
Front Panel Switch Type: Paddle
Color: IBM blue and grey

Power: 28 amp unregulated power supply with onboard regulators

Power Requirement: Under 50 watts for basic system
Maximum Power Capability: Up to 500 watts
Power Type: 115 VAC, 60 hz. single phase

Connections: Mounting space for 10 EIA-type 25-pin connectors on the back panel. Opening and cable clamp provided for flat cables to exit from the cabinet. 3M flat cable system used throughout.

CABINET ASSEMBLY INSTRUCTIONS

Begin by installing the correct number of plastic card guides on the chassis part C's. The card guides should be placed from the front backwards, an equal number on each piece C, taking care that the wedge - shaped opening of the slot is positioned upwards. Note that the two ends of piece C are not symmetrical. The end with the wider space between the last small hole for mounting the card guide and the end flange is placed toward the back of the cabinet, so that the guides will line up with the connectors on the Mother board.

The card guides should be assembled starting from the front end (with card guide mounting holes placed closer to the end flange). Make sure you place the card guide so as to form a left hand and a right hand mounting-rail piece. If this is not done, then the card guides will be upside down on one of the two piece 'C's when they are mounted into the cabinet. The card guides are most easily mounted using a small press and placing the tab of each card guide in position started into the hole and pressing them into place until the mounting tabs snap through. A drill press with a large flat - headed screw mounted in the chuck works well with this operation. (Alternately, the card guides may be installed very carefully using needle nosed pliers). Care should be taken that the tabs are started into the hole when beginning to press the guide into place, otherwise one or both may be bent out flat and broken off. One end of the guide at a time should be inserted rather than trying to press both ends in simultaneously.

If a fan is to be installed in the chassis, it should be assembled on the back frame piece A1 at this time using the hardware in the fan kit. The fan terminals should be towards the top and towards the Mother board side of the chassis.

Next, the power cord should be inserted using the special grommet in the hole provided on the back panel. 4 to 6 inches of the power cord should be left on the inside of the cabinet. If the power cord grommet is squeezed together with a pair of pliers before insertion into the cabinet back, it will ease the job of inserting this tight fitting grommet. To insert the grommet, the power cord should be pulled through the hole nearly to the point where the grommet has been placed around the power cord, then the outer edge of the grommet can be grasped with a pair of pliers and squeezed slightly and inserted in the hole and worked in while slight tension is also being put on the cord from the back side to assist. Working this grommet in by rocking it back and forth works better than just pushing harder.

The front and back frames can now be screwed to the base plate using 6-32x5/16" machine screws. Note that the back frame fits under the base plate and the front frame fits on top of the base plate, set back about 1" from the front edge of the base plate. Next, install

the two card frames between the front and back frames. Use two 6-32x5/16" machine screws at each end of each card frame. The front and back frames have slotted holes allowing the card frames to be adjusted slightly when the Mother board is installed on the base plate and boards are inserted in the card frames.

The self-adhesive rubber feet can then be separated from each other, the protective backing removed, and placed on the bottom of the cabinet spaced 3 inches along the left hand and right hand edge of the bottom, to support the cabinet weight.

BASE PLATE HOLE IDENTIFICATION

The base plate currently being shipped is a universal base plate, with extra holes for accomodating two styles of mother board mounting systems and two styles of power supplies. For the power supply and mother board systems shipped with your kit:

1. Place the Power Supply p.c. board in the base plate cavity and line up the holes in the p.c. board with the corresponding holes in the base plate and mark (e.g., with a felt-tip pen) which holes are to be used.

2. The mother board mounting system uses the two rows of 12 holes each on the left side of the base plate.

SWITCH ESCUTCHEON INSTALLATION

When the CP-A Front Panel Assembly has been mounted, the Switch Escutcheon (piece A2B) can be installed on the base plate at the front of the computer using four 6-32x5/16" Phillips pan head machine screws. Note that the Escutcheon should fit under the base plate.

CABLE CLAMP INSTALLATION

Cables that do not fit the connector holes on the back frame of the chassis may be clamped for strain relief at the top of the back frame using the L - shaped aluminum bar, piece K. Install using two 6-32x½" Phillips pan head machine screws. Depending on the thickness of the cables being clamped, either of the two sides of the angle may be used.

TABLE TOP COVER INSTALLATION

To install the table top cover, slide the cover carefully over the chassis frame and hold in place with four 6-32x½" Phillips pan head machine screws.

Refer to Appendices for an exploded view of the chassis cabinet.

RACK MOUNT SYSTEM ASSEMBLY INSTRUCTIONS

For the rack mount system, begin by installing the rack mount cover on the chassis. Use five 6-32x5/16" Phillips pan head machine screws. Next install the left and right side plates to the chassis with the front flanges pointing outwards. Use four 6-32x½" Phillips pan head machine screws on each side plate. The forward holes in each pattern on the side plates should be used.

Next mount the assembly in the rack using two screws on each side of the front flanges. Hardware requirements for mounting the assembly into the rack will vary according to the individual rack. It is suggested that the rear of the assembly also be supported in the rack. Finally, mount the front face panel onto the side plate flanges using four #10 round head screws and clips.

NOTE: for installations without slides where easy removal of the computer is desired, the side plates can be mounted directly in the rack and the computer can be slid on its rubber feet on the bottom flanges of the side plates. The rear of the side plates in this case should be fastened securely to the back of the rack cabinet.

8080 Rack Mount
Parts List

ITEM	IMSAI PART #	QUANTITY	DESCRIPTION
	93-3010008	1	Rack Mount Front Panel Rev. C
	93-3070001	1	Rack Mount Left Slide Rev. C
	93-3070002	1	Rack Mount Right Slide Rev. O
	93-3010012	1	Rack Mount Cover Rev. B
Screw	20-3302001	5	6-32x5/16" Phillips Pan Head Machine Screw
Screw	20-3502001	8	6-32x½" Phillips Pan Head Machine Screw
Screw	20-5707001	4	#10x3/4" Flat Head Type B Self-Tapping Sheet Metal Screw
Screw	20-5708001	4	#10x3/4" Button Head Type B Self-Tapping Sheet Metal Screw
Nut	21-5650001	8	Speed Nut, Tinnerman C 9031-10Z-1

8080 Chassis
Parts List

ITEM	IMSAI PART #	QUANTITY	DESCRIPTION/IDENTIFYING MARKS
Back Frame	93-3010003	1	Back Frame "A1"
Front Piece	93-3010010	1	Painted Front Piece "A2B"
Cabinet Base	93-4010004	1	Cabinet Base "A3"
Front Frame	93-3010001	1	Front Frame "B"
Card Frame	93-3010002	2	Card Frames "C"
Cable Clamp	93-3010013	1	Cable Clamp "K"
"DANGER" Label		1	"DANGER" Label on right card frame
Rubber Feet	28-0400001	6	Adhesive backed rubber feet
Screw	20-3302001	25	6-32x5/16" Phillips pan head machine screws
Screw	20-3502001	2	6-32x½" Phillips pan head machine screws
Capacitor Brace	91-0300001	2	Capacitor Braces with foam backing
Cover	93-4010005	1	Table Top Cabinet Top
Screws	20-3502001	4	6-32½" Phillips Pan Head Machine

INTRODUCTION

This chapter contains the following sections:

1. Kit Unpacking Instructions

2. Construction Hints - general notes on how to build your kit.

3. Recommended Overall Order of Assembly (includes cross-reference to chapters where specific assembly instructions for the various submodules will be found).

4. Mainframe Assembly - assembly instructions for integrating Chassis with Power Supply, Mother board and Front Panel, and instructions for testing the Power Supply.

5. System Functional Test - how to check out your overall system.

KIT UNPACKING INSTRUCTIONS

1. Remove all packages from the outer box. For a standard IMSAI 8080 kit, these will consist of:

   a. Documentation Set (Manual plus two books)
   b. Cabinet Base Plate
   c. Table Top Cover (or Rackmount cover and Rackmount painted pieces)
   d. Two large inner boxes
   e. Two small inner boxes.

2. Largest inner box contains flat parts such as pc boards, small sheet metal parts, two plastic panels and a mailing tube containing the front panel mask and paper backing sheet (latter is deleted if an OEM machine has been ordered).

