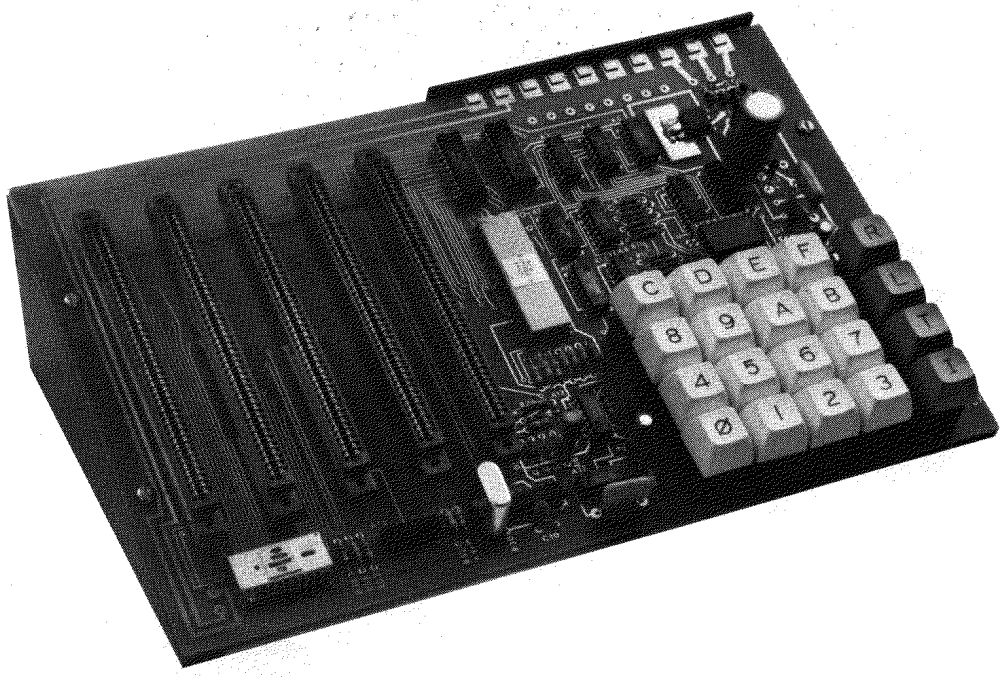
BY MARTIN MEYER



Build a PERSONAL MICROCOMPUTER FOR $100

THE COSMAC 1802 microprocessor can serve as the heart of a relatively inexpensive (about $100) microcomputer trainer that also features powerful application and expansion capabilities. The microprocessor circuitry here can also serve admirably as the basis for a variety of control applications, such as a security system, electronic games, time delay control, sequential lighting, temperature sensing, and so on.

The basic computer—COSMAC ELF—was originally introduced as a perforated-board project last year in POPULAR ELECTRONICS, followed by a series of articles that introduced new features. Elf II, presented here, incorporates all these upgraded features plus new ones, as follows:

* Double-sided PC board.
* Hexadecimal keypad with associated logic.
* An 86-line bus for system expansion.
* Video graphics.
* Seven-segment LED readouts.
* 256 bytes of RAM.
* A.c. operation.

The Basic Elf. The basic computer circuit shown in Fig. 1, and the graphics interface shown in Fig. 2 are essentially the same as the original Elf's.

Whereas the original Elf used a pair of relatively expensive hexadecimal decoders/latch/readouts to monitor the data lines, Elf II uses a pair of conventional 7-segment LED displays to do the same thing. Besides the saving in cost, the only difference between the two approaches is that in the Elf-II method, lower-case 'b' and 'd' are used instead of capital letters. However, these cannot be mistaken for any other alphanumeric character. The new circuit is shown in Fig. 3. Integrated circuits *A8* and *A12* accept the digital information from the data bus—buffered by *A7* and *A11*—and convert this data to drive the common-cathode 7-segment LED readouts forming *DIS1*. Besides the data information, this circuit also accepts the strobe signal coming from *A5* of Fig. 1 (the original *IC10*, pin 9).

The original Elf used eight discrete toggle switches to insert data. In contrast, Elf II incorporates a calculator-type hexadecimal keypad, which is much simpler to work with.

As shown in Fig. 4, the calculator-type hex keypad contains normally open-momentary close spst switches in the matrix. The keypad is decoded by *A10*, which features a 2-key rollover. The output of *A10* is used to drive data bus driver *A3*, and at the same time also drive *A9*. The latter drives data bus driver *A4*. Keyboard decoder *A10* contains its own internal oscillator (used to sample the keys); its frequency is determined by the external passive components.

The "front panel" circuit is shown in Fig. 5. The RUN (*S4*), LOAD (*S3*), and MEMORY PROTECT (*S2*) switches can be locked in either the on (down) or off (up) positions. To use these switches, simply depress to turn on; and depress again to unlock and turn off.

Bus. The Elf-II has been provided with an 86-line (twin 43) bus structure to carry the signals shown in Fig. 6. Note that at this time, only the even-numbered connections are used, excepting pins 1 and 3 which carry the +5-volt supply. All of the 1802 signals are present on this bus, which includes the system +5-volts, ground, and the 3.58-MHz signal from the video clock. Any connections made to this bus must be buffered if a CMOS device is not used.

