your own little PHOTOPLETHYSMOGRAPH

Unusual project shows heart action and blood flow

Hundreds of times each day, in the leading hospitals of the world, surgeons perform miraculous feats of surgery made possible by daring innovations in technique and an array of the finest equipment money can buy. An important member of the surgical team is the anesthetist. He leans heavily on modern medical electronic instrumentation, and can now keep his full attention on the unconscious form before him while the important heart data is supplied to him aurally. This information comes in the form of a soft rhythmic "bleep" emanating from an electronic monitor. If the *bleep* should falter, the signal can be switched from an audible to a visual presentation. The anesthetist would then be able to study the heartbeat waveform displayed on the face of his small, battery-operated oscilloscope.

This heartbeat signal originates in a photocell transducer that has been slipped over one of the patient's fingers. It has the rather formidable name of photoplethysmograph, usually abbreviated to PPG. The "plethysmo" portion of the word is derived from the Greek "plethore," meaning "to be full." Basically, the transducer measures the blood volume flow in the finger to which it is attached. This is an excellent indication

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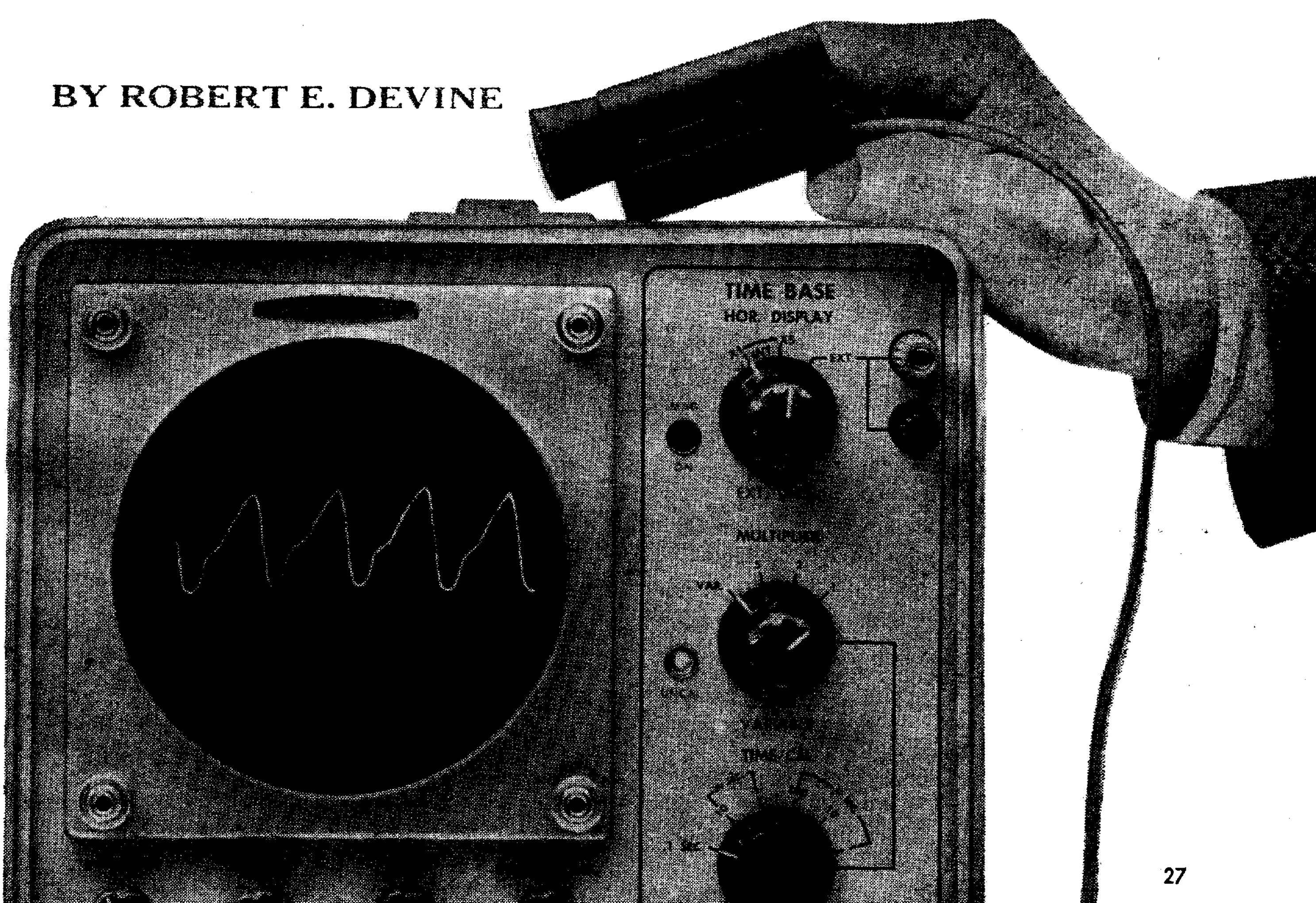


