The Photo(Tach)-Pulser

A phototachometer adapter for frequency counters

By Crady VonPawlak

When you need a phototachmometer to troubleshoot an infrared remote control transmitter for a TV receiver or VCR, to determine the rpm of a spinning shaft, etc., nothing else will do. Commercial phototachometers, of course, are expensive instruments. Fortunately, you can build the Photo-Pulser accessory described here at a cost that should not exceed about $30 for all new parts, including enclosure. Its low cost is made possible by connecting it to a frequency counter.

Our Photo-Pulser is a fairly simple accessory device to build and use. It is designed to serve as the "front end" for a frequency counter from whose display you can read revolutions per minute directly. Its TTL-level output will directly drive almost any digital frequency counter now in use, including the Frequency Counter Accessory for Digital Multimeters described in the November 1987 issue of *Modern Electronics*.

This accessory has only two controls: a combined power switch and rotary SENSITIVITY control and a pushbutton switch to turn on a built-in infrared-emitting energy source for those occasions when ambient or reflected light level is too low to provide a reliable reading.

About the Circuit

The complete schematic diagram of the Photo-Pulser is shown in Fig. 1. As light strikes the sensitive surface of phototransistor *Q1*, a proportional current is passed through the col-

lector-emitter junction. This current is then converted to a voltage by potentiometer *R2*. The magnitude of the voltage developed is determined by the amount of light that strikes *Q1* and its proportional current and the resistance of *R2*. By varying *R2*'s resistance, the threshold or "sensitivity" of the circuit can be set to an incoming signal.

An LM324 quad operational amplifier is used in this circuit for *U1*. This particular chip was selected because it is conveniently designed specifically for use with a single supply voltage, eliminating the need for a more complex and costly split power supply normally required by many op amps. Consequently, the LM324 is an ideal choice for a battery-powered project, which this one is. The tradeoff, though, is the LM324's narrow bandwidth, which is unity gain at 1 MHz.

To prevent *U1* from reacting to small changes in ambient light, the chip's input is coupled to the emitter of *Q1* through capacitor *C1*. If the value of *C1* is small enough, simple changes in room or outdoor lighting will not be passed on and amplified. The penalty for this small value of capacitance is that it passes little current. To compensate for this, the value of *R4*, which provides the op amp's noninverting (+) input with a dc path to ground, must be fairly large to prevent attenuating the incoming signal. There is a penalty here, too. That is, if *R4*'s value is made too large, current through *C1* can cause the output of *U1* to latch. If *R2* is set to a high enough resistance, the amplifier can break into oscillation.

To obviate the possibility of oscillation and increase overall bandwidth of the circuit, the amplifier is made up of two op-amp stages as shown. The first stage, following *C1*, is a noninverting amplifier with a gain of 101. Here, gain is determined by the relationship of *R6* and *R5*, where $V_{out} = (R6/R5) \times V_{in} + 1$. The same is true for the second stage, which has a gain of 11. Therefore, overall gain with both op-amp stages in cascade is 101 × 11, or approximately 1,111.

If a gain on the order of 1,000 is selected, bandwidth is moved closer to 1 kHz. To achieve an overall gain of 1,000 and still retain reasonable bandwidth, the pin 7 output of the