The use of this bus, not present in the original Elf design, will allow easy system expansion for added memory, I/O ports, cassette or printer interface, ROM operating system, or an alphanumeric keyboard.

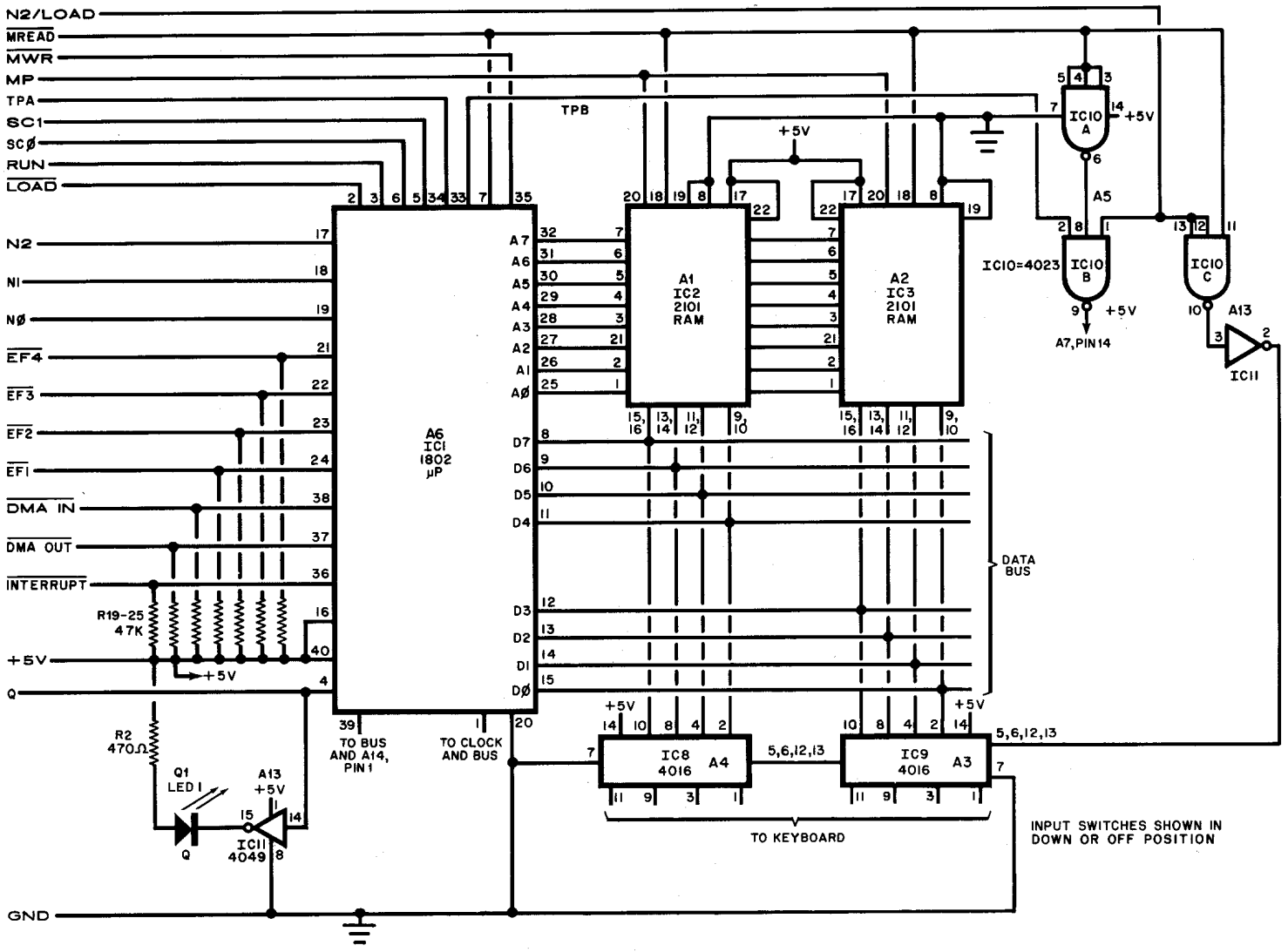


Fig. 1. The basic Elf circuit is modified as shown here. Note that the IC's are now A-prefixed, and the passive components are renumbered.

