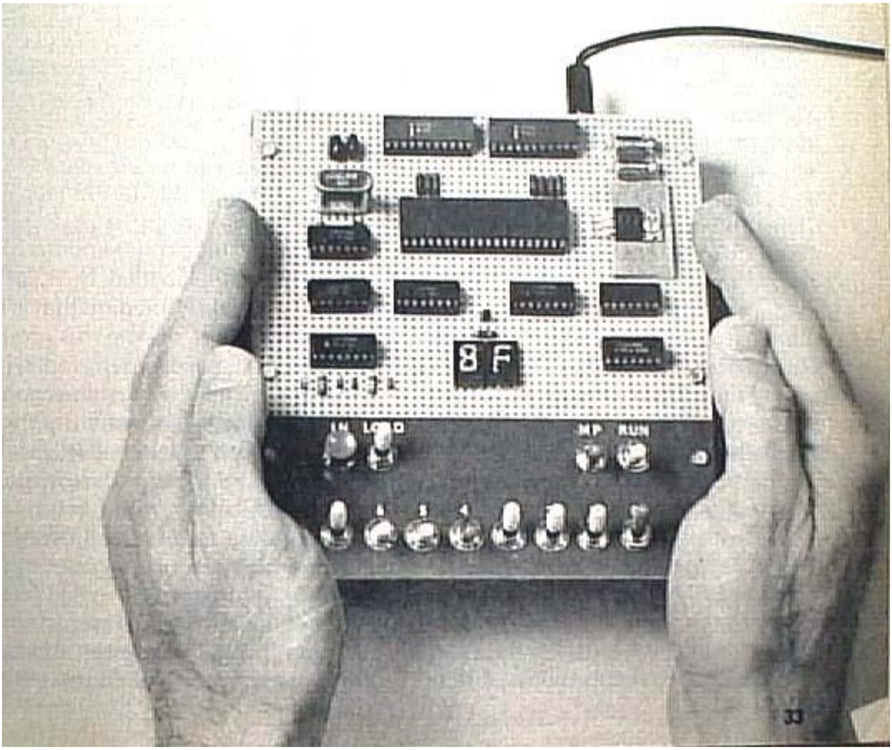


Build The COSMAC "ELF" A Low-Cost Experimenter's Microcomputer

BY JOSEPH WEISBECKER

Part 1: Simple-to-build computer trainer can be expanded for advanced applications

Part 2: Some hardware improvements and more programming details

Part 3: How to expand memory, plus more programs

Part4: Build the PIXIE Graphic Display - Adding one chip to the Elf provides complete video interface and animated graphicscapability for less than $25

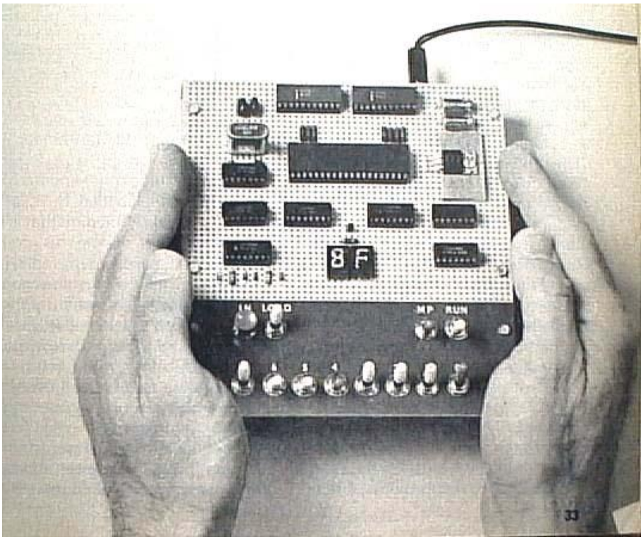
Build The COSMAC "ELF" A Low-Cost Experimenter's Microcomputer

Part 1

PE Tested

Simple-to-build computer trainer can be expanded for advanced applications.

BY JOSEPH WEISBECKER



There are basically two ways in which you can get involved with microcomputers on the nonprofessional level. You can buy one of several reasonably priced hobby computer kits, add a TV or typewriter terminal, and learn to use high-level language. On the other hand, you can build your own inexpensive system from scratch. This permits you to experiment with simple applications that do not require an expensive terminal or a large memory. You can communicate with the computer in a relatively simple language.

The "Elf" microcomputer project gives you the latter category of computer system -- for about $80. It is an excellent hardware and software trainer that uses machine language and can be easily expanded to do just about anything a full-blown microcomputer can. Packaging, however, is up to you.

The basic Elf has toggle-switch input, hex LED display, 256 bytes of RAM, four input lines and a latched output line. It can be used to play games, sequence lights, control motors, generate test pulses, count or time events, monitor intruder-alert devices, etc. You can do all these things while learning how to program in order to produce a "real" output to determine whether or not the program you designed works. If you prefer not to control or time things, a simple LED can be used to indicate whether or not your program works.

Our focus here is on the construction of the low-cost computer and some simple examples of programming.

Design Details. The heart of the Elf microcomputer is the new RCA CDP1802 COSMAC microprocessor chip that sells for less than $30. The chip can use any combination of standard RAM and ROM devices and can address up to 65,536 (65 k) bytes of memory. It has flexible programmed I/O and program-interrupt modes, an on-chip DMA (direct memory access), four I/O flag inputs directly tested by branch instructions, and a 16 x 16 matrix of registers for use as multiple program counters, data pointers, or data registers.

Other features of the 1802 chip include voltage operation between 3 and 12 volts dc at very low current drain, TTL compatibility, built-in clock, and simplified interfacing. There is also a built-in program loading capability that allows you to load a sequence of bytes without having to toggle in a new address for each byte. No ROM is required for the minimum trainer system described here. The multiple program counters permit some interesting programming "tricks," and the many single byte instructions keep programs short.

A block diagram of the Elf system is shown in Fig. 1. The pinout for the 1802 microprocessor chip is shown in Fig. 2.

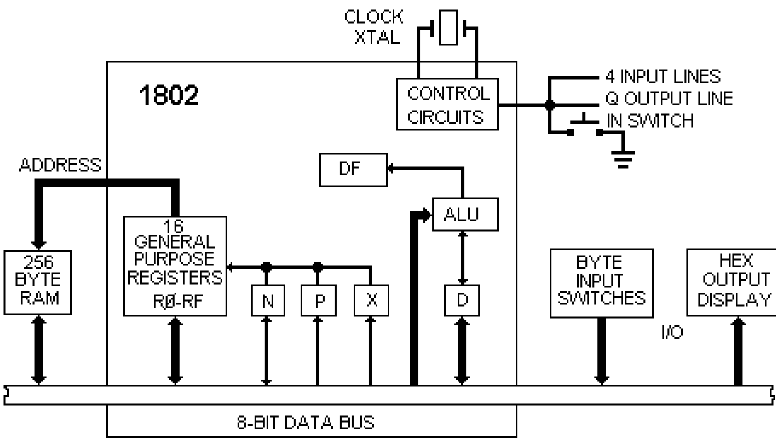


Fig. 1. Block diagram of basic computer. Up to 65K bytes of memory, 91 instructions, and varied I/O ports can be added as the system grows.

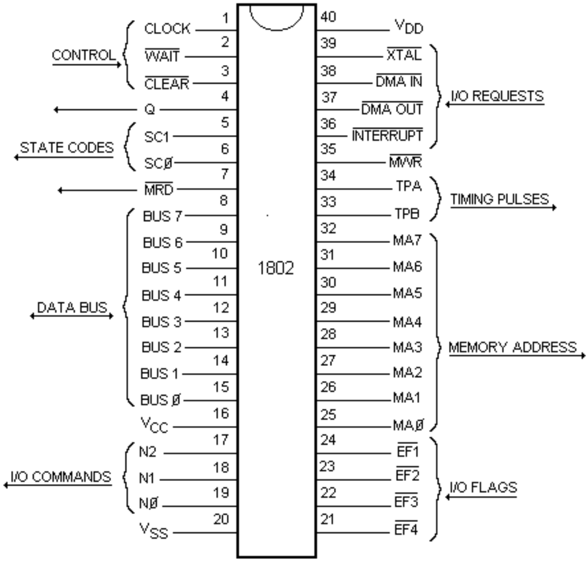


Fig. 2. Pin out for the CDP1802 COSMAC microprocessor.

Basic Operation. The key to understanding the computer is the method used for addressing the memory. At first, the procedure may appear to be complicated, but you will soon see that it is not difficult.

The 1802 chip contains 16 general-purpose registers, each holding 16 bits (two bytes) of memory addresses for data. The registers are labeled R0 through RF to conform to the hexadecimal numbering system, as shown in Fig. 3. (In the diagrams, and in computer technology in general, a Danish zero -- a zero with a slash through it -- is used to distinguish zero from a capital letter O.) Hence, if we refer to the low-order, or least-significant, byte of R1, we can call it R1.0, while the high order byte of RF would be called RF.1.

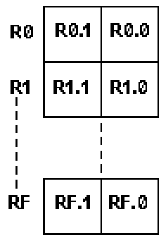


Fig. 3. The 16 registers in the 1802 are labelled R0 through RF (hex).

There is also an 8-bit D register that is used to move bytes around. In the instruction set shown in part in the instruction Subset Table, note that the 8N (8 with a digit) code will copy a low order general register byte into register D. Writing this instruction as 81 in a program will cause R1.0 to be copied into D when the instruction is executed. We can then use instruction BF (BN in the table, with B and a digit) to copy the D byte into RF.1. It takes two bytes, 81 BF, to transfer a byte from R1.0 to RF.1 via temporary holding register D. The byte in D can also be used in arithmetic operations performed by the ALU (arithmetic logic unit) circuits.

There are three other important registers that are labelled N, P, and X. Each can hold a 4-bit digit that is used to select one of the 16 general-purpose registers. For example, if you wanted to talk about the general-purpose register selected by the hex digit in X, you would call it RX. If you wanted just the low-order byte of RX, call it RX.0. RN would refer to the general-purpose register designated by the 4-bit digit currently contained in N; if the digit is 4, RN = R4.

The general-purpose registers can contain 16-bit memory addresses. Suppose register R3 contains data 0012. M3 would mean the memory location specified by the contents of R3, and M(0012) means memory location 0012 directly. MX means the memory location addressed by the contents of the general register selected by the current digit in X. If X = 3, MX = M3; if R3 = 0012, MX = M3 = M(0012).

Since the basic computer has only 256 bytes of memory, we use just the low-order bytes of the general registers to address the memory. In expanded-memory systems, you can use the high-order bytes of the general-purpose registers to select individual 256-byte pages of random-access memory (RAM).

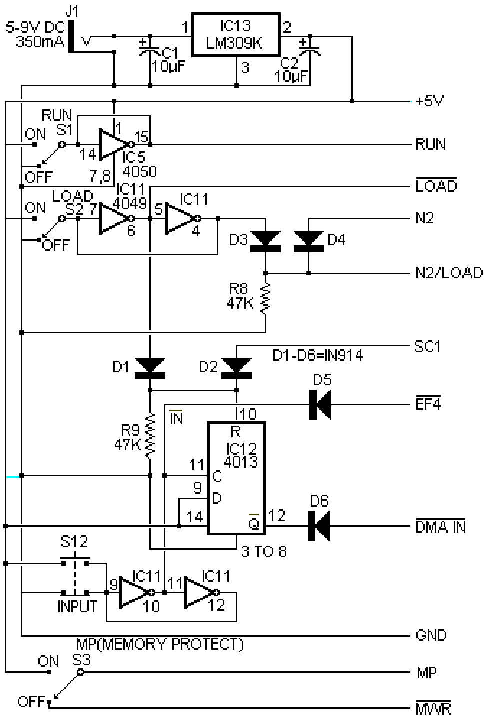


Fig. 5. Control circuits for the computer. Connections at right go to similarly marked connections on main circuit.

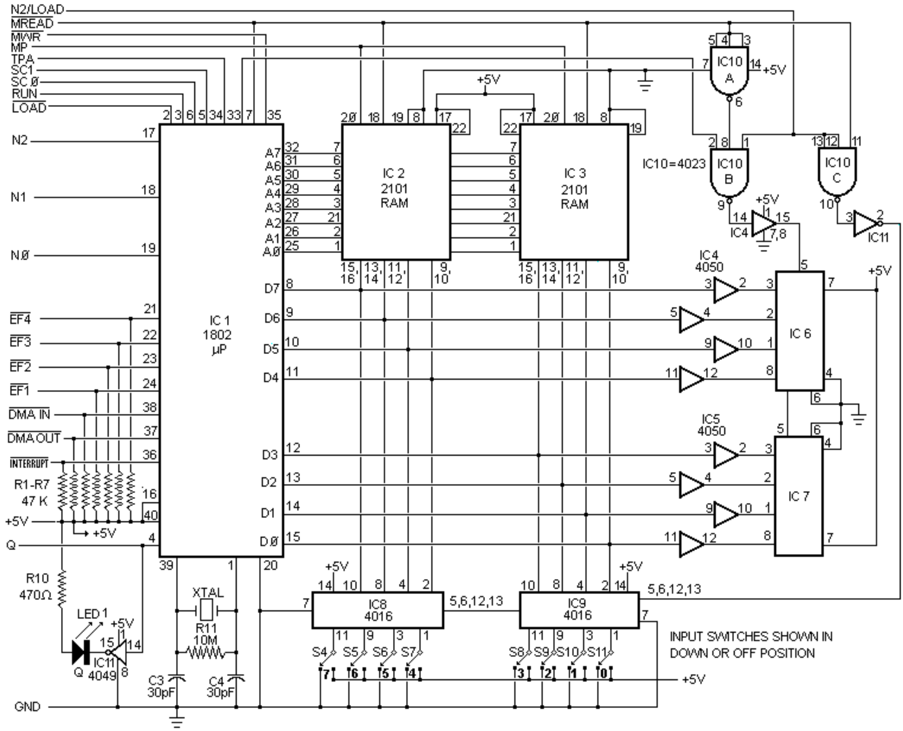


Fig. 4. Complete circuit for the Elf computer. Identified connections on the left go to the "front panel" with the eight data switches. The remaining can be left "floating" at 1802, or tied to terminal strip.

