POWER LINE MODEM FOR HOME CONTROL

This power-line modem lets your personal computer send signals over your home's wiring to control lights and appliances.

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THE PERSONAL COMPUTER MAKES it possible to control just about anything these days—if you have the right hardware and software. This article tells you how to build the PLM-1, a power-line modem that, under the control of a personal computer, will let you operate and monitor your home lighting and appliances over a network formed by your home's power wiring. This system provides a more comprehensive and versatile control than commercially available controllers.

In 1978 a power-line carrier (PLC) code format called X-10 was introduced for the control of household lights and appliances by means of remote modules plugged into AC electrical outlets. Then as now, those interface and transmit-receive modules, as well as a simple controller for the X-10 systems, are sold by retail hardware stores and home improvement centers as consumer-installable items.

These products, which include remote modules, command center/ controllers, handheld controllers, and remote wall switches are sold under the trade name "Plug'n Power." Table 1 is a listing of fourteen different kinds of X-10-compatible receiver and transceiver modules such photocell light-control sensors, appliance modules, and wall switches made by many different manufacturers. Only one module is required at each outlet where a light or appliance is to be controlled.

Figure 1 is a diagram of a complete light and appliance control system. It includes the PLM-1 power-line modem, a personal computer, a purchased TW-523 transmitter-receiver module, and a selection of receive modules. The TW-523 module plugs into an AC power outlet and acts as the interface with the power wiring. The personal computer-to-PLM-1 connection is made with a three-wire serial communications cable, and the PLM-1-to-TW-523 connection is made with a four-conductor, straight-through telephone cord.

In addition to acting as the interface with the household power line, the purchased TW-523 transmit-receive module is capable of controlling as many as 256 purchased receive or transmit-receive modules that can be plugged or wired into the home power wiring. It includes three optocoupled lines for the *transmit*, *receive*, and *zero-cross* signals. The optocoupled circuitry within the TW-523 that isolates it from the AC line meets UL and CSA safety standards.

All the codes in the X-10 protocol are synchronized to the AC voltage zero-crossings of the household power wiring. The personal computer generates X-10 code packets that are sent to the PLM-1 modem for the timing and message formatting required by the TW-523. The TW-523, in turn, modulate the power line with 120-KHz pulses. The PLM-1 modem permits all existing and future X-10 codes to be sent.

A string of ASCII characters sent from the PC's serial port to the PLM-1 modem will cause it to generate the correct X-10 signal envelope for the TW-523. The PLM-1 "listens" to the AC power line, receives all valid X-10 commands and sends back a serial message in ASCII form to the PC that indicates which plugged-in appliance was "talking."

The PLM-1 also offers a feature called transmit "collision detection." When an X-10 signal is requested for transmission, the PLM-1 sends the correct envelope to the TW-523. Simultaneously, the PLM-1 "listens" to its own transmit signal. If any of the required data is missing, the PLM-1 will retry the entire message. After two unsuccessful attempts, the PLM-1 relays a *collision* message to the PC that can trigger remedial responses in the system.

The software related to this article is on a 5-1/2-inch diskette available from the source given in the Parts list and on the