PARTS LIST

B1—22.5-volt battery
B2—1.5-volt battery
I1—Pilot bulb #222, or "grain-of-wheat" bulb
J1—Three contact polarized socket
P1—Three contact polarized plug
PC1—Photocell sensitive to approximately 7350 Angstroms (Clairex CL903L or similar)
R1—5600-ohm, ½-watt resistor
R2, R3—10,000-ohm, ½-watt resistor
S1—D.p.s.t. switch
Misc.—Block of wood or opaque plastic approximately 2½" x 1½" x ½", thin metal plate, battery holders, length of 2-conductor flexible shielded cable with three-pin polarized plug (from transducer to bridge), length of phono cable with two-pin polarized plug (from bridge to preamp or scope), finger support (see text), connector for scope or preamplifier (optional), 25,000-ohm potentiometer (optional, see text), terminal strips, hardware, etc.

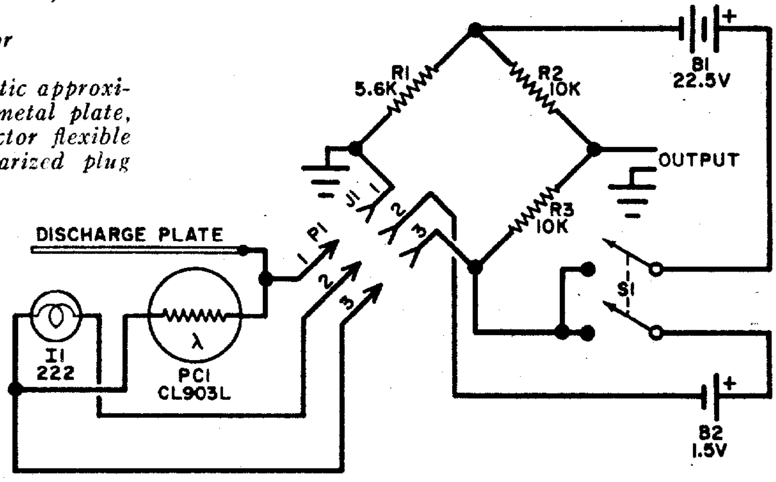


Fig. 1. The PPG circuit is a simple bridge with photocell PC1 as the variable arm. The plate bleeds off static electricity. The shield of the transducer cable is the common ground lead and is connected to pin 1 of P1. The output cable is a shielded single-lead microphone cable.

of how efficiently the heart is working. If the patient's condition warrants it, this pressure pulse monitor will accompany the patient to the recovery room. The PPG is also used in intensive care hospital rooms. Its signal can be carried by cable to a central observation point where it may be monitored continuously by either visual display or an audible signal. The electronic vigil will watch-and-warn for that critical 200 seconds—the period between the instant the heart ceases to pump, and death. The heart must be restarted during this critical interval to save the patient's life.

The actual waveform generated by the pressure pulse has a frequency of only one or two hertz—much too low to be heard by the human ear. In an aural setup this signal triggers an electronic tone generator whose frequency has arbitrarily been selected to be something "easy to listen to." The important information conveyed by the *bleep* is the tempo and regularity of the heartbeat. On the other hand—when the waveform is displayed on an oscilloscope, all the above information, plus other physiologically significant events, can be extracted from a visual observation of the waveform.