PARTS LIST

• C1, C2--10-µF, 16-volt electrolytic capacitor • C3, C4--30-pF disc capacitor • D1 through D6--IN914 switching diode • IC1--CDP1802 COSMAC microprocessor chip (RCA) • IC2, IC3--2101 (256 x 4) static RAM IC • IC4, IC5--4050 noninverting hex buffer IC	• IC12--4013 dual D flip-flop IC • IC13--LM309K 5-volt regulator IC • LED1--Red light-emitting diode • R1 through R9--47,000-ohm, ¼-watt resistor • R10--470-ohm, ¼-watt resistor • R11--10-megohm, ¼-watt resistor • S1 through S11--Spdt toggle switch	5½" x 2" (14 x 5.1cm) piece of thin aluminum; ¾" x 3/8" (19.1 x 9.5 cm) pine for chassis rails; 14-pin IC sockets (4); 16-pin IC sockets (3); 22-pin IC sockets (2); 40-pin IC socket; connector for power supply; 9-volt, 350-mA dc power source; 1¼" x ¾" x 1/8" (31.8 x 19.1 x 3.2 mm) piece of aluminum; dry-transfer lettering kit; machine and wood

• IC6, IC7--Hex LED display (H-P No. 5082-7340) • IC8, IC9--4016 quad bilateral switch IC • IC10--4023 triple 3-input NAND gate IC • IC11--4049 inverting hex buffer IC	• S12--Pushbutton switch with one set each normally open and normally closed contacts • XTAL--1-to-2-MHz crystal (see text) • Misc.--5½" x 4" (14 x 10.1cm) perforated board with 0.1" (2.54 cm) hole spacing;	hardware; hookup wire; solder; etc. **Note:** the CDP1802 COSMAC microprocessor chip is available from any RCA parts distributor as is the COSMAC user manual.

The memory contains both instructions and data bytes. Instruction bytes tell the computer what to do with the data bytes. One-byte instructions have two hex digits, where high-order bits 7, 6, 5, and 4 tell the computer what type of operation to perform. Low-order bits, 3, 2, 1, and 0 are usually placed in the N register when a new instruction is fetched from memory.

Any one of the general-purpose registers can be used as a program counter. The program counter addresses instruction bytes in memory. Each time an instruction is fetched from memory, the program counter is automatically incremented so that it points to the next instruction to be fetched. Branch instructions can be used to change the address in the program counter to permit jumping (branching) to a different part of the program when desired. The digit in the 4-bit P register specifies which 16-bit general-purpose register is being used as the program counter.

Timing Sequence. Since many of the 1802 microprocessor's instructions are only one-byte long and require two machine cycles, the first cycle is always an instruction fetch, or memory read. The fetched instruction is executed during the next machine cycle, which could be a memory-read memory-write, or register-transfer type of cycle.

Program execution always consists of a sequence of fetch-execute cycles, and the two SC0 and SC1 lines (see Fig. 4 and Fig. 5) indicate what type of cycle is being performed according to the following criteria:

SC1	SC0	Type of Machine Cycle
0	0	instruction fetch
0	1	instruction execute
1	0	DMA in/out
1	1	interrupt

Direct memory access (DMA) and interrupt are special types of cycles, which we will discuss later.

Circuit timing is shown in Fig. 6.

Note that each machine cycle requires eight clock pulses.

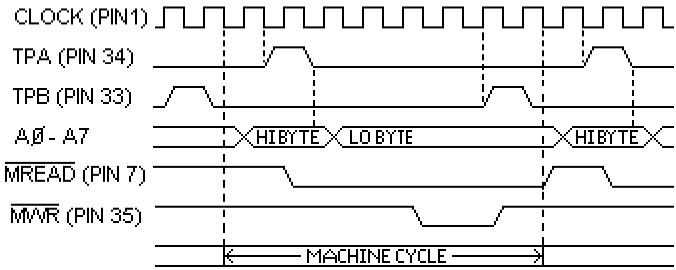


Fig. 6. Microprocessor timing. One machine cycle requires eight clock pulses. TPA and TPB control various functions, both on and off the computer.

The microprocessor has an internal single-phase clock circuit. Connecting a crystal between pins 1 and 39 of the 1802 chip causes the clock to run continuously. If desired, XTAL, C3, C4, and R11 can be omitted and an external clock with a 5-volt swing can be substituted between pin 1 and ground.

During each machine cycle, timing pulses TPA and TPB are available at pins 33 and 34 of the 1802. TPA occurs at the beginning of each machine cycle and can be used to clock the high-order byte of a 16-bit memory address into a memory page-selection register. Note that the 1802 sends out memory addresses as two 8-bit bytes. The high-order byte appears on address lines A0 through A7 first. Then the low-order byte is held on the A0 through A7 lines for the remainder of the machine cycle. This low-order address byte can, by itself, specify one of 256 locations in the minimum 256-byte memory.

TPB occurs toward the end of the machine cycle and is used to clock a byte from the RAM into an output device (such as the hex display used here). An input byte, to be stored in the RAM, is gated to the bus for the duration of the input (memory-write) machine cycle so that no time pulse is needed for input bytes.

The ~MREAD line is low during any memory-read machine cycle. When low, it opens the pin-18 RAM data output gates of *IC2* and *IC3*, permitting the byte stored in the RAM location addressed by A0 through A7 to appear on the data bus. The RAM's access time is such that the output byte appears on the bus prior to TPB. The bus byte from the RAM can then be clocked into an internal register of the 1802 or clocked to an external register (such as the hex display) with TPB, depending on the type of instruction being executed.

[**Note:** The ~MREAD above has a line over the MREAD instead of using the tilde, in the article. However, there isn't any HTML tag to put a line over characters, so I'm using the tilde convention instead. The overhead line, or tilde represent active-low signals.]

When the 1802 is performing an instruction cycle that requires a byte to be stored in the RAM, the ~MREAD line is held high to disable the RAM output bus gates. The microprocessor then causes the byte stored in the RAM to be gated onto the bus during the memory-write cycle. This byte can come from an internal register of the 1802 or from an input device such as switches, depending on the type of instruction being executed. The 1802 then generates a low memory-write pulse (~MWR) that causes the bus byte to be stored in the RAM location addressed by the A0 through A7 lines.

Circuit Operation. Using Fig.4, Fig.5, and the Instruction Subset Table we can now discuss the logic of the Elf microcomputer. The RAM access is sent out on lines A0 through A7. Eight tri-state bidirectional bus lines are used to transfer the data bytes back and forth between the 1802's registers and the *IC2-IC3* RAM. A RAM byte can be transferred to hex displays *IC6* and *IC7* via the data bus using *IC4* and *IC5* to supply the current drive for the displays. Displays *IC6* and *IC7* contain latches to store the display byte.

The basic clock frequency of the processor is determined by XTAL which should not go above 2 MHz in this circuit. The ~MREAD and ~MWR lines control the read and write cycles of the RAM, while TPA and TPB provide the timing pulses. TPA can be used for memory expansion address latching. TPB to clock bytes into output circuits. SC0 and SC1 indicate the type of cycle being performed by the 1802.

The N0, N1, and N2 lines are used to select input or output devices in the Elf, selection can be made among four input and four output devices. The table details the values of the N0, N1, and N2 lines during the machine cycle in which an input or output instruction is executed. Instructions 69, 6A, 6B, 61, 62, and 63 are spares that can be used to add I/O devices or ports to the computer. When 6C is executed, the N2 line goes to a logic-1 state and the bus byte is written into the RAM. Since this is a write cycle, ~MREAD will be high. With both N2 and ~MREAD high, the output of gate *IC10C* will be low, putting the input toggle switch byte on the bus so that it can be stored at the memory location addressed by RX. This input byte will also be placed in the 1802's D register.

When a 64 instruction is executed, N2 is high and ~MREAD is low, making the output of *IC10C* high and preventing the input switch byte from getting onto the bus. Instead, gate *IC10B* generates an output clock pulse with TPB that clocks the RAM output byte into the hex display.

The four external flag input lines– EF1, EF2, EF3, and EF4–can be pulled low by external switches. These four lines can be tested by instructions 34, 3C, 35, 3D, 36, 3E, 37 and 3F. Note in Fig. 5 that the INPUT pushbutton switch, debounced by portions of *IC11*, is connected to the ~EF4 line. This means that ~EF4 = 1 when *S12* is depressed and ~EF4 = 0 when *S12* is in its normal position.

Latched output line Q can be set high by a 7B instruction or reset to low by a 7A instruction. The Q LED comes on when Q is high. The ~DMA~IN, ~DMA~OUT, and ~INTERRUPT lines can be pulled low to cause these operations to occur.

ONE BYTE INSTRUCTIONS		TWO BYTE INSTRUCTIONS	
1N	RN+1	30MM	GO TO MM
2N	RN-1	31MM	GO TO MM IF Q=1
8N	RN,0–>D	39MM	GO TO MM IF Q=0
9N	RN,1–>D	32MM	GO TO MM IF D=00
AN	D–>RN.0	3AMM	GO TO MM IF D != 00
BN	D–>RN.1	33MM	GO TO MM IF DF=1
4N	MN–>D,RN+1	38MM	GO TO MM IF DF=0
5N	D–>MN	34MM	GO TO MM IF EF1=1
DN	N–>P	3CMM	GO TO MM IF EF1=0
EN	N–>X	35MM	GO TO MM IF EF2=1
7A	0–>Q (LIGHT OFF)	3DMM	GO TO MM IF EF2=0
7B	1–>Q (LIGHT ON)	36MM	GO TO MM IF EF3=1
F0	MX–>D	3EMM	GO TO MM IF EF3=0
F1	MX or D–>D	37MM	GO TO MM IF EF4=1 {IN SWITCH
F2	MX and D–>D	3FMM	GO TO MM IF EF4=0 {IN SWITCH
F3	MX xor D–>D	F8KK	KK–>D
F6	SHIFT D RIGHT, BIT 0–>DF	F9KK	KK or D–>D
76	ROTATE D RIGHT, DF–>B7,B0–>DF	FAKK	KK and D–>D
FE	SHIFT D LEFT, BIT 7–>DF	FBKK	KK xor D–>D
7E	ROTATE D LEFT, DF–>B0,B7–>DF	FDKK	KK-D–>D,CARRY–>DF
F5	MX-D–>D,CARRY–>DF	FFKK	D-KK–>D,CARRY–>DF
F7	D-MX–>D,CARRY–>DF	FCKK	KK+D–>D,CARRY–>DF
F4	MX+D–>D,CARRY–>DF	7CKK	KK+D+DF–>D,CARRY–>DF

ONE BYTE INPUT INSTRUCTIONS		N2	N1	N0	1-BYTE OUTPUT INSTRUCTIONS		N2	N1	N0
69	BUS–>MX,D	0	0	1	61	MX–>BUS,RX+1	0	0	1
6A	BUS–>MX,D	0	1	0	62	MX–>BUS,RX+1	0	1	0
6B	BUS–>MX,D	0	1	1	63	MX–>BUS,RX+1	0	1	1
6C	INPUT SWITCH BYTE–>MX,D	1	0	0	64	MX–>HEX DISPLAY,RX+1	1	0	0

Table 1. Instruction Subset Table shows required sequence of steps.

The ~LOAD and RUN lines control the operation of the microprocessor according to the following conditions:

~LOAD	RUN	Mode
gnd	gnd	load
+5V	gnd	reset
gnd	+5V	–
+5V	+5V	run

RUN and LOAD switches *S1* and *S2* in Fig. 5 control the operation of the computer. With both switches set to OFF, ~LOAD is +5V and RUN is at ground potential. This resets the 1802. Neither TPA nor TPB are generated in the reset state and R0 = 0000, P = 0, X = 0 and Q = 0 after the 1802 is reset. When the LOAD switch is set to ON, ~LOAD goes low and RUN stays low, forcing the system into the load mode. Now you can load a sequence of bytes into the RAM, starting at address 0000, by setting the bytes into the input toggle switches, one at a time, and operating the INPUT switch.

In the load mode, the 1802 does not execute instructions but waits for a low to appear on the ~DMA~IN line. When this happens, the 1802 performs one memory write cycle during which the switch input byte is stored in memory. R0 is used to address memory. during the DMA IN cycle. After the input byte is stored at the address specified by R0, this register is incremented by one so that input bytes will be sequentially loaded into RAM locations. Line SC1 goes high during the DMA IN cycle so that the control circuits know when the input byte has been stored in the RAM.

