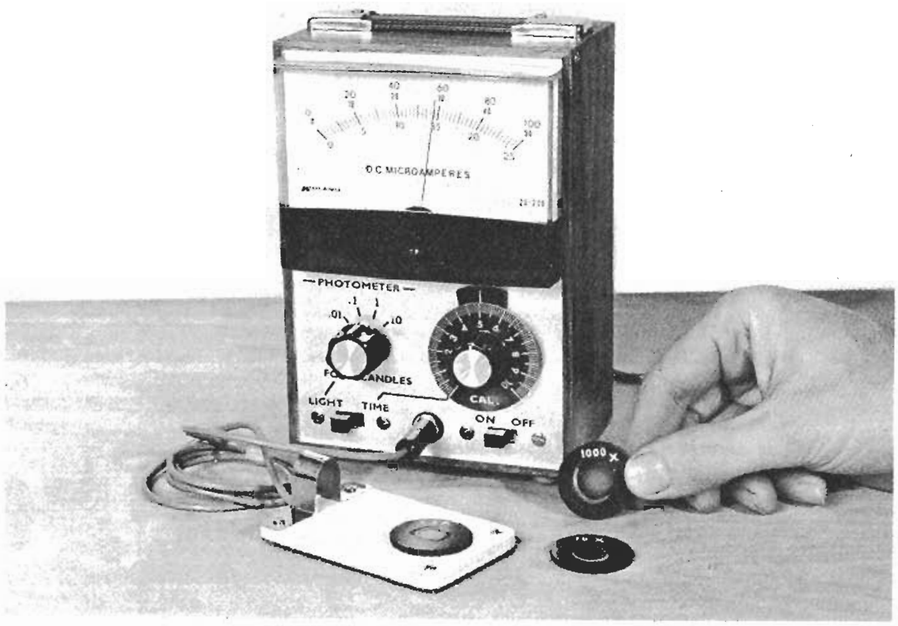

BUILD A

Wide-Range Photometer/Enlarger and/Exposure Meter

BY A. A. MANGIERI

Valuable darkroom accessory covers broad spectrum of light intensities and exposure time ranges

IF YOU do any type of photographic enlarging, contact printing, light-intensity measuring, etc., you need a photometer/exposure-time meter. Here is a high-resolution instrument with 0.01-, 0.1-, 1.0 and 10-foot-candle (ft-c) ranges that are usable down to 0.0005 ft-c. Neutral-density filters can be used to extend the upper range to 10,000 ft-c.

Exposure-time ranges include 0 to 25, 50, and 100 seconds at any multiple or intermediate range desired. A calibration control accounts for differences in paper speed and other factors. And a number of contrast ranges assist in paper grade selection.

The assembled instrument features an illuminated meter scale, and a high-stability operational amplifier IC that has instant-on, zero drift, and immunity from line-voltage variations. A high-speed linear cadmium-sulfide photocell is used to sense the measured light.

About the Circuit. In the simplified light-measuring circuit shown in Fig. 1A, as the light intensity on *PC1* increases, the photocell's resistance decreases. This causes an increase in the input current, I_{in}. The feedback current in light-range resistor *R* produces a voltage, V_F, across this resistor which is the same as V_{out}. Consequently, *M1* indicates in direct proportion to the intensity of the light.

In the basic time-measuring circuit

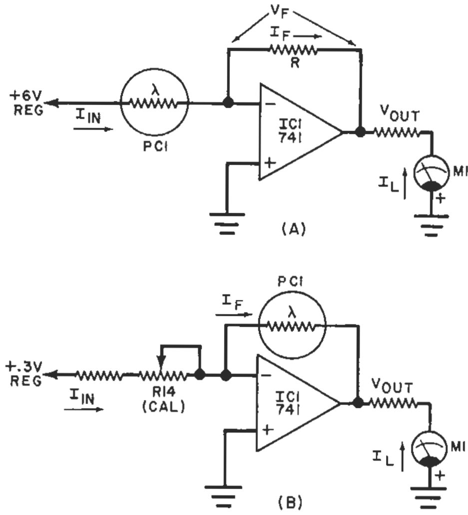

Fig. 1. Simplified op amp circuit for measuring light level (A) and exposure time (B).

shown in Fig. 1B, *PC1* is placed in the op amp's feedback circuit. Calibration potentiometer *R14* presets the input current—and feedback current—to a fixed level. With a decrease in light intensity striking *PC1*, the resistance of the photocell increases and the input and feedback currents remain equal and unchanged, but the feedback and output voltages increase. Thus, the meter indications are inversely proportional to the intensity of the light falling on *PC1*. An appropriate setting of *R14* provides a direct reading in seconds on *M1*.