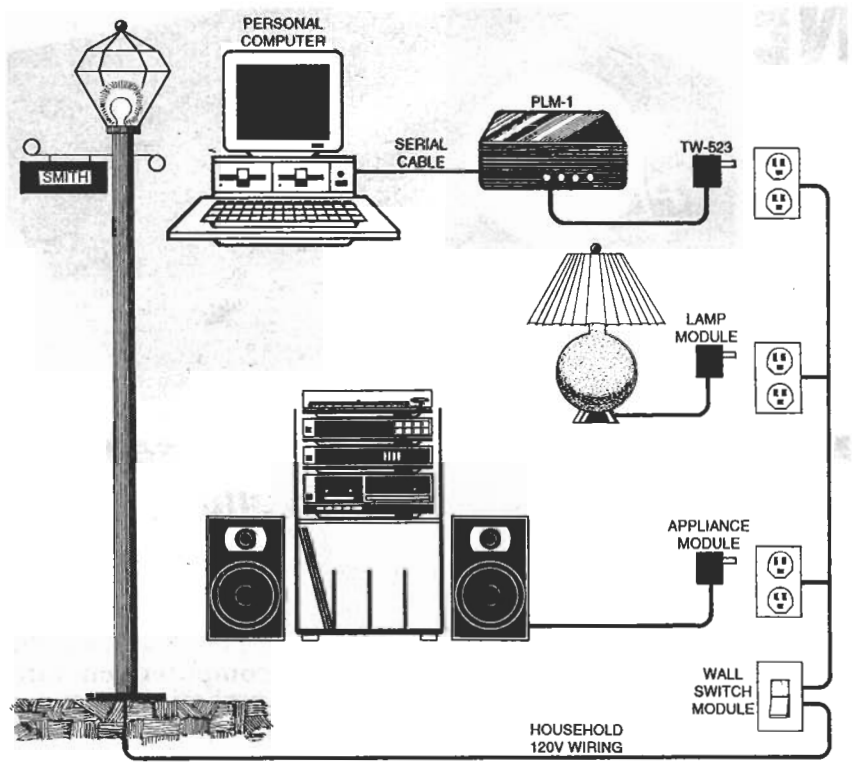


FIG. 1—A PERSONAL COMPUTER-BASED X-10 system for the control of lights and appliances. Household power wiring serves as the communications bus.

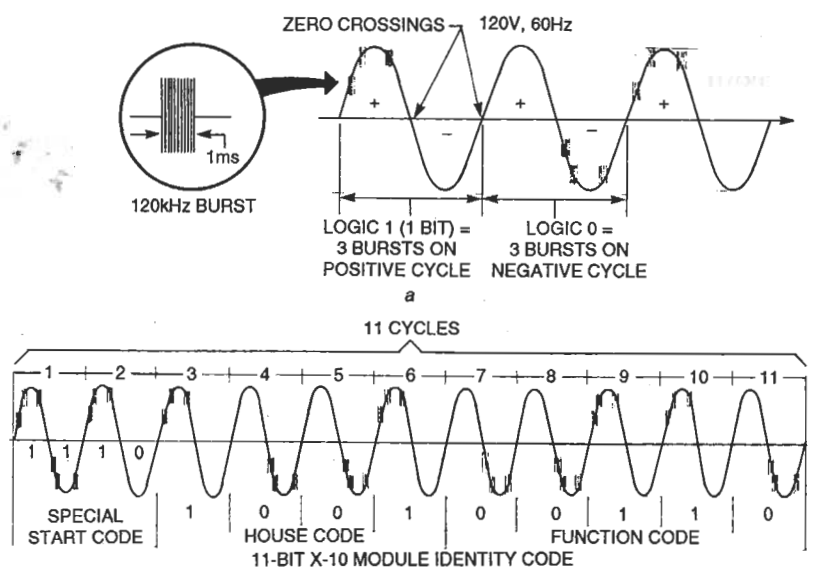


FIG. 2—THE POSITION OF THREE 120-kHz BURSTS on the 120-volt, AC waveform establishes the logic code of each cycle (*a*). An X-10 receive module is identified by 11 start, house, and function bits (*b*).

Electronics Now BBS (516-293-2283) as PLM1.ZIP. Included on the disk are the source code and hex code for programming the microcontroller within the PLM-1, sample programs for interfacing the PLM-1 to a personal computer, and samples of C, Pascal, and Visual BASIC.

X-10 protocol theory

All X-10 transmissions are synchronized to AC-voltage zero crossings as illustrated in Fig. 2. All signals must be transmitted as closely as possible to the AC-line voltage zero cross, and their durations must be no longer than 200 microseconds. The TW-523 interface provides 60-Hz square waves as shown in Fig. 2 with a maximum delay of 100 microseconds from the zero-crossing point.

The maximum delay between the transmit request from the personal computer and the generation of the 120-kHz burst by the TW-523 is 50 microseconds. This means that the transmit request must be made within 50 microseconds of the zero-crossing square wave.

A *1* is represented by a 1 millisecond burst of 120-KHz signal at the zero crossing. A *0* is formed by the absence of the burst. The 120-kHz burst is generated by the TW-523, so only a *1* need be sent for 1 millisecond.

As shown in Fig. 2, eleven cycles of the 60-Hz power line are required to transmit a complete message in X-10 code. The first two cycles represent the start code. The next four are assigned as *house* codes, and the last five are the *number* or *function* codes. With the exception of *bright* and *dim* functions which must be transmitted continuously, all complete blocks must be sent in groups of two, with three complete power-line cycles between them.

CYCLES	CODE
2	Start
4	House
5	Function (number)

A data check is performed by sending the house and function (number) codes in complimentary form on alternate half cycles of the AC line. The start code does not conform to this rule; it must always be in the "1110" form to distinguish it from the house and function codes.