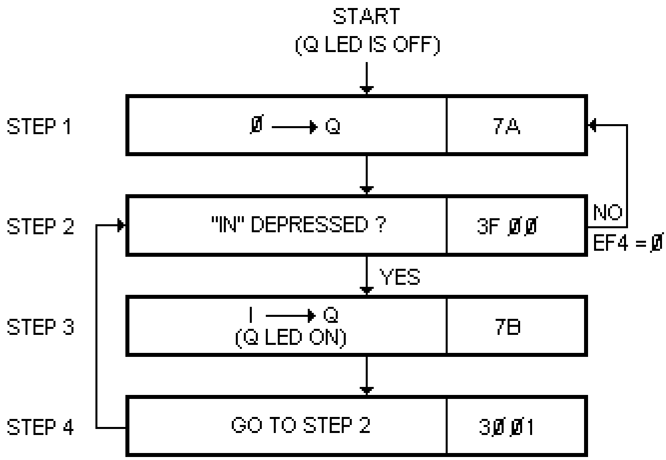


Fig. 7. Program turns on Q-LED when INPUT switch is operated.

INTRODUCTION TO PROGRAMMING

Once you have built your Elf, you must learn how to load a sequence of bytes into memory and then go back and display the sequence. Let us write a simple program that can be loaded into the memory and run.

Suppose you want to program the computer to turn on the Q LED whenever the INPUT switch is set to ON. First, you must draw a flow chart that shows the required sequence of steps (Fig. 7). Locate the correct instructions in the Instruction Subset Table. A 7A instruction will perform Step 1. Load this instruction into M(0000). Note that when the INPUT switch is not depressed, EF4 = 0. A two-byte 3F 00 instruction will jump (branch) back to the 7A instruction at M(0000) as long as the INPUT switch is not operated (EF4 = 0). This condition is known as a "loop," and the program will stay in this loop while it is waiting for the INPUT switch to be depressed. Load 3F 00 into memory locations M(0001) and M(0002) to perform the second step in the flow chart. All GO TO MM instructions shown in the Table put MM into the low-order byte of the program counter if a GO TO condition exists. Otherwise, the next instruction in sequence is fetched by the 1802.

Loading a one-byte 7B instruction into M(0003) takes care of Step 3, while a 30 01 instruction will jump back to the 3F 00 instruction at M(0001). Load the 30 01 instruction at M(0004) and M(0005) to complete the program.

You load this 6-byte program by placing the LOAD switch on the ON position, with RUN and MP set to OFF, setting up the toggle switches for the hex number 7A, and depressing the INPUT switch. Release the INPUT switch, insert 3F and operate the INPUT switch again. Then load 00 and so on until the last byte, 01, has been stored at M(0005). If you "blow" the program, set MP to ON and LOAD to OFF. Then set LOAD to ON and operate the INPUT switch until you get to the byte immediately preceding the wrong entry. Set MP to OFF, set up the correct byte, and operate INPUT. Flip MP back to ON to protect what you have stored in memory.

To start the program running, set LOAD to the down position to reset the 1802 and set the RUN switch to ON. Nothing should happen until you depress the INPUT switch, at which time the Q LED should come on. Releasing the INPUT switch should cause the LED to extinguish. If you like, you can now observe the timing signals of the 1802 on an oscilloscope while the program is running.

Another simple program involves counting the number of times the INPUT switch is operated and then turning on the Q LED at the end of the count. The flow chart for this program is shown in Fig. 8. When you load and run this program, nothing will happen until you operate the INPUT switch five times, at which point the LED will come on and remain on. Note in Step 1 that you can change the number of times the INPUT switch is operated. Step 6 just loops on itself to terminate the program after the INPUT switch has been operated the specified number of times.

Depressing and releasing INPUT switch S12 sets flip-flop *IC12* (Fig. 5). The ~Q output of this stage goes low, causing the required low on the ~DMA~IN line. The 1802 responds to this request with a memory-write cycle during which SC1 is high. During this cycle, ~MREAD is high and, since LOAD switch *S2* is also ON, the N2/LOAD signal causes gate *IC10C* to go high, gating the switch input byte to the data bus and storing it in memory. When SC1 goes high, it also resets *IC12*, which causes ~DMA~IN to return to its high state. The computer then waits for the next switch input byte and LOAD switch operation.

Following each DMA IN cycle, the 1802 holds the A0 through A7 lines at the address of the byte just stored in the RAM. ~MREAD is also held low while waiting for the next input byte. This means that the previously loaded byte is being gated to the bus (from the RAM) while waiting for a new byte. This bus byte is continuously clocked into the hex display, since the LOAD switch is holding *IC10B* open.

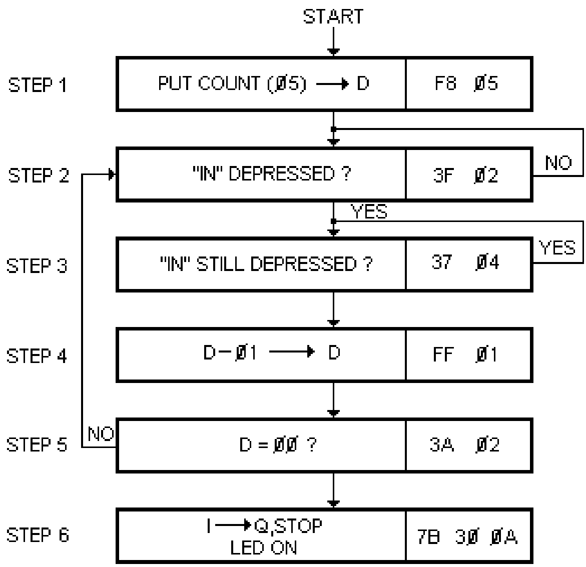


Fig. 8. Program counts number of times INPUT switch is operated.

A sequence of program bytes can be loaded into the RAM starting at M0 = M(0000) by setting the LOAD switch to the ON position, with the RUN switch set to OFF. Set the eight input switches, S4 through S11, to the desired byte code (in hexadecimal) and depress the INPUT switch to store the byte in the RAM. The value of this byte will be displayed with the hex displays *IC6* and *IC7*. Repeat this procedure for each byte to be loaded. Setting the LOAD switch to OFF puts the

1802 back in the reset state where R0 = 0000, P = 0, X = 0, and Q = 0. If you wish to see what is stored in memory, set MP (memory-protect) switch S3 and the LOAD switch to ON. Now, each time you operate the INPUT switch, successive bytes in the RAM, starting with M(0000), will be displayed.

To change a byte, proceed to the byte just before the one to be changed. Flip the MP switch to OFF, set the input toggle switches to the hex value of the new byte, and depress the INPUT switch once. This new byte will be displayed and stored in the RAM at the location following the byte at which you stopped. Place the MP switch in the ON position. You can now continue to operate the INPUT switch to sequence through the RAM without modifying the bytes in memory.

To start the executive cycle of a program, set both the LOAD and RUN switches to OFF (to reset the 1802). Then set the RUN switch to ON. The program counter is always specified by the hex digit in register P, which can be set to zero by reset so that the program counter will always initially be R0. Set R0 to 0000 by resetting so that instruction fetching, or program execution will always begin at M(0000). Instructions will continue to be fetched from the RAM and executed until the RUN switch is set to OFF, resettting the computer. Make sure that the MP switch is OFF when running programs so that computer operation is not inhibited.

Construction Notes. Hardware assembly is relatively simple, permitting the project to be put together with ordinary perforated board with 0.1" (2.54-mm) hole spacing and IC sockets, using either Wire Wrap® or a wiring pencil. (See photo.) The perf board measures 5½"L × 4"W (14 × 10.2 cm) and is supported on a base made up of lengths of ¾" × 3/8" (19.1 × 9.5) pine. A sheet of thin aluminum provides the support for the eight toggle-type data switches. The LM309 voltage regulator IC (*IC13*) is mounted on a 1¼" × ¾" × 1/8" (31.6 × 19.1 × 3.2-mm) piece of aluminum to serve as a heat sink.

Do not mount the IC's (except the display devices) in their sockets until after all wiring is complete. Socket, switch, and component layout should be roughly the same as shown in the photo. Be sure to locate the crystal close to pins 1 and 39 of the microprocessor's socket. Then wire the circuit in accordance with the schematics in Figs. 4 and 5.

Any crystal with a frequency of between 1 and 2 MHz can be used in the Elf, or you can substitute a simple 555 or CMOS oscillator with a 5-volt signal swing between pin 1 of the 1802 and circuit ground, in which case, you will have to omit *XTAL*, *C3*, *C4*, and *R11*. There is no lower limit to the clock frequency, but most of the sample programs discussed in this series of articles are based on a clock frequency between 1 and 1.8 MHz.

Displays *IC6* and *IC7* are relatively expensive hex devices. They are the only TTL devices in the computer and, as a result, draw most of the power required by the circuit. If you wish to economize, you can substitute ordinary LED's for the displays. (Next month, we will discuss how to make the substitution.)

An inexpensive 9-volt, 350-mA dc battery eliminator, like those used as battery charger/eliminators for calculators, can be used to power the Elf.

When the computer is completely assembled, use a dry-transfer lettering kit to label all switches and positions. IC socket locations, and pins 1 of all sockets. Then, exercising the usual safety procedures for handling MOS devices, install the integrated circuits in their respective sockets.

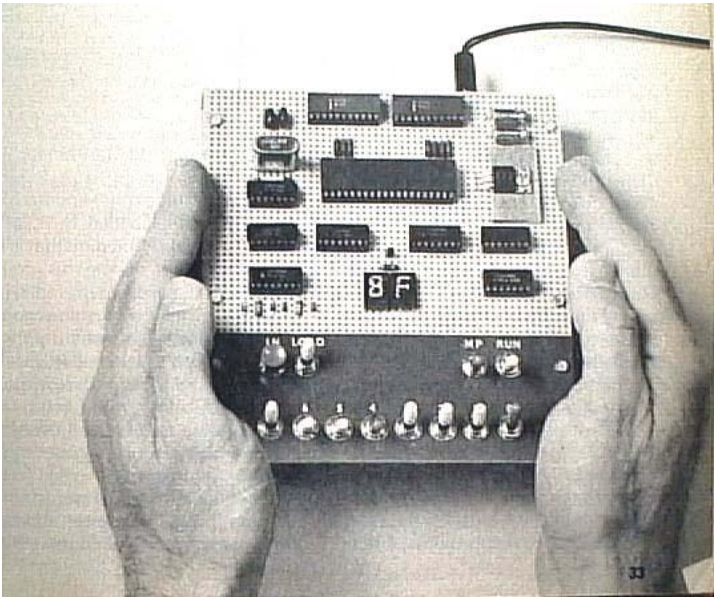
Coming Up. In future articles, we will provide more programs as well as methods of adding other types of inputs and relay-control output circuits. We will also detail how to save programs in battery-powered COSMOS RAM's and describe a simple operating system that lets you read/write any memory location and inspect general register contents for program debugging purposes. Memory expansion, hex keyboard input, and an inexpensive video graphics display are other subjects we will cover in detail.

Build The COSMAC "ELF" A Low-Cost Experimenter's Microcomputer

Part 2

Some hardware improvements and more programming details

BY JOSEPH WEISBECKER



Last month, we discussed the construction of the low-cost Elf microcomputer/trainer and gave some examples of simple programming. This month, we will describe hardware and how to make a low-cost LED replacement for the relatively expensive hex display and add a simple 8-bit I/O port. Then we'll add a 16- switch monitor that among other things will allow you to use a hex keyboard. We'll finish up the hardware section by showing how to use a 9-volt battery as power for a RAM circuit to hold a program for as long as six months.

When we're finished with the hardware details, it's back to the software continuing with our programming discussion.

The Hardware. The hex displays called for in the original Elf project can be replaced with a discrete LED circuit as shown in Fig. 1. You will need a CD4508 eight-bit register, eight low-current LED's, two 4049 hex inverters, and eight 470-ohm, ½-watt resistors. When the LED circuit is substituted for the hex displays, current consumption will be reduced by about 150 mA. The input comes from the data bus which formerly went to hex displays *IC4* and *IC5*.

When you use the LED display, you must count the LED's to arrive at the hex number displayed. The upper four LED's form the first digit, the lower four, the second digit.

You can mount the LED's on the front panel. Be sure you carefully identify each. Also, when making the conversion, don't forget to modify the RUN switch circuit as shown.

You can connect an inexpensive cadmium-sulfide (CdS) cell between the EF1 line and ground. Be sure to use a photocell that has a dark resistance in excess of 200,000 ohms and a light resistance of less than 10,000 ohms. If you use any other photocell, you may have to increase the value of the resistor to pull up the EF1 line of the 1802 microprocessor. The high input impedance of the CMOS logic eliminates the need for photocell amplification. Also several photocell inputs can be used, each connected to a different flag (EF) line.

Using a photocell input, you can program the computer to start counting when an object moves past one photocell and stop counting when the object passes a second cell. This technique allows you to determine the speed of a moving object. It can also be used to count people, monitor motor speed, provide targets in a computer-controlled light gun or "eyes" for a computer-controlled robot, etc.

Magnetic reed switches, simple make/break switches, or similar devices can be connected to the computer via the flag-line inputs.

Several inexpensive methods of expanding the number of input and output lines can be used with this computer. One example is shown in Fig. 2. Here, a CD4058 IC is used in both the input and the output positions, while other IC's provide the necessary gating. A 69 instruction will store the values of the eight input lines in memory as a single byte.