3. The next smaller size inner box contains plastic sacks of components. (There will be a plastic sack with a parts list corresponding to each pc board, plus sacks for the chassis and rackmount hardware and a sack containing the paper tape for the IMSAI Self-Contained System software.

4. One of the two small boxes contains the large components for the Power Supply (transformer, capacitors, etc.).

5. The second small box is either empty (serving as a spacer box for packaging purposes) or contains overflow from the sack parts box.

6. Unpack plastic sacks only when you are ready to begin assembly of that particular module. If any parts are missing, contact IMSAI Customer Service for immediate replacement.

7. Be careful in handling the painted sheet metal parts, the plastic parts and the film negative to avoid scratching. PC boards should not be stacked without protective material between to avoid destroying or shorting traces.

CONSTRUCTION HINTS

GENERAL

The IMSAI 8080 microcomputer is a complex piece of electronic equipment. This section covers a number of items, each of which must be followed to insure a working system at the completion of assembly. This entire section must be read completely before beginning assembly, and the builder must refer back to the notes in this section often enough to insure that no components are installed incorrectly. While each assembly step is easy to do correctly, there are many steps and it is also easy to do one or more incorrectly, and much more time will be spent solving a problem than would have been needed to prevent it.

There may be items about which you are not completely sure during assembly. Should this occur, DO NOT CONTINUE. Study the manual to see if you can resolve your question, or seek the help of someone more knowledgeable in digital electronics. If you feel your question is not resolved by further study or asking whoever is available to you, call IMSAI. This will enable you to do a better construction job, and it will enable us to revise the manual so that it will be of more assistance to you. We recognize that some builders will have had very little experience in assembling electronic kits, and it is our intention to continually revise the manual based on comments by users, so that even the most inexperienced builder can achieve the best unit available with a minimum of effort. No question is too simple to call about if you're not sure about it.

TOOLS AND WORKPLACE

It is next to impossible for even an experienced builder to produce a good machine unless proper tools and an adequate workspace are available. The kit does not require much space to work in, but enough table surface should be available for the piece being worked on, all the tools needed for that piece, and an orderly arrangement of the components which will be used in assembling that piece. The work area should be very well-lit, with no shadows. If the entire room is not well-lit by ceiling or window light, then at least two bright lamps should be used, preferably one on either side and slightly behind the chair to help eliminate shadows. You may want to protect the table surface with cardboard or newspaper.

The most important single item in assembly is the soldering iron. It is critical enough that a separate part of this section is devoted to it. Other tools which are absolutely necessary to do an adequate assembly job are screwdrivers to fit the screws used in the kit (both straight slot and phillips), a small pair of diagonal cutters (preferably a 4" pair, flush-cutting), small needle-nosed pliers, and a wire stripper. A 1/4" nut driver will make cabinet assembly very much easier, as the sheet-metal screws used are designed primarily to use a nut-driver. A voltmeter should be available for testing. Any inexpensive meter (VOM) with DC voltage scales between 5 and 30 volts should do. Do not attempt to assemble the kit until you have the tools necessary; damaged parts cannot be replaced under warranty.

SOLDERING

Almost every problem with an assembled kit is a soldering problem. If you have never soldered before, or if you have done some soldering but do not yet have facility in making good soldering joints both quickly and every time, practice before beginning assembly on the IMSAI 8080 boards. Obtain some extra #20 hook-up wire and solder locally and solder pieces together until you feel comfortably able to quickly make a good joint. The importance of good solder joints is just too great to convey adequately here; but don't be scared off, because once you get the hang of it, they're very easy to do.

Soldering Irons

There are a great many tools available with the name "soldering iron". Two thirds of these are not appropriate to small electronics assembly and if used are almost certain to damage both parts and boards. The problem with most of these are that they are too big and too hot. Note that most every soldering "gun" is in the too big, too hot class. Proper soldering irons are easily available at any local hobbyist electronics outlet, and they are not expensive. Use a 30-40 watt iron with a small tip, such as an Ungar 776 with a 7155 tip. If you wish to invest in a top-quality tool, a temperature-controlled tip model such as the Weller W-TCP with a small 700^{o}F tip is well worth the extra cost. Many irons are available with either unplated copper tips or plated tips. Though slightly more expensive, the plated tips last very much longer and give superior service.

Solder

Using the proper solder is as important as using the proper iron, and there are many solders to choose among. In normal electronics assembly, separate paste or liquid flux is not used. Rather, a solder with a "core" of rosin (or resin) base flux is used. This flux (contained in the hollow center of the solder) should be sufficient. Absolutely avoid any solders using an acid flux. (Or any cans of acid flux - unless a can of flux says"rosin" you may safely assume it is an acid flux. Acid fluxes are used for mechanical soldering where the surfaces are not as clean as those in electronic assembly. They are corrosive and will typically damage a printed circuit.

Also very important is the ratio of tin to lead used in the solder. Best to use is 63% tin, 37% lead, called 63/37 or eutectic. Much more common is 60/40, which is still a very good solder. Avoid using 50/50 or 40/60, even though they're a little cheaper. The higher-lead ratios solidify gradually, while the 63/37 solidifies almost instantaneously, making "cold solder joints" very much less likely.

Also important is the gauge (or diameter) of the solder. For fine electronics work a fine gauge should be used, such as #20 (from #19 to #22 is OK). Again, the correct solder is easy to obtain from any local hobbyist electronics outlet or TV repair shop. ERSIN Multicore or KESTER are two brands you can count on for good results. The solder included in the kit should be sufficient. If for some reason it is not, and you cannot obtain the proper solder locally, DO NOT USE any substitutes. More solder of the proper type can be obtained from IMSAI.

Soldering Technique

For a joint to solder correctly, enough heat must be applied so that both pieces of metal get hot enough to melt the solder. The tip of the iron should be applied so that it touches both the wire and the foil pad on the board. The end of the solder should then be touched to the junction of the iron, lead, and pad, so that a small amount melts and "wets" the joint (flows smoothly on both the lead and pad). As soon as the joint has wet, the iron can be removed, and the joint inspected immediately. Careful inspection of each joint is the key to successful soldering. While the solder is being applied, watch the joint carefully. You should be able to

see the solder flow onto the two surfaces. It should flow around the lead, and if you see that the solder has flowed only on one side of the lead, the iron should be re-applied (while watching the joint) to heat the joint enough for the solder to flow. (The typical reason for solder to flow only half-way around a lead is that not enough heat was applied.) For the normal joint, only a small amount of solder is needed (approximately 1/8" of 20 gauge solder wire) for it to flow all the way around the lead. Also, for the normal joint, only 2 to 4 seconds of heat applied from the iron is necessary. More heat and solder will be needed for some joints with larger leads and holes or large foil areas, but if more heat or solder is needed on typical component leads (like IC's), it is an indication that something is not right.

Since nearly all the holes in IMSAI printed circuit boards are plated-through (the inside walls of the hole have a metal surface, connecting the pads on the opposite sides and providing greater area for solder to adhere to) some solder will typically wick through and be visible on the top side of the board. This is normal. If small drops of solder appear on the top side, it is an indication that too much solder is being applied, along with more than sufficient heat. These balls of solder can easily short to neighboring pins and must be avoided. If the correct amount of heat or less than the correct amount was used along with too much solder, the solder remains on the bottom of the board (the side the solder is always applied from) and forms a blob which can easily short to neighboring pads or traces. If one of the small gaps between foil pads or traces has been shorted with too much solder, it can often be unshorted by running the hot iron lightly down the shorted trace, re-melting the solder at the shorted point and pulling it away with the iron. Do not leave iron on traces or pads too long when soldering or fixing a short, as overheated traces easily come off the board. As a result, very special care must be exercised for any component removal operation.

The tip of the iron must be kept clean to work well. Most stores that carry irons also carry small sponges in holders designed for cleaning hot tips. The tip is simply wiped on the wet sponge quickly. A damp rag will serve as well though less convenient. The tip must be kept adequately tinned at all times to avoid an oxide coating forming. It should appear bright and shiny. A small amount of solder should be melted onto the tip each time it is cleaned unless

a joint is to be made immediately. If a tip becomes oxidized, dipping it in a can of rosin flux is usually sufficient to enable solder to flow on it again. They may be cleaned of oxide by fine steel wool or other abrasive, but a plated tip should never be filed.