Circuit description

Figure 3 is the schematic for the PLM-1. It is designed around a 87C51 CMOS, single-chip microcontroller (MCU) designated IC1. It is a CMOS version of Intel's 8751 MCU selected because of its lower power consumption. The 4 kilobytes of internal one-time programmable EPROM

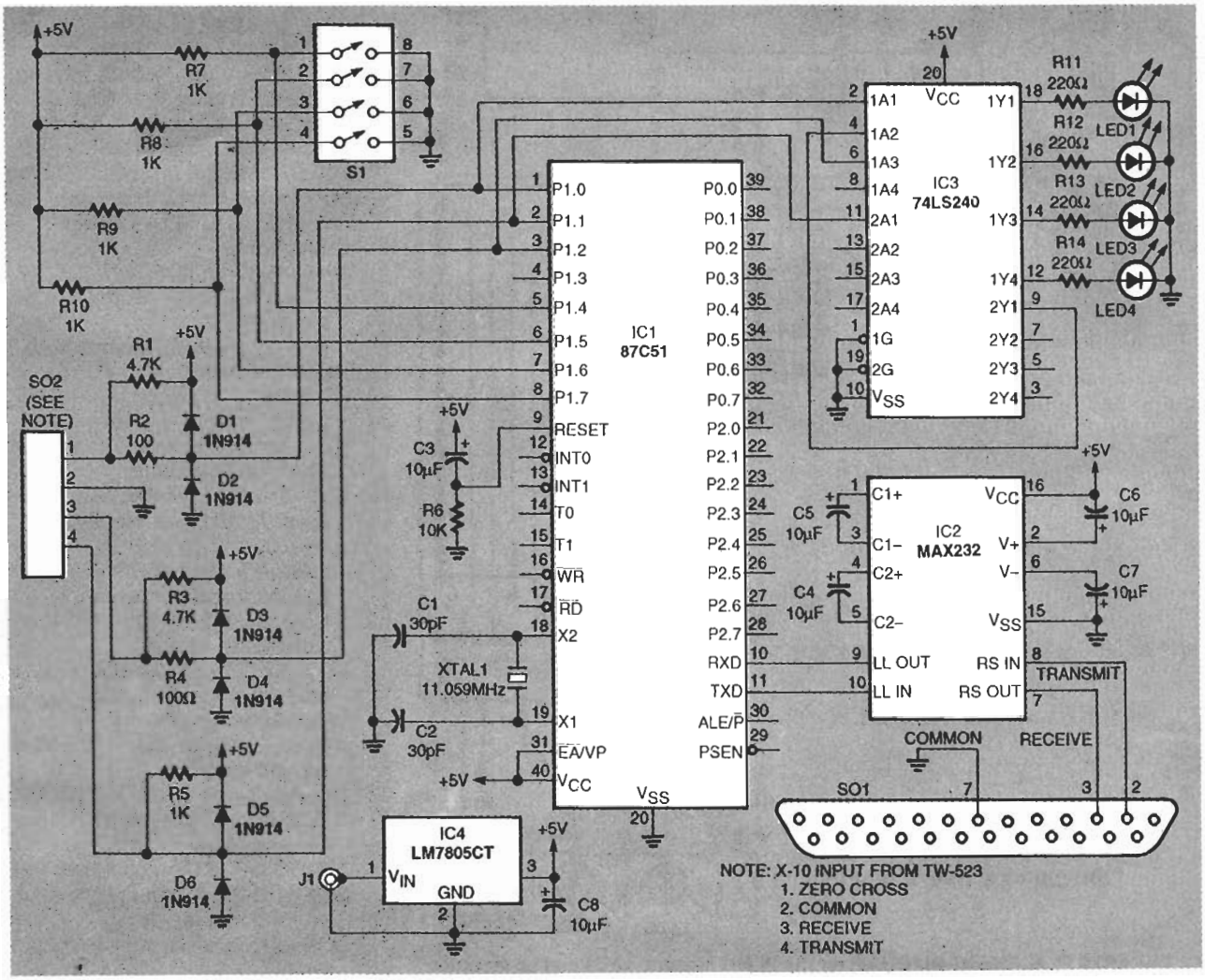


FIG. 3—SCHEMATIC FOR THE PLM-1 MODEM that conditions X-10 codes from a personal computer for use by an X-10 two-way power-line interface in a home light and appliance control system.

must contain the complete program required for X-10 interfacing. The 87C51 also has a full duplex serial port, two timers, and 128 bytes of RAM. The PLM-1 modem depends on IC1's port 1 for all input/output functions except those specified for the serial port.

The clock oscillator for IC1 is the 11.059-MHz crystal XTAL1 with 30 picofarad capacitors C1 and C2 across its electrodes. When power is applied, a reset circuit, formed by resistor R6 and electrolytic capacitor C3, initializes IC1. Because the program that controls the interface is internal, pin 31 of IC1 must be held at +5 volts.