In the output port section, a 61 instruction sets a memory byte into this port. The output port can control up to eight output lines, but you will have to add CD4050/CD4049 buffers if you wish to drive TTL loads. You can use these output lines to drive suitable transistors to control relays, lamps or LED's, or battery-powered motors, you can have the computer sequence lights, control animated displays or robots, or control a slide projector in response to tones from an audio tape. You can use the existing Q line output in the same manner for a single operation.

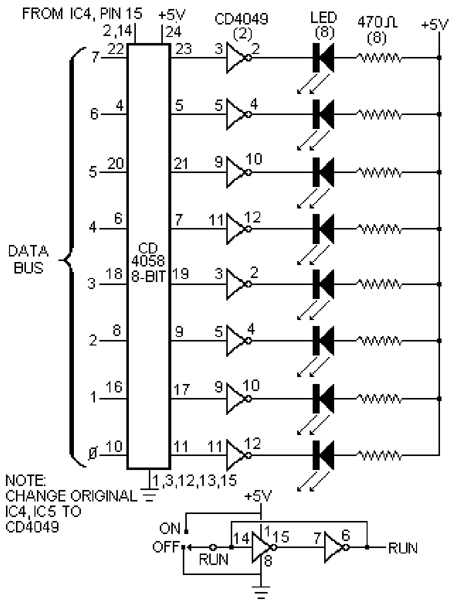


Fig. 1 (9) Circuit for a discrete LED display.

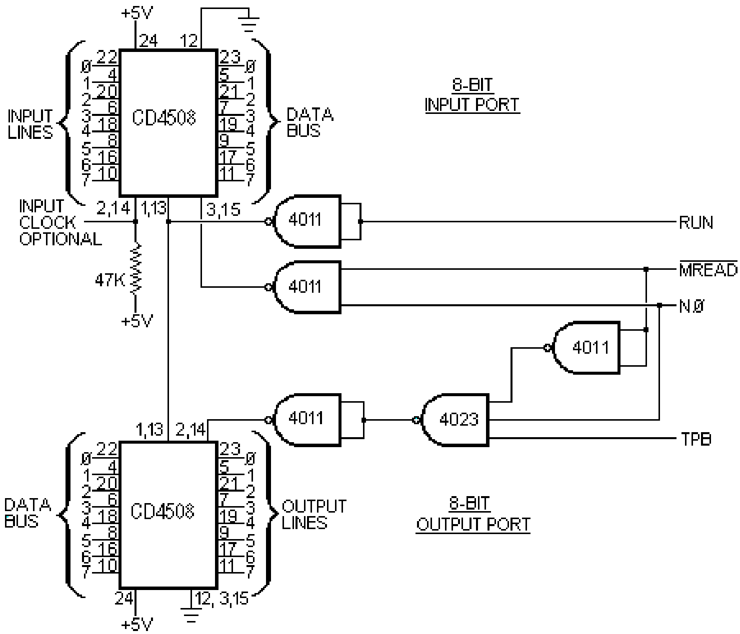


Fig. 2.(10) A way to expand the number of input and output lines using two CD4508 integrated circuits.

A simple method of controlling up to 16 output lines or monitoring the states of 16 switches is shown in Fig. 3. A 62 instruction will set the low-order digit of a memory byte into the 4-bit CD4515 register. The output line corresponding to this digit will go low, while the other 15 remain high. To make things more interesting, the computer can determine whether the switch attached to the selected output line is closed or not by testing EF2 with a branch instruction.

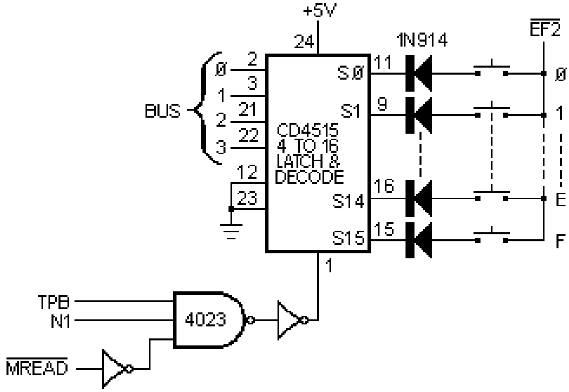


Fig. 3.(11) A method of controlling up to 16 outputs.

The following program continuously examines all 16 switches in sequence and stops with the number of any closed switch from 0 to F in the low-order digit of R3.0:

```
Step   M     Bytes    Comment
  1  0000  F8 FF A2   FF-->R2.0 (memory pointer)
  2  0003  13 52 E2   R3 + 1, R3.0-->MX, 2-->X
  3  0006     62 22   MX-->CD4515 (select switch)
  4  0008     3D 03   Repeat step 2 if switch is open
  5  000A     30 0A   Stop with R3.0 = closed switch number
```

The diodes can be omitted if only one switch at a time will be closed. This circuit and an appropriate program could permit data and instruction bytes to be loaded into memory a digit at a time from a hex keyboard instead of toggle switches. Switch debouncing could be performed with a programmed delay following each key depression. A 64-character keyboard could be used by treating it as four groups of 16 keys each, with the common side of each key group connected to a different flag line. In fact, a program to generate the Morse code equivalent of each key could be written using the Q line as the output.

This circuit can also be used to select one of 16 external devices or I/O ports if desired. Using the latter technique would permit up to 128 I/O lines. Cascading CD4515's would permit even larger numbers of I/O lines to be handled.

A low-cost video terminal can be made using the "Scopewriter" (POPULAR ELECTRONICS, August 1974), or you can interface your computer with a cassette data interchange system.

We have only scratched the surface of I/O circuits for the Elf. The real fun (and program training) starts when you think of new things to attach to the output lines and start writing programs to activate them.

The major drawback with a RAM, or memory, system is that data stored in it is erased when the main power source is shut down. (Of course, if you could use a ROM, this wouldn't be a problem. However, ROM's must be preprogrammed with the memory data you wish to save, a costly and time-consuming approach.) Adding a cassette interface doesn't entirely eliminate the problem because a "bootstrap" is still required to be stored in memory to run the cassette.

The use of low-power COSMOS RAM IC's and a 9-volt mercury battery, as shown in Fig. 4, will allow you to save programs in memory for up to six months even with the main power to the computer turned off. The 1822 RAM's shown are in-compatible with the 2101's specified for the original project, but some of the RAM's must be rewired as shown.

With the COSMOS RAM's installed, you can turn off power to the computer at any time. The mercury battery will supply the required standby power to the memory system so that the program will be ready to run immediately when the computer is again powered up. The newly added STANDBY switch should be turned on (+5 volts) only after power is turned on. It should be off to hold pin 17 of the RAM's at ground potential before removing power from the system.

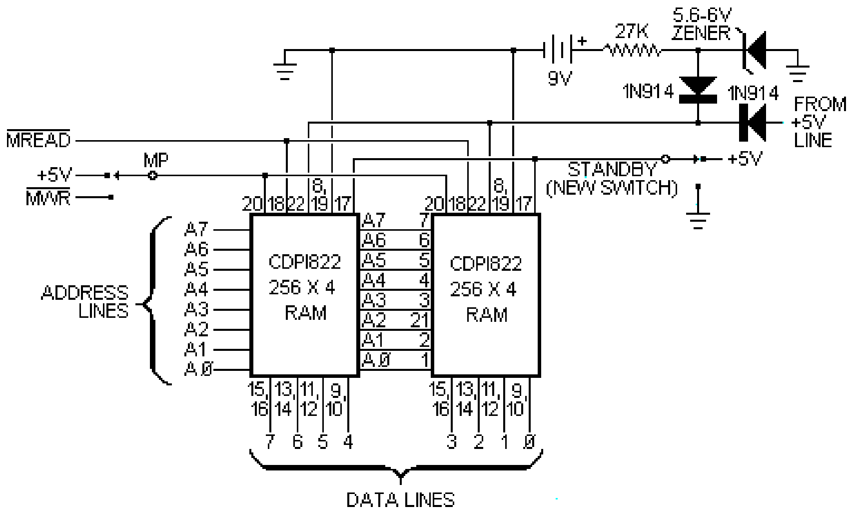


Fig. 4.(12) Using a low-power COSMOS RAM and a 9-volt battery permits saving programs in memory.

Periodically check the battery's output; if it should fall too low, the memory system won't be able to hold data.

The last piece of hardware we will discuss here is the simple output driver shown schematically in Fig. 5. This is a conventional driver for almost anything that doesn't require more current than the transistor is capable of safely handling. The diode in the relay circuit removes the reverse transient spike that might otherwise damage the transistor. You can substitute a LED or even a load resistor for driving a power stage.

More Programming. The single-line output program shown below is a simple program that will flash the Q LED at a preset rate. It also provides a programmable square wave on the Q line.

```
Step   M      Bytes    Comment
  1  0000      7A      0-->Q
  2  0001   F8 10 B1   10-->R1.1
  3  0004      21      R1.1
  4  0005      91      R1.1-->D
  5  0006    3A 04     Repeat step 3 if D = 00
  6  0008    31 00     Go to step 1 if Q = 1
  7  000A      7B      1-->Q
  8  000B    30 01     Go to step 2
```

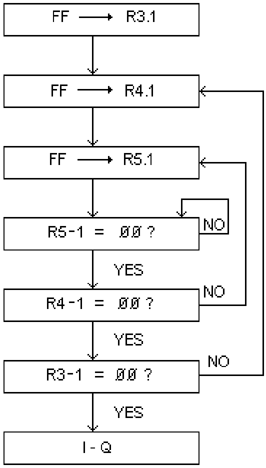
When you run this program, the square-wave frequently depends on the settings of the input switches. You can change frequency at any time. For higher frequencies, change B1 at M(0006) to A1 and 91 at M(0008) to 81. You can now select any of 256 different frequencies by altering the settings of the switches.

To modify the program to sweep the audio frequency range, use the following program:

```
Step   M      Bytes    Comment
  1  0000   F8 FF A2   FF-->R2.0
  2  0003      7A      0-->Q
  3  0004    82 A1     R2.0-->D; D-->R1.0
  4  0006    21 81     R1.1; R1.0-->D
  5  0008    3A 06     Repeat step 4 if D = 00
  6  000A    31 03     Go to step 2 if Q = 1
  7  000C   7B 22 82   1-->Q; R2.1; R2.0-->D
  8  000F    32 00     Go to step 1 if D = 00
  9  0011    30 04     Go to step 3
```

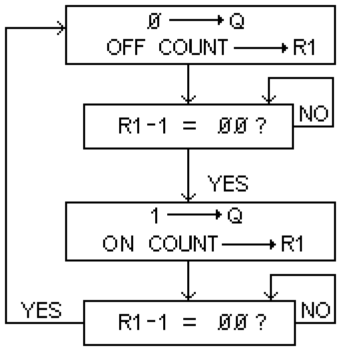
This program can be used in audio test applications. Note that R2 is used as a second counter that causes the square-wave frequency to change after each cycle. You can hear what this sounds like by using the circuit shown in Fig. 5.

Very low frequency square waves or long-interval timing, can be programmed by cascading counters as illustrated in the following flow chart:



The Q line can then be used to activate a relay (as in Fig. 5), which can control house lights, motors, etc.

Suppose you wish to program a variable-pulse generator instead of square-wave generator. Use separate counts for the pulse off and on times as illustrated in the following flow chart:



This program will flash the Q LED and put a square wave on the Q line at a rate determined by the contents of memory M(0002) from a 10 to some other number. By referring back to the instruction Subset Table in last month's article, you should be able to interpret the above program.

Note in the program that R1 is used as a 16-bit decrementing counter (steps 3, 4, and 5). When the high- order eight bits of this counter reaches 00, the Q line goes to its opposite stage. Changing steps 2 and 4 to use the low-order byte of R1 increases the Q line's output frequency by a factor of 256.

If you use a 1-MHz crystal in the clock, the above program can generate square waves at frequencies between 0.3 and 80 Hz, depending on the byte in M(0002).

By changing the B1 instruction at M(0005) to 81, square waves between 80 and 20,000 Hz can be generated. In this manner, your basic computer becomes a presettable square-wave generator.

We can rewrite the program so that the square wave's frequency becomes a function of the settings of the toggle switches as follows:

```
Step   M     Bytes    Comment
  1  0000  F8 FF A2  FF-->R2.0
  2  0003     E2     2-->X
  3  0004     7A     0-->Q
  4  0005    6C B1   Switch byte-->MX, D:D-->R1.1
  5  0007    21 91   R1.1; R1.1-->D
  6  0009    3A 07   Repeat step 5 if D = 00
  7  000B    31 04   Go to step 3 if Q = 1
  8  000D  7B 30 05  1-->Q; Go to step 4
```

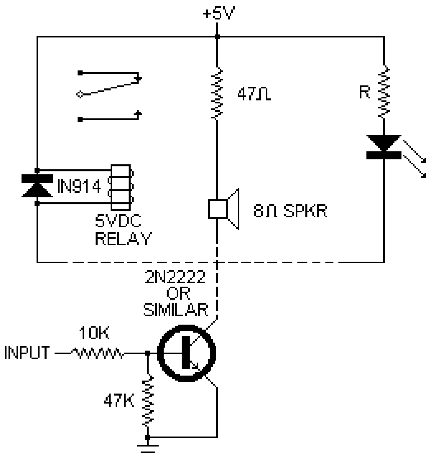


Fig. 5.(13) Circuit to provide outputs used for testing

In a similar manner, you can program bursts of pulses, variable-interval pulse trains, etc. You can even write a program where a list of bytes specifies a sequence of different tones to make a programmable music box.

