

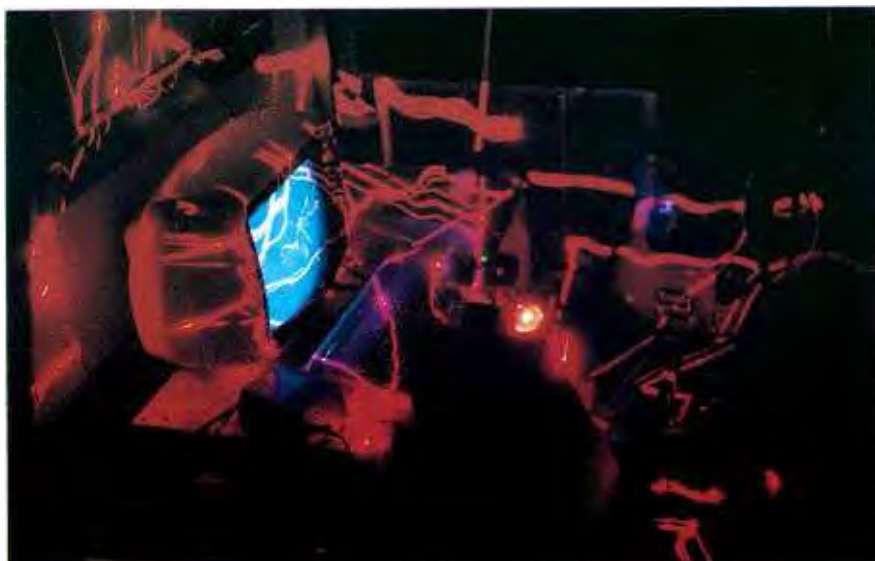
# Computer-Controlled Laser Light Show

*A low-power He-Ne laser, two miniature servos, some build-it-yourself circuitry and a home computer let you create dramatic lighting effects to accompany your music*

By Ronald A. Peterson

If you've ever attended a rock concert, you've probably been impressed by the dramatic effect of the special lighting that added new excitement to the music being heard. You can create a similar effect at home with a computer, a low-power helium-neon laser and model-aircraft servos. While the effect of our Laser Light Show may not be quite as dramatic as that in a concert hall, it can give your listening a new dimension with a complex interplay of light and sound.

A simple BASIC program and a Commodore 64 home computer, plus some inexpensive build-it-yourself circuitry are all you need to create this exciting visual effect at a tiny fraction of the cost of the professional systems that cost thousands of dollars. The Laser Light Show works in conjunction with a joystick controller you plug into the C-64 and position as you wish to swing the laser beam to create a hemispheric lighting effect "dome" in your listening room or a small hall. By pressing the "fire" button on the joystick, you can feed into the C-64's memory a series of coordinates to which you wish the beam to go, making the pattern to be described as simple or as complex as you wish. The fire button lets you play back the pattern in the sequence in which it was fed into



memory. It doesn't take complex geometry or special programming knowledge to do, either.

There are practical benefits to building the Laser Light Show as well. For example, you can omit the laser and mirror needed for the Light Show function and attach a lightweight gripper on a slideable shaft to the servos instead to use the servo system as a simple robot arm. And with a heftier set of servos, it can be converted into a remote-controlled pan/tilt head for a video or movie camera.

## System Operation

Model aircraft servos are an ideal

choice for building a computer-controlled precision positioner for the laser beam used in the Laser Light Show. These servos are relatively inexpensive, accurate and, just as importantly, easy to interface to the parallel ports of most home computers. A typical example of such a servo is the Royal Titan No. RP-1F that develops an output torque of 39.4 ounces and has a stop-to-stop transit time of 0.6 second. Just about any other brand of servo will serve as well in this project.

There are usually three wires on a servo to provide the ground, positive dc voltage and control lines. Color coding of the wire insulation follows a certain convention: black or green