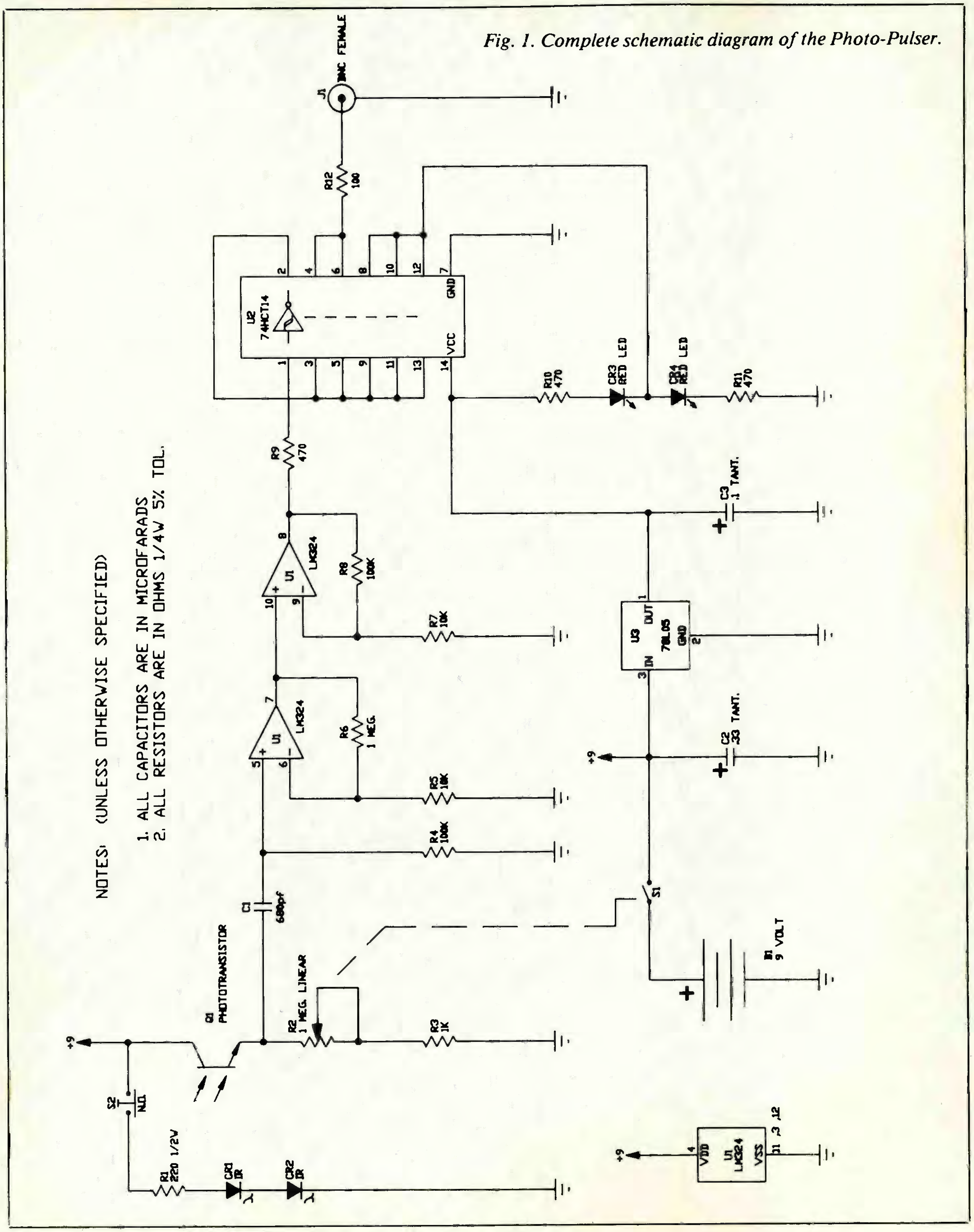

Fig. 1. Complete schematic diagram of the Photo-Pulser.

PARTS LIST

Semiconductors

CR1,CR2—High-output infrared light-emitting diode in T-1¾ package

CR2,CR3—Diffused-lens red light-emitting diode in T-1¾ case

Q1—Broadband phototransistor in T-1¾ case

U1—LM324 quad operational amplifier

U2—74HCT14 high-speed CMOS hex Schmitt trigger

U3—78L05 fixed +5-volt regulator in TO-92 package

Capacitors

C1—680 to 1,000 pF

C2—0.33-µF tantalum

C3—0.1-µF tantalum

Resistors (¼-watt, 5% tolerance)

R3—1,000 ohms

R4,R8—100,000 ohms

R5,R7—10,000 ohms

R6—1 megohm

R9,R10,R11—470 ohms

R12—100 ohms

R1—220 ohms, ½-watt

R2—1-megohm, linear-taper, panel-mount potentiometer

Miscellaneous

B1—9-volt battery

J1—Male BNC connector (see text)