The tip of the iron should never have enough solder on it that it could drip off. If you find that solder tends to drip off the tip, you are undoubtedly using too much solder. A solder drip on a P.C. board is often extremely difficult to see, since it is the same color as the traces, and it is sure to short several traces and cause trouble or damage components when the board is operated. Inspect your boards very carefully for any such solder drips, shorts near soldered leads, incompletely soldered leads, and unsoldered leads. A 100% inspection of soldering should catch 99% of all problems before the board is even turned on. When soldering components with long leads (resistors, etc) we suggest clipping the leads after soldering so that lead clipping gives you an easy and positive way to check all the joints on those components. A completed unit will typically run when first turned on if the soldering was done correctly.

MOS IC HANDLING

Some of the chips in the kit are MOS type chips (such as the 8080A, 8111 and 8251). MOS chips are sensitive to static electricity and other large transient voltages. In order to prevent damaging these, some precautions should be followed. They all relate to avoiding the discharge of static through the pins on one of these chips.

Avoid working in a room with very low humidity. Wearing cotton fabric or other non-static forming fabrics will help. Air directly from a heater vent is typically extremely low in humidity and should be avoided in the work area. Keeping everything involved (chip, board, iron, tools, boxes, chip containers, work surfaces and you) at the same potential is required, and the biggest step in achieving this is continuous physical contact between them. For example, before removing a chip from a box and setting it on the table, the box should be set on the table, you should touch the table, and only then pick up the chip to place it on the table. Try to handle the chip from the ends rather than the pins as

much as possible, and always touch the chip's container or surface which it is touching before picking up the chip. Also touch a surface or container before placing the chip back in it. Touch a PC board before inserting the chip. Touch the soldering iron to the work surface or to a small piece of metal foil on the work surface before touching it to the PC board for soldering. In general, make sure the chip is not the path for any static discharge. Save MOS IC insertion as the last steps in assembly to avoid unnecessary exposure.

POLARITY

Many electronic components will not work if they are connected backwards. Any component which it is important to insert one way only will have a mark of some sort to indicate which way is which. The board where they go will have some sort of corresponding mark at each place, or an indication that all such components go the same way as a marked "typical" one.

I.C.'s

All I.C.'s must be inserted with Pin 1 in the correct location to avoid damaging the I.C. Pin 1 is indicated on the chips by several different marks. The most common is a rounded or square notch in the center of the end near Pin 1. Another common one is a slightly depressed or raised dot in the corner of the chip next to Pin 1. One or both of these will always be present to indicate Pin 1. Sometimes there are other circular markings on the centerline of the chip, usually towards one or both ends; these should be ignored. Often there is some kind of Pin 1 mark on the bottom of the chip also. (Note: Many I.C.'s have a code for date of manufacture which is a 4 digit code. e.g. 7425 would indicate manufacture in the 25th week of 1974. Do not confuse these with the device number. The code will be alone, the device number will have manufacturer-dependent suffixes and prefixes. e.g., SN7404N is a 7404 type chip. On the PC board, some Pin 1 indication will be found, such as a square pad, a dot, an arrow showing Pin 1 direction with the note "typical" (indicating all chips on the board face the same way), or similar mark.

The board or the chip is very likely to be damaged if there is a need to unsolder a chip that was soldered in with pin 1 in the wrong direction. Unless you are completely sure you are capable of unsoldering an integrated circuit without damage to the circuit or the board, you should send the board back to the factory to have the work done for you. Remember that on these boards with plated-through holes, pins are not only soldered on the top where you see the visible bead of solder, but is soldered inside the hole which makes it much more difficult to remove.

Diodes

Diodes will typically have a band around the body, next to the cathode end. This corresponds to the bar on the typical diode symbol. The same is true for Zener diodes. A diode symbol should be found on the board or assembly diagram to indicate the proper mounting direction.

Capacitors

Some capacitors have a plus and minus lead; among them the tantalum and power supply electrolytic capacitors. Some mark on the body of the capacitor will indicate the plus lead, typically a + sign near it. There will be a mark (typically a + sign) on the board or assembly diagram to indicate the proper direction to mount the capacitors. A capacitor of this type is usually destroyed very quickly if power is applied to it in the reverse direction, so check your assembly carefully.

Transistors

Most transistors have a flat side or a small tab to indicate the lead orientation. If this indication is oriented according to the assembly diagram the leads should fit in the holes with little bending and no crossing.

MOUNTING COMPONENTS

Integrated Circuit Chips (IC's)

Some of the chips come in a little plastic rectangle with an open bottom and top. These can be used as inserters by setting the carrier with the chips on a piece of felt or similar material on a table top and pushing lightly with a pencil eraser or small object that will fit in the top of the carrier, until the chip has slid down with the leads resting against the table. Now, because of the material, the leads will be sticking out beyond the carrier a little bit. If you then pick up the carrier and the chip and set it on the board, you can line up the little protruding tips of the IC's ends into the holes into which they are supposed to go, and while you are holding the carrier, push the chip the rest of the way into the board again with a pencil eraser or with an object that will fit inside of the carrier.

For the chips that do not come in a carrier, after you insert the ones that did come in a carrier, you could use those carriers to insert the others also, by turning the carrier upside down and setting one of the other chips on the carrier and pushing it into the carrier and then just continuing the same process described above, to insert it in its location.

For chips with no such inserter aid available, the pins should be bent inwards far enough to line up with the holes in the board. Bend the pins on each side equally. The whole row of pins on one side can be bent in uniformly if they are all pressed against a flat surface to bend them. After putting the chip in the board, two diagonally opposite pins can be

bent slightly to hold the I.C. in the board while soldering.

Take special care on each and every chip to observe the following points:

1. That Pin one is in the correct direction. Refer to marking on the board or assembly instructions to determine which direction Pin one belongs.

2. After inserting the chip and before soldering, check that every pin went through the hole properly. Sometimes a pin will catch on edge of a hole and bend under the chip instead of going through. Care should be taken to avoid this happening and to check before soldering to make sure it has not happened.

After inserting one or two chips, get a feel for how much pressure is needed to push it out of the carrier. Any chips that seem to take more pressure indicate that perhaps one or more pins are not lined up with the holes properly. Most chips after insertion, will stay in the board securely due to the fact that the leads are normally bent outward somewhat and will hold the chip by pushing outward against the holes. Some chips, however, will be loose after inserted. Extra care should be taken to see that these are properly against the board when they are soldered. The board can either be set flat against the table or other surface that will hold the chips against the board or two diagonally opposite ends may be bent slightly to prevent the chip from dropping out.

Power Regulators

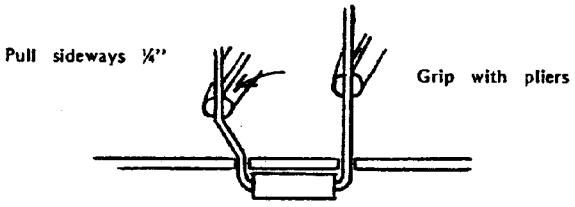
The 7805 regulators for the +5 volts are supplied with a heat sink and mounting hardware. The three leads must be bent down at the proper lengths to match the solder pads, and this should be done with the needle-nose pliers. The lead should come straight out and bend sharply down, rather than slope gradually towards the hole. After the leads are bent, the regulator can be fastened to the board along with the heat sink, using the short 6-32 screw down from the top, with the lockwasher and nut on the back. The regulator should be held to prevent turning while the nut is tightened firmly. The nut should be tight enough to insure good heat conductivity between the regulator and heat sink and board. Heat sink grease may be used if desired.

Discrete Components

Resistors and diodes can be installed most neatly using a lead bender to bend the leads consistantly. Most pads for this sort of component are .5" apart.

Disc ceramic capacitors often have the dipped insulation extending down the leads a short distance, preventing these from being pulled down all the way to the board. This insulation may be broken off by squeezing it in the pliers. Take it off until the bare wire comes up to the level of the bottom of the capacitor.

All discrete components should be held in their desired final position while being soldered. Normally this means holding them against the board by putting a slight bend in the lead behind the board so the component cannot lift from the board. (See the sketch for a way of bending the leads we find works better than simply finger-bending them slightly.) Components not held in place look sloppy and it is much harder to move them once they are soldered. In some cases, a little extra lead is needed, such as to lay the disc capacitors down on top of the chips on the front panel board. In these cases the solution is again to hold them in their final position during the soldering operation. This insures that the leads are left the proper length.