The following two programs are "games" that demonstrate how the COSMAC instructions can be used. No added I/O circuits are required to run these programs.

Load the following sequence:

```
Step   M      Bytes   Comment
  1   0000     E1     1-->X
  2   0001  F8 0F A1  0F-->R1.0
  3   0004     64     MX-->display; X + 1
  4   0005    3F 05   Wait for INPUT switch to be depressed
  5   0007     6C     Switch byte --> MX,D
  6   0008  F8 0A F7  0A-->D; D-MX-->D
  7   000B    51 64   D-->M1; MX-->display; X + 1
  8   000D  30 0D 00  Stop; 00
```

Set both the LOAD and MP switches to off then flip RUN to on. Have someone select any digit between 1 and 9 multiply by 10, add the original digit. Set the binary code for the least significant digit of the final answer into switches 3, 2, 1, and 0, and place the other input switches in the down position. When you depress the INPUT switch, the computer will display the unknown digit.

This program illustrates how to set a memory byte into the output display with a 6C instruction. Note the use of R1 as a memory pointer and the use of the binary subtract instruction in step 6.

The following program makes the computer "think" of a byte, which you must guess in no more than seven tries:

```
Step   M      Bytes   Comment
  1   0000    8A AB   RA, 0-->RB.0 = secret byte
  2   0002  F8 AA A3  AA-->R3.0 = memory pointer
  3   0005    53 E3   D-->M3; 3-->X
  4   0007  F8 07 A4  07-->R4.0 = number of turns
  5   000A    64 23   M3-->display; 3 + 1; 3 - 1
  6   000C  2A 3F 0C  RA + 1 until INPUT is depressed
  7   000F    37 0F   Wait for INPUT to be released
  8   0011    6C 8B   Switch byte-->M3; RB.0-->D
  9   0013  F5 33 1A  M3-D-->D; Go to step 12 if M3 > RB.0
 10   0016    F8 01   01-->D
 11   0018    30 22   Go to step 16 (show D)
 12   001A    3A 20   Go to step 15 if D = 00
 13   001C    53 64   D-->M3; M3-->display; 3 + 1
 14   001E    30 1E   Stop loop
 15   0020    F8 10   10-->D
 16   0022  53 64 23  D-->M3-->display; 3 + 1; 3 - 1
 17   0025    24 84   R4-1, R4.0-->D (turn counter)
 18   0027    3A 0C   Go to step 6 if D = 00
 19   0029    8B 7B   RB.0-->D; 1-->Q
 20   002B    30 1C   Go to step 13 (show D and stop)
```

Place both the MP and LOAD switches in the off position after toggling the program. When you start the program by operating RUN; AA is displayed. Now, try to guess what byte the computer has selected by setting the eight INPUT switches and depressing the main INPUT switch. If 00 is displayed you guessed correctly; if 01 is displayed, your guess is too low; if 10 is displayed, your guess is too high. You lose after seven wrong tries, at which point, the computer turns on its QLED and the displays indicate the hidden byte. To try again, set RUN to off and then on.

The subtract instruction in step 9 sets an arithmetic overflow flag (DF) if MX is equal to or greater than D. The COSMAC instruction manual covers a detailed explanation of the use of this overflow flag in arithmetic and shift operations.

In Closing. Now that you have some familiarity with programming for the Elf, look through your back issues of POPULAR ELECTRONICS for some challenging programs to write. Try the "Logidex" game in the November 1973 issue, "Tug-of-War" game in February 1975, "Electronic Dice" in July 1975, and the "Executive Digital Temper Countdowner" in December 1975. These are just a few of the many electronic games you can *program* instead of building.

HEX NUMBER SYSTEM

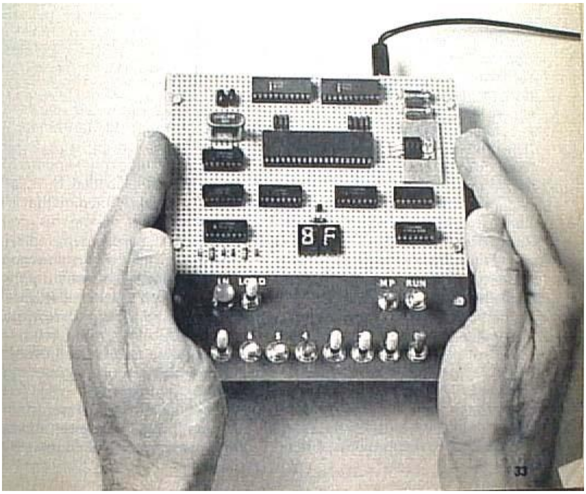
Decimal	Binary	Hex
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
10	1010	A
11	1011	B
12	1100	C
13	1101	D
14	1110	E
15	1111	F

BY JOSEPH WEISBECKER

Build The COSMAC "ELF" Microcomputer

Part 3:

How to expand memory, plus more programs



IN TWO previous articles (POPULAR ELECTRONICS, August 1976 and September 1976), we discussed the construction of the low-cost Elf microcomputer, gave some programming examples, and described some low-cost optional input/output circuits. Here we will examine some software operating systems and discuss adding 1024 bytes of memory for as little as $20.

Operating Systems. An operating system is a program that makes it easier to program and use your computer. For example, if you want to change M(43) in the basic Elf memory, you would have to start at M(00) and step through memory to location 43 before you could change it. Program 1 is a simple opoerating system for the Elf microcomputer. It lets you directly examine or modify any memory location. It also allows you to start program execution at any memory location. We call Program 1 ETOPS-256 (Elf Toggle OPerating System for 256-byte memory). After loading ETOPS in RAM, it can be used to help you load and run other programs.

To examine a memory location using ETOPS, set 01 into the toggles. Flip the RUN switch up and 01 will be displayed. Now set the address of the memory byte you want to examine into the toggles and push the INPUT switch. The next time you push the INPUT switch, you'll see the selected memory byte displayed. Keep pushing the INPUT switch to see the sequence of bytes stored in memory.

To modify any memory location, set 02 into the toggles and turn the RUN switch up. 02 will appear. Set the address of the memory byte you want to modify (via the toggles).

Push the INPUT switch and the Q light comes on. Now set the toggles to the value of the byte you want to place in the selected memory location and push the INPUT switch to store it in RAM. You can store a sequence of new bytes by setting each byte into the toggles and pushing the INPUT switch. The Q light warns that you are modifying memory.

If you have the toggles set to 00 when you flip the RUN switch up, you can then set the toggles to the beginning address of a program you want to execute. Just push the INPUT switch to start executing your program at the selected address. Your program will begin execution with R3 as the program counter.

If you've added the battery RAM option to your system, ETOPS will be ready to use as soon as you turn on power. Since ETOPS uses only 32 bytes, you still have 224 bytes available for your own programs.

Keyboard Systems. Adding a hex keyboard would make your Elf microcomputer even easier to use, with 16 keys labelled 0 through F, you would have to press only two keys for each byte you want to store in memory. In the second article, we described a circuit for monitoring the status of 16 switches or keys. (See POPULAR ELECTRONICS, Sept. 1976, page 38, Fig.3). If you add this circuit and a 16-key hex keyboard, you can use Program 2--EHOPS-256 (Elf Hex OPerating System for 256-byte memory). This program requires 74 bytes of RAM so you still have 182 bytes left for your own programs. You can also use the hex keyboard subroutine as part of your program if desired.

```
       PROGRAM 1--ETOPS-256

0000    F8  20  A1   R1.0 = work
  03    E1           X=1
  04    6C  64  21   D = toggles
  07    3F  07       Wait for IN on
  09    37  09       Wait for IN off
  0B    32  1D       M(1D) if D=00
  0D    F6  33  11   M(11) if D=01
  10    7B           Q=1
  11    6C  A1       R1.0 = toggles
  13    3F  13       Wait for IN on
  15    37  15       Wait for IN off
  17    39  1A       M(1A) if Q=0
  19    6C           M1 = toggles
  1A    64           Show M1, R1 + 1
  1B    30  13       Repeat M(13)
  1D    6C  A3       R3.0 = toggles
  1F    D3           P=3
  20    00           Work area
  21    User programs from
          M(21) to M(FF)
```

After loading EHOPS in memory, you can use it as follows. To load a byte into any memory location from the hex keyboard, set the toggles to 02 and flip the RUN switch up. The 02 toggles tell EHOPS that you want to store bytes in memory. On the hex keyboard, press the most significant digit of a memory address followed by the least-significant digit. This address byte will be displayed and tells EHOPS where you want to start loading bytes in memory. You can now load a sequence of bytes into memory via the hex keyboard. Just press the two digits (most significant first) of each byte you want to load and they will be stored sequentially in memory starting at the selected location.

```
        PROGRAM 2--EHOPS-256
 0000   F8   FF   A2   R2.0 = work
   03   F8   23   A5   R5.0 = BSUB
   06   F8   33   A6   R6.0 = HSUB
   09   F8   0D   A3   R3.0 = M(0D)
   0C   D3             P=3
   0D   D5   A1        BSUB, R1.0=D
   0F   6C             D, M2 = toggles
   10   3A   14        M(14) if D != 00 (Note: != means 'not
equal')
   12   81   A3        R3.0 = R1.0
   14   F6   3B   1C   M(1C) if D=02
   17   D5   E1        BSUB, X=1
   19   64             Show M1, R1+1
   1A   30   17        Repeat M(17)
   1C   D5   E1        BSUB, X=1
   1E   51   64        M1=D, show M1, R1+1
   20   30   1C        Repeat M(1C)
   22   D3             P=3 (return)
  BSUB
   23   D6             HSUB
   24   FE   FE        D left x 2
   26   FE   FE        D left x 2
   28   A0   D6        R1=D, HSUB
   2A   80   F1   52   M2=R1 or M2
   2D   64   22        Show M2
   2F   30   22        Go to M(22)
   31   F0   D5        D=M2, P=5
  HSUB
   33   E2   FC   01   X=2, D+1
   36   FA   0F   52   M2=D and 0F
   39   62   22        Select key M2
   3B   3D   33        M(33) if key off
   3D   7B   F8   09   Q=1, D=09
   40   B4             R4.1=09
   41   24   94        R4-1
   43   3A   41        M(41) if R4.1 != 00
   45   7A             Q=0
   46   35   46        Wait for key off
   48   30   31        Go to M(31)
```

To examine any memory location (without changing its contents), set the toggles to 01 before you flip the RUN switch up. Using the hex keyboard, enter the one-byte starting address of the sequence of memory locations you want to examine. Press any hex key twice to step through memory and display the stored bytes.

To run a program you've loaded using EHOPS, set the toggles to 00 before flipping the RUN switch up. Using the hex keyboard, enter the one-byte starting address of your program. It will begin running with R3 as the program counter.

```
          PROGRAM 3

0050  F8  FF  A1         R1.0 = work
  53  F8  00  51         M1=00
  56  E1  64  21         Show M1
  59  F0  FC  01  51     M1+1
  5D  F8  10  B2         R2.1 = delay
  60  22                 R2-1
  61  92  3A  60         M(60) if R2.1 != 00
  64  30  56             Repeat M(56)
```

EHOPS controls the hex keyboard with two subroutines called BSUB and HSUB. BSUB calls HSUB by changing the program counter to R6 with a D6 instruction. HSUB continuously scans all 16 hex keyswitches until one is pressed. It provides a switch debounce delay and waits until the key has been released. It then returns control to BSUB with the value of the pressed key in the least-significant digit of the byte in D and M2.

BSUB is called by changing the program counter to R5 with a D5 instruction. It waits until two hex keys have been pressed before returning control to the calling program with the values of the two keys in the two digits of the byte in D and M2. The most-significant digit represents the first key pressed. Any program you write with R3 as the program counter can call BSUB to obtain a byte from the hex keyboard. If you drive a speaker with the Q lines as described in the September article, you will hear an audible click each time a hex key is pressed.

Program 3 can be loaded and run using either ETOPS or EHOPS: This program continuously counts up at a rate determined by the byte at M(5E). Be sure to start execution at M(50).

```
            PROGRAM 4

*C0      F8  F0  AA      RA.0=F0

 C3      F8  08  A8      R8.0=08
```

```
 C6      D5  5A          BSUB, MA=D
 C8      1A  28          A+1, R8-1
 CA      88  3A  C6      M(C6) if R8.0 != 00
*CD      F8  F0  AA      RA.0=F0
 D0      F8  08  A8      R8.0=08
 D3      EA  F0  A7      R7.0=MA
 D6      64  28          Show MA, A+1, 8-1
 D8      F8  FF  AC      RC.0=FF
 D8      7B  87          Q=1, D=R7,0
 DD      FF  01          D-01
 DF      3A  DD          M(DD) if D != 00
 E1      7A  87          Q=0, D=R7.0
 E3      FF  01          D-01
 E5      3A  E3          M(E3) if D != 00
 E7      2C  8C          RC-1
 E9      3A  DB          M(DB) if RC.0 != 00
 EB      88  3A  D3      M(D3) if R8.0 != 00
 EE      30  CD          M(CD) if R8.0=00

 F0-F7 = Table of tone values
```

Program 4 should be loaded and run using EHOPS. You should also have a speaker attached to the Q line. Start this program at M(C0) with EHOPS. You can then enter eight bytes via the hex keyboard. These bytes should have values between 02 and 7F for best results. Each byte represents the frequency of a tone you will hear via the speaker. After you enter the eighth byte you'll hear the eight-tone sequence repeated over and over. You can restart the program at M(CD) to hear a previously entered tone sequence.