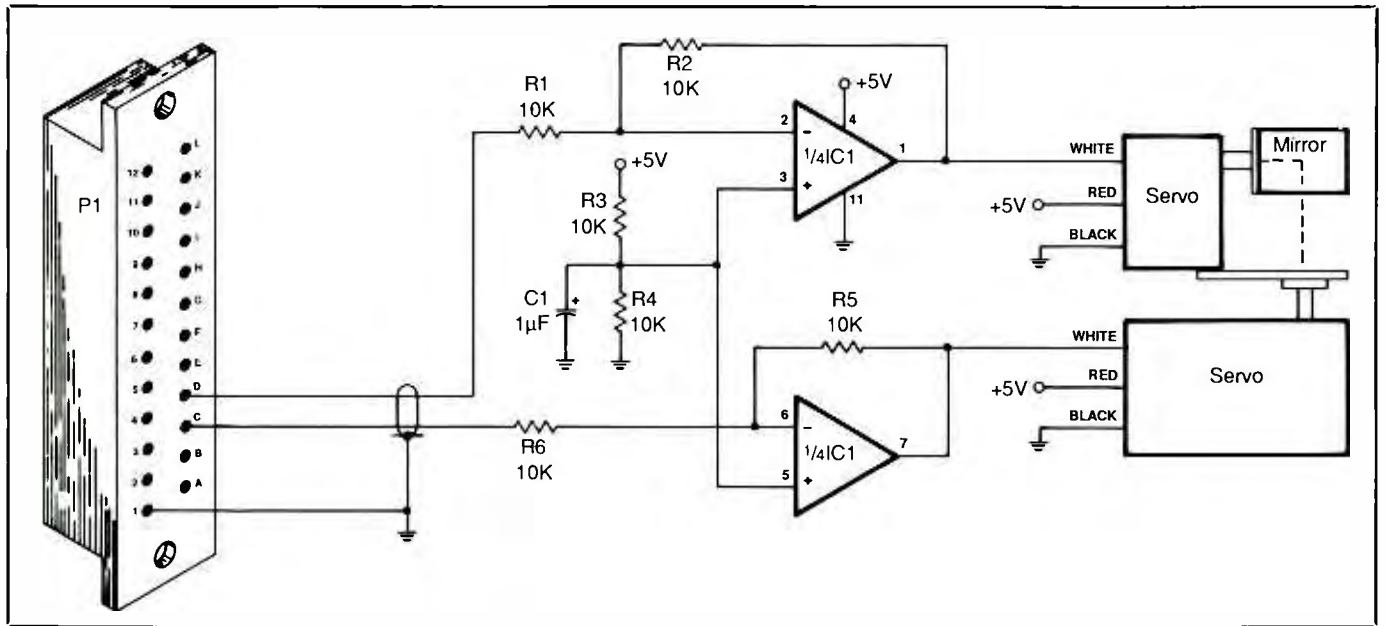


Fig. 1. Schematic of buffer interface.

for ground, red for positive dc and the remaining line, usually white, for the control input.

Figure 1 shows the schematic diagram of the circuit needed to drive the servos. To keep costs down, the circuit hardware was made as simple as possible, with the control logic implemented in software. The Fig. 1 interface circuit is built around IC1A and IC1B that perform as buffers between the computer and servos. Operational amplifiers were selected for the buffer function simply because a quad op-amp IC was available, but a 7404 TTL inverter would probably work just as well.

The buffers are connected to the C-64 computer's User Port through a 24-pin connector. The pinout for the User Port, along with pertinent signal information for each of the Port's contacts, are shown in Fig. 2.

Shown in Fig. 3 is the basic ac-line-operated, low-voltage dc power supply for both buffer interface and servos. This is a standard full-wave bridge rectifying circuit with filtering supplied by C2 and voltage regulation supplied by IC2. Ac receptacle SO1 provides the means by which the

Pin	Type	Note	Pin	Type	Note
1	GND		A	GND	
2	+5V	MAX. 100 mA	B	FLAG2	
3	RESET		C	PB0	
4	CNT1		D	PB1	
5	SP1		E	PB2	
6	CNT2		F	PB3	
7	SP2		H	PB4	
8	PC2		J	PB5	
9	SER. ATN IN		K	PB6	
10	9 VAC	MAX. 100 mA	L	PB7	
11	9 VAC	MAX. 100 mA	M	PA2	
12	GND		N	GND	

The diagram shows a 24-pin connector with pins 1 through 12 on the top edge and pins A through N on the bottom edge. The pins are arranged in a standard D-sub connector layout.

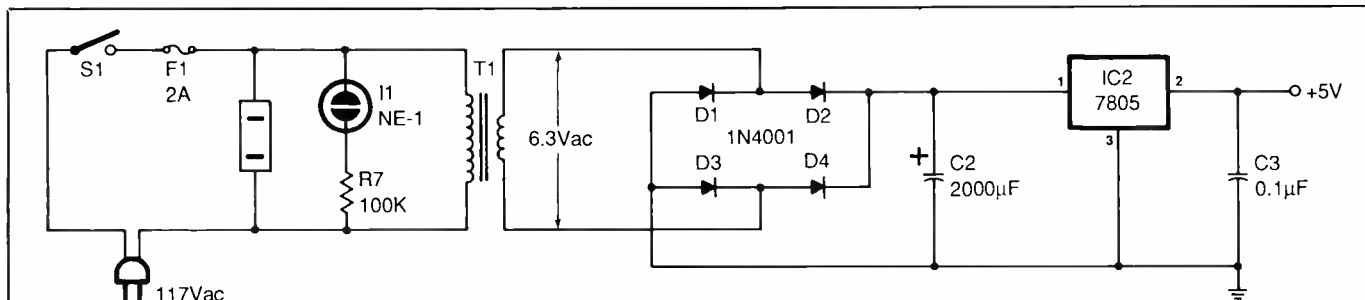
Fig. 2. Pinouts and signal information for C-64's User Port connector.