RECOMMENDED ORDER OF ASSEMBLY

Step	Description	Described In
1	Assemble MPU and RAM boards. Check carefully.	MPU Chapter RAM Chapter
2	Assemble CP-A including switches and flat cable. Check carefully.	CP-A Chapter
3	Assemble electronic components on Power Supply. Check carefully.	PS-C Chapter
4	Assemble Mother board(s). Check carefully	Mother Board Chapter
5	Assemble Chassis sheet metal: a. Install required number of card guides on card frames. b. Install fan (if supplied) on back frame. Install line cord through grommet. c. Bolt together sheet metal parts. Install rubber feet.	Cabinet Assembly Chapter
6	Install Power Supply Board in chassis. a. Bolt board in place. b. Bolt transformer in place. c. Cut wires to length and crimp on (or solder on) lugs. d. Connect up Power Supply except for wires to Mother board(s).	Mainframe Assembly Section
7	(Connect Mother boards together and) install Mother Board(s) in chassis.	Mainframe Assembly Section
8	Connect wires to Mother board. Check carefully.	Mainframe Assembly Section
9	Prepare front plastic panel assembly.	CP-A Chapter
10	Plug CP-A board into Mother board. Connect wires to CP-A board. Install front panel assembly. Hold CP-A DIP cable out of way.	Mainframe Assembly
11	Check complete assembly carefully before applying power. Plug in machine and turn on. Test Power Supply voltages.	General Assembly and Test Instructions
12	Plug in MPU board and RAM board(s) and test system.	General Assembly and Test Instructions
13	Assemble other individual boards. Check carefully.	(Individual board chapters)
14	Install individual boards.	
15	Install required cables. Install Cable Clamp.	Cabinet Assembly Section
16	Install Switch escutcheon and cover and/or Rackmount parts.	Cabinet Assembly Section

MAINFRAME ASSEMBLY

Assembly of the mainframe consists of the following steps:

- Power supply installation
- Mother board installation
- Connection between power supply and mother board
- Installation of CP-A panel.
- Connection of power supply and front panel

POWER SUPPLY INSTALLATION

Remove #8 hardware from transformer on Power Supply p.c. board. Take care to not let the transformer damage the p.c. board. Put the five #8 screws in the cabinet bottom and secure with the 8-32 threaded spacers. Install the four ¼"-20 nuts and spacers for the transformer similarly. Carefully lower the Power Supply Assembly onto the mounting screws so all the screws extend through the board. Fasten with washers and nuts. See Figure 1. Complete the power supply by attaching the capacitor brace plate to the bases of the large capacitors with the adhesive backed foam tape on one side of the brace plate.

MOTHER BOARD INSTALLATION

Attach the Mother board to the cabinet base with the hardware supplied with the Mother board as shown in Figure 2. The front 100-pin connector should be located in front of the sheet metal front frame to accomodate the CP-A assembly.

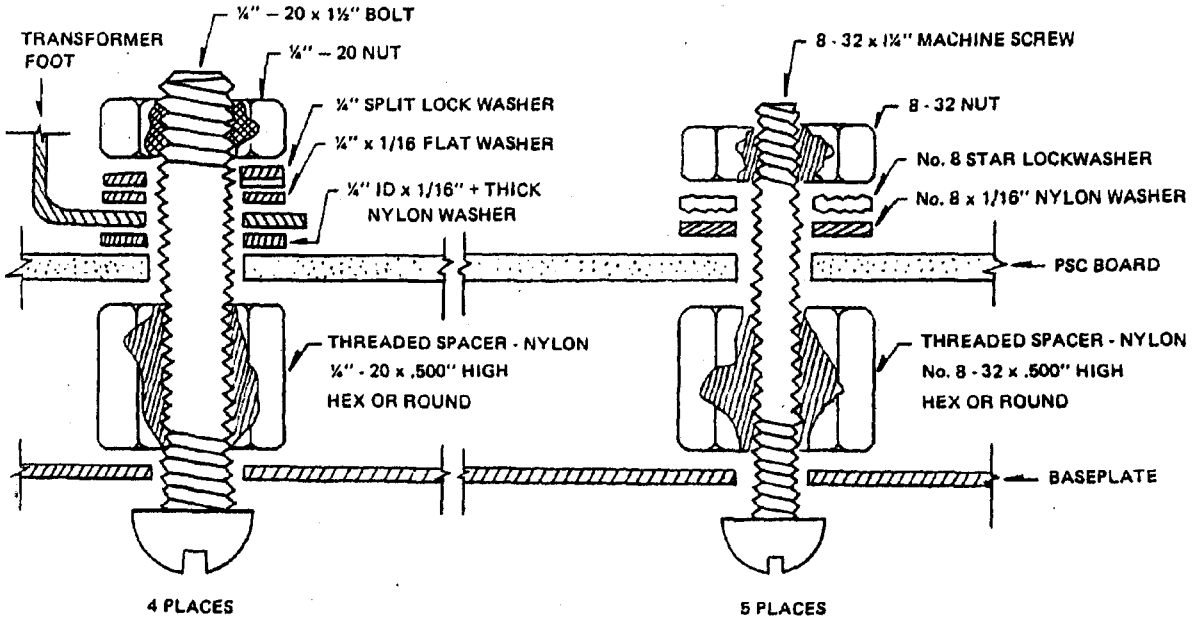
CONNECTION BETWEEN POWER SUPPLY AND MOTHER BOARD

See the wiring drawing in the Power Supply chapter. Connect the following wires between the Power Supply and the system:

a) 1 or 2 #18 gauge wire from holes at edge of -16 volt plane to -16 volt trace on Mother board.

b) 1 or 2 #18 gauge wire from holes at edge of +16 volt plane to +16 volt trace on Mother board.

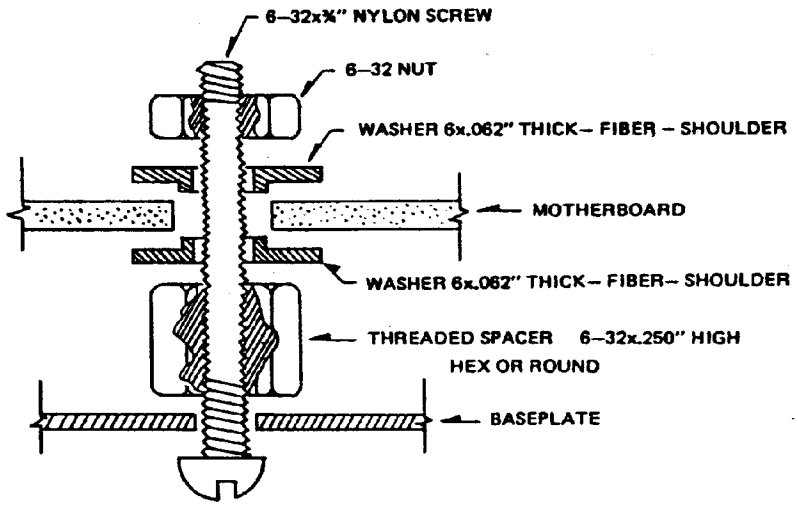
c) 2 or 3 #14 or #12 gauge wire from +8 volt plane to +8 volt bus on Mother board.



PS-C BOARD MOUNTING SYSTEMS

MAINFRAME ASSEMBLY
FIGURE 1

MOTHERBOARD MOUNTING SYSTEM



MAINFRAME ASSEMBLY
FIGURE 2

d) 2 or 3 #14 or #12 gauge wires from ground plane to ground bus on Mother board.

e) 2 #18 gauge wires from External Switch pads to power switch on CP-A or on back panel.

f) 2 wires (#18 or #20 gauge) from switched AC pads to fan (if fan installed) install insulated tubing over fan terminals.

g) 3 wires from power cord to terminals W, G, and B on PS-C. Make sure the power cord wire colors match the label on the panel

INSTALLATION OF CP-A PANEL AND CONNECTION TO POWER SUPPLY

Plug the completed CP-A panel into the front 100 pin connector on the Mother board. Install the eight Allen head screws into the PEM nuts on the sheet metal front frame. Solder the two #18 gauge wires from the External Switch pads on the Power Supply assembly to the power switch pads on the CP-A panel. Provide as much clearance as possible between the connections on the CP-A board and the sheet metal front frame. Be careful not to damage the acrylic panels with the soldering iron.