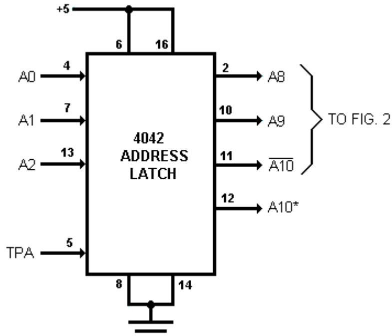


*Fig. 1.(14) Address latch. *Connect pin 19 of original 2101 RAM's to A10 instead of ground.*

PROGRAM 5

```
0000     F8  00  B1            R1.1=00
  03     F8  FF  A1            R1.0 = work
  06     F8  00  51            M1=00
  09     E1  64  21            Show M1
  0C     F0  FC  01  51        M1+1
  10     F8  10  B2            R2.1 = delay
  13     22                    R2-1
  14     92  3A  13            M(13) if R2.1 != 00
  17     30  09                Repeat M(09)
```

An operating system can be designed to incorporate any desired feature. For example, you might want to examine the contents of internal 1802 registers or control the operation of a cassette recorder. As more features are needed, you may want to dedicate the entire 256 bytes of memory in the basic system to your operating system and add another section of memory for your other programs. The 256-byte operating-system memory can be battery powered and protected from modification by the MP switch so that it is always ready for use.

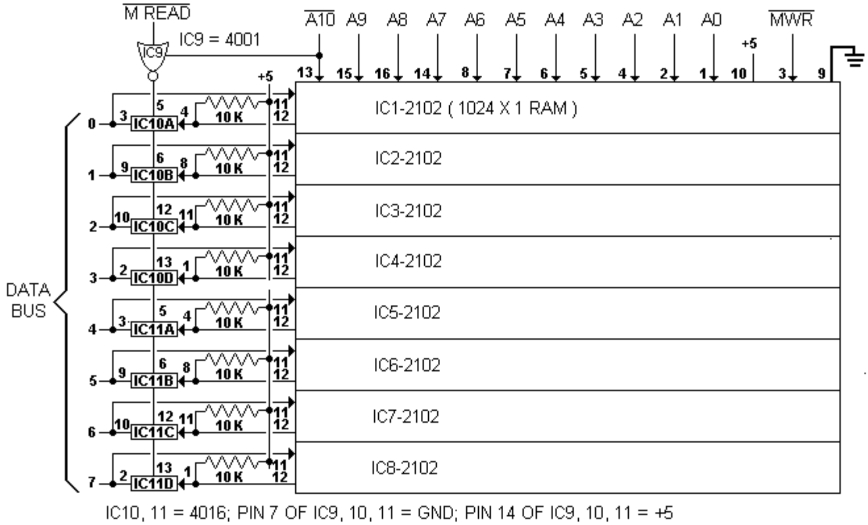


Fig. 2.(15) Eight low-cost readily available 2102 RAM's (1024 x 1) and two transmission gate packages.

Memory Expansion. You can add 1024 bytes of memory to an Elf microcomputer using inexpensive, readily available 2102-type static RAM's as shown in Figs. 1 and 2. The 10k bus pull-up resistors are required if the high-output level of the RAM chips isn't at least 3 volts. Bits 0 and 1 of the high-order address byte are clocked into the address latch with TPA (Fig. 1). These two latched bits are used with the low-order COSMAC address byte to provide the required 10-bit address for the 2102 RAM's. Bit 2 of the high-order address byte is clocked into the address latch for use in selecting eith the original 256-byte RAM or the added 1024-byte section of RAM. Disconnect pin 19 of the original two 2102 RAM chips from ground and connect to pin 12 of the 4042 address latch in Fig. 1.

The original 256-byte memory will now be addressed as 0000-00FF and the new 1024-byte memory will be addressed as 0400-07FF. Since all of the previous programs assumed one-byte addresses, they will *not* run in this expanded memory system. Programs for systems with more than 256 bytes of memory must have both the high-order and low-order bytes of address registers properly set. The previous programs can be easily modified to run in the expanded system by initializing both high- and low-order bytes of any 16-bit register used to address memory. The foregoing counting program could be modified to run at M(0000) in an expanded RAM system as shown in Program 5. In general, it adds only a few bytes to program for an expanded-memory system. By adding bits to the address latch of Fig. 1, you could address up to 64k bytes of RAM. Instead of addressing extra memory, the high-order address bits could be used to select input/output circuits or devices.

Don't forget that adding memory will increase system power requirements. As the system is expanded, make sure your external power supply can handle the increased current requirements. With this in mind, you'll find that the Elf can be tailored to your needs at low cost. •

A READER'S ELF PROGRAMS

I recently constructed the COSMAC Elf described in your August (1976) issue and thoroughly enjoyed the construction and testing of this microprocessor system. I build approximately two projects a month that are illustrated in your magazine–plus some from other sources. This particular project turned out to be the most interesting I have ever constructed. Here are three programs that I found useful in illustrating various system functions.

Program I is simply an expansion of your Q-light program with additional decisions that alternately turn the Q light on and off when the input switch is depressed.

Program II displays and increments successive hex characters each time the input button is depressed. To do this, it was necessary to learn how to input to and output from the memory, using pointers in registers, and also to do simple arithmetic through the accumulator register (D register).

Program III plays SOS in Morse code. The program should be loaded through the system switch registers if you have a half hour without interruption. With this program, registers are used for pointers to subroutine loops set up for time delay. Three subroutines for 0.5 second, 1 second and 3 seconds are established, addressed by changing the program counter. The main program simply turns the Q light on and off at intervals determined by the subroutines. The memory provided in the basic Elf system (256 bytes) is enough for approximately 19 code elements. Each code element requires only 10 instructions for an on and off interval in the main program. The timing loops require the use of two registers to provide a sufficient time. In my Elf, I used a 1-MHz crystal. Obviously, changing one instruction in the loop subroutines will vary the time as necessary. Changing or adding to the main program can change the code.

Try loading this program with the switch register if you have enough patience.

–Robert Klein

PROGRAM I

SWITCH ON AND OFF	**3F**
	00
	37
	02
IF Q OFF GO TO 09	**39**
	09
IF Q ON, TURN OFF AND	**7A**
RETURN TO 00	**30**
	00
IF Q OFF, TURN ON AND	**7B**
GO TO 00	**30**
	00

PROGRAM II

STORE DEPENDENT VARIABLE 00	**E4**
IN LOCATION 77 WITH POINTER	**F8**
IN R4--DESIGNATE R4 AS RX	**77**
	A4
	F8
	00
	54

STORE INDEPENDENT VARIABLE 01	**F8**	
IN LOCATION 76 WITH POINTER	**76**	
IN R5	**A5**	
	F8	
	01	**(size of INCR)**
	55	
DISPLAY AND DECREMENT RX	**64**	
	24	
LOOK FOR INPUT SWITCH ON AND	**3F**	
OFF	**0F**	
	37	
	10	
ADD TWO VARIABLES AND PUT	**05**	
RESULT IN LOCATION 77	**F4**	**(F5 subtract)**
(can be changed to subtract	**54**	
to count down)		
RETURN TO START OF LOOP	**30**	
	07	

PROGRAM III

MAIN PROGRAM **7B** **7B**
7B
D3 **D4**
D3

```
INITIALIZE     F8      THIRD DOT  F8                  F8
F8
 POINTERS      65 *               65 *                79 *
65 *
               A3                 A3     THIRD DASH   A4
FIFTH DOT   A3
               F8                 7A                  A4
7A
               79 *               D3                  7A
D3
               A4                 F8                  D3
F8
               F8                 65 *                F8
65 *
               8D *               A3                  65 *
A3
               A5                                     A3
                                  7B
7B
               7B                 D4                  7B
D3
FIRST DOT      D3     FIRST DASH  F8                  D3
F8
               F8                 79 *                F8
65 *
               65 *               A4     FOURTH DOT   65 *
SIXTH DOT, A3
               A3                 7A                  A3
PAUSE AND   7A
               7A                 D3                  7A
RETURN TO   D5
               D3                 F8                  D3
START       F8
               F8                 65 *                F8
8D *
               65 *               A3                  65 *
A5
               A3                                     A3
30
                                  7B
00
               7B                 D4
               D3                 F8        * If a different
number of
               F8                 79 *        code elements is
used,
SECOND DOT     65 *  SECOND DASH A4           change the
starting address
               A3                 7A          of each sub
routine, or
               7A                 D3          move to the end
of memory
               D3                 F8          page if
flexibility is
```

F8 65 * desired.
65 * A3
A3

PROGRAM III

SUB ROUTINES (Must be loaded in order indicated after main program is loaded.)

½-Sec Loop 1-Sec Loop 3-Sec Loop

All instructions same as ½-Sec Loop except where indicated

PUT 256 IN REG #1
F8 . .

FF . .

A1 . .
PUT VARIABLE INTO
F8 . .
REG #2 08 * 0F * 30 *

A2 . .

C4 . .

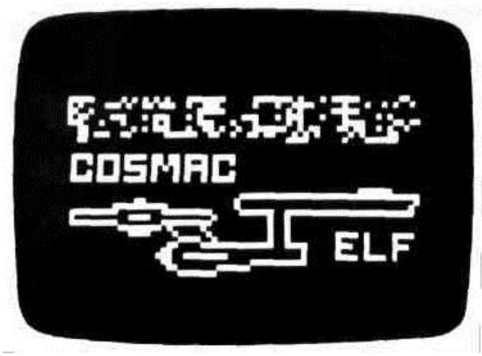
C4 . .
DECREMENT AND LOOP THRU
C4 . .
R1 UNTIL ZERO. THEN
C4 . .
OUTPUT TO DECREMENT
C4 . .
REG #2
21 . .

81 . .

```
3A                  .                    .
                              6B **                 7F **
93 **
LOOP BACK TO START
22                  .                    .
R #1 CYCLE UNTIL
82                  .                    .
TOTAL TIME IS USED UP
3A                  .                    .
                              6B **                 7F **
93 **
RETURN TO MAIN PROGRAM
D0                  .                    .
```

* Sets Time

** If a different number of code elements is used, change this instruction to starting address of each subroutine wait loop (first C4)



PE TESTED
BREAKTHROUGH PROJECT!
BY JOSEPH A. WEISBECKER

PART IV:

Build the PIXIE Graphic Display

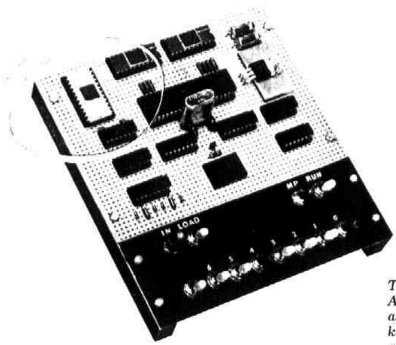
Adding one chip to the Elf provides completevideo interface and animated graphicscapability for less than $25.

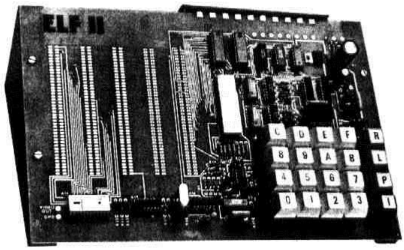
If you own an Elf microcomputer (see POPULAR ELECTRONICS August 1976) or are planning to build one soon, the addition of a single IC and a handful of support components, and a change in the crystal frequency, can give you Pixie graphics. The entire graphics system is built into the new CDP 1861 LSI chip that sells for less than $20 from RCA parts distributors. (A complete kit is available; see Parts List.) The two other IC's in the optional add-on system are for a crystal oscillator that allows the graphics IC to generate the correct TV horizontal and vertical sync pulses.

The photo at the top of this page illustrates what can be done with the original 256 bytes of memory in the Elf when the Pixie graphics system is added. In this article, we will show you how to install and program the Pixie system to produce this type of graphics.

Some Details. The unique Pixie graphics system employs the direct memory access (DMA) capability built into the 1802 microprocessor in the Elf [42] to work in conjunction with the new graphics IC. This allows you to display any 256-byte segment of memory on a CRT monitor or TV receiver. The output of the new chip is a 1-volt composite video/sync signal.

that sells for it





The basic Elf project orginally published in the August 1976 issue of POPULAR ELECTRONICS is shown at left with Pixie components added. Elf II is a complete kit including a pc board, hexadecimal keypad, Pixie graphics components and expansion bus (see Parts List).

The basic Elf project originally published in the August 1976 issue of POPULAR ELECTRONICS is shown at left with the Pixie components added. Elf II is a complete kit including a pc board, hexadecimal keypad, Pixie graphics components and expansion bus (see Parts List).

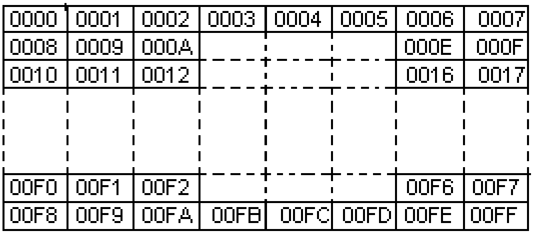


Fig. 1. Memory addresses of bytes mapped onto TV screen in sample program.