laser gets power from the ac line. This arrangement allows the entire system to be turned on and powered down via S1.

Position information supplied to the servos must be variable-width pulses of between 1 and 2 milliseconds in duration. The pulses are repeated at a fairly slow rate of between 30 and 120 pulses per second. The Machine-Code Interrupt Handler Routine shown in Listing 1 pro-

vides this signal by toggling two of the User Port's lines. The C-64's 60-Hz internal interrupt clock, used for keyboard scanning and other simple I/O (input/output) functions, is set to trigger execution of this routine every 16.67 milliseconds (1/60 of a second) to provide a stable pulse train to each of the servos.

Every 16.67 ms, the routine alternates between two independent timing loops that provide the variable



### PARTS LIST

#### Semiconductors

D1 thru D4—1N4001 rectifier diode  
 IC1—LM324 quad operational amplifier (see text)  
 IC2—7805 +5-volt regulator

#### Capacitors (15-volt or more)

C1—1-µF electrolytic  
 C2—2,000-µF electrolytic  
 C3—0.1-µF disc

#### Resistors (¼-watt, 5% tolerance)

R1 thru R6—10,000 ohms  
 R7—100,000 ohms

#### Miscellaneous

F1—2-ampere fuse and fuse holder  
 I1—Panel-mount neon-lamp assembly  
 P1—24-pin card-edge connector (Digi-Key Part No. C1-12; \$2.90)  
 S1—Spst slide or toggle switch  
 SO1—Chassis-mount ac receptacle  
 T1—6.3-volt ac, 1.2-ampere power transformer  
 Low-power He-Ne laser (see text and Note below); 2 model-airplane servos (Titan RP-1F or similar; available from local hobby shop); 32 × 40-mm front-surface mirror (Edmund Scien-

tific Cat. No. F30,429; \$5.35—see text and Note below); perforated board and soldering or Wire Wrap hardware or printed-circuit boards (see text); suitable metal enclosures for buffer interface, low-voltage and high-voltage laser power supplies (see text); ac line cord; materials for enclosure; machine hardware; hook-up wire; solder; etc.

**Note:** A ready source of supply for front-surface mirrors and low-power lasers is: Edmund Scientific Co., 101 E. Gloucester Pike, Barrington, NJ 08007.

Fig. 3. Schematic of low-voltage power supply.

pulse widths required to position the servos. The advantage of using an interrupt handler to drive the servos is that a simple BASIC program can then be run simultaneously to provide the "smarts" for overall direction of the laser beam without having to deal with timing problems. The machine code in Listing 1 is given only for reference purposes, since it is contained in the DATA statements of the BASIC program and is automatically loaded when this program is loaded and run.

Shown in Listing 2 is the BASIC program that reads the information inputted at the joystick port of the computer and communicates position requirements to the interrupt handler as two numbers between 0 and 255. Communication takes place through memory locations 33792 and 33793 (\$8400 and \$8401, respectively, in hex).

If the joystick's "fire" button is

pressed, the position coordinate numbers read from the joystick port are also stored in arrays PX and PY. If the joystick is moved again after the values are stored, the program reverts to manual-positioning mode to allow another position to be inputted. If instead of inputting another set of positioning coordinates, the fire button is pressed once again, the stored values are recalled and are cycled through, causing the servos to track the laid-out pattern point by point. Pressing the fire button one more time resets the program and jumps the system into the manual-positioning mode again.

Because the chip that handles screen updates in the C-64 steals some time from the 6510 processor chip, the screen must be blanked during the period the servo timing loops are running to keep the timing accurate. Because of this, a simple beeper has been included to provide audible

indication when a point has been successfully stored in memory.

Since the C-64 operates with a 1-MHz clock, there is a limit to how fast the machine-code timing loops can operate. This limit determines how fine a change can be made in the width of the servo-control pulses, thus setting a minimum step between servo positions. The machine-code routines in the program have been optimized to give as fine a step range as possible within the hardware limitations.