S1—Spst normally-open, momentary-action pushbutton switch

S2—Spst switch (part of R2; see text)

Printed-circuit board; sockets of U1 and U2; suitable enclosure (Pac Tec No. HP-9VB or similar; see text); pointer-type control knob for R2; heat-shrinkable tubing; clear self-stick plastic sheet (see text); hookup wire; solder; etc.

first stage, which has a moderate gain of 100, is fed into the second stage—at the pin 10 noninverting (+) input—which has a lower gain of 10. With this type of arrangement, any noise produced by the first stage is amplified by the second stage, which makes this setup a poor choice where minimal distortion and low noise are key factors. However, in the case of the Photo-Pulser, the effects of this type of noise are insignificant.

Once the incoming signal has been amplified to a usable level, it is fed through dropping resistor *R9* to 74HCT13 high-speed CMOS hex Schmitt trigger *U2*, which has LS/TTL-compatible outputs. The output of *U3* is impedance and risetime matched with LS (low-power Schottky) devices. A 74HCT-14 was chosen for *U3* instead of a garden-variety 74LS14 for its low power consumption and increased fan-out characteristics.

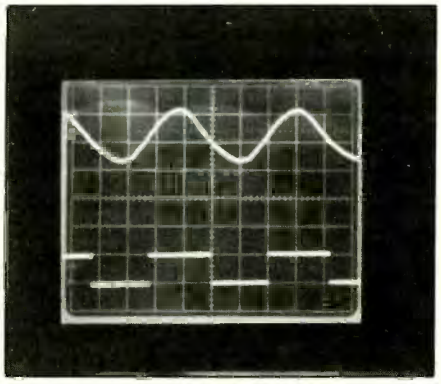

Fig. 2. Built-in hysteresis allows Schmitt trigger to operate on sine waves (upper trace) to produce square-wave output (lower trace).

A Schmitt trigger operates like a simple inverter, except that it has a small amount of hysteresis. For the output of the Schmitt trigger to change state from low to high or from high to low, the input waveform must pass through upper and lower thresholds. So long as this is true, the shape of the actual waveform is irrelevant. An example of this is illustrated in Fig. 2.

The upper trace in Fig. 2, taken at the emitter of *Q1*, shows a 120-Hz sine wave (generated by a fluorescent light 10 feet away) that has an amplitude of +200 millivolts. This sine wave is then amplified to meet the lower and upper threshold requirements of the Schmitt trigger. Hence, even though the signal at *Q1* is a sine wave, after amplification to at least VT+ (2.7 to 3.3 volts dc) and going below VT− (1.3 to 2.1 volts dc), it produces an output from the Photo-Pulser that is a clean 0-to-5-volt, TTL-level square wave whose frequency is the same as that of the input signal.

The square-wave output appears at two points: female BNC jack *J1* for connection to a frequency counter or oscilloscope, and at light-emitting diodes *CR3* and *CR4*. The LEDs serve two functions: When no signal is present, only *CR3* will be on and doubles as a power-on indicator; when a signal of proper amplitude appears at *U2*, *CR3* and *CR4* alternately flash at the rate of the input frequency.

In addition to simply indicating proper triggering, *CR3* and *CR4* will appear to glow (they are actually flashing) with equal intensity. On the other hand, if the signal is spiky, one LED will appear brighter than the other. This "spike" indication is important because even if the light source has a 50-percent duty cycle, as with a fluorescent light, the actual received signal may be greater or less than 50 percent due to reflections from nearby objects adding to (in-phase) or subtracting from (out-of-phase) the waveform. Careful aiming of *Q1* (moving the light source or the Photo-Pulser) will minimize the effects of reflections

Power for the project is supplied by a single 9-volt transistor battery (*B1*). This battery's output is regulated down to a stable 5 volts by positive low-power regulator *U3*. (Although the 78L05 operates identically to the 7805, its pinout is reversed. Input is at pin 3, output is at pin 1 and common or ground is at pin 2.) Tantalum bypass capacitors *C2* and *C3* stabilize the output and prevent *U3* from breaking into oscillation.