The complete schematic diagram of the photometer/timer is shown in Fig. 2. Switch *S2* provides either light-level or time modes, while *S1* is used to select the light range. A split zener-diode power supply (*D1* and *D2*) provides the regulated voltages for *IC1*. Potentiometer *R16* sets the op amp's input bias, while *R15* is the offset-voltage null adjustment.

Meter movement protection is provided by the limiting (saturating) action of the op amp, while *C5* prevents rapid pegging of the meter's pointer. Capacitors *C1* and *C3* minimize the amplifier response to any ac present on the signal leads.

Construction. Except for *S1, S2, S3, R14, M1,* and *T1,* all components can be mounted on perforated board with push-in solder clips. Use a socket for *IC1*. Install *C1* and *C2* close to the IC socket. (A completely wired board assembly is shown in Fig. 3.)

Select an enclosure that is large enough to accommodate the meter and other front-panel controls, with enough depth to permit mounting the board assembly and *T1*. Start assembling the system by machining the enclosure's front panel to accept the controls and meter movement, and mount the parts in their respective holes. Do not forget to install phone jack *J1* on the front panel. Note that a two-circuit phone jack and plug are used. Only the tip and ring contacts of the plug (and their respective jack contacts) are used for the *PC1* lead connections. This is necessary because the photocell's leads must not be connected to ground. If you wish, use two-conductor shielded cable between *P1* and *PC1*, leaving the shield "floating" at the *PC1* end and connecting to the barrel contact on *P1*.

The meter scales (0-25 and 0-100) must be properly labeled to provide the appropriate meter readings. This can be accomplished with the aid of a dry-transfer lettering set. Carefully remove the snap-on cover from the meter movement and label the scales as shown in the lead photo. While the cover is off the movement, you can install the optional illumination lamps (*I1* and *I2*). Uniform scale illumination can be obtained by installing a bright reflective metal strip above the meter scales.

Use a well-subdivided scale for calibration potentiometer *R14*. Either

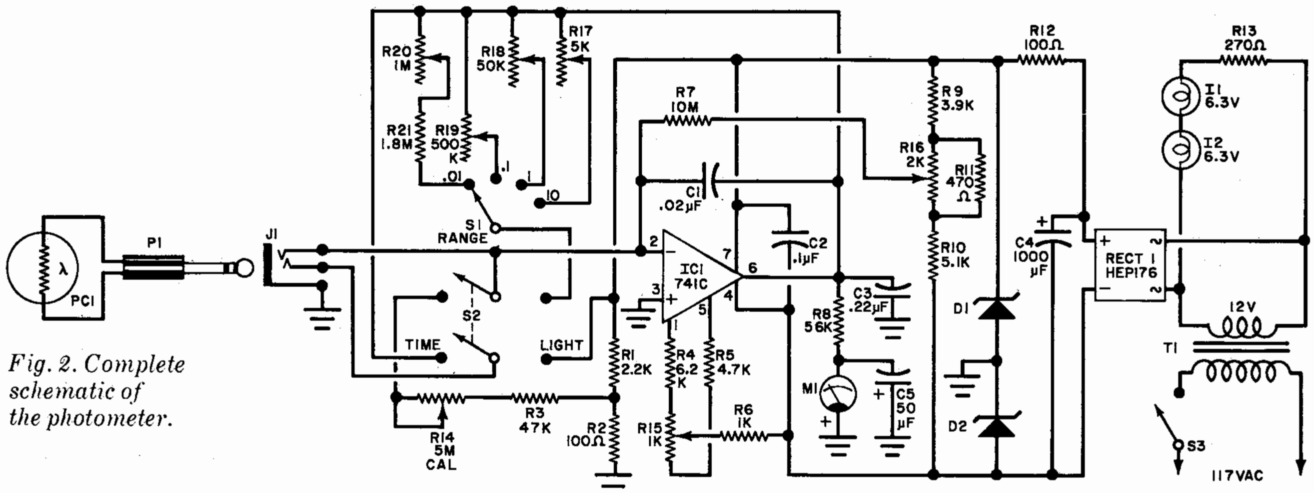

Fig. 2. Complete schematic of the photometer.