CHECK OUT OF POWER SUPPLY

Before plugging in circuit boards except the CP-A board, the unit should be plugged into the AC power supply and the power supply turned on by depressing the front panel rocker switch. The voltages at the outputs should then be measured (any DC volt meter with a full scale voltage of 20 to 50 volts will do) and the voltages should read approximately 18 volts on the +18 and -18 volt outputs, and 10 volts on the +8 volt output. If the voltage does not come to these values, a check should be made that the positive and negative terminals of the capacitors are connected properly and the diodes are mounted properly. If there is a problem with any of these items a wiring error has probably been made and the wiring should be re-checked carefully. If the wiring is checked and no error is found, assistance should be sought from a person knowledgeable in electronics or from the factory.

When the voltage of the capacitors has been checked out to be satisfactory, the unit may be turned off. A 10 minute wait will permit the capacitors to discharge. While there is considerable energy stored in the power supply filter capacitors when they are fully charged, the voltage levels are not high enough to present a danger. Some care should be taken, however, not to discharge the capacitors by shorting them with a tool or other metallic object.

With the Power Supply checked out and operating properly, the rest of the system is ready to be tested. The MPU board should be inserted in the slot behind the front panel with the flat cable inserted into the socket in the upper right hand corner of the MPU board before the board is fully seated.

The memory board should then be inserted in the third slot. While it is not necessary that the first memory board be addressed beginning at position 0, it is normally expected and the rest of this section will assume that the memory board jumpers were wired according to the directions in the User Guide section of the RAM-4A board for addressing the board at 0.

The slots in the Mother board are not unique and if a larger version (e.g., 22 slot) was ordered with more edge connectors, the boards need not be plugged into the second and third slot as directed but may be plugged into any slots.

SYSTEM FUNCTIONAL TEST

When the boards are installed, the machine is ready to test. Turn the power on with the front panel rocker switch and depress the RUN/STOP switch momentarily to STOP position and release. The WAIT light should be on and the RUN and HOLD lights should be off, with the other lights in various states at this time. Raise the RESET switch momentarily to the RESET position and release. All the lights on the bottom row in the ADDRESS BUS section should be indicating that the program counter is set to location 0. The WAIT light should still be on with the RUN and HOLD lights off. The DATA BUS lights may show various random bits on and the STATUS byte should have three lights on: MEMR, M1, and $\overline{WO}$. With all 16 ADDRESS switches in the down or 0 position, the EXAMINE/EXAMINE NEXT switch

should be raised momentarily to the EXAMINE position and released. Check that the lights after this operation are exactly the same as described for after the RESET switch was operated.

The machine is now ready to enter a small test program. For complete description of program operation in computers, read An Introduction To Microputers. For the initial machine test, the following program should be entered:

TEST PROGRAM 1

ADDRESS	HEX	BINARY	OCTAL	
0	DB	1101 1011	333	INPUT
1	FF	1111 1111	377	ADDRESS
2	D3	1101 0011	323	OUTPUT
3	FF	1111 1111	377	ADDRESS
4	C3	1100 0011	303	JUMP
5	00	0000 0000	000	LOW ADDRESS
6	00	0000 0000	000	HIGH ADDRESS

TEST PROGRAM 2

ADDRESS	HEX	BINARY	OCTAL	
0	DB	1101 1011	333	INPUT
1	FF	1111 1111	377	ADDRESS
2	2F	0010 1111	057	COMPLEMENT DATA
3	D3	1101 0011	323	OUTPUT
4	FF	1111 1111	377	ADDRESS
5	C3	1100 0011	303	JUMP
6	00	0000 0000	000	LOW ADDRESS
7	00	0000 0000	000	HIGH ADDRESS

The address is now at 0 as indicated by the lights labelled ADDRESS BUS. Into position 0 we wish to put an input instruction.

The bit pattern for the input instruction must be set in the center group of switches labelled ADDRESS-DATA. Switches 7, 6, 4, 3, 1 and 0 should be placed in the up position. Compare these switch positions with the binary representation of the input instruction listed on the first line of test program 1. We wish now to deposit this bit pattern in memory position 0. Raise the DEPOSIT/DEPOSIT NEXT switch up momentarily to the DEPOSIT position and release. The address bus should still show 0 (no lights lit) and the data bus should now show the bit pattern set in the switches (bits 7, 6, 4, 3, 1 and 0 lit and bits 5 and 2 off).

Next, the bit pattern for the address of the input port should be written in position 1. This can be done by setting all eight ADDRESS-DATA switches up, corresponding with the address listed on line 2 of Test Program One, and the DEPOSIT/DEPOSIT NEXT switch depressed momentarily to the DEPOSIT NEXT position and released.

Now the address bus light should show position 1 (address bus light 0 on and all other address bus lights off). The data bus should show all eight lights lit corresponding to the bit pattern written here. Similarly, the next five lines of Test Program One should be set into the ADDRESS-DATA switches and deposited by operating the DEPOSIT NEXT switch, each time checking to make sure that the data bus lights correspond with the settings of the ADDRESS-DATA switches and that the address is correct indicating that no steps have been skipped or done twice.

When the last byte has been deposited in address position 6, then all 16 address switches should be returned to the 0 position (down) and the EXAMINE switch operated. This should reset the address bus lights to 0, and display the contents of the bottom word in memory on the data bus lights. (This should still be the binary pattern listed in line 1 of the Test Program). The EXAMINE NEXT switch can then be operated and the address bus lights should indicate address 1 (bit 0 on and all other bits off). The Data Bus should show the contents now of memory location one which should correspond to the second line of Test Program One listing (all ones).

The EXAMINE NEXT switch can be repeatedly operated, each time checking that the data located in the consecutive memory location corresponds exactly to the listing for Test Program One.

The EXAMINE switch can again be raised momentarily with the address switches all down, to return the machine to position 0, once it has been determined that all lines listed in Test Program One are stored correctly in the memory.

Now we can single-step through this program and watch the operation of the machine. With the machine sitting at 0 with the correct instruction on the data bus, and the MEMR, M1 and $\overline{WO}$ lights lit in the status byte, the processor is reading the first instruction out of memory into the processor for execution. If the SINGLE-STEP switch is either depressed or raised once, it will permit the processor to complete its cycle and begin the next cycle. The address bus lights will show position 1, the data bus will show all ones corresponding to the bit pattern in the Test Program, and the status byte will show MEMORY READ and $\overline{WO}$. The lack of an MI light in a status byte indicates that the processor is no longer fetching an instruction to execute, but rather this cycle it is fetching the address for the instruction which it has already stored internally.

If the SINGLE-STEP switch is operated once again, the address bus lights will all be lit. The status byte will show INP and $\overline{WO}$ and the data bus will at first show no lights on. If one or more switches in the left hand group of eight switches is now raised or lowered, the corresponding light on the data bus indicators will turn on or off. The processor is now executing the first instruction which was an input data from address FF hex (377 octal) which is the address for the programmed input port on the front panel. By means of this instruction with this address the processor is able to read the position of the eight switches in the left hand group. (The address being read is indicated by the lights in the address bus and, on input or output instructions, the address appears in both groups of eight lights on the address bus. Thus, for this address, all the lights in the address bus are lit.)

The switches in the left hand group should be left in the position of some up and some down to provide a recognizable pattern before continuing. With the pattern left in the left hand group of switches, the single step switch can be operated once more permitting the processor to complete the execution of the input instruction, and begin the next cycle. Having completed the input instruction, the next cycle will be a fetch cycle during which the processor reads the next instruction to be executed, which it will find in memory address position 2. The address bus lights should now show positon 2 (bit 1 on and all others off), and the data bus should indicate the bit pattern listed on line 3 of Test Program 1 for address position 2. This is the output instruction.