As written, the code divides the approximately 180-degree swing of the servos into about 250 steps. This yields a roughly 0.7-degree accuracy in servo positioning. It also means that there is a little bit of discernible "wobble," due to moving in discrete steps, that shows up in the reflected laser beam when the mirror is moved manually. This wobble is less apparent when the servos are swung directly from one position to another

---

under automatic playback via the BASIC program.

Employing D/A (digital-to-analog) converters to drive a variable-pulse-width oscillator might have provided greater accuracy in positioning and smoother beam travel, but the cost of building the project would have been much greater. Going this route would also have made the software considerably more complex.

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### **Construction**

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Circuit layout and wiring are not critical in the electronic portions of the project. You can use perforated board with holes on 0.1" centers and suitable soldering or Wire Wrap hardware and wire the circuits point-to-point. Alternatively, you can design and fabricate separate printed-circuit boards for the buffer interface and low-voltage power-supply circuits. Whichever method of wiring you choose, be sure to use a socket for *IC1*.

Wire the circuits exactly according to Figs. 1 and 3. Make certain that you properly orient the IC and electrolytic capacitor in the buffer interface circuit and the rectifier diodes, filter capacitor and voltage regulator in the power-supply circuit.

House the buffer interface circuit-board assembly inside a metal box. Also, use shielded cable to the connector that goes to the computer (*P1* in Fig. 1) and the lines going to the servos, especially if they're long, to keep stray noise from getting into the circuit and disrupting smooth operation. The 5-volt dc power supply should be housed in a metal enclosure, too, but make sure there is adequate ventilation to allow heat to escape.

Packaging for the servo controller will be determined by the application you've chosen for the project. A suggested arrangement for the Laser Light Show is detailed in the Fig. 4 drawing and is shown in the photos of the prototype in Figs. 5 and 6. Here, the laser tube, 5-volt dc power

supply, high-voltage supply for the laser and the servos are shown mounted on a triangular-shaped wooden enclosure with *S1* and *I1* in Fig. 3 mounted on the "front" panel. This arrangement assumes that the laser tube and high-voltage laser power supply are separate items (as they were for the kit laser used in the prototype). If you use such a kit laser, mount its power supply inside a metal enclosure for safety, and provide good ventilation for it.

Since they are to move the laser beam along predefined paths to create the Laser Light Show, mount the servos at a 45-degree angle to the beam as shown. Additionally, the servos must be mounted at right angles to each other to assure that the sweep of the laser beam will be hemi-

spherical. With the servos mounted in this manner on the laser's platform set at the 45-degree angle illustrated, the beam will, indeed, be able to describe a hemispherical pattern.

The kit laser used for the prototype made it easy to mount the laser tube and servo/mirror assembly in the proper locations and orientations. The tube was held in place in a pair of wooden V blocks with strong rubber bands, and the power supply was mounted inside the project's wooden enclosure. However, you can use an assembled laser with the tube and power supply housed inside a single enclosure without experiencing any mounting difficulty in getting the system to work properly. You simply have to use heavier-duty V blocks and a more substan-