PARTS LIST

A1,A2—2101 (256x4) static RAM
A3,A4—4026 quad bilateral switch
A5—4023 triple 3-input NAND gate
A6—1802 COSMAC microprocessor (RCA)
A7,A11—4050 non-inverting hex buffer
A8,A12—9368, 7-segment decoder/driver/latch (Fairchild)
A9—74C173 latch
A10—74C922 keyboard decoder with 2-key rollover
A13—4049 inverting hex buffer
A14—1861 video TV chip (RCA)
A15—74L00 quad 2-input NAND gate
A16—7474 dual-D flip-flop
A17—4013 dual-D flip-flop
A18—7805 5-volt regulator
C1—10-μF, 16-volt electrolytic capacitor
C2—1000-μF, 16-volt electrolytic capacitor
C3—2.2-μF, 16-volt electrolytic capacitor
C4,C9—.15-μF Mylar capacitor
C5,C7,C8—25-μF, 16-volt electrolytic capacitor
C6—not used
C10—330-pF disc capacitor
D1 through D4—1N4001
D5 through D10—1N4148
DIS1—NSN-373 dual 7-segment display (National)
Q1—Red light emitting diode
R1—optional dropping resistor if T1 output greater than 6.3-volts at 400 mA.
The following resistors are ¼-watt:
R2,R31,R32—470-ohm
R3,R27,R28—390-ohm
R4 through R17—120-ohm
R18—not used
R19 through R26, R29—47,000-ohm
S1, S5 through S20—spst momentary keypad switch
S2, S3, S4—spst latching keypad switch
T1—transformer, 6.3-volts, 400-mA
XTAL—3.58-MHz color-TV crystal
Misc—86-pin bus connectors (optional), 10-screw terminal strip, mounting rails and hardware, line cord, sockets for all IC's.
Note—A complete kit for the Elf-II (except for T1) including double-sided pc board with plated-through holes is available from Nettronics Ltd., 333 Litchfield Rd., New Milford, CT 06776 for $99.50 plus $3.00 postage and handling. COSMAC 1802 Users Manual $5.50.

Power Supply. Elf II's power supply uses an on-board bridge rectifier and filter that drives the 5-volt regulator IC (*A18*). This permits the use of a conventional 6.3-volt, 400-mA transformer (which is mounted off the board). If you elect to use a higher-voltage transformer, a suitable dropping resistor (*R1*) must be placed in series between filter capacitor *C2* and the input to the voltage regulator, as shown in Fig. 7. (The original Elf was battery powered.)

Construction. Elf-II is constructed on a double-sided pc board such as that shown in Fig. 8, along with the component placement. If desired, the system may be wire-wrapped using perforated board and wire-wrap sockets and component pins.

Observe the correct polarity when installing the electrolytic capacitors, LED (*Q1*), as well as the pin-1 identifiers on all the ICs. Sockets are suggested for all IC's. This is especially important for the two memory chips (*A1* and *A2*) so that they can be easily removed when expanding the memory via the new bus.

The keypad switches are installed by

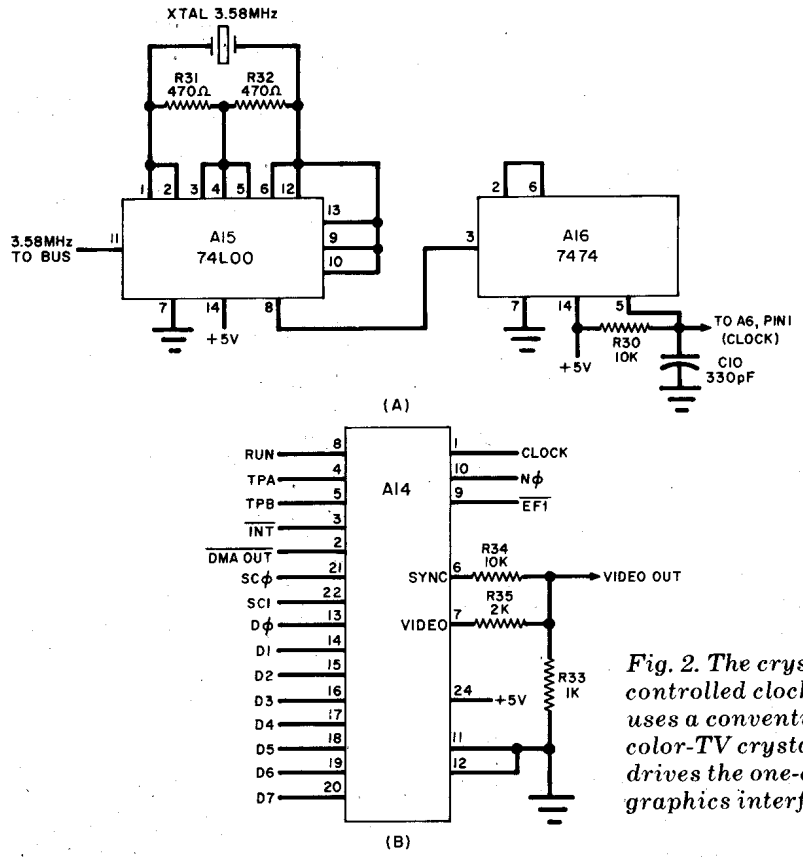


Fig. 2. The crystal-controlled clock (A) uses a conventional color-TV crystal and drives the one-chip graphics interface (B).

properly orienting them and inserting their plastic alignment pins in the appropriate holes at each switch position. The correct key placement is shown in the photograph. Make sure that the tops of all keys, including the control keys, are the same height above the pc board before soldering the leads in place. Also be certain that the RUN, LOAD, and MEMORY PROTECT (P) switches can be locked down (on) or up (off) before soldering.