The selected segment of memory appears on-screen as an array of small squares that represent individual memory bits. If a memory bit is a 1, the appropriate square will be white, while if a bit is a 0, the square will be dark. Changing the bit pattern within the memory will change the pattern that appears on-screen. You can store several different bit patterns (pictures) in memory and, [43]

TABLE I -- TEST PROGRAM

Label	M	Bytes	Comments
Start	0000	90 B1 B2	R1.1,R2.1=00
	0003	B3 B4	R3.0,R4.0=00
	0005	F8 2D A3	R3.0=(main)
	0008	F8 3F A2	R2.0=(stack)
	000B	F8 11 A1	R1.0=(interrupt)
	000E	D3	P=3 (go to main)

Return	000F	72	restore D,R2+1
	0010	70	restore XP,R2+1
Interrupt	0011	22 78	R2-1,save XP @ M2
	0013	22 52	R2-1,save D @ M2
	0015	C4 C4 C4	no-op (9 cycles)
	0018	F8 00 B0	
	001B	F8 00 A0	R0=0000(refresh ptr)
Refresh	001E	80 E2	D=R0.0
	----	------	8 DMA cycles (R0+8)
	0020	E2 20 A0	R0-1,R0.0=D
	----	------	8 DMA cycles (R0+8)
	0023	E2 20 A0	R0-1,R0.0=D
	----	------	8 DMA cycles (R0+8)
	0026	E2 20 A0	R0-1,R0.0=D
	----	------	8 DMA cycles (R0+8)
	0029	3C 1E	go to refresh (EF1=0)
	002B	30 0F	go to return (EF1=1)
Main	002D	E2 69	X=2,turn TV on
	002F	3F 2F	wait for IN pressed
	0031	6C A4	set MX,D,R4.0=toggles
	0033	37 33	wait for IN released
	0035	3F 35	wait for IN pressed
	0037	6C	set MX,D=toggles
	0038	54 14	set M4=D,R4+1
	003A	30 33	go to M33

using software, display them successively onscreen to produce animation effects. Low-resolution alphanumerics can also be created.

Since the basic Elf has only 256 bytes of memory, we will show how to display the entire memory on the screen. The memory is mapped as shown in Fig. 1, in an array of 64 spots wide (eight bytes with eight bits/byte) by 32 spots high to make a total of 256 bytes.

The byte at M(0000) is displayed at tthe upper-left of the screen; each row on the screen is equivalent to eight memory bytes. Byte M(00FF) appears at the bottom-right of the screen.

Circuit Operation. The entire schematic diagram for the Pixie graphics display system is shown in Fig. 2A. It consists of five components: the 1861 chip, a phono jack for the video output, and three resistors. The circuit shown in Fig. 2B may be used to replace the original crystal used in the Elf microcomputer. This is necessary because, to use the graphics display, the original crystal frequency must be changed to approximately 1.760640 MHz to generate the correct TV horizontal and vertical sync pulses. Crystals of this frequency may be expensive. The Fig. 2B circuit uses a [44] readily available 3.58-MHz color-TV crystal and frequency divider to generate 1.789773 MHz, which is close enough for the 1861 chip to perform properly.

The 1861 chip uses the same clock as the 1802 µP chip to trigger internal counters to provide the TV-like composite sync at pin 6. The graphics display is directly refreshed from the memory 60 times each second, accomplished by an interrupt request sent to the 1802 at the same rate.

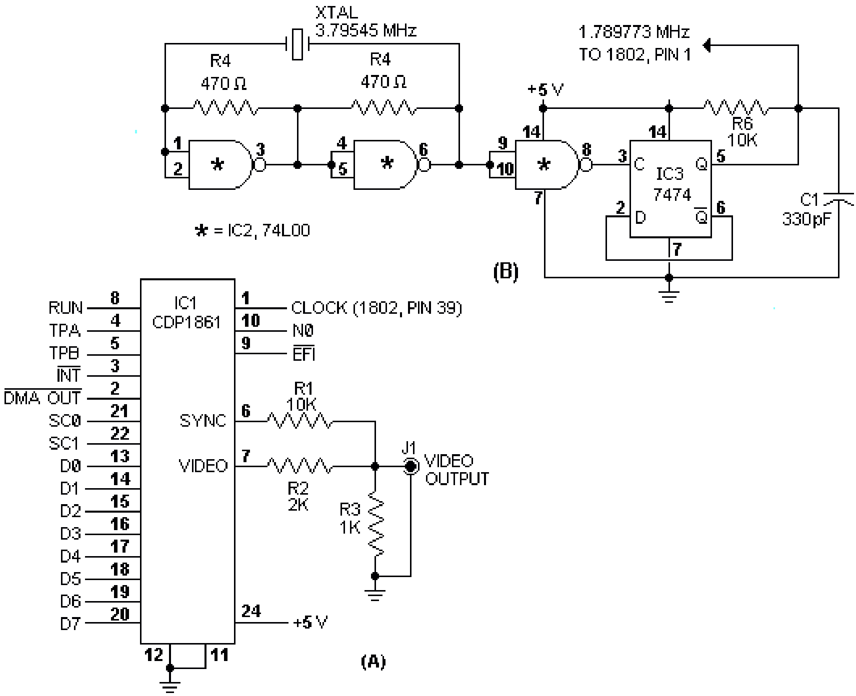


Fig 2. (16) Video display chip connections are shown at (A), Optional circuit to replace original Elf crystal is at (B).

"PIXIE PARTS LIST"

C1 -- 330-pF disc capacitor
IC1 -- CDP 1861 video IC (RCA)
IC2 -- 74L00 low-power quad 2-input NAND gate IC
IC3 -- 7474 dual-D flip-flop IC
J1 -- Phono jack
All resistors 1/4-watt, 10% tolerance:
R1,R6 -- 10,000 ohms
R2 -- 2000 ohms
R3 -- 1000 ohms
R4,R5 -- 470 ohms
XTAL -- 3.58-MHz crystal
Misc. -- Printed circuit or perforated board;
IC sockets (one 24-pin, two 14-pin);
spacers; machine hardware;
hookup wire solder; etc.
Note: The following are available from Netronics,
333 Litchfield Rd., New Milford, CN 06776:
kit including all of above components except
those under "Misc." at $24.95;
complete Elf II kit (basic Elf plus Pixie
components and hexadecimal keyboard), including
pc board, keyboard support IC's and expansion
bus at $99.95, plus $3.00 shipping.
Connecticut residents, add 7% sales tax.

When the 1802 receives the interrupt request, it temporarily stops the program it is executing and immediately branches to the interrupt routine previously stored in memory. This branch occurs when P is automatically set to 1 and X is set to 2. The interrupt routine program counter is always R1, which must be set to the address of the interrupt routine before the 1861 is activated and starts sending interrupts to the 1802. A pulse from NO is sent to pin 10 of the 1861, permitting this chip to start sending interrupts. A 69 instruction can be used to generate the 1861 activation pulse. The 1861 is always turned off when the Elf is stopped with the RUN switch down.

In the program shown in Table I, R1 is set to the address of the interrupt routine at M(0011), R2 is set to the address of the work area (or stack) used subsequently for byte storage, R3 is set to the main program starting at M(002D), and setting P=3 causes a branch to M(002D) with R3 as the program counter. The main program permits entry of the bytes at any time via the Elf's toggle switches. This permits you to see what is happening to the CRT screen as memory bytes are changed. The program loops on itself until an interrupt signal is generated by the 1861, activated by the 69 instruction at M(002E).

Exactly 29 machine cycles after the initiation of the interrupt routine, the 1861 requests eight sequential memory bytes by putting down the DMA-OUT (pin-2) request line for eight bytes (eight machine cycles). This automatically causes eight memory bytes, addressed by R0, to be sequentially fetched and transferred to the 1861 via the data bus. Note that the C4 instructions at M(0015) are special no-op instructions that require three cycles for each execution. These are used only to provide the delay required to between the beginning of the interrupt routine and the first eight-byte DMA request generated by the 1861 display circuits.

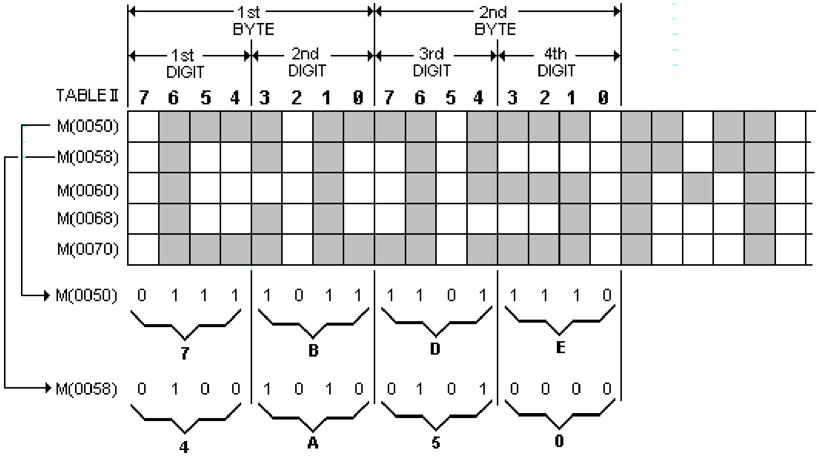


Fig. 3.(17) Diagram showing how to create your own display. This one is for parts of five lines of Spaceship Program.

TABLE II -- SPACESHIP PROGRAM

M	Byte Sequence
0040	00 00 00 00 00 00 00 00
0048	00 00 00 00 00 00 00 00
0050	7B DE DB DE 00 00 00 00
0058	4A 50 DA 52 00 00 00 00
0060	42 5E AB D0 00 00 00 00
0068	4A 42 8A 52 00 00 00 00
0070	7B DE 8A 5E 00 00 00 00
0078	00 00 00 00 00 00 00 00
0080	00 00 00 00 00 00 07 E0
0088	00 00 00 00 FF FF FF FF
0090	00 06 00 01 00 00 00 01
0098	00 7F E0 01 00 00 00 02
00A0	7F C0 3F E0 FC FF FF FE
00A8	40 0F 00 10 04 80 00 00
00B0	7F C0 3F E0 04 80 00 00
00B8	00 3F D0 40 04 80 00 00
00C0	00 0F 08 20 04 80 7A 1E
00C8	00 00 07 90 04 80 42 10
00D0	00 00 18 7F FC F0 72 1C
00D8	00 00 30 00 00 10 42 10
00E0	00 00 73 FC 00 10 7B D0
00E8	00 00 30 00 3F F0 00 00
00F0	00 00 18 0F C0 00 00 00
00F8	00 00 07 F0 00 00 00 00

Each of the eight display refresh bytes requested by the 1861 is internally converted to a bit serial form and used to provide the luminance (brightness) pulses that come out of the 1861 at pin 7. The actual raster display consists of 262 horizontal lines for each frame, and there are 60 frames per second. Each display spot is four raster lines high, which means that each eight-byte display row must be repeated four times. With the interrupt routine, R0 is initially set to M(0000) to M(0007) to be fetched and displayed. The time of each raster line is exactly 14 machine cycles to permit the transfer of eight bytes (eight cycles) plus the execution of three two-cycle instructions during each raster line time. Following the eight DMA cycles required to refresh the first eight bytes, R0 is restored to its original value so that it remains pointing at the same eight bytes.

The E2 20 A0 instructions at M(0020), M(0023), and M(0026) are used to occupy six machine cycles between the DMA requests and to restore R0 to its initial value before incrementing it by eight during the eight-byte DMA request. The 20 instruction decrements R0.1 back to its initial value if a 256-byte page boundary was crossed during the preceding eight DMA cycles.

After the first group of eight bytes has been displayed for four raster line times, R0 is permitted to advance to the next group of eight bytes to be displayed. This process is continued until 32 groups of eight bytes each (256 total) have been displayed. At this time, the circuits in the 1861 chip cause line EF1=1 (at pin 9) and the interrupt routine terminates.

Other Considerations. The raster refresh involves the display of 32 groups of eight bytes, and each row of eight bytes is repeated on four raster line scans. This means that the display refresh ties up the 1802 µP for slightly more than 128 raster lines (32 x 4). Since there are 262 raster lines per frame, the µP spends about 50% of its time performing the display-refresh function.

Since the 1802 and the 1861 clocks must remain synchronized, none of the three-cycle instructions described in the 1802's user's manual should be used in programs that run concurrently with this display. The only exception is the use of the C4 instruction in the interrupt routine.

The sample program given in Table I was designed to run in expanded-memory systems as well as in the basic 256-byte Elf. In the expanded system, just change the bytes at M(0019) and M(001C) so that R0 initially points to any 256-byte segment of the memory you wish to display on the raster. You can write any other main program to run concurrently with this interrupt routine.

The 1861 chip can also be used to display any number of memory bytes from eight to 1024 by rewriting the interrupt routine. For example, change the byte at M(0024) from 20 to 80, and you will see 512 bytes displayed on the CRT screen as 64 spots horizontally by 64 spots vertically. If you have only 256 bytes of memory in your system, you will ass the same 256 bytes repeated twice on the screen. When displaying 512 bytes, each spot represents half the height of those displayed when 256 bytes are displayed.

One of the main advantages of mapping main memory directly into the monitor or TV raster is the ability to manipulate the display using the normal instruction set. In systems that employ an external frame buffer for refresh, specialized instructions are required to change the buffer contents. The buffer memory also costs more money. With the refresh buffer approach toward animation, you must store two picture patterns in memory and alternately transfer them to the buffer memory. Using the Pixie graphics display described here, you store the same two-picture patterns in memory but you need only change the initial value of R0 to alternately display them. Not only do you save the cost of a refresh buffer, you can greatly simplify the programming.