The interface to the TW-523, RJ-11 telephone socket SO2, is provided by three simple clamping circuits consisting of diodes D1 through D6 and resistors R1 through R5. The signals from IC1 are sent to SO2 from pins 1, 2 and 3 (P1.0, P1.1, and P1.2, respectively). These three signals are also connected to the 74LS240AN bus transceiver IC3 that drives the status-indicating light-emitting diodes LEDs 1 through 4. These LEDs indicate the presence of the zero-crossing signal from the TW-523, X-10 transmit and receive, and entry errors from the serial port.

The RS-232C serial interfacing is performed by IC2, a MAX232, which generates the negative voltage required by the RS-232C specification. Four 10µF capacitors, C4 through C7, function as charge pumps and filters. For a standard three-wire interface, pins 7 and 8 of IC2 are connected to pins 2 and 3, respectively, of D-type DB-25 socket SO1, and pin 7 of SO1 is grounded. A cable from socket SO1 couples the PLM-1 to the personal computer.

The four-position DIP switch S1, shown in Fig. 3, permits communications and message options to be selected. Before applying power to the PLM-1, the correct baud rate must be selected. Fig. 4 shows the front face of S1 schematically and it includes a table of settings for the baud rates supported. (The location of switch S1 is shown in the parts placement diagram, Fig. 5.)

The switch in Fig. 4-*a* is shown set for 1200 baud. The format is no parity, 8 data bits, 1 stop bit. *The software terminal program must be set to the values given in Fig. 4-b for the system to work.* Switch position 3 is not used, and switch position

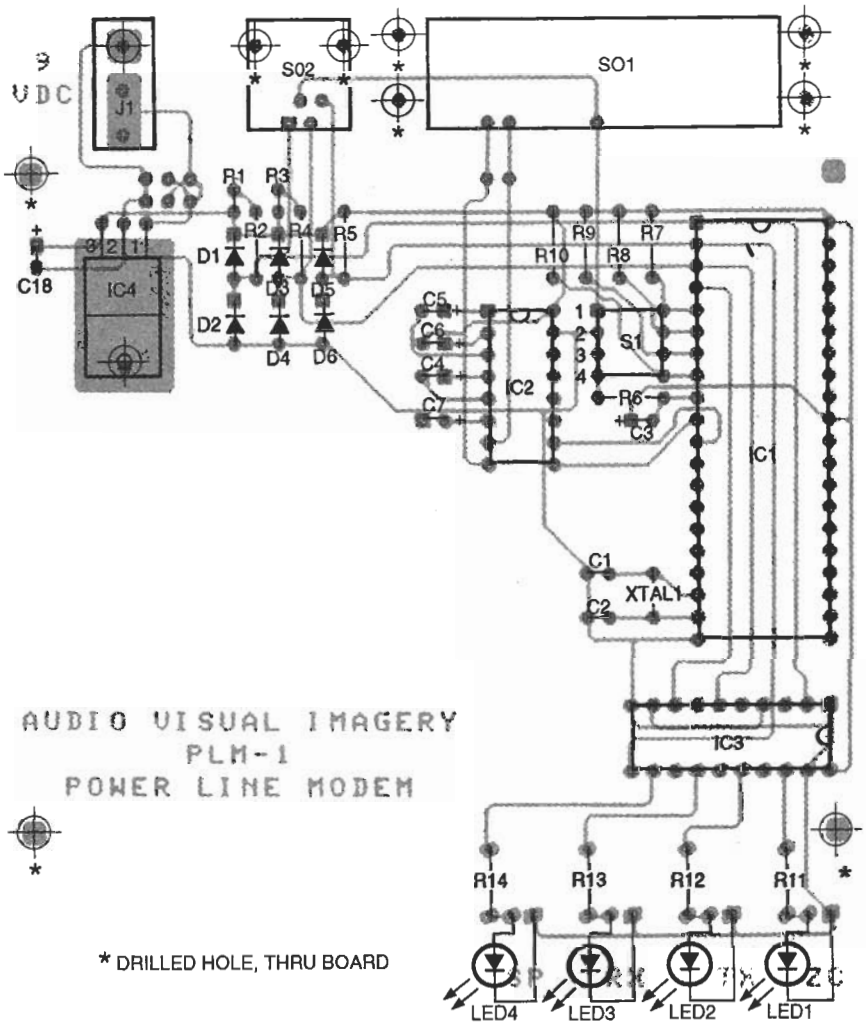


FIG. 4—PARTS PLACEMENT DIAGRAM for the PLM-1 modem. LEDs can be mounted off the board and inserted in formed holes in the end panel.

TABLE 1
X-10 DEVICES AVAILABLE

Lamp modules (dimmable)
2-pin Appliance modules
3-pin Appliance modules
Wall-switch modules
Three-way wall-switch modules
Screw-in lamp modules
Drapery controllers
Chime modules
Universal modules (contact closure & beeper)
Thermostat set-back modules
Alarm interface
Flood lamps
Motion sensors
Barking-dog alarms

4 controls message format.