There are 10 solder pads along the

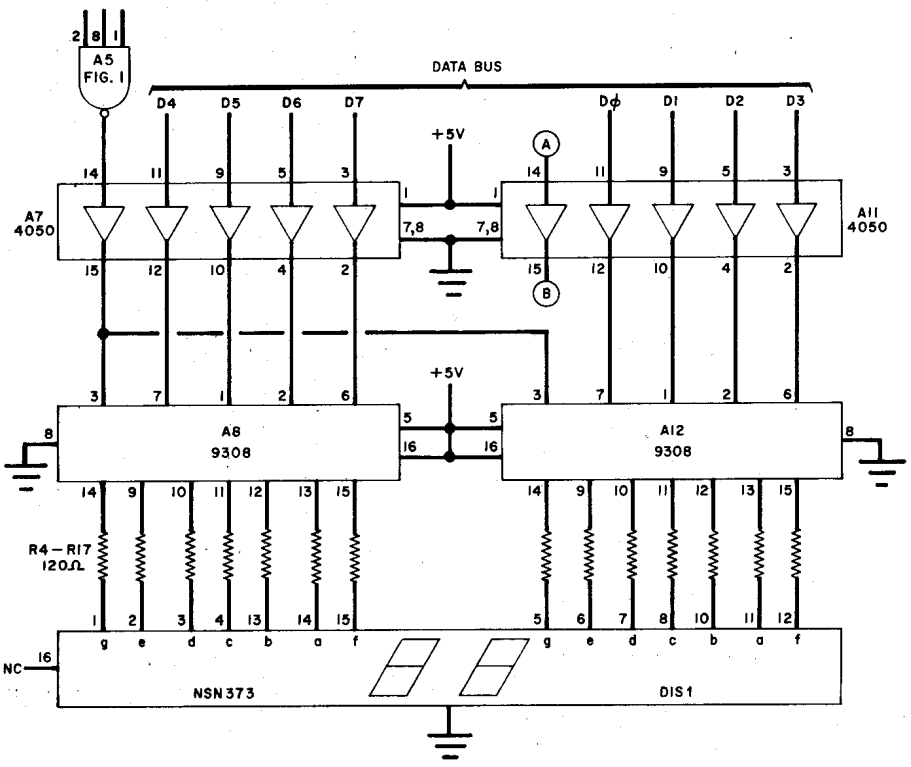


Fig. 3. A pair of 7-segment LED readouts working with a pair of decoder/latch/driver IC's form the low cost hex display.

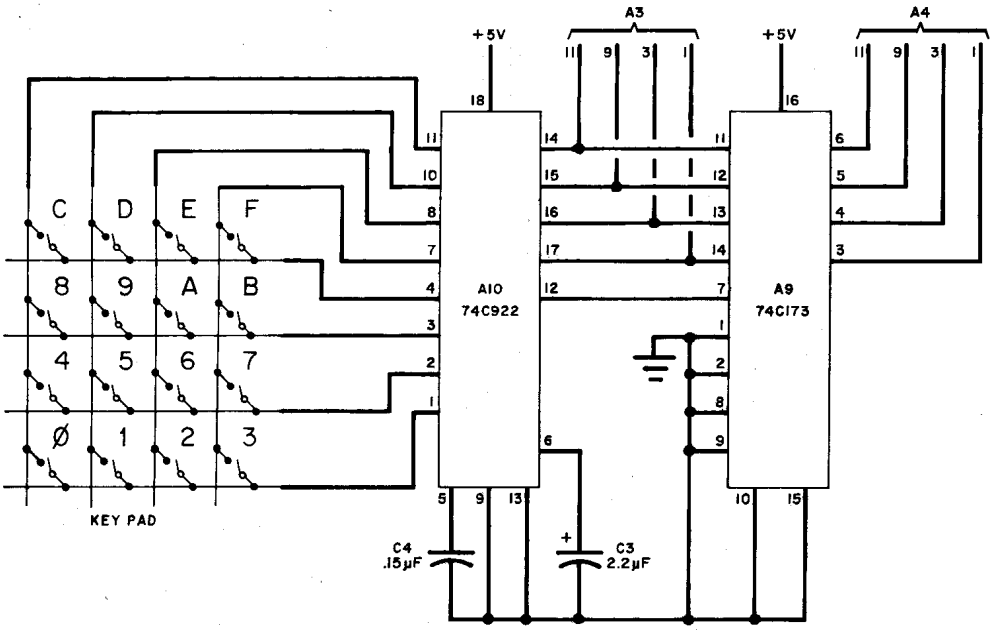


Fig. 4. Standard hex keypad works in conjunction with a keyboard decoder chip having a 2-key rollover.

upper right-hand corner of the board. The two rightmost pads accept the 6.3-volts ac from the off-board transformer, while the third pad is connected to an earth ground. The two leftmost pads are for the video output, with the leftmost pad for ground and the pad next to it for carrying the video signal to be connected to the CRT monitor or converted television set.