If you have a good oscilloscope, you

PARTS LIST

B1—22.5-volt battery
C1—12-µF, 20-volt tantalum capacitor
C2—75-µF, 6-volt electrolytic capacitor
J1—Two contact polarized socket
Q1—N-channel FET (Motorola MPF103 or similar)
R1, R4—2-megohm } *all resistors ½-watt*
R2—470-ohm
R3—7500-ohm
S1—S.p.s.t. switch
S2—S.p.s.t. momentary contact switch
Misc.—Metal case 4" x 2¼" x 2¼", transistor socket, battery holder, length of shielded flexible cable (from amplifier to scope), terminal strips, hardware, etc.

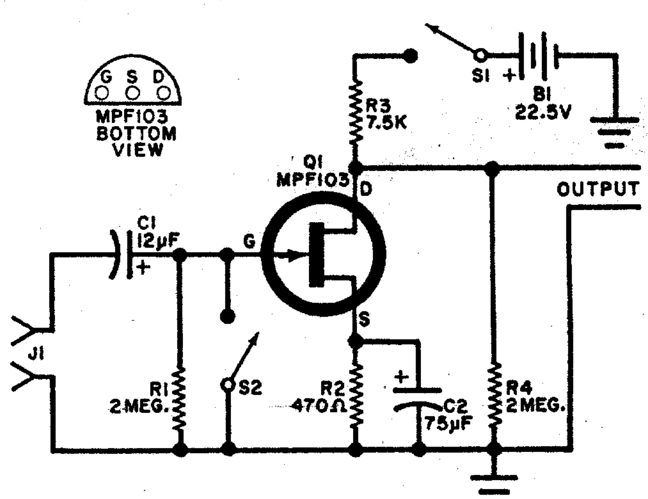
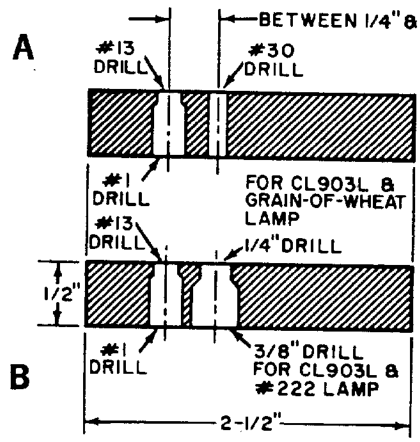


Fig. 2. Output level of the bridge is very low and this special preamplifier may be required. Capacitor *C1* is made of tantalum foil.