The Status Byte will again have MEMR,M1, and $\overline{WO}$ lights lit and the others off. When the single step switch is operated once again, the processor is permitted to complete the cycle during which it reads in the output instruction and begin the next cycle during which it will read the address of the output device. Since it is reading this address from the next memory position, (memory position 3), the address bus will have bits one and 0 on and the others off. The Data Bus will have all lights on indicating the bit pattern we stored in memory position 3. The status bit will show MEMORY READ and WRITE OUT lights on, and the M1 light is off at this time, indicating that this is not an instruction fetch cycle, but rather it is one of the cycles required to execute the last instruction fetched-in this case, reading the address to which the data will be output. When the SINGLE STEP switch is operated once again, the processor is permitted to complete the cycle of reading the output address in and begin the next cycle which is the output operation.

The output operation looks similar to the input in that the address of the output device appears in both the upper and lower half of the Address Bus, (again in this case lighting all the lights), and the data being output appears in the Data Bus, which should show the pattern previously set in the left hand group of switches. Since the data is being output from the accumulator in the processor where it was previously stored in the input instruction, it will not be affected by moving the switches in the left hand group at this time. The Status Byte shows the MEMR light off at this time and shows the out light on indicating that the processor is executing an output instruction. The $\overline{WO}$ light is off indicating that the processor's WRITE strobe is active. If the SINGLE STEP switch is operated once more, it will permit the processor to complete the WRITE operation and begin the next cycle. At this time, the PROGRAMMED OUTPUT lights at the top left of the panel, should be lit according to the complement of the pattern that was set in the switches. That is, for each switch that was set in the up position, the light will be out, and each switch that was set in the down position, the corresponding light will be on.

Since the processor has completed the output instruction the next cycle is used to fetch the next instruction to be executed, which it will read from memory position 4. In memory position 4 we had stored the jump instruction

which should now appear on the lights on the data bus indicators. As the SINGLE STEP switch is operated again, permitting the processor to complete the fetch of the jump instruction, and start the next cycle of executing that jump instruction, we find that the processor is reading the low half of the address from memory position 5. The status byte shows the MEMR and $\overline{WO}$ lights lit, and the M1 light is off at this time.

If the SINGLE STEP switch is operated once again, it will be seen that the processor is reading the high address byte previously stored in memory location 6.

The next operation of the SINGLE STEP switch permits the processor to complete the execution of that jump instruction, which is instructing the processor to take its next instruction to be executed not from memory position 7 but from memory position 0 as was stored in the two bytes following the jump instruction.

The Address Bus lights should now be all off indicating that the processor is indeed fetching the next instruction from memory location 0. The Data Bus should show the pattern that we wrote in memory position 0 as the input instruction. We have now completed one cycle of the loop in Test Program 1. Further operations of the SINGLE STEP switch will let the processor step through the execution of the loop additional times and each time through the loop it is possible to set a different pattern in the left hand group of switches to be read in and later to be written out to the PROGRAMMED OUTPUT light. The RUN/STOP switch can be momentarily raised to the RUN position and released. This will permit the processor to run at the full clock speed which will result in the loop being executed roughly 50,000 times every second. Thus, as any of the switches in the left hand group of eight are moved while the program is running, the machine reads the new position essentially instantly and displays it in the PROGRAMMED OUTPUT port above.

It may have been puzzling that the lights in the PROGRAMMED OUTPUT port seem to indicate the opposite of what might have been expected when a bit was read in as a 1 and output to the PROGRAMMED OUTPUT port. This will serve as an example of the way logic design has been affected by the appearance of large scale integration and microprocessors. While it would have been entirely possible

and easy to provide a circuit modification such that when the data was put out as a 1 the light would be lit rather that turned off, such as addition to the circuit would have cost you more that the cost for byte of memory. The same function as the added circuit can be accomplished by adding one instruction to the loop which complements the data, that is, changes all ones to 0's and all 0's to 1's. Test Program 2 is exactly the same as Test Program 1 with the addition of one instruction between the input instruction and the output instruction, which will complement the data read in from the switches before it is output. If the machine is stopped and reset, Test Program 2 may be entered exactly the same way as Test Program 1 was and checked and then run through one or more cycles with the operation of the machine and to double-check that the program truly has been entered correctly. Then the RUN switch may be actuated to permit the loop to run at high speed.

With this change in the program, the PROGRAMMED OUTPUT port will show a light lit when the switch is positioned up to enter a 1 bit. Not only is this a less expensive way to achieve the function of causing the lights to turn on when the bit is entered as a 1, but it is a much more versatile solution since the operator can change his mind at a later date and either remove the complement instruction or change it to yet another instruction for a different result.

When single stepping through Test Program 2, the compliment data instruction is seen to use up only one cycle of the processor. We are able to see it being fetched to be executed, and when the SINGLE STEP switch is operated again, we are immediately fetching the next instruction. This will be true of any instructions which operate only on data which is already stored within the processor. Additional cycles are only necessary if additional information must be read in or out of the program processor itself.

After either loop is running, the RUN/STOP switch may be depressed to STOP at any time and the operation processor will stop during the fetch of the next instruction. Due to the speed at which the processor operates, it is impossible to tell beforehand at what point in the loop the processor will be at the exact instant that the RUN/STOP switch is moved to STOP, so that the processor will stop at different places in the loop for different times when the switch is actuated.

The switch may be raised to the RUN position starting at any point in the loop and the processor will continue to run at high speed beginning at the point. The flip-flop set by the RUN/STOP switch simply instructs the processor to wait at each cycle for a pulse which is generated by the SINGLE STEP switch to be received before executing the next cycle, and apart from waiting for this pulse, the processor executes exactly the same whether it is in the single run mode or stop mode.

The definition of a computer involves both the ability to execute in sequence of instructions which is stored inside the machine, also the ability to make a decision between on the value of data and as a result of that decision, choose between alternate possible paths of program step sequences to execute. Test programs 1 and 2 involve only the execution of a sequence of stored program steps and do not involve any decisions. Program 3 will illustrate the use of decisions in a computer program and should provide some interesting entertainment as well. It is a game program using the INPUT switches and the PROGRAMMED OUTPUT lights on the IMSAI 8080 front panel.

A pattern of lights in the PROGRAMMED OUTPUT ports is moved to the left one bit at a time, and the left hand bit which is "pushed off" the end of the programmed I/O register re-appears at the right end of the register. The rate at which the bit pattern is shifted to the left can be chosen by the binary number set in the front panel switches when the program is first started or when the machine is reset to start again. When a higher binary number is entered in these switches and program restarted, the bit pattern will shift to the left at a higher rate of speed. Initially, switches should be set for 2, that is all switches down except PROGRAMMED INPUT switch bit 1 on, in order that the bit pattern will be shifted slowly enough to easily see what the game program is doing. Once the program has been started, the rate at which the bit pattern is shifted to the left is not affected by any further movement of the front panel switches. From this time on, any time any one of the eight switches in the PROGRAMMED I/O group is changed, then the bit in the PROGRAMMED OUTPUT port which is directly above that switch at the moment is was moved, will change. If it was off before, it will turn on; and if it was on before it will turn off. The direction of travel of the switch is not significant--only that its position was changed. After a switch change is detected, and the light above it turned on or off as

appropriate, no further switch movements will affect the condition of any of the lights until the next shift to the left has occurred. This was done to give the switches time to stop bouncing and stay closed as the processor in this machine is quite fast enough to see the slight bouncing of the switch contact when it initially closes.

By waiting for the next data shift before recognizing any more switch changes, we are prevented from falsely interpreting a bouncing contact as a switch which was repeatedly opened and closed. The object of the game can be either to turn out all the lights in the shifting bit pattern by moving a switch when the bits are passing directly over it, or alternately to turn on all the bits in the shifting bit pattern by moving a switch when a bit which is off is directly over it. Any time the shifting bit pattern is all 0's or all 1's, no movement will be seen in the PROGRAMMED OUTPUT port but by moving any switch, one of the lights will be changed so that the motion is again apparent.

Players can compete for the shortest time to go from all 0's to all 1's, or the other way - from all 1's to all 0's. When the game has been mastered at one rotation speed, the switches can be set for a higher binary number and the system reset to cause the processor to go back to memory location 0 and begin execution of the program again, and a new switch setting will be read to result in a higher rate of rotation, which makes it harder to move a switch at the exact instant the bit desired to be changed is directly above it. If there were only a single light on, circulating across the output port, and the player, (in attempting to turn it off by moving the switch when the bit was directly over that switch) was too slow, then the bit will have shifted away so that it is now over the next switch to the left, not only will that bit not be turned off, but the bit behind will be turned on so that now there are two bits circulating across the register and the player is further away from achieving all bits turned off.