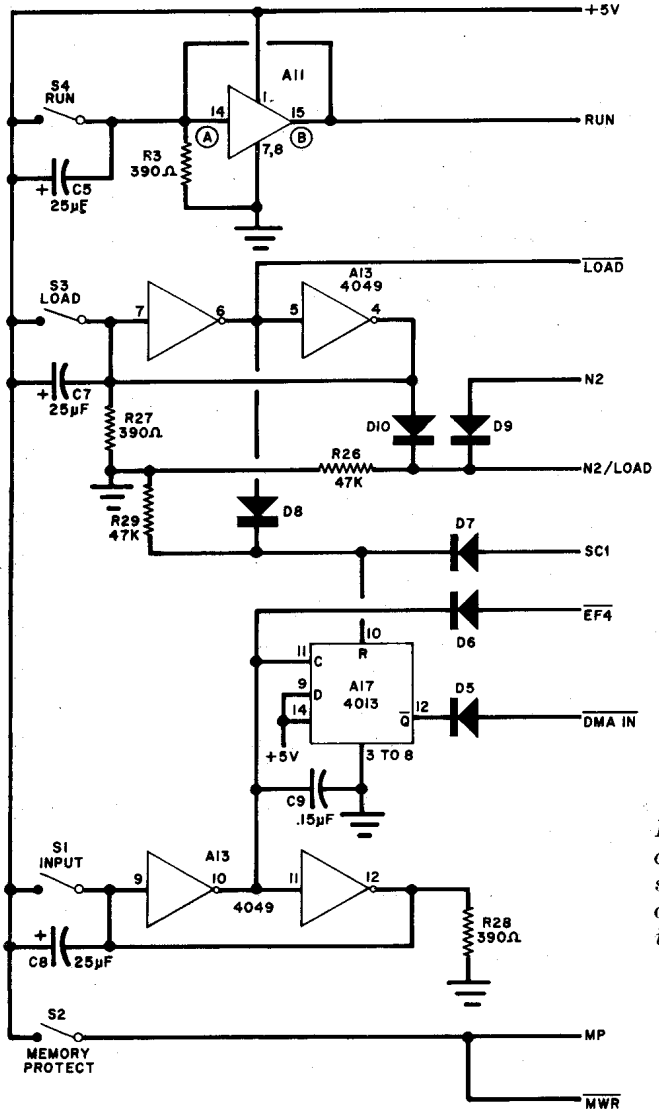


Fig. 5. Because the calculator-type control switches as spst, the original 'front panel' is slightly modified.

A mating clip-on connector strip is mounted to the pc board directly above the 10 pads, and tabs on the connector strip are soldered to the associated board pads. The other side of this terminal strip (the side away from the pc board) is fitted with screw connectors, for making external connections. After installing this strip, mount *A18* (the 5-volt regulator) on a 1" x ¾" x ¼" thick aluminum strip positioned directly under the lug of the regulator.

Once wired, the board can then be se-

ELF Connector	Name	1802 pin #
2	+5 volts	—
4	+5 volts	—
6	clock	1
8	clock	39
10	LOAD	2
12	DMA IN	38
14	RUN	3
16	DMA OUT	37
18	Q	4
20	INT	36
22	SC1	5
24	MWR	35
26	SCØ	6
28	TPA	34
30	MREAD	7
32	TPB	33
34	D7	8
36	A7	32
38	D6	9
40	A6	31
42	D5	10
44	A5	30
46	D4	11
48	A4	29
50	D3	12
52	A3	28
54	D2	13
56	A2	27
58	D1	14
60	A1	26
62	DØ	15
64	AØ	25
66	EF1	24
68	N2	17
70	EF2	23
72	N1	18
74	EF3	22
76	NØ	19
78	EF4	21
80	GND	20
82	GND	20
84	not conn.	—
86	3.58 MHz	—

Note: Odd numbered pins on left side of connector (with the exception of pins 1 and 3 which are +5-volts) are not used at this time.

Fig. 6. The Elf-II bus structure enables easy system expansion.

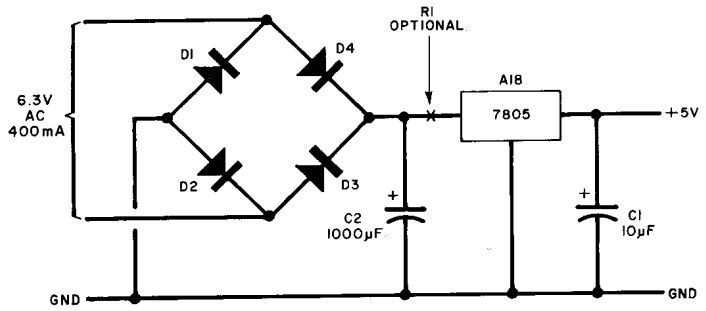


Fig. 7. The power supply, except for the transformer, is mounted on the Elf-II pc board.

cured to a pair of wood side supports using suitable wood screws passed through the two holes on each of the narrow sides of the board. Once the board has been mounted and all the passive components and IC sockets are in place, the IC's have to be installed.