When power is first applied to the PLM-1, the word READY is sent to the computer. ENTRY ERROR is sent whenever the message from the serial port is not in the correct PLM-1 format. If a transmit collision happens, COLLISION DETECTED is sent.

These messages might take too much time in critical systems, so they can be removed by setting position 4 of switch S1 in the up (ON) position. This will transform each message into a single ASCII numeric character so that X-10 receive messages will not be affected. Position 4 of switch S1 in Fig. 4-*a* is shown set for word messages.

After the PLM-1 completes its requested task, it responds with an alphabetic or numeric message as described. Table 1 lists the numeric responses and gives their alphabetic or word equivalents.

Software explanation

The program within microcontroller IC1 is interrupt activated. At reset, the internal RAM is cleared and the timers are initialized. The interrupt priority is set and the main loop is started. The main loop confirms that a TW-523 is connected to the the modem, checks for new received X-10 messages, and expedites retries resulting from collisions.

The serial interrupt routine is responsible for all serial communications between the host and the PLM-1. The X-10 interface is basically five timing loops. When a *1* is required for X-10 transmission, the TXD

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise specified.
R1, R3—4,700 ohms
R2, R4—100 ohms
R5, R7, R8, R9, R10—1000 ohms
R6—10,000 ohms
R11, R12, R13, R14—220 ohms
Capacitors
C1, C2—30 pF, mica
C3, C4, C5, C6, C7—10µF, 16 volts, tantalum
C8—10µF, 16 volts, aluminum
Semiconductors
IC1—P87C51, microcontroller, CMOS, Intel or equivalent
IC2—MAX232, line transceiver Maxim or equivalent
IC3—74LS240, octal buffer/line driver, Motorola or equivalent
IC4—7805CT positive 5-volt regulator, 1.5 ampere, TO-220 package, Motorola or equivalent
D1, D2, D3, D4, D5, D6—1N914 silicon diode
LED1, LED2, LED3, LED4 —Light-emitting diode, T1¾, red
Other components
XTAL1—crystal holder, 11.059 MHz, two-pin case
S1—4-position digital DIP switch, PCB mount, Digi-Key A5204 or equivalent
J1—DC jack, PCB mount (see text)
SO1—DB-25, 25-pin D-style socket, PCB mount
SO2—4-pin RJ-11 modular phone jack
Miscellaneous PC board or 0.1-inch-grid punched circuit board, two-piece plastic case (see text), DIP-style IC sockets: one 60-pin, one 20-pin, and one 16-pin, 120-volt AC-to-9-volt DC adapter rated for at least 0.5 amperes (see text), plastic two-piece case (see text), solder, TW-523 interface module, length of telephone

cord terminated with RJ-11 plugs, length of 3-wire cable terminated by DB-25 plugs, solder, nuts and bolts.

Note: The following companies are sources for the manufactured modules and accessories in the system:

TW-523 interface modules and transmit/receive modules:

- **X-10 (USA) Inc., Northvale, NJ 07647**
- **Home Automation Labs, Smyrna, GA 30080**
- **Home Control Concepts, San Diago, CA 92126**

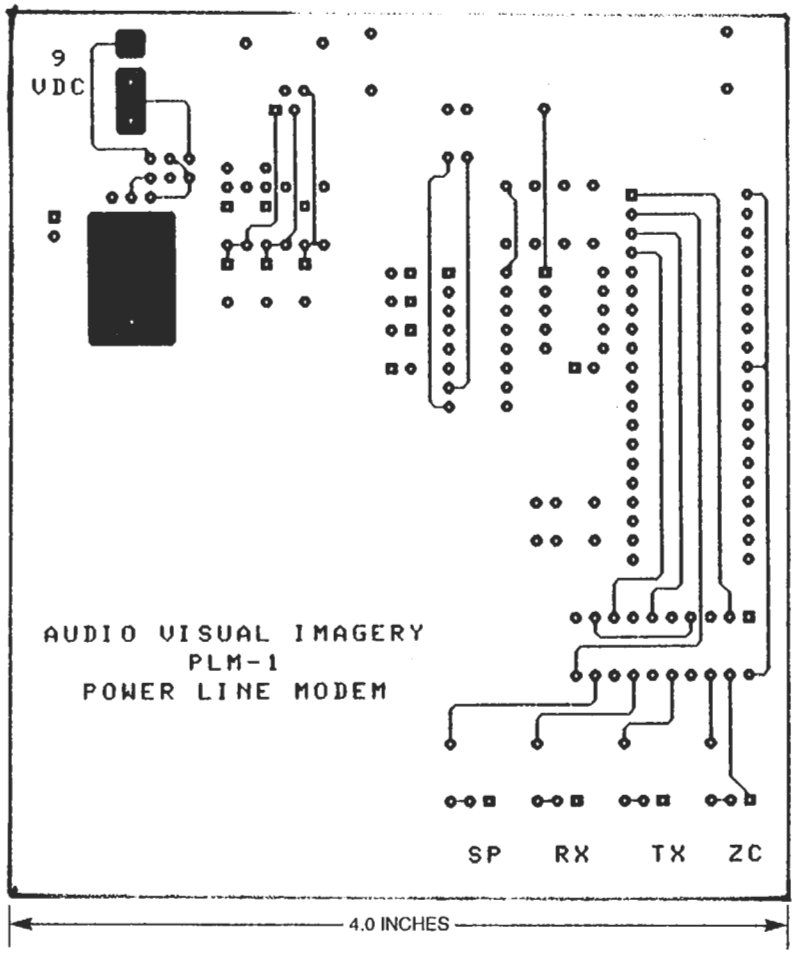
Two-piece case:

- **Pac-Tec, Philadelphia, PA 19104**

The following selection is available from Audio Visual Imagery, P.O. Box 332, Randolph, MA 02368

- **Assembled and tested PLM-1 modem, one TW-523 interface module, plug-terminated phone cord, and D-style connector terminated cable—$149.95**
- **Complete kit of all active and passive components and printed circuit board, less case and TW-523 X-10 interface module—$99.95**
- **Programmed 87C51 microcontroller—$34.95**
- **TW-523 X-10 interface module—$34.95**
- **Printed circuit board—$29.95**

A diskette with sample files will be included with all orders. Add $3.00 for shipping and handling to all orders. Massachusetts residents add 5% sales tax.



FOIL PATTERN FOR COMPONENT side of PC board.

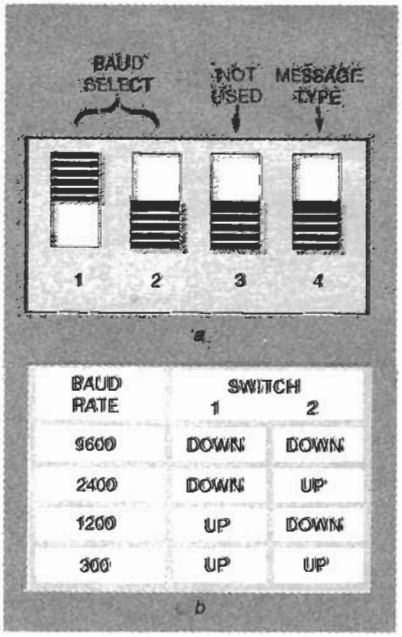


FIG. 5—DIAGRAM OF FOUR-POSITION DIP switch S1 (*a*), and a table for setting baud-rate with switches 1 and 2 (*b*).

TABLE 1
ALPHA AND NUMERIC RESPONSE EQUIVALENTS

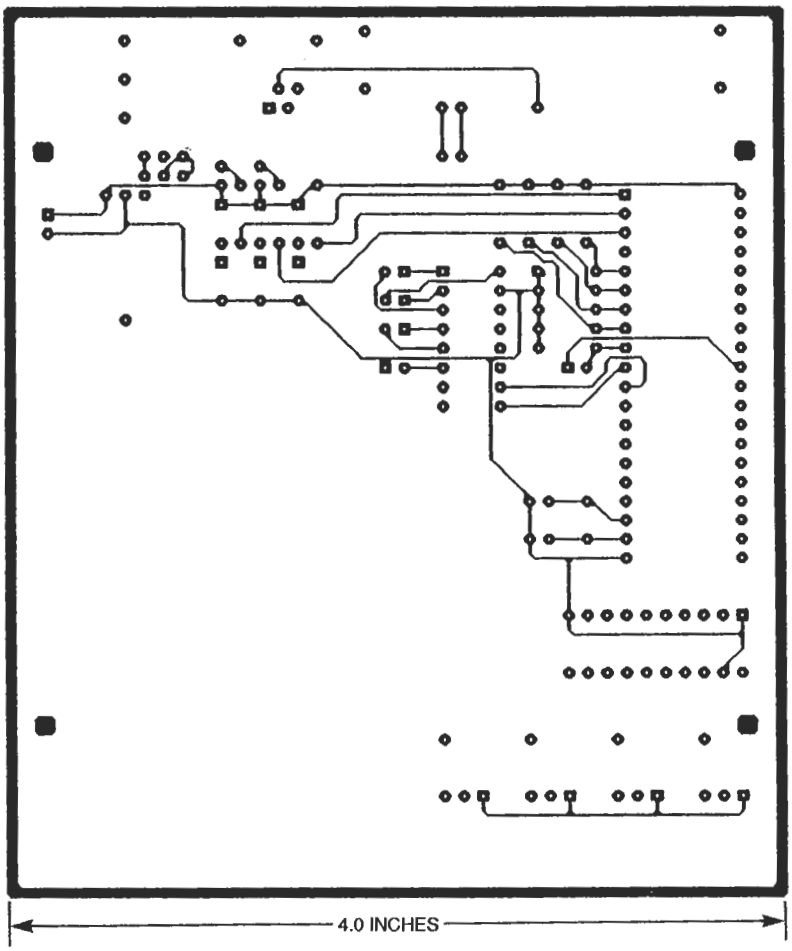
Numeric Response	Alpha Response
0	READY
1	ENTRY ERROR
2	COLLISION DETECTED
3	CHECK TW-523
4	TW-523 OK