For *CR1* and *CR2*, infrared-emitting diodes were chosen for greater efficiency and an output wavelength that is closest to that of a given phototransistor's peak sensitivity. These IR-emitting diodes provide an on-demand reflected point-source of light via pushbutton switch *S2*. If you

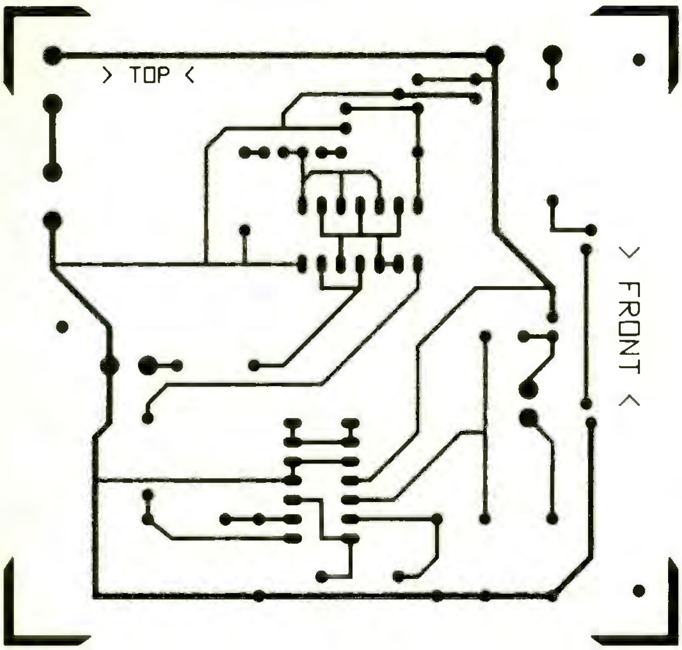

Fig. 3. Actual-size etching-and-drilling guide for fabricating printed-circuit board.

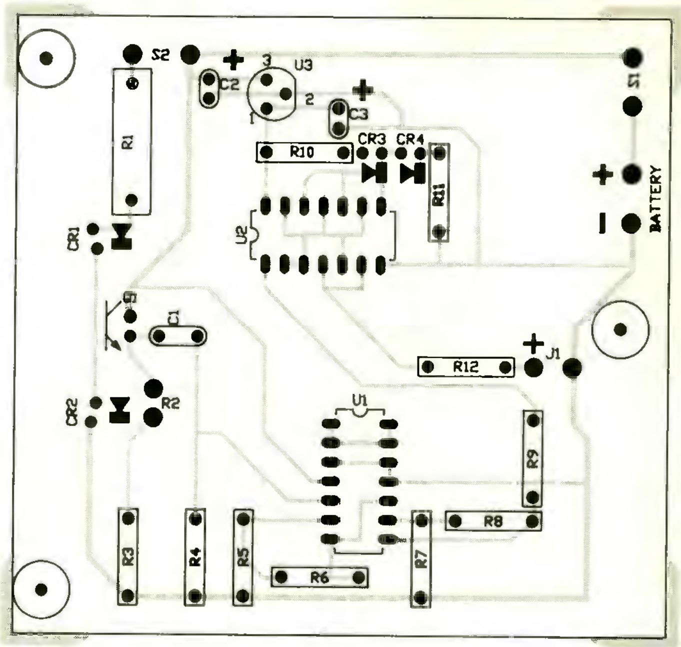

Fig. 4. Wiring guide for pc board.

were to measure the rpm of a spinning shaft that has alternating black and white surfaces in poor or indirect reflected light, for example, *CR1* and *CR2* would provide a light source for making measurements.