As many of the IC's are CMOS types, extra care must be taken in both handling and installing them. Hold the IC's by the case edges, not the pins. Keep one hand on the board foil pattern when installing the IC's to prevent static buildup, then install the IC's in their proper places using the component placement guide of Fig. 8. Make sure that you observe all pin-1 designators.

Other than installing bus connectors, the Elf-II should now be assembled and ready for testing. However, before turning on the power, recheck the board for correct installation of all components. Then check to see if there are short circuits between any closely spaced pc foil traces.

Testing. There are two tests that can be made to check Elf II operation. The first uses the flashing of the *Q1* LED to check computer operation, while the second test checks out video operation.

Program 1, listed in an accompanying table, is the computer test. Before entering this program the Elf-II must be powered. To do this, connect the secondary of the 6.3-volt, 400-mA transformer to the two screw terminals at the right side of the 10-pad connector strip. Connect the primary of this transformer to the line power. When the Elf-II is powered, the two displays should indicate a random pair of hex digits. Make sure that the three control switches—RUN, LOAD, and P (memory protect) are all in their up (off) positions. Placing the LOAD switch in its down (locked) position automatically causes the system to go to address 0000.

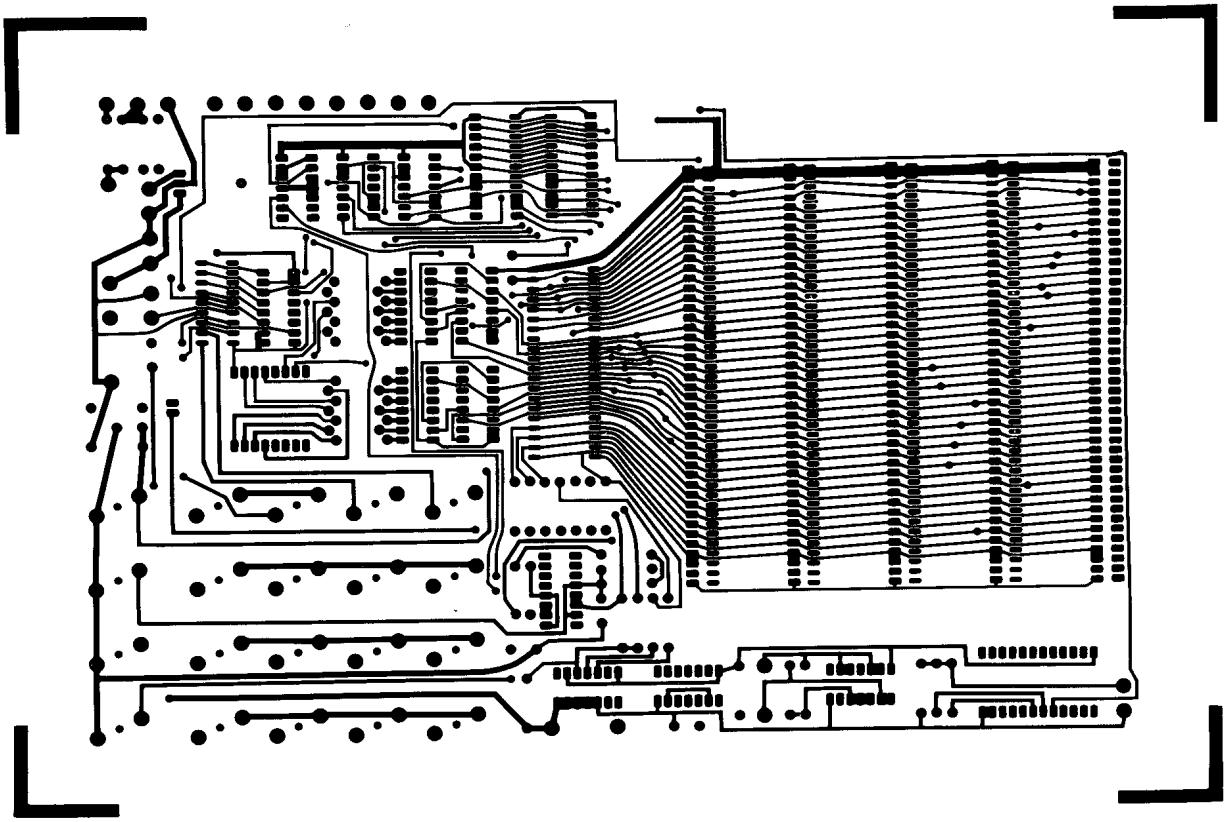
PROGRAM 1 Q-LED TEST

Memory Location	Data
0000	7A
0001	F8 10 B1
0004	21
0005	91
0006	3A 04
0008	31 00
000A	7B
000B	30 01

Release the LOAD switch and, using the hex keypad, touch the two keys associated with the first op code of Program 1. (This is 7A.) Then depress the INPUT key. The data (7A) will then appear on the two readouts. In the same manner, insert the remainder of Program 1 into the system.

When the complete program is in memory, move the LOAD switch back to its upper position. Then depress the RUN switch, which will lock down. You should observe that the single LED alongside the two 7-segment readouts will start to flash.