Knowledge of some of the internal structure of the 8080 processor will be necessary to understand the game program. The Intel data book contains complete information and functional specifications on the internal structure of the 8080 processor, but only the basic aspects of the structure need be known to understand the program operation.

Figure 1 shows the structural blocks in the processor which are important to the programmer. Central to the processor's operation is the register named the ACCUMULATOR. This register and all the others is like one eight bit position in memory or a small "blackboard" with room for only eight bits of either 1's or 0's to be written. When the input instruction was executed during programs 1 and 2, the pattern from the switches on the front panel was read into the ACCUMULATOR register, and when the OUTPUT instruction was given it was again the contents of the ACCUMULATOR which was output to the PROGRAMMED OUTPUT port on the front panel. All arithmetic is done in the ACCUMULATOR and, except for special instructions, (to permit other registers to be read to or from memory) all programmed input/output from either memory or input/out interfaces goes to and from the ACCUMULATOR. The INSTRUCTION register is another "blackboard" with room to store the address where it last read a program byte from memory so that when it finished the execution of that step, it can increment that address by one and use it to determine where to get the next instruction.

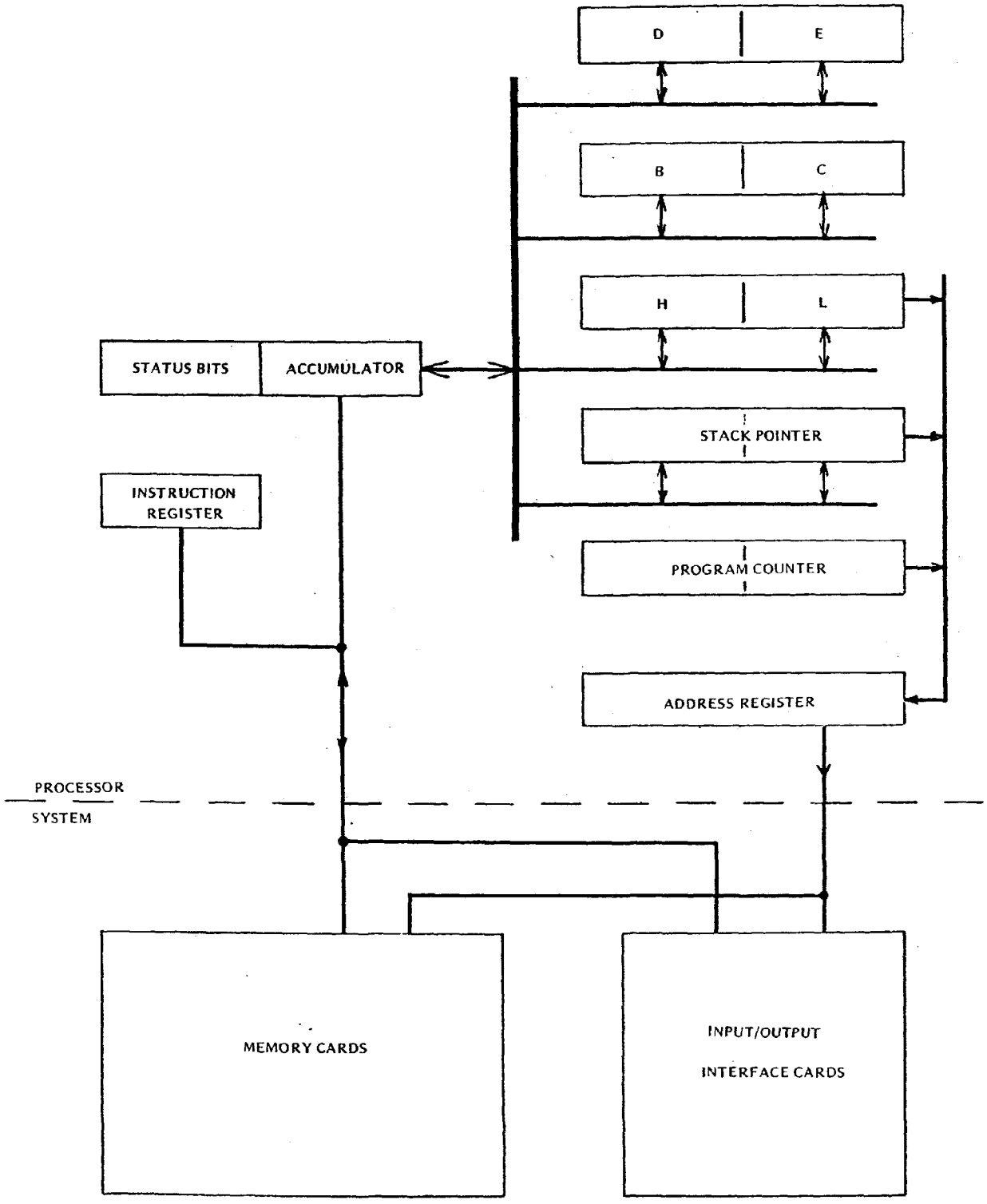
The STATUS BITS are 5 bits that are set to 1 or 0, according to the results of the last data operation performed in the ACCUMULATOR. One of the STATUS BITS or condition flags is the Z bit (zero bit) which is turned on when the last operation in the ACCUMULATOR resulted in the ACCUMULATOR being left all 0's. Otherwise, this bit is turned off. The second condition flag is the sign bit. If the most significant bit of the result of the last operation in the ACCUMULATOR has the value 1, this flag is set to 1, otherwise it is reset to 0. Three other condition flags are the sign parity and the auxilary carry, and their functions are described in the Intel Data Book on page 4-2. The fifth condition flag is a carry flag which is turned on if the last arithmetic operation produced an overflow. An overflow is produced, for example, when two numbers are added together and their sum is too large to be contained in the register into which it is put. For instance, if the ACCUMULATOR contained eight 1's and another number was added which contained the value 6, the correct answer would be the combination of the value 5 and a bit turned on in the 9th position. Since the ACCUMULATOR has only eight positions, the carry bit would be turned on.

Some of the STATUS BITS are affected by the operations in other registers than the ACCUMULATOR. For instance the carry bit is affected by additions made in the H and L registers by using the double add instructions. Use is made of this in the game program. There are five other registers in the processor, each of which is 16 bits long, and some of which are divided in half so that operations may be done with only 1/2 at a time. The ADDRESS REGISTER is a 16 bit register over which the programmer has no control. It is simply used to output either the memory address or the input/output address necessary to execute the next cycle. The other four 16 bit registers can all be used by the programmer. There are many instructions in the 8080A processor's instruction set whose function is to move data from any register to any other register, to permit arithmetic operations between a register and the ACCUMULATOR (with the result always being left in the ACCUMULATOR), and some special instructions to permit direct transfer of data from memory to a register, or vice versa.

The B, C, D, and E half registers are all general purpose registers. The H and L register pair and the STACK POINTER register pair both have special functions in addition to being usable for general purposes. The game program does not make use of these special functions.

With the basic structure of the processor in mind, we can now look at the operation of the game program. Larger programs cannot be readily understood or written by working directly on the list of machine instructions, such as we did for Test Programs 1 and 2. A flow diagram is essential to quickly follow the sequence of the instructions and understand how they work together to achieve the desired result.

Figure 2 shows a flow diagram for Program 2. Each program function is briefly described in a separate box, and the flow of the executive of the program is indicated by the lines. Test Program 2 was a simple loop with no decisions so that after executing the short sequence of instructions, the flow of the program is back to the beginning of the loop to begin again. Figure 3 shows the flow diagram for the game program. Although it need not be understood to execute the game program, a thorough understanding of how this flow diagram achieves the operation of the game will be a useful step towards writing your own programs.