PARTS LIST

C1—0.02-µF, 25-V disc capacitor
C2—0.1-µF, 25-V disc capacitor
C3—0.22-µF, 25-V disc capacitor
C4—1000-µF, 35-V electrolytic capacitor
C5—50-µF, 15-V electrolytic capacitor
D1, D2—6.2-V, 1-W zener diode (HEP103 or similar)
I1, I2—Meter illumination lamp kit (Midland F71)*
IC1—741C operational amplifier
J1—Miniature phone jack
M1—0-50-microampere, 4-in. dc meter (Midland F64)*
PC1—Linear high-speed photocell (Clairex CL705HL) (Do not substitute)
P1—Miniature phone plug
R1—2200-ohm, ½-W, 10% resistor
R2—100-ohm, ½-W, 10% resistor
R3—47,000-ohm, ½-W, 10% resistor
R4—6200-ohm, ½-W 5% resistor
R5—4700-ohm, ½-W, 5% resistor
R6—1000-ohm, ½-W, 10% resistor
R7—10-megohm, ½-W, 10% resistor
R8—56,000-ohm, ½-W, 5% resistor
R9—3900-ohm, ½-W, 5% resistor
R10—5100-ohm, ½-W, 5% resistor
R11—470-ohm, ½-W, 10% resistor
R12—100-ohm, 1-W resistor (see text)
R13—270-ohm, 2-W resistor (see text)
R14—5-megohm, audio-taper potentiometer (Mallory U65 or similar)
R15—1000-ohm wirewound pc-type potentiometer (Centralab V-1000 or similar)
R16—2000-ohm wirewound pc-type potentiometer (Centralab V-2000 or similar)
R17—5000-ohm carbon pc-type potentiometer
R18—50,000-ohm carbon pc-type potentiometer
R19—500,000-ohm carbon pc-type potentiometer
R20—1-megohm carbon pc-type potentiometer
R21—1.8-megohm, ½-W resistor
RECT1—1-A, 200-V PIV bridge rectifier (HEP176 or similar)
S1—Single-pole, four-position, shorting-type rotary switch
S2—Dpdt slide switch
S3—Spst slide switch
T1—12-V, 0.3-A filament transformer (Radio Shack 273-1385 or similar)
Misc.—Perforated board; flea clips; case 3" x 4½" x 6½" (Vector W30-66-46); miniature shielded cable; line cord; dial plate; knobs; IC socket; 1/16" phenolic sheet; 22-megohm carbon resistors (2); 15,000-ohm carbon resistor; etc.

* The following are available from Electronics Distributors, Inc., 4900 N. Elston Ave., Chicago, IL 60630; meter (F64 less lamps), meter scale illumination kit (F71).

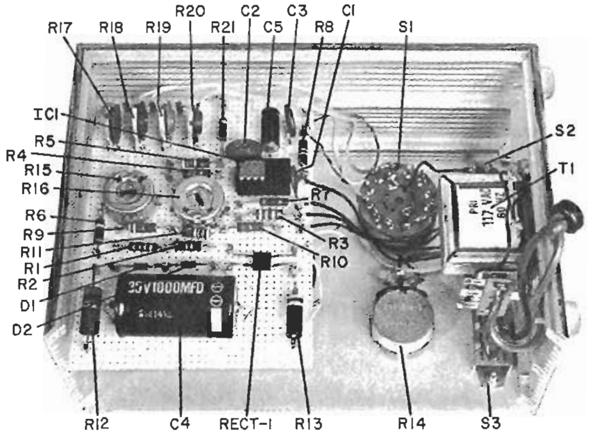

Fig. 3. Interior view of prototype showing placement of all parts.

a panel-mounted dial plate or a rotating dial flange can be used. Identify the front-panel controls with dry-transfer lettering.