Before you select a phototransistor for *Q1*, make certain that it is sensitive to a broad spectrum of visible light. Motorola's MRD series is sensitive to light ranging from 450 to 1,000 nanometers (nm) in wavelength, with peak sensitivity in the 800-nm range. Using good judgment here will extend both the sensitivity and versatility of the Photo-Pulser.

If you want to learn more about pyroelectric devices, I highly recommend the *Optoelectronics Device Data Book* from Motorola. This book is chock full of circuit examples ranging from simple optical switches to ultra-high-speed fiber-optic data links. It also contains a detailed section on photo-semiconductor theory.

Construction

The small output at *Q1* and high gain of *U1* makes printed-circuit board construction of the Photo-Pulser almost mandatory to assure quiet operation. You can fabricate the single-sided pc board from the actual-size etching-and-drilling guide shown in Fig. 3. Wire the board exactly as shown in Fig. 4, using sockets for *U1* and *U2* (do *not* install the ICs in the sockets until after initial checks have been made). Make sure the LEDs, IR-emitting diodes and tantalum capacitors are properly polarized before soldering their leads to the copper pads on the bottom of the board. Also, make sure you properly base the transistor.

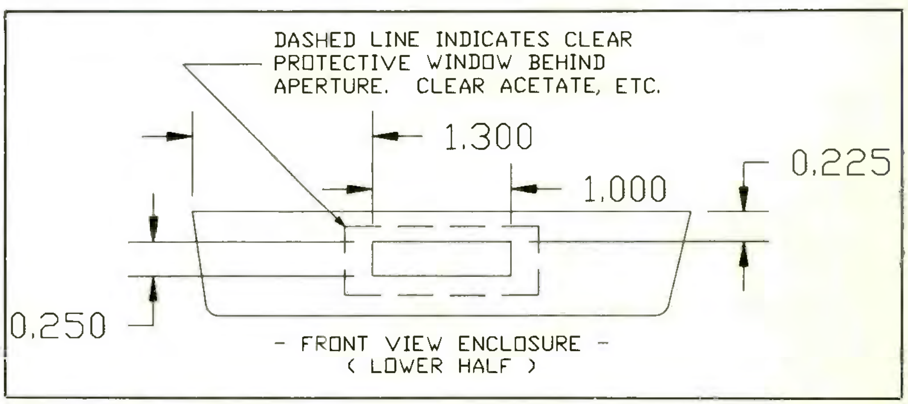

Fig. 5. Cutout details for machining end panel of enclosure lid to permit IR-emitting diodes and phototransistor to face outward.

A Pac-Tec No. HP-9VB enclosure is ideal for the project because it has a separate battery compartment with its own separate slide-off/on cover for convenient battery replacement. If you use this particular enclosure (or another with roughly the same dimensions), use Fig. 5 to guide you in cutting the slot through which *Q1*,