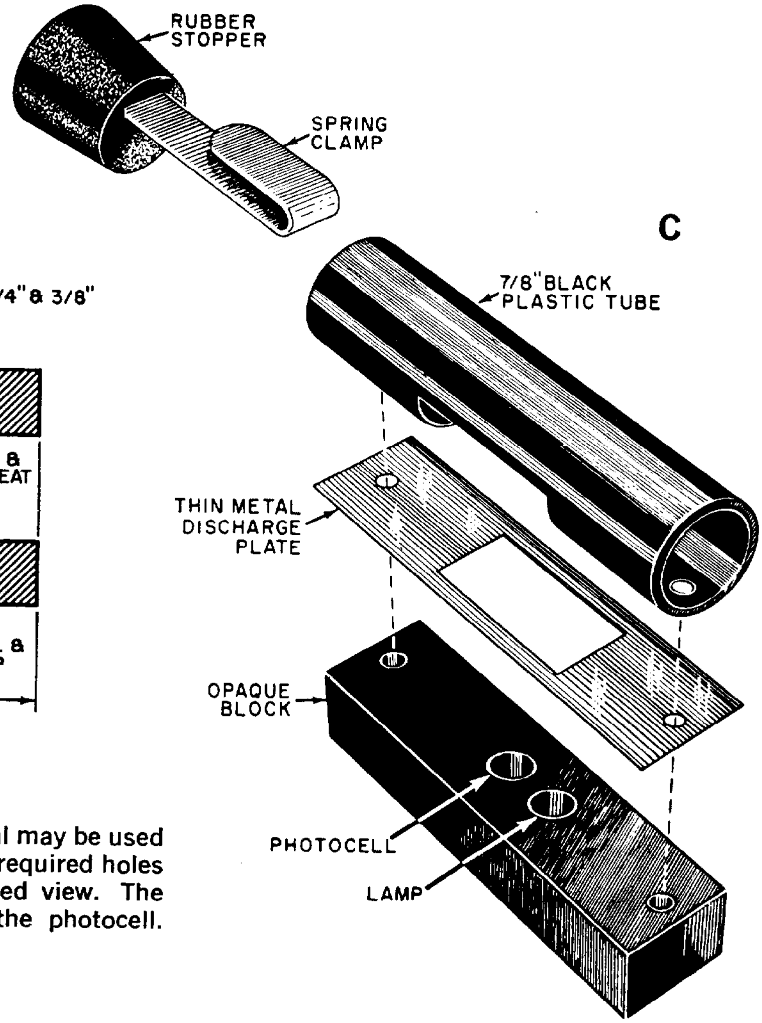


Fig. 3 Any workable opaque material may be used to make the transducer body. Drill required holes and assemble as shown in exploded view. The discharge plate is connected to the photocell.

can reduce the cost of building your own PPG to approximately six dollars. Construction time should be just a few hours.

Construction. The PPG is divided into three cable-connected sections: the finger-mounted transducer assembly, the measuring bridge, and a FET signal preamplifier (optional). The circuit for the transducer and bridge is shown in Fig. 1 and the schematic for the FET preamplifier is shown in Fig. 2.

To make a transducer, a piece of opaque plastic or wood approximately 2½" x 1½" x ½" is drilled to accept the photocell and lamp as shown in Fig. 3. There are two methods of drilling the holes for the light source. Fig. 3(a) shows the drilling requirements for a grain-of-wheat lamp, while Fig. 3(b) shows the drilling for a #222 lamp. In both cases, the hole for the photocell remains the same size. Each unit should be submerged within the opaque block so that they do not "see" each other unless

HOW IT WORKS

The PPG takes advantage of the fact that tissues of the human body are relatively transparent to the red part of the light spectrum (near infrared region from 7000 to 8000 Angstroms), while the blood is not.

When you place your finger across the gap separating the reddish light source and the photocell, your flesh will provide a path for the light rays to reach the photocell from light source. With each systole, or contraction of the heart muscles, the amount of blood in your peripheral extremities increases as the blood vessels momentarily dilate. Since blood is opaque to the red light, this reduces the amount of light reaching the photocell during the pressure pulses. The change in light causes the photocell to change its resistance with each pulse.

The photocell is connected in a bridge circuit (see Fig. 1) with *R1* being its opposite bridge element. Equal value resistors *R2* and *R3* provide a mid-point pickoff for the output signal. Each time the photoresistor changes its resistance value, an output signal is generated by the bridge.

Because the bridge output is a low-level, low-frequency signal, the FET preamplifier shown in Fig. 2 may be used to increase the signal level to a point usable by some scopes. This preamplifier is a conventional FET stage having the required very high input impedance so as not to reduce the low-frequency coupling *(C1)* at these one-to-two-Hz subaudible frequencies.