To test the graphics output, connect the CRT monitor to the two connector strip screws that carry the video output and ground (be sure that you connect ground to ground). DO NOT use any



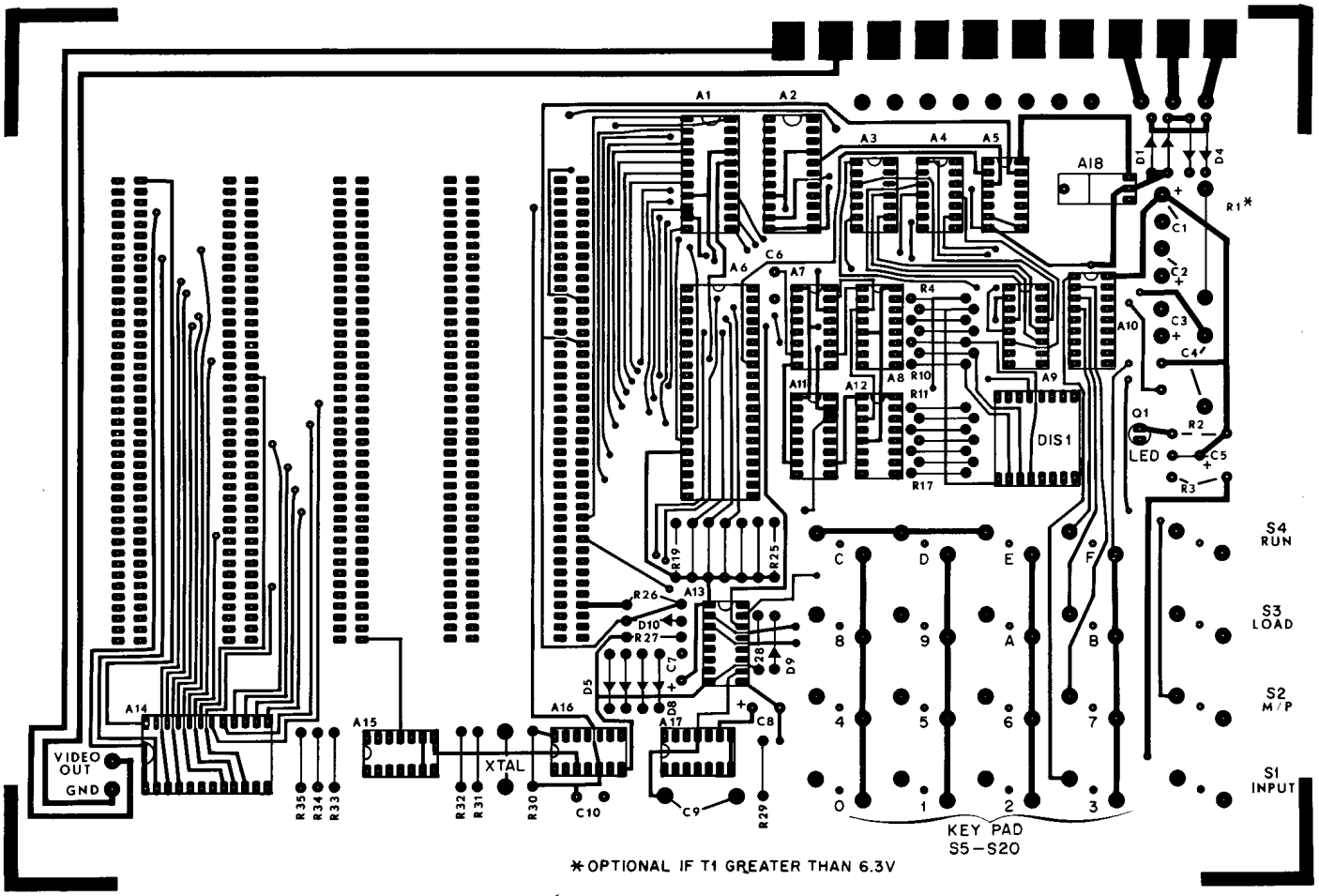
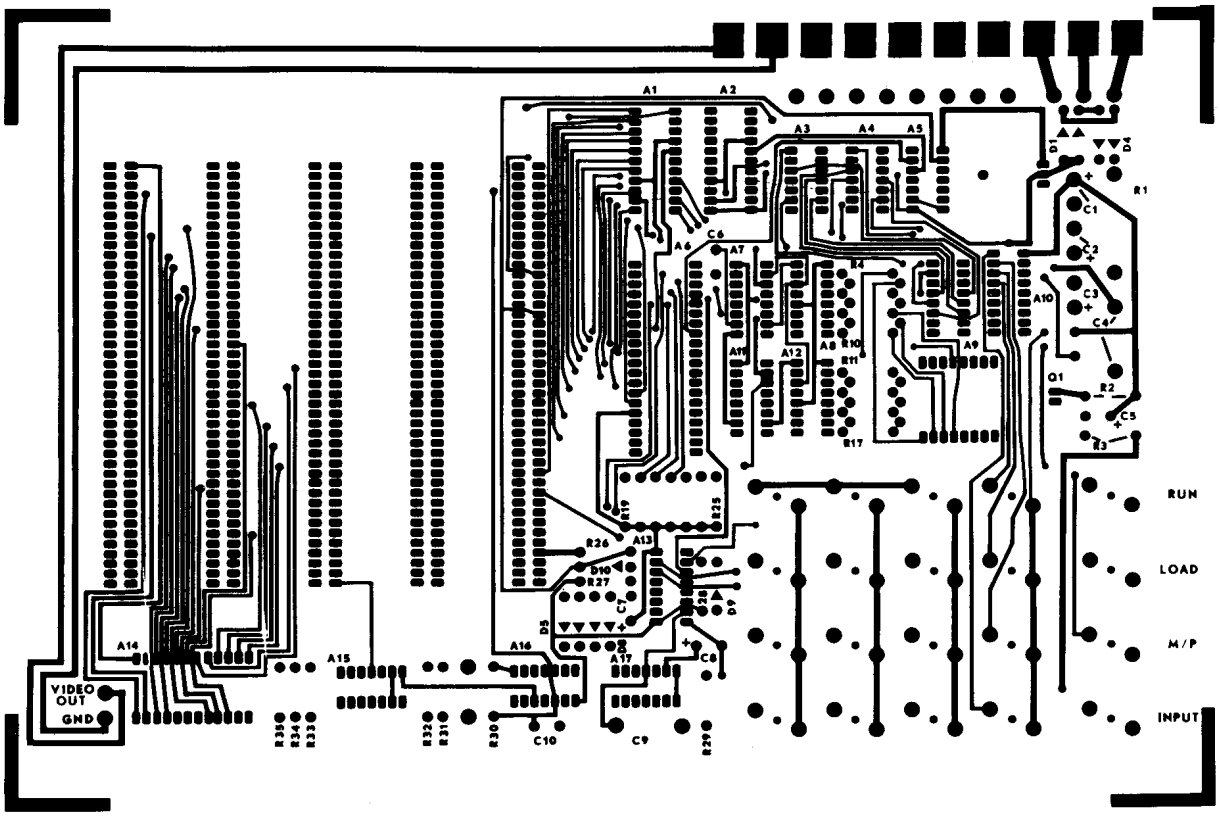