Mount *PC1* between two pieces of thin phenolic board, allowing the sensitive surface of the cell to protrude through a hole in the upper board. The protrusion should be about $1/16$ in. (1.59 mm) above the board's surface. After properly mating the boards, remove *PC1* and spray the outer surfaces a flat (matte) white paint.

Connect and solder the two inner conductors of a thin two-conductor shield cable to the leads of *PC1*. (Do *not* connect the shield to the photocell.) Insulate the solder joints with electrical tape. Place *PC1* in position and secure the two pieces of board together, with the cable sandwiched between them. A metal finger loop can be mounted on one end of the assembly for ease in positioning the sensor.

Connect the free end of the microphone cable to *P1*. The shield goes to the barrel contact, while the inner conductors go to the ring and tip contacts.

Power transformer *T1* can be mounted to the bottom or one wall of the enclosure with machine hardware. Connect its primary leads to a two-lug, *non*-grounding type terminal strip. Route the line cord through a rubber-grommet-lined hole drilled through the rear wall of the enclosure. Connect it to *S3* and *T1* as shown in Fig. 2.

Adjustment and Calibration. Using clip leads, connect a milliammeter in series with *R12*. If necessary, adjust the value of *R12* for an indicated current of approximately 70 mA. Install *R13* and measure the voltage drop at the meter lamp terminals; it should be 6.3 volts across both lamps. If not, adjust the value of *R13*. Check that there are about 20 volts dc across *C4*, and about 6 volts across *D1* and across *D2*.

To adjust the bias current of *IC1*, set *S2* to TIME, *R14* to maximum resistance, and remove *R1* from the circuit. Connect about 44 megohms of resistance (two 22-megohm carbon resistors in series) to a phone plug and insert it into *J1*. Then, adjust *R16* until *M1* indicates zero. If this cannot be accomplished, replace *R10* with a resistance between 3900 and 7500 ohms. Alternatively, you can increase (or omit) *R11* for a broader range.

The next adjustment compensates *IC1*'s input offset voltage. With 44 megohms plugged into *J1* and all other conditions as above, connect a 15,000-ohm, 10-percent resistor across pin 2 (input) and pin 3 (ground) of *IC1*. Adjust *R15* for a zero indication on *M1*. If this is not possible, slightly increase the value of *R5* and decrease *R4*, or vice versa. Maintain the sum of *R4* plus *R5*, at 8000 ohms or more.

Upon removing the 15,000-ohm resistor, *M1* should remain at zero. If not, repeat the input bias and offset adjustments. Install *R1* and check to see that there is a 0.3-volt dc drop across *R2*. Adjust *R1* or *R2* if necessary.

The final adjustments are made to calibrate the foot-candle ranges. The nominal resistance of *PC1* is 28,000 ohms at 2 ft-c and 56,000 ohms at 1 ft-c. Set range potentiometers *R17* through *R20* about halfway through their travels and set *S2* to LIGHT. Connect a 5600-ohm resistor to a phone plug and insert it in *J1*. This simulates the ideal resistance of *PC1* at 10 ft-c.

Set *S1* to the 10-ft-c range and adjust *R17* until *M1* indicates full-scale. Similarly, use a 56,000-ohm, a 560,000-ohm, and a 5.6-megohm resistor, respectively, to calibrate the 1-, 0.1-, and 0.01-ft-c ranges while adjusting the corresponding potentiometers. The simulating resistors used should have 5-percent or better tolerances. If an accurate photometer is available, you can use it to calibrate the light ranges.

Although neutral-density filters can be used to extend the light ranges, filters using film negatives are satisfactory for non-critical use. Using the enlarger as a light source, focus it and remove the film from the carrier. Place *PC1* on the enlarger easel and set *S1* to the 1-ft-c range. Stop down the lens until *M1* indicates 1 ft-c. For the X10 multiplier, select a portion of unwanted negative that, when placed over the sensor, causes the meter to indicate 0.1 ft-c. Affix the film to a thin blackened washer or disc that fits over the top of the photocell. Place the glossy side up to protect the emulsion from scratches. Selected film bits should be uniform and without detail.