8080 PROCESSOR
FIG. 1

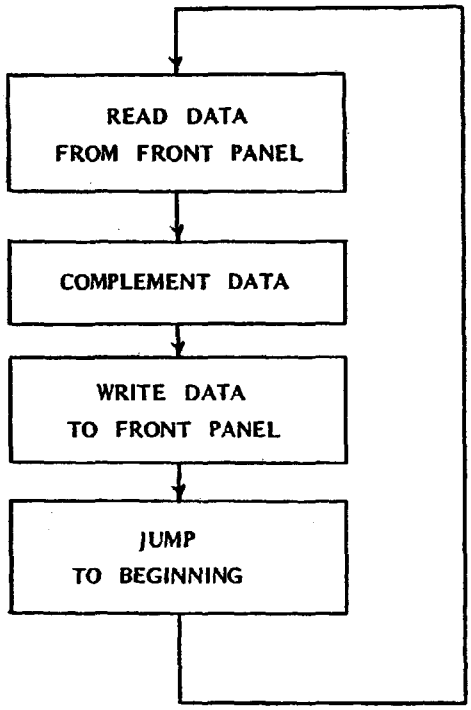

READ DATA
FROM FRONT PANEL
COMPLEMENT DATA
WRITE DATA
TO FRONT PANEL
JUMP
TO BEGINNING

FIG. 2

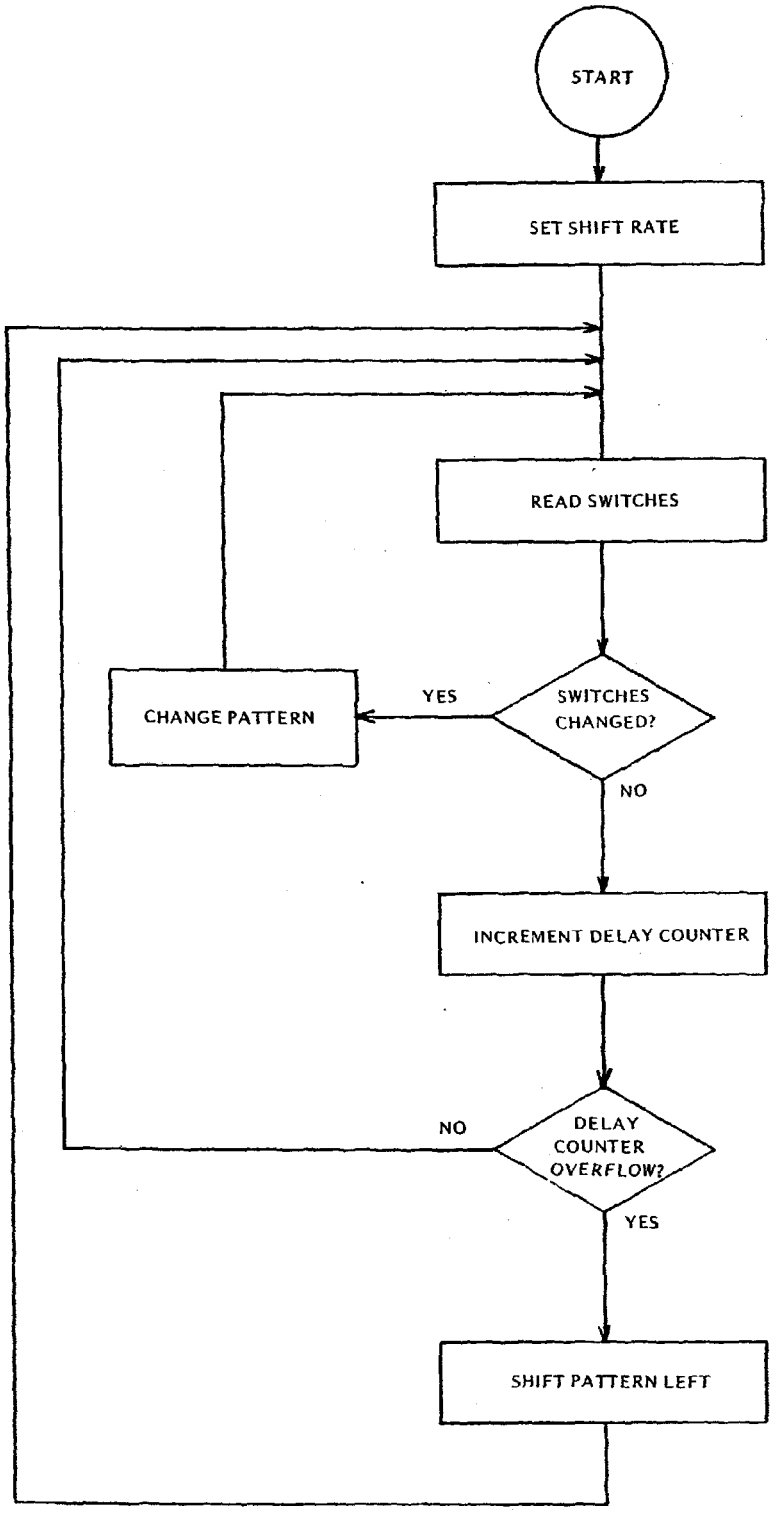


FIG. 3

GAME PROGRAM BASIC FLOWCHART

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GAME PROGRAM LISTING

OCTAL ADD.	OCTAL INST.	HEX ADD.	HEX INST.	MNEMONIC	DESCRIPTION
000 000	257	0000	AF	XRA, A	Exclusive OR A to itself (put zero in A)
001	147	01	67	MOV H, A	Move A to H (put zero in H)
002	333	02	DB	INP	Input data
003	377	03	FF		from front panel switches
004	157	04	6F	MOV L, A	Move A to L
005	371	05	F9	SPHL	Put H&L reg. into SP
006	257	06	AF	XRA, A	Exclusive OR A to itself (put zero in A)
007	201	07	81	ADD C	Put C in A, affecting flag bits
010	302	08	C2	JNZ	Jump if not zero
011	023	09	13		(skip switch test for debounce after a switch change)
012	000	0A	00		
					IF NORMAL, CONTINUE
013	123	0B	53	MOV D, E	Move E to D
014	333	0C	DB	INP	Input data
015	377	0D	FF		from front panel switches
016	137	0E	5F	MOV E, A	Move A to E
017	252	0F	AA	XRA, D	Exclusive OR D to A
020	302	10	C2	JNZ	Jump if result not all O's
021	041	11	21		(change display if switch position changed from last time)
022	000	12	00		
					IF SWITCHES UNCHANGED, CONTINUE
023	071	13	39	DAD SP	Add SP to HL
024	322	14	D2	JNC	Jump if no carry results
025	006	15	06		(return to read switch loop if no carry yet)
026	000	16	00		
					IF CARRY, CONTINUE
027	170	17	78	MOV A, B	Move B to A
030	007	18	07	RLC	Rotate left 1
031	107	19	47	MOV B, A	Store A in B
032	323	1A	D3	OUT	Output A
033	377	1B	FF		in front panel lights
034	257	1C	AF	XRA, A	Exclusive OR A to itself (put zero in A)
035	117	1D	4F	MOV C, A	Move A to C (Reset debounce indicator)

GAME PROGRAM LISTING (CONT.)

OCTAL ADD.	OCTAL INST.	HEX ADD.	HEX INST.	MNEMONIC	DESCRIPTION
036	303	1E	C3	JMP	Jump
037	006	1F	06		(to read loop)
040	000	20	00		
					CHANGE DISPLAY IF SWITCH DIFFERENT
041	250	21	A8	XRA, B	Exclusive OR B with A
042	107	22	47	MOV B, A	Store A in B
043	323	23	D3	OUT	Output A
044	377	24	FF		in front panel lights
045	257	25	AF	XRA, A	Exclusive OR a with itself A (put zero in A)
046	147	26	67	MOV H, A	Move A to H (set counter to insure enough delay for debounce)
047	057	27	2F	CMA	Complement A (to all 1's)
050	117	28	4F	MOV C, A	Move A to C (set C to debounce)
051	303	29	C3	JMP	Jump
052	006	2A	06		(to read loop)
053	000	2B	00		

NOTE:

Exclusive OR of two switch patterns results in 1's in positions which were changed, with all 0's elsewhere.

B= DISPLAY BYTE STORAGE

C=SWITCH DEBOUNCE INDICATOR
I=DEBOUNCE 0=NORMAL OPERATION

D=LAST SWITCH SETTINGS

E=CURRENT SWITCH SETTINGS

H,L=DELAY COUNTER

SP=INCREMENT FOR DELAY COUNTER

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