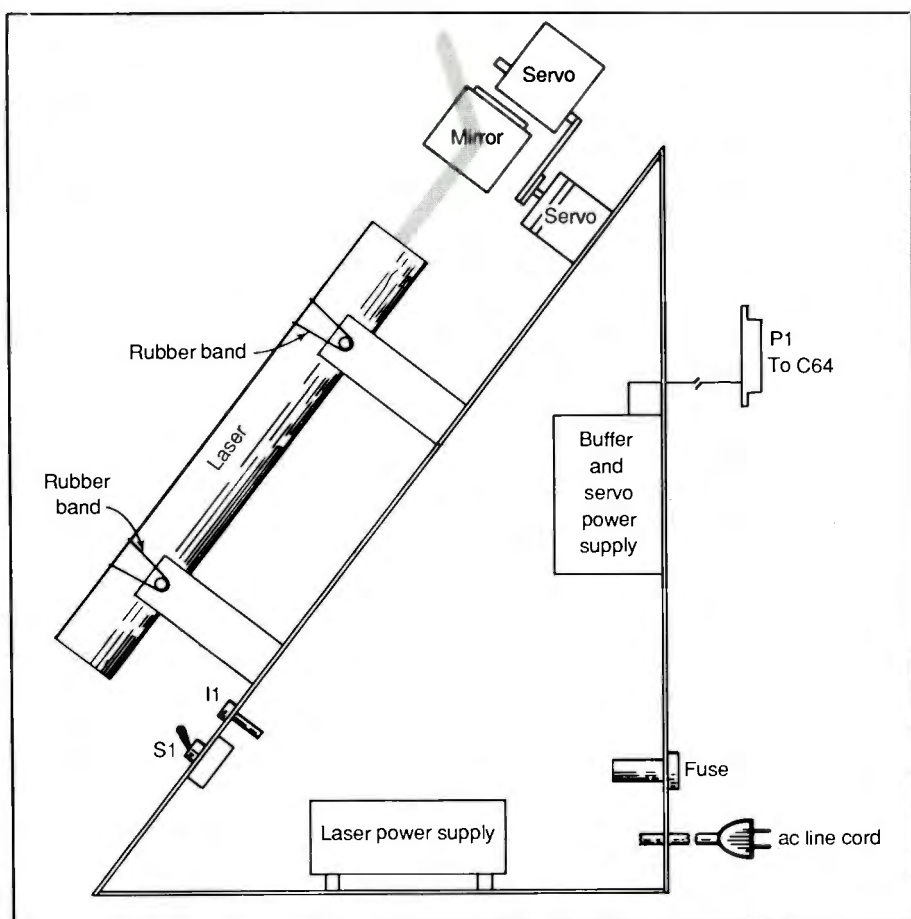


Fig. 4. A suggested enclosure and layout for project's laser, servo/mirror assembly, buffer interface, power supplies and power indicator and switch.

tial method of securing the laser to the V blocks.

Whether you use a kit laser with separate tube and power supply or an assembled integrated laser, it's important that you mount it so that its beam is parallel to the mounting surface. Otherwise, the beam is likely to strike the reflecting surface of the

### Words of Caution

If you use a laser, you should exercise care to protect your eyesight and that of anyone else who may be in the vicinity of an operating laser. Tests with anesthetized monkeys have shown that as little as 7 milliwatts of laser light focused directly onto the retina causes observable damage. Though it doesn't affect vision, this damage is, nevertheless, detectable with instruments. Other tests show that a minimum of 20 milliwatts is required to produce a similar effect on human eyes (perhaps because the test subjects were not sedated, which caused their eyes to wander about). The information regarding retinal damage cited here was taken from a page in a Metrologic Laser catalog, which summarized research papers on this topic.

Workers who have been "zapped" accidentally with as much as 60 milliwatts of laser light have reported a temporary loss of sight in only a small area of their vision for a few weeks. So with a low-power laser of 2-milliwatt output or less, there *appears* to be little danger, particularly if the beam is constantly moving. But keep in mind that even a low-power laser's beam is very bright.

It's always best to exercise caution, regardless of the output power of the laser beam. Therefore, you and anyone else in the vicinity should avoid staring into the beam from a laser for long periods of time. If you don't take this advice, you'll suffer from spotted vision, at the very least, just as you would after staring at a 150-watt incandescent light bulb or taking a brief glimpse of the sun. Though the evidence so far doesn't support it, it's even possible for permanent retinal damage to occur.

Listing 1. Machine-Code Interrupt Handler Routine

```

LINE# LOC  CODE      LINE
00002 0000      ;
00003 0000      ; CONSTANTS DEFINITION
00004 0000      ;
00005 0000      BDIREC=#DD03
00006 0000      PORTB=#DD01
00007 0000      ;
00008 0000      ; ZERO PAGE VARIABLES
00009 0000      ;
00010 0000      CNT1=#FB      ;LO BYTE OF COUNTER
00011 0000      CNT2=#FC      ;HI BYTE
00012 0000      PORT=#FD      ;MIRRORS PORTB STATUS
00013 0000      ANG1=#8400    ;COUNTER VALUES
00014 0000      ANG2=#8401    ;PASSED FROM BASIC
00015 0000      FLAG=#FE      ;ALTERNATE SERVOS
00016 0000      ;
00017 0000      ; PUT IN HI RAM SO CAN RUN BASIC
00018 0000      ; PROGRAM CONCURRENTLY #8000=32768
00019 0000      ;
00020 0000      *=#8000
00021 8000      ;
00022 8000      ; S E R V O . M A C
00023 8000      ;
00024 8000      ;
00025 8000      ; SET UP DATA DIRECTION REGISTER
00026 8000      ;
00027 8000  A9 FF      LDA #21111111 ;1=OUT,0=IN
00028 8002  8D 03 DD    STA BDIREC     ;FROM C64.
00029 8005      ;
00030 8005      ; ZERO COUNTERS
00031 8005      ;
00032 8005  A9 00      ZERO LDA #00
00033 8007  85 FB      STA CNT1
00034 8009  85 FC      STA CNT2
00035 800B  85 FE      STA FLAG
00036 800D      ;
00037 800D  A9 08      LDA #200001000
00038 800F  8D 11 D0    STA $D011     ;BLANK SCREEN
00039 8012      ;
00040 8012      ;
00041 8012      ; SET OUTPUTS HIGH
00042 8012      ;
00043 8012  A9 03      LDA #200000011
00044 8014  8D 01 DD    STA PORTB
00045 8017  85 FD      STA PORT      ;INIT MIRROR OF PORT
00046 8019      ;
00047 8019      ; INIT IRQ VECTOR
00048 8019      ;
00049 8019  78      SEI          ;DISABLE INTERRUPT
00050 801A  A9 00      LDA #00       ;POINT IRQ VECTOR
00051 801C  8D 14 03    STA $314     ;TO THIS HANDLER
00052 801F  A9 81      LDA #81
00053 8021  8D 15 03    STA $315
00054 8024  58      CLI          ;ENABLE INTERRUPT