Construction. The Pixie circuit can be mounted on the original Elf board by relocating the crystal and two capacitors to the center of the board. Now the 1861 IC goes on the upper left of the board, and the output jack on the rear apron of the chassis.

Remove the crystal from the Elf and wire the Fig. 2B frequency divider to pin 1 of the 1802 µP. Then interconnect the two boards exactly as shown in Fig. 2A and B, including the power lines. Jack *J1* can be mounted on a small metal bracket and secured to the add-on board with No. 4 machine hardware. Also, mount *R1* and *R2* on the add-on board via "flea" clips because they may have to be changed for different-value resistors to suit the modulation requirements of the particular monitor you are using.

Sample Display Program. To test the Pixie, load the program given in Table I, starting at location M(0000). When this program is run, a random spot pattern should be displayed on-screen. At this time, you may have to alter the values of *R1* and *R2* to produce a tight sync lock and the desired modulation level of the spots. These are only level-adjust resistors and play no role in the actual sync or video production. The displayed pattern represents whatever is stored in the Elf's memory. The top eight rows represent the program given in Table I.

You can familiarize yourself with the new graphics ability of your computer if you visualize a grid of 64 boxes wide by 32 boxes deep, assuming a 256-byte memory. Bear in mind that the operating program given in Table I occupies the top eight lines. Since the program ends at memory location M(003B), load 00 into memory location M(003F) to complete that line.

Now, to display the spacecraft shown in the lead photo, load the programs given in Tables Iand II in that order, starting the Table II program at memory location M(0040). Reset and switch to RUN.

If you wish to create your own display, Fig. 3 illustrates how to arrive at the correct hex digits. (In this case, the example used is for a small area of the program in Table II.) Use graph paper to "draw" your picture, shading in the "spots" you want to be white on the CRT screen. Then transfer the line bit pattern into the eight hex bytes per line as shown in Fig. 3.

Conclusion. The Pixie system described here adds video graphics to your Elf microcomputer at very low cost. So far, we have described how the Pixie system can be used to put simple, stationary images on-screen. Accompanying this article is a program that will put the graphics in motion. • [Part 4A]

PIXIE ANIMATION PROGRAM

BY EDWARD C. DEVEAUX

THE PROGRAM given here can be used with the Pixie version of the Elf microcomputer to create animation graphics using only the original 256 bytes of memory. The interrupt routine uses the same timing as described in previous Elf articles. However, a counter has been added to this routine, and we load the refresh address into R0 from R4. The main line of the program has been completely rewritten and contains shift, roll, and INPUT switch read routines.

The shift routine shifts 16 lines of the display to the right one bit at a time; bits shifted off the rightmost byte are shifted back onto the display in the high-order position of the first byte on the line.

```
LOC  COSMAC CODE   SOURCE LINE

                   .. AN 1802 ANIMATION PROGRAM by E. DEVEAUX
                   ..
78                 BEGSFT=#78  .. ADDRESS OF FIRST LINE SHIFTED.
                   ..
                   .. THIS PROGRAM PROVIDES VARIABLE SPEED
                   .. ANIMATION OF THE IMAGE LOCATED AT #78 to
                   .. #F7 IN MEMORY.
                   .. SPEED CONTROL IS PROVIDED BY INPUT
SWITCHES.
D0   90                        GHI R0      ..ZERO HIGH ORDER OF
01   B1                        PHI R1      ..R1 R2 R3.
02   B2                        PHI R2
03   B3                        PHI R3
04   B4                        PHI R4      ..R4 POINTS TO
REFRESH
05   A4                        PLO R4         ADDRESS
06   F816                      LDI A.0(INTRPT)
08   A1                        PLO R1
09   F813                      LDI A.0(STACK)
0B   A2                        PLO R2
0C   F831                      LDI A.0(MAIN)
0E   A3                        PLO R3
0F   D3                        SEP R3      ..GO TO MAIN_LINE
10   01020300                  DC#01020300 ..STACK AREA
13                 STACK =*-1
```

```
                   ..
                   ..THIS PROGRAM USES A MODIFIED VERSION
                   ..OF THE INTERRUPT ROUTINE THAT APPEARED
                   ..IN COSMAC ELF PART 4.
                   ..
                   ..A SHIFT ROUTINE HAS BEEN ADDED THAT MOVES THE
                     .. STARSHIP FROM LEFT TO RIGHT ACROSS THE CRT.
                      ..
14   72                RETURN,LDXA
15   70                       RET           ..CYCLES
16   22                INTRPT,DEC   R2      .. 2
17   78                       SAV          ..4 R5 COUNTS REFRESH
18   22                       DEC   R2      ..6 CYCLES, USED TO
19   52                       STR   R2     ..8 DETERMINE WHEN TO
1A   15                       INC   R5      ..10 SHIFT /ROLL.
1B   C4                       NOP           ..13
1C   94                       GHI   R4      ..15 R4 TO R0
```

The 32 lines of the display can be moved up one line by incrementing the starting refresh address by eight between refresh cycles. Decrementing register 4 (R4) allows the display to be rolled down. Hence, varying the frequency of shifts or rolls varies the animation speed of the displayed image.

Control of the speed is via the Elf's conventional INPUT switches. Setting all switches to zero and depressing the INPUT pushbutton causes a hex 00 to be read into location 13 (stack), in which case, there will be no movement of the displayed image. Loading any nonzero bit through the INPUT switches will animate the image. Any bits loaded are compared to the bits in the low-order byte of R5 and the bits in the byte read into location 13. Register 5 is used to count the refresh cycles and is incremented by one every interrupt cycle.

```
LOC  COSMAC CODE  LNNO   SOURCE LINE

1D   B0                        PHI  R0      ..17 REFRESH ADDRESS
1E   84                        GLO  R4      ..19
1F   A0                        PLO  R0      ..21
                                            ..
20   80                        GLO  R0      ..23
21   80                        GLO  R0      ..25
22   80                 REFRESH:GLO  R0     .. 27
23   E2                         SEX  R2     .. 29  8 DMA CYCLES
                                            ..
24   E2                         SEX  R2     ..
25   20                         DEC  R0
26   A0                         PLO  R0     ..      8 DMA CYCLES
                                            ..
27   E2                         SEX  R2
28   20                         DEC  R0
29   A0                         PLO  R0     ..      8 DMA CYCLES
                                            ..
2A   E2                         SEX  R2
2B   20                         DEC  R0
2C   A0                                     ..
                                            ..
2D   3C22                       BNI  REFRESH .. ON EF1 REFRESH
```

```
2F   3014          64                 BR   RETURN    .. IS OVER.
31   E2            65         MAIN:SEX    R2        .. RX=2
32   69            66                 IMP  1        .. TELL 1861 TO
                   67                               .. TURN ON CRT.
                   68 ..SFREAD READS INPUT SWITCHESTO CONTROL
                   69 ..SPEED OF SHIFTS/ROLLS.
                   70 ..INPUT SWITCH IS STORED AT STACK M(R2).
                   71 ..
                   72 ..INITIAL VALUE OF STACK IS ZERO AND THERE IS
                   73 ..NO MOVEMENT OF STAR SHIP UNTIL A NON ZERO BIT
                   74 ..IS INPUT.
33   3F38          75       SPREAD:BN4   CKSHIF    .. IF NO INPUT GO
SEE
35   3735          76       WTREAD:B4    WTREAD    .. IF TIME TO SHIFT.
37   6C            77              INP   4         .. READ INTO STACK.
                   78 ..                           ..
38   85            79       CHKSHIF:GLO  R5        .. GHI R5 VARY/SPEED
39   F2            80               AND            .. OF STAR SHIP.
3A   3233          81               BZ   SPREAD    .. SHIFT/ROLL BIT
MATCH.
3C   F800          82               LDI  A.1(BEGSFT)   ..BR ROLL 3061
3E   B9            83               PHI  R9            ..ROLL NO SHIFT
```

The numbers in the program flow chart (right) refer to the line numbers in the program. The program can be set up to shift or roll, or shift and roll. The program is loaded into locations 78 through F7. (Try using the program for the starship shown in Table II of the Pixie article.) Only the data loaded into 78 through F7 is shifted, but the entire area from 00 through FF is rolled.

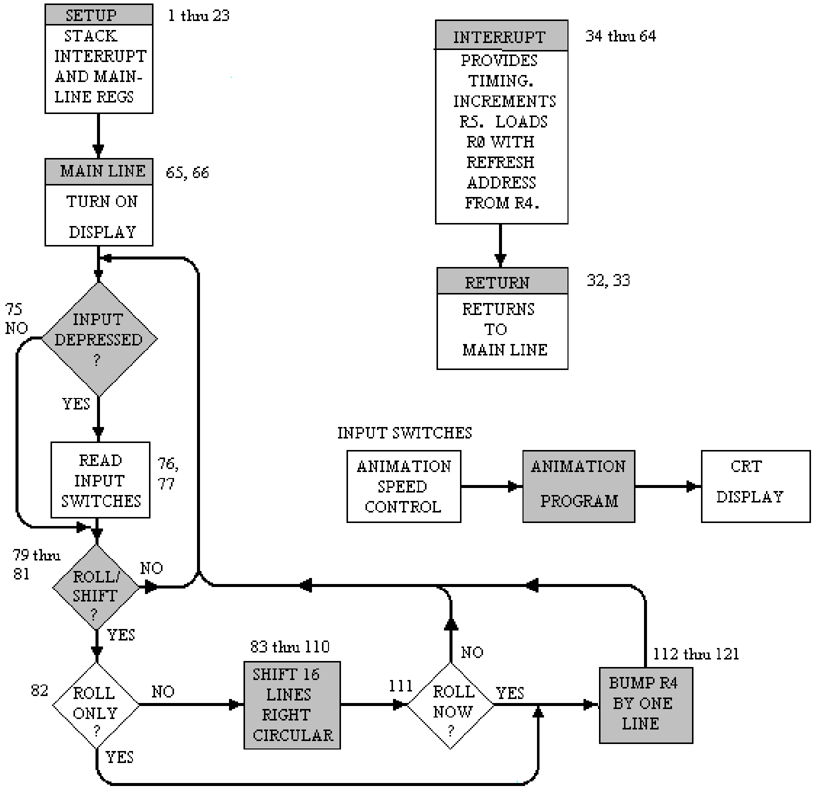
Loading the program exactly as it is listed here will enable the shift routine only. Loading a 38 (SKP instruction) in location 5F (line 111) will enable both shift and roll routines. Loading 30 61 (BR ROLL) in locations 3C and 3D (line 82) will enable only the roll routine.

After loading and running the program, animation of the display will begin after any nonzero byte is loaded via the INPUT switches and operation of the INPUT pushbutton. By varying the INPUT bit pattern, you can control the speed of the animation.

If you have never seen a stack in "motion" when a program is running, take a look at displayed location 13. Then vary the speed. •

```
3F   F878        84             LDI   A.0(BEGSFT)
41   A9          85             PLO   R9              ..R9=FIRST LINE
42   F810        86             LDI   16              ..TO SHIFT.
44   A6          87             PLO   R6         ..SHIFT 16 LINES.
45   99          88      MXTLNE:GHI   R9
46   BA          89             PHI   RA        ..SAVE ADDRESS OF 1st
47   89          90             GLO   R9         ..ON LINE IN RA
48   AA          91             PLO   RA
49   F807        92             LDI   7         ..R7=BYTES TO SHIFT-1.
4B   A7          93             PLO   R7
4C   09          94             LDN   R9
4D   B8          95             PHI   R8         ..SAVE 1ST BYTE ON
4E   76          96             SHRC             ..LINE IN R8.1
4F   19          97      MXTBYT:INC   R9    ..POINT R9 TO NEXT BYTE.
50   09          98             LDN   R9            ..LOAD NEXT BYTE.
51   76          99             SHRC                ..SHIFT RIGHT.
52   59          100            STR   R9            ..STORE BYTE
53   27          101            DEC   R7
54   87          102            GLO   R7         ..CHECK IF ALL BYTES
55   3A4F        103            BNZ   MXTBYT        ..SHIFTED.
57   98          104            GHI   R8         ..PUT BIT 0 of 8TH
58   76          105            SHRC                ..BYT ON BIT 7 OF
59   5A          106            STR  RA             ..1ST BYT ON LINE.
5A   19          107            INC  R9          ..R9=BYTE 0 NXT LINE.
5B   26          108            DEC  R6
5C   86          109            GLO  R6           ..CHECK IF 16 LINES
5D   3A45        110            BNZ  NXTLNE         ..SHIFTED.
5F   3033        111            BR   SFREAD ..SKP 38 ROLL AND SHIFT.
61   84          112       ROLL:GLO    R4   ..INCREMENT R4 ONE LINE
62   FC08        113            ADI  8              ..ROLL SCREEN UP.
64   A4          114            PLO  R4
65   94          115            GHI  R4          ..CHANGE LNNO 116 TO
66   F800        116            LDI  00         ..ADCI 0 7C00 IF MORE
68   B4          117            PHI  R4             ..THAN 256 BYTES.
69   3233        118            BZ   SFREAD
6B   84          119            GLO  R4
6C   B4          120            PHI  R4
6D   3033        121            BR   SFREAD
6F   00          122            DC   #00

                 123 ..ENTER IMAGE TO BE SHIFTED IN LOCATIONS
                 124 ..X'78' - x'F7'.
                 125          END
```



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