output port pin 11 of IC1 is set high, and the timer delays the output 1 millisecond. The TXD port pin is then set low and a delay of 1.778 milliseconds is introduced. This sequence is repeated two more times.

The compliment of this delay is then sent. This simple error-checking function is part of the X-10 protocol specification. The bits of each transmission are rotated out the TXD port pin 11, each synchronized to an AC zero-crossing.

As stated earlier, the main loop also checks for received X-10 messages. It does this by polling P1.2 pin 3 of IC1. Because IC1 runs significantly faster than X-10, the chances of it missing a message are remote. The received data is then processed to accept its core information and formed into an ASCII message that is loaded into the serial-transmit buffer of IC1. The serial-interrupt routine then performs the RS-232C transmission. The X-10 receive section of the code also permits the PLM-1 to carry out collision detection.

The data on the power line can be degraded by noise or other X-10 transmissions in the



FOIL PATTERN FOR SOLDER side of PC board.

TABLE 2
PLM-1 CODE EQUIVALENTS

PLM-1 Code	House Code	Unit Code	Function Code	Relative Brightness (Percent)
0	A	1	ALL UNITS OFF	100.00
1	B	2	ALL LIGHTS ON	93.75
2	C	3	ON	87.50
3	D	4	OFF	81.25
4	E	5	DIM	75.00
5	F	6	BRIGHT	68.75
6	G	7	ALL LIGHTS OFF	62.50
7	H	8	EXTENDED CODE	56.25
8	I	9	HAIL REQUEST	50.00
9	J	10	HAIL ACKNOWLEDGE	43.75
A	K	11	PRESET DIM (1-8)	37.50
B	L	12	PRESET DIM (9-F)	31.25
C	M	13	EXTENDED DATA	25.00
D	N	14	STATUS = ON	18.75
E	O	15	STATUS = OFF	12.50
F	P	16	STATUS REQUEST	6.25

system. However, the TW-523 transmit-receive interface can "hear" anything it "says," so the PLM-1 can ensure data integrity by comparing transmission requests with what was sent.

Other routines are included for Hex and ASCII conversion, LED display and blink, message parsing, and ROM date and version information. The complete source code for IC1 is available from the source in the Parts List, and it is on the **Electronics Now** BBS, 516-293-2283.

Building the PLM-1

Refer to the parts placement diagram Fig. 5. The circuitry of the PLM-1 is so simple that it can be built on stock 0.10-inch grid punched circuit board by point-to-point wiring. However, construction will be faster and the end result will look more professional if a two-sided printed-circuit board is used. A circuit board is available from the source given in the Parts List, but if you prefer to make your own, component- and solder-side foil patterns are included in this article.

All conventional methods for electronic component insertion and soldering on a circuit board apply to this project. The circuit board layout calls for the axial-leaded resistors R1 through R5 and diodes D1 through D6 to be inserted vertically on the circuit board. Carefully bend one lead of each of those resistors and the cathode lead of those diodes 180° so they effectively become radial-leaded components.

Insert, solder, and trim the leads of all the diodes, resistors and capacitors at the locations shown in Fig. 4. Verify that the correct polarities of all diodes and electrolytic capacitors have been observed. Insert and solder sockets for ICs 1 through 3 after verifying the correct locations for pin 1 of each IC.

The way you mount the four LEDs will depend on your PLM-1 packaging preference. If you want to view the LEDs through a translucent red filter at one end of the case, grasp the LED leads close to the lens with needle-nose pliers and bend their ends 90° so that the LEDs lie flat on the PC board when they are inserted. Then solder and trim the leads.

However, if you prefer that ends of the LED lenses project through holes in an opaque plastic end panel, insert the leads in the board so that their ends are flush with the solder side of the board, and solder them in position. (The LED

leads can then be bent later so that the lens ends will project through the end-panel holes after the circuit board has been attached to the bottom half of the case.)