```

mirror at the wrong angle for proper system operation.

Use only a front-surface mirror. With this type of mirror, the reflecting material is on the viewing surface—not buried behind the thickness of glass. If you don't use a front-surface mirror, the surface of the glass and the reflecting material behind it will both give reflections that can spoil the effect of the Laser Light

Show. One good source of front-surface mirrors is Edmund Scientific Co. (see Parts List for address). Other sources are optics suppliers.

You can check whether or not your mirror is indeed a front-surface type with the aid of a sharpened pencil. Simply place the mirror, reflective side up and *gently* touch the point of the pencil to it at an angle. If the mirror is a front-surface type,

```

LINE# LOC  CODE      LINE
00055 8025 60              RTS              ;RETURN TO BASIC
00056 8026              ;
00057 8026              ; START OF TIMING ROUTINE
00058 8026              ; THIS IS IRQ ENTRY POINT
00059 8026              ;
00060 8026      **$8100      ;START HANDLER AT
00061 8100              ; KNOWN LOCATION
00062 8100 78              SEI              ;DISABLE IRQ
00063 8101 AD 00 84      LDA ANG1        ;GET ANGLES
00064 8104 85 FB      STA CNT1        ;PASSED FROM BASIC
00065 8106 AD 01 84      LDA ANG2
00066 8109 85 FC      STA CNT2
00067 810B              ;
00068 810B              ; CHECK FLAG TO ALTERNATE SERVOS
00069 810B              ;
00070 810B A5 FE              LDA FLAG
00071 810D D0 1A              BNE SERV02
00072 810F              ;
00073 810F A9 01      SERV01 LDA #01
00074 8111 85 FE              STA FLAG
00075 8113              ;
00076 8113 A9 01              LDA #20000001    ;OUTPUT LOW
00077 8115 8D 01 DD      STA PORTB
00078 8118              ;
00079 8118 A0 7A              LDY #122         ;SETS MIN PULSE
00080 811A 88              DEY             ;WIDTH.
00081 811B D0 FD              BNE DELAY1
00082 811D              ;
00083 811D 06 FB      LOOP1 DEC CNT1        ;TIME PULSE WIDTH
00084 811F D0 FC              BNE LOOP1
00085 8121              ;
00086 8121 A9 03              LDA #20000001    ;OUTPUT HI
00087 8123 8D 01 DD      STA PORTB
00088 8126 4C 31 EA              JMP $EA31
00089 8129              ;
00090 8129 A9 00      SERV02 LDA #00
00091 812B 85 FE              STA FLAG
00092 812D              ;
00093 812D A9 02              LDA #20000001    ;OUTPUT LOW
00094 812F 8D 01 DD      STA PORTB
00095 8132              ;
00096 8132 A0 7A              LDY #122         ;SETS MIN PULSE
00097 8134 88              DEY             ;WIDTH.
00098 8135 D0 FD              BNE DELAY2
00099 8137              ;
00100 8137 06 FC      LOOP2 DEC CNT2        ;TIME THE PULSE
00101 8139 D0 FC              BNE LOOP2
00102 813B              ;
00103 813B A9 03              LDA #20000001    ;OUTPUT HI
00104 813D 8D 01 DD      STA PORTB
00105 8140 4C 31 EA              JMP $EA31
00106 8143              ;
00107 8143              .END

```

there will be no gap between the point of the pencil and its image in the mirror. If it's not, there will be a definite gap equal to the thickness of the glass on which the reflective material is deposited. Note, though, that with some mirrors, both surfaces appear to be equally reflective. If this is the case, use the front surface to reflect the laser beam.