Fig. 8. The Elf-II uses a double-sided, plated-through, single pc board, having the foil pattern shown here (reduced to ½ size). The figure also shows component placement.



PROGRAM 2 VIDEO TEST

	Memory Location	Data
Start	0000	90 B1 B2
	0003	B3 B4
	0005	F8 2D A3
	0008	F8 3F A2
	000B	F8 11 A1
	000E	D3
Return	000F	72
	0010	70
Interrupt	0011	22 78
	0013	22 52
	0015	C4 C4 C4
	0018	F8 00 B0
	001B	F8 00 A0
Refresh	001E	80 E2
	0020	E2 20 A0
	0023	E2 20 A0
	0026	E2 20 A0
	0029	3C 1E
	002B	30 0F
Main	002D	E2 69
	002F	3F 2F
	0031	6C A4
	0033	37 33
	0035	3F 35
	0037	6C
	0038	54 14
	003A	30 33

form of modified ac/dc TV set unless it uses a line isolation transformer.

With the CRT monitor connected and power applied, a raster should be seen on the screen. Using the same technique that was used to load the flashing LED program, load Program 2, the video test software. Once loaded, depress the RUN switch, and note that the CRT monitor should synchronize to the Elf-II sync signals and display a stable raster, with a "cloud-like" display near the top of the raster. This cloud-like layer is actually the program you just inserted. The 1's appear as bright boxes, while the 0's are represented as dark boxes. (Refer to POPULAR ELECTRONICS July, 1977 issue for further details on video programming including how to animate the display.

Adjust the CRT monitor brightness and contrast controls for the best picture. If the sync appears to be unstable, or there does not seem to be enough contrast, one or two resistors in the Elf-II might require a different value, to increase or decrease the sync level. For instance, resistor *R34*'s value can be changed. To make changes in the video level *R35* can be altered. Neither resistor affects circuit operation, just the level of its associated signal source.

Programming. Although learning to program the 1802 is not very difficult, training and practice are required. The reader is urged to purchase the COSMAC User's Manual, which is available from your local RCA Distributor or from the source listed in the Parts List. The reader is also urged to read the four "Build the COSMAC Elf" articles that appeared in POPULAR ELECTRONICS. They include details on programming as well as how to animate a video display:

1. Part 1, August, 1976. This first article covered the construction of the Elf, discussed the 1802, fundamentals of memory addressing, use of registers, and an introduction to programming.

2. Part 2, September, 1976. The second article covered the use of a photocell or switch as a flag input, how to expand the I/O lines, a method of controlling up to 16 outputs, and further programming details.

3. Part 3, March, 1977. This section covered operating systems, how to hook up a keyboard, and how to expand memory. A few reader-supplied programs were illustrated.

4. Part 4, July, 1977. This article covered the installation of a single-chip graphics interface, showed some graphics programming and how to animate. ◇