Bend the ends of the leads of the TO-220-packaged voltage regulator IC4 90° and insert them on the board so that the heat sink tab lies flat against the heat sink patch on the circuit board. Fasten the heatsink tab of IC4 to the board with a nut and bolt through the hole in the tab to mount the voltage regulator more securely to the board and improve its heat-sinking properties. Solder and trim the leads.

Assemble and solder DIP switch S1. Unless the D-type connector S1 has only leads 2, 3 and 7 exposed, trim all the other leads close to the connector body. Insert those three pins of SO1 in the circuit board as shown in Fig. 4, and fasten the socket with nuts and bolts. Then solder and trim leads 2, 3, and 7 close to the solder side of the PC board.

Insert the four leads of RJ-11 socket SO2 through the PC board and seat it by inserting the plastic mounting pins through the formed holes. Solder and trim the leads, and melt the ends of the plastic pins on the solder side with a soldering iron to secure it in position. Insert the pins of coaxial DC jack J1 in the board and seat it. Solder and trim the leads.

Finally, after rechecking the polarities of the diodes and capacitors for proper orientation and making certain there are no inadvertent solder bridges or cold solder joints, insert the DIP-packaged ICs 1, 2 and 3.

Packaging the PLM-1

The prototype PLM-1 was packaged in a two-piece plastic case that measures 5 × 5¼ × 1½ inches. The halves can be separated by removing two screws. In the prototype, a red translucent filter was substituted for one of the two opaque plastic 4¾ × 1⁵⁄₁₆-inch end panels included. Identification markings for the four LEDs—ERROR, RX, TX and READY—were silk screened

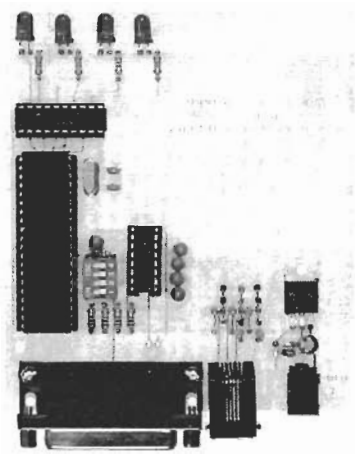


FIG. 6—COMPLETE PLM-1 CIRCUIT board.

on the filter. The socket end of the case was left open.

Alternatively, you can form four holes in one of the two opaque plastic end panels so that the ends of the four LEDs can be press fit into those holes. The holes should be sized so that only the ends of the tapered lenses project from the end panel. Determine the size by measuring the actual LEDs precisely. The holes can be labeled with the four functions stated earlier.

After the complete circuit board is fastened to the bottom of the case with four screws, the LED leads can be carefully bent in pairs so that the ends of their lenses project through the corresponding holes formed in the end-panel.

Monitor operation

Connect the TW-523 interface module to the PLM-1 with a length of telephone cord terminated with RJ-11 plugs, and connect the PLM-1 to your PC with a three-wire serial cable terminated with matching plugs. Start any communications program that you prefer on your personal computer. Any communications software that offers a terminal mode can be used (Procomm, Bitcomm, QModem, Windows Terminal).

After verifying that the center conductor of the cord from the 120-volt AC-to-9-volt DC wall outlet adapter has a negative polarity (see the diagram on the adapter's label), plug it into jack J1 on the PLM-1 circuit board.

A "READY" message should appear on the PC monitor. Refer to the the commands given in the Message Structure section that follows, and then send the desired command to the TW-523 interface.

Message structure

Note: All serial data sent to the interface must be transmitted as upper case characters; lower case characters will be interpreted as errors. All commands must be terminated by pressing the RETURN key. Six different X-10 starting characters are used:

* Send normal commands
# Send multiple dim and bright commands
$ Direct unit control
@ Direct function control
& Send multiple direct function controls
? Obtain software date and its revision

Each character has its own specific format.

The normal message format is *HUF where * is the start character, H is the *house* code, U is the *unit* code, F is the *function* code. To send a command that will turn unit A-1 on, refer to Table 3 and organize the command as follows:

* Start character
0 House code A
0 Unit 1
2 ON

To send the ON command, key *002, then hit RETURN.

To send the OFF command, key *003, then hit RETURN.

To send the DIM A-1 command, key *004, then hit RETURN.

To send the BRIGHTEN A-1 command, key *005, then hit RETURN.

Here are some sample commands:

*A02 K-1 ON
*A03 K-1 OFF
*A04 K-1 DIM
*A05 K-1 BRIGHT
*C42 M-5 ON
*C43 M-5 OFF
*C44 M-5 DIM
*C45 M-5 BRIGHT

To send multiple dim or brighten commands, use the start character #. The format is

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