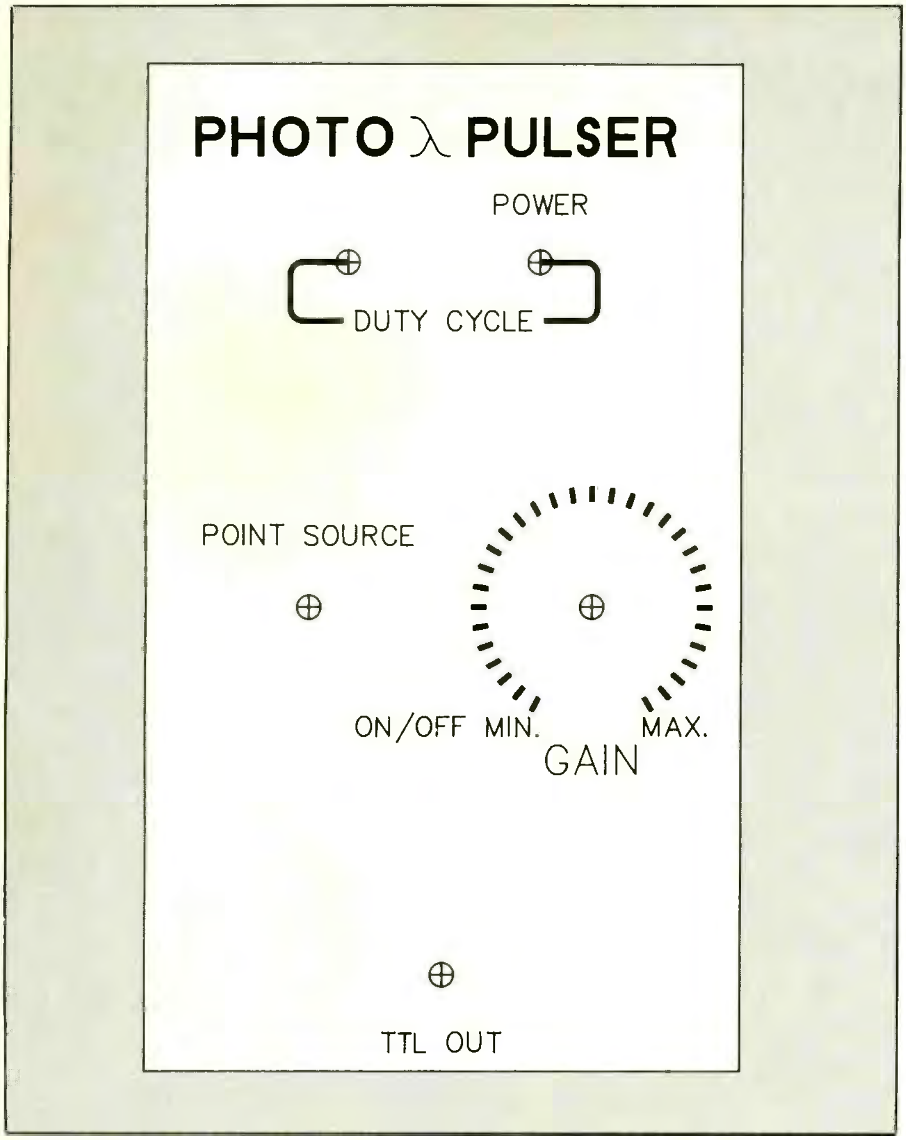

Fig. 6. Front-panel machining and legend details. Make photocopy of this artwork and use directly as panel label, as detailed in text.

CR1 and *CR2* point outward. Then use Fig. 6 to locate the holes for the LEDs, pushbutton switch, rotary control and BNC connector.

Make two same-size photocopies of Fig. 6. Trim one copy along the outside edge of the border line. Place this copy on the lid of the enclosure, carefully centering it all around, and mark the locations of the five holes on the box lid. Drill pilot holes with a ⅟₁₆-inch bit and follow up with a ½-inch bit. Then enlarge each hole as needed with a tapered reamer to just accommodate the LEDs, pushbutton switch, potentiometer and BNC connector.

Use the second photocopy of Fig. 6 as a panel label. Before trimming it to the outer border, carefully apply a sheet of clear self-stick "document protector" plastic to the artwork side. Work slowly and carefully. This self-stick plastic sheeting can be obtained from most stationery stores.

Once the plastic is down on the artwork, turn it over and apply enough wide double-sided permanent-type adhesive tape to cover the entire exposed area of the label. Do *not* remove the protective layer on the tape until you are ready to apply the label to the panel. Turn over the label and carefully trim it to the outside edge of the border.

Peel the protective layer from the tape and *carefully* apply the label to the panel, making sure the cross-points of the cutouts are centered in the holes in the panel. Burnish away any bubbles. Then use an X-acto knife fitted with a No. 11 blade to trim away the label material that covers the panel holes.

I used a potentiometer switch from Radio Shack for *S2*, attaching it to *R2*. To wire *R2* as a rheostat as shown in Fig. 1, first turn the shaft of the pot fully clockwise. Then use an ohmmeter to determine which of the pot's outer lugs register maximum resistance with respect to the center wiper lug. Solder 3-inch lengths of hookup wire to the wiper and maximum-resistance lugs of the pot. If you wish, you can solder a wire from the remaining lug to the center lug; otherwise, leave the minimum-resistance lug unconnected.