To make the servo/mirror assem-

bly, you must first mount the servos at a right angle to each other so that one servo pivots the other and the second servo pivots the mirror (see Fig. 4). When securing one servo to the other, align both servos so that the center of the mirror is on-axis with both servos, as illustrated in Fig. 1. Otherwise, as the mirror is pivoted, it might be taken completely out of the path of the laser beam,

which will limit the angle of travel.

A quick-setting epoxy cement is ideal for mounting the mirror to the small plastic actuator that comes with the servos. One servo can be attached to the actuator of the other with a small metal angle bracket machined to match the mounting holes on the servo.

To obtain the best effect from the project, alignment of the servo/mirror assembly with the axis of the laser beam is relatively critical. The beam should always be centered on the mirror, no matter what angle to which it is set. This will assure that the mirror will never swing out of the beam's path. Hence, take care in locating the assembly with respect to the beam.

A simple alignment must be performed to get the mirror to point in the proper direction. Use the BASIC program (see Using the Software below) to send the servos all the way to one end of their travel. Then attach the actuators so that the mirror is parallel to the laser beam with the front surface facing directly into the beam. You should now be able to use the joystick to swing the mirror through a  $-90$ -degree to  $+90$ -degree arc both left/right and up/down as the beam remains centered on the front surface of the mirror. If necessary, adjust servo/mirror positioning to obtain the proper results.

### Using the Software

Before installing the project, fire up your computer and type in the BASIC program in Listing 2. Save it on tape or disk and then power down the computer. Attach 24-pin connector *PI* to your computer via its User's Port. Then power up the computer and servos and connect a joystick to Port 2 on the computer. Now recall the BASIC program and run it. If everything is okay, the computer's screen should go blank and the servos should turn as you operate the joystick. If the servos do not turn,

## Listing 2. BASIC Program for Operating Laser Light Show

```

10 REM--LOAD INTERRUPT HANDLER
20 FOR I=32768 TO 32805
30 READ A:POKEI,A
40 NEXT I
50 FOR I=33024 TO 33090
60 READ A:POKEI,A
70 NEXT I
75 REM--SET UP SOUND CHIP
80 GOSUB 800
90 REM--MAIN ROUTINE
100 DIM FX(50),PY(50)
110 NP=0
120 I1=120:I2=120:SYS 32768
130 JV=PEEK(56320):FR=JVAND16
135 JV=15-(JVAND15)
140 IFFR=0THEN GOSUB 290
150 IF JV=1 THEN I1=I1+1
160 IF JV=2 THEN I1=I1-1
170 IF JV=4 THEN I2=I2-1
180 IF JV=5 THEN I2=I2-1:I1=I1+1
190 IF JV=6 THEN I2=I2-1:I1=I1-1
200 IF JV=8 THEN I2=I2+1
210 IF JV=9 THEN I2=I2+1:I1=I1+1
220 IF JV=10 THEN I2=I2+1:I1=I1-1
230 IF I1>255 THEN I1=255
240 IF I1<3 THEN I1=3
250 IF I2>255 THEN I2=255
260 IF I2<3 THEN I2=3
460 GOTO 110
470 DATA 169,255,141,3,221
480 DATA 169,0,133,251,133
490 DATA 252,133,254,169,8
500 DATA 141,17,208,169,3
270 POKE 33792,I1:POKE 33793,I2
280 GOTO 130
285 REM--STORE POINT SUBROUTINE
290 POKE 54283,33:POKE 54283,32
295 NP=NP+1:PX(NP)=I1:PY(NP)=I2
300 JV=PEEK(56320):FR=JVAND16
310 IFFR=0 THEN GOTO 300
320 JV=PEEK(56320):FR=JVAND16
325 JV=15-(JVAND15)
330 IF JV=0 AND FR=16 THEN GOTO 320
340 IF JV<>0 THEN RETURN
350 JV=PEEK(56320):FR=JVAND16
360 IFFR=0 THEN GOTO 350
370 FOR ID=1 TO NP
380 FOR I=1 TO 300: NEXT
390 POKE 33792,PX(ID)
395 POKE 33793,PY(ID)
400 JV=PEEK(56320):FR=JVAND16
410 IFFR=0 THEN GOTO 440
420 NEXT
430 GOTO 370
440 JV=PEEK(56320):FR=JVAND16
450 IFFR=0 THEN GOTO 440
510 DATA 141,1,221,133,253
520 DATA 120,169,0,141,20
530 DATA 3,169,129,141,21
540 DATA 3,88,96
550 DATA 120,173,0,132,133
560 DATA 251,173,1,132,133
570 DATA 252,165,254,208,26
580 DATA 169,1,133,254,169
590 DATA 1,141,1,221,160
600 DATA 122,136,208,253,198
610 DATA 251,208,252,169,3
620 DATA 141,1,221,76,49
630 DATA 234,169,0,133,254
640 DATA 169,2,141,1,221
650 DATA 160,122,136,208,253
660 DATA 198,252,208,252,169
670 DATA 3,141,1,221,76
680 DATA 49,234
800 REM--SOUND INITIALIZATION
810 S=54272:FQ=10
820 FOR L=ST09+24:POKE L,0:NEXT
830 POKE 54283,33
840 POKE 54285,122
850 POKE 54296,15
860 POKE 54280,FQ
870 POKE 54283,32
880 RETURN
READY.