Application. Measure light with *S2* set to LIGHT and *S1* set to the desired range. Measure time with *S2* set to TIME and *R14* set to a previously determined calibration setting for the particular application. The calibrating procedure for *R14* accounts for paper speeds, mode of operation, time scale in use, and processing factors. This is performed once for each set of conditions and recorded for future use. When calibrating or using the instrument, all darkroom lights must be off. Avoid directly illuminating *PC1* by the meter's lights.

Select an average negative and make the best possible print in the conventional manner using test strips. As an example, let us assume the best print required 15 seconds of exposure time at f/8 aperture. For the integrated light method, you will need a 2½-in. (6.35-cm) square piece of ground glass as a light scatterer. With the enlarger undisturbed, place *PC1* at the center of the projected image and set *S2* to TIME. Hold the light scatterer up to the enlarger's lens. Then adjust and record the settings of *R14* that result in 15 seconds indication on the 25-, 50-, and 100-second scales where possible. Also, record the data on the projection paper in use.

To use the exposure meter at a later date, set *R14* to the recorded setting for the particular paper and time scale. At almost any lens aperture and print magnification, use the light scatterer and observe the required exposure time. You can select the exposure time desired by varying lens aperture (or vice versa). A blackened paper tube from a 35-mm film carton positioned over the sensor checks or eliminates the effect of stray light. During exposure, *S3* can be switched off.

Calibrate *R14* with the lens aperture set to one or two stops larger than the exposing aperture of the test print when using the instrument with small lamp enlargers. In the example, open the lens one full stop to f/5.6. Calibrate *R14* for 15 seconds indication on each time scale where possible. Using this mode of measurement, observe exposure time at any selected aperture and close down one stop before exposing. Alternatively, you can halve the indicated exposure and expose at the measuring aperture.

The spot method determines exposure time at print shadows without the use of a light scatterer. To calibrate, place *PC1* at important print shadows (bright portion of the projected image) and adjust *R14* until the meter indicates 15 seconds on each time scale. To use this mode, set *R14* as recorded for the paper and time scale, place *PC1* at the print shadows, and observe the required exposure time.

Contrast measurements use the light scales to determine the ratio of light levels at the bright and dark portions of the image. The table gives various contrast ranges with the setup requirements.

S1 Range (initial)	**M1(%) (preset)**	**S1 Range (final)**	**Contrast Range**
0.01	100	0.1	10
0.01	100	1	100
0.01	100	10	1000
0.1	40	0.1	2.5
0.1	40	1	25
0.1	40	10	250
0.1	20	0.1	5
0.1	20	1	50
0.1	20	10	500

Because it is used most frequently, set up the 0-to-25 range with *S2* on LIGHT and *S1* on the 0.1-ft-c range. Place *PC1* at the darkest area of the image and adjust the lens aperture until *M1* indicates 40 percent of full-scale. Advance *S1* one decade to the 1-ft-c range. Note that *M1* now indicates 1 on the 0-to-25 scale.

Move *PC1* to the brightest area of the image and read image contrast directly on *M1*. Middle contrasts of 8 to 15 indicate the use of normal-contrast paper. By keeping notes, relate contrast measurements with the required paper grade.

The integrated light method, preferably used with negatives of average balance, requires either a correction or recalibration of *R14* for negatives of predominantly light or dark scenes. The spot method, capable of handling almost any negative, assumes that projected print shadow areas are larger than the photocell's diameter.

By installing a photocell in the tip of a probe, you can take measurements on contact print boxes, viewing screens, etc. For camera applications, choose between the LIGHT and TIME scales. The TIME scales can be interpreted in any convenient manner, such as 0 to 2.5, 5, and 10 seconds or 0 to 250, 500, and 1000 milliseconds, and easily converted to fractional shutter speed if desired.

Bear in mind that CdS cells exhibit a memory effect related to previous light history. Therefore, avoid exposing *PC1* to sunlight or bright room lights prior to use. Also, response time increases with decreasing light levels. So, allow time for the meter indication to settle at very low light levels. Long-term meter drift proved to be nonexistent in use, but you can check meter zero by setting *S2* to LIGHT and removing *P1*. ◈