Mount the pot in its hole on the enclosure panel and rotate it's shaft fully counterclockwise. Place a pointer-type knob on the shaft, aligning the pointer on the knob with the MIN index on the panel. If necessary, remove the knob and reposition the pot to obtain perfect indexing.

Female BNC connector *J1* is too long to fit over the battery compartment. Therefore, modify it as follows: Use an X-acto or similar miniature saw to trim the connector's threaded length to about ⁵⁄₁₆ inch long. Then bend the center conductor at a 90-degree angle to the conductor's normal axis; make sure the center conductor does not short against the threaded portion of the connector.

Plug the BNC connector into the TTL OUT hole in the enclosure's panel. Solder a 3-inch length of hookup wire to the washer that came with the connector. Slide the washer onto the threaded end of the connector and follow with the supplied hex nut.

If you prefer not to modify the BNC connector as detailed above, you can use the *J1* hole as an exit for a 50-ohm coaxial cable (not longer than 1 meter) terminated in a male BNC connector at the outside end. The other end then directly connects to the appropriate points on the circuit-board assembly. Make sure to connect the cable's shield to circuit ground and the center conductor to the signal-output hole. Also, find a way to provide mechanical strain relief for the cable. A convenient means is to use a nylon cable tie that binds the cable to the circuit board via a small hole drilled in an unused area of the latter.

Note in Fig. 4 that even though *CR1* and *CR2* are positioned slightly forward of *Q1*, energy given off from the sides of the cases of these devices can strike and saturate the phototransistor. To prevent this from happening, slide a ¼-inch length of appropriate diameter heat-shrinkable tubing over *CR1* and *CR2* and shrink into place. Make sure that the forward-facing portions of the lenses on these IR emitters are not obstructed. Shrink the tubing until it just begins to conform to the shape of the diodes.

Wire visible LEDs *CR3* and *CR4*, BNC connector (or cable), switch/pot assembly and pushbutton switch to the circuit-board assembly as per Figs. 1 and 4. Tightly twist together the fine wires in each conductor of the battery snap connector and lightly tin with solder. Pass the free ends of these wires into the enclosure through the battery compartment and plug the red one into the + BATTERY and black one into the – BATTERY holes in the circuit board and solder into place.

Checkout & Use

With *U1* and *U2* still not installed, snap the battery into its connector. With power turned off, measure the voltage delivered to the circuit at the + BATTERY ("hot" meter lead) and – BATTERY points to confirm that the battery is delivering approximately +9 volts dc.

Turn on the power by rotating the control knob just until you hear and feel the click. Connect the meter's common lead to pin 11 and its hot lead to pin 4 of *U1*'s socket. The meter should indicate +9 volts. Next, connect the meter's common lead to pin 7 and its hot lead to pin 14 of *U2*'s socket. This time, your reading should be +5 volts.

Once you are satisfied that your wiring is okay, turn off power to the circuit and install *U1* and *U2* in their sockets. Make sure that each is properly oriented and that no pins overhang the sockets or fold under between ICs and sockets.

With power on once again and gain set to minimum (*R2* fully counterclockwise, just before the click of the switch), *CR3* should light. If not, check the wiring of *CR3* and *CR4* for proper polarity.

If everything looks good so far, aim the Photo-Pulser at a turned-on fluorescent light up to 15 feet away or a CRT screen between 1 and 2 feet away and adjust the gain until both LEDs light. To test the point-source LEDs, adjust *R2* for about mid-gain and wave your hand in front of the window at the end of the enclosure while pressing *S2*. Now *CR3* and *CR4* should flash as your hand or fingers pass by.

Once you know that your Photo-Pulser is working as it should, the project is ready to be put into service. To use it, simply connect its output to the input of a frequency counter via the TTL OUT connector or cable, turn on both instruments and select an appropriate range on the counter. Finally, adjust sensitivity as needed.