```



*Fig. 5. In this photo of the assembled project, note how the laser tube is mounted in V blocks and is held in place with rubber bands. If an integrated laser/power supply is used, blocks must be larger and heavy-duty straps must be used.*

you have to check for one or more errors in your entered program or your wiring of the circuit or both. If you find no errors, you have a bad com-

ponent in the buffer interface or power supply.

To determine if you made any program-entry errors, list the program

and compare your entry with the listing keystroke by keystroke. If after making the comparison and correcting any errors in wiring, the project still doesn't run, you have to troubleshoot the circuitry with an oscilloscope or a signal tracer. If you don't have either of these instruments, you can use an amplifier/speaker arrangement to trace the positioning signals from computer output, through interface buffers to the servos. This 30-Hz square-wave pulse appears nicely on an oscilloscope screen or the indicators of a logic probe, and is easy to hear through a speaker or headphone.

Once everything is okay, use the joystick to move the laser beam to a given position. Hit the "fire" button on the joystick to store the coordinates for this location in the computer's memory. You should hear a "beep" as you do this. Moving the joystick should now cause the servos to reposition the beam for a second set of coordinates, which you can also store in memory with the fire button. You can repeat this proce-



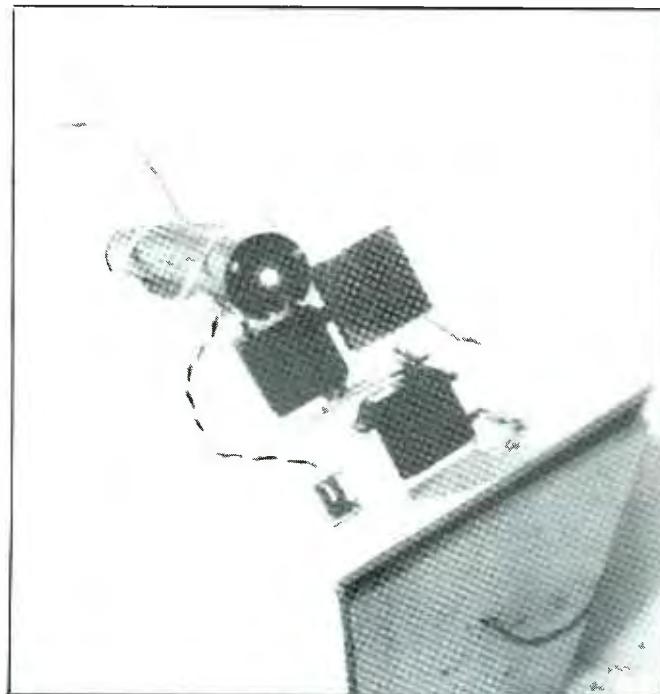


Fig. 6. These photos show proper servo and mirror mounting left (left) and location and orientation of servo/mirror

assembly with respect to path of laser beam (right). Note that beam strikes center of mirror.

ture to store up to 50 sets of position coordinates. If you wish to store a greater number of coordinates, increase the size of arrays PX and PY.

To play back the positions stored in memory, simply hit the fire button a second time after storing the last set of coordinates *instead* of moving the joystick. The servos should now automatically swing to each pair of position coordinates in the same sequence in which you stored them. Hitting the fire button once again should reset the program so that you can define a new series of coordinates for playback. To halt the program at any time, hit the Run/Stop key and type in POKE 53265,24 to reactivate the screen.

You can easily modify or replace the BASIC program with one you write yourself, but don't change the DATA statements and the part that loads the machine code. But you can add your own code to calculate the positions in whatever fashion you prefer. Then POKE them into memory locations 33792 and 33793. The interrupt handler will automatically

read them and position the servos as you command.

Because the interrupt handler is located at \$8000 in memory, your BASIC programs can't use all of the memory space usually allocated for

BASIC without writing over the machine code. This should not be a problem for most people. But if you do need more space for BASIC, you can move the machine code into a higher memory location. **ME**

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