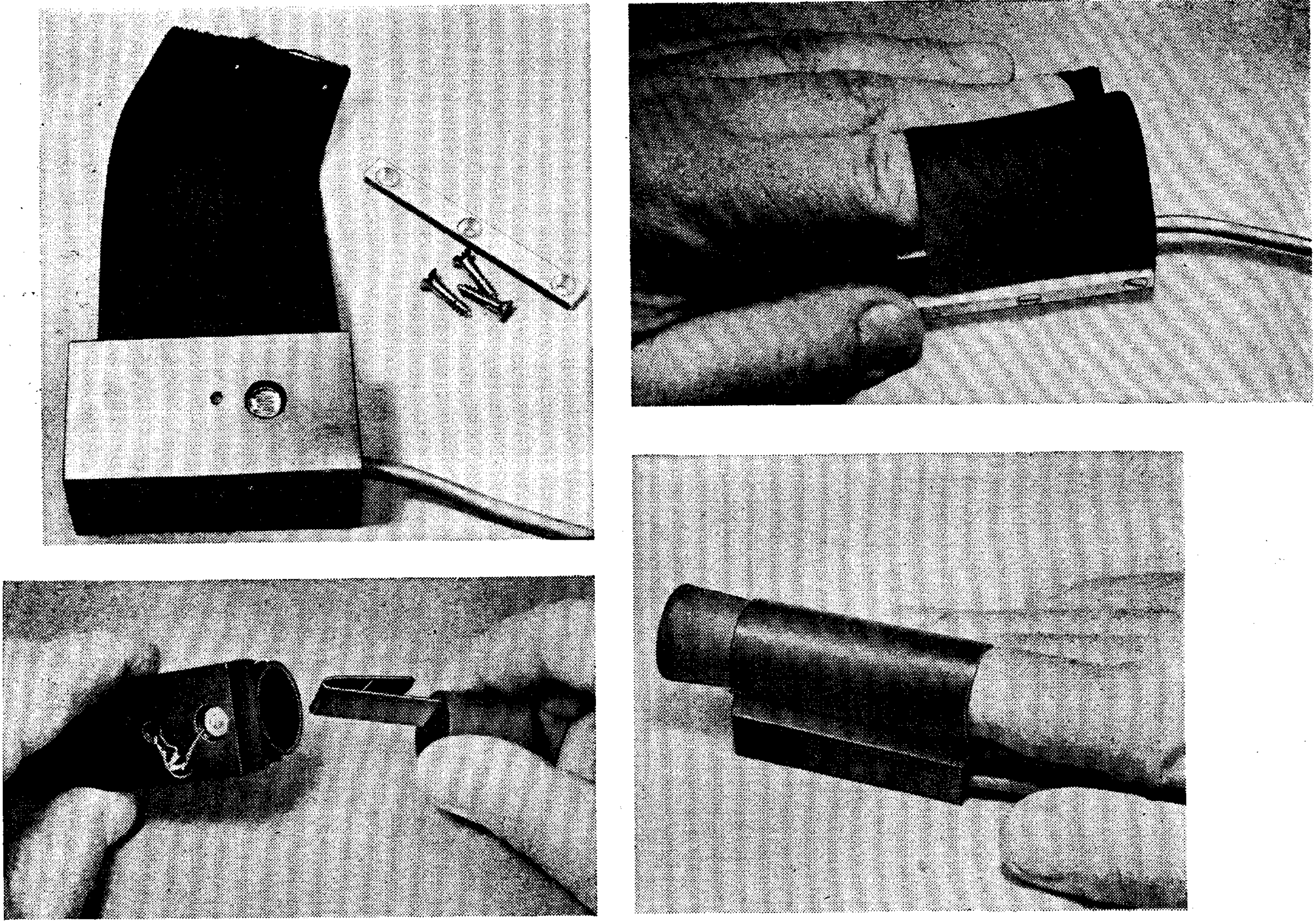


Fig. 4. Two preferred methods of assembling a transducer are shown. In the upper two photos, an elastic cloth has been used to secure the finger and block off outside light. The photocell and light source are visible through the holes in the metal plate. The two lower photos show tube transducer.

a finger is so placed as to make a reflective bridge between photocell and lamp.

To remove any static electricity charge, a thin metal plate covers the top of the opaque block with a cutout over the lamp and photocell holes. This is shown in Fig. 3(c). The metal plate is connected to the ground lead of the transducer-bridge cable.

A light shield surrounding the finger and the photocell is recommended. Use a black (opaque) plastic tube that can be bolted to the opaque block, with a cutout as shown in Fig. 3(c). To make sure that the finger correctly bridges the *I1-PC1* gap, make up a clamp using a rubber stopper and a home-made spring. The stopper should be a tight fit in the end of the plastic tube. The spring clamp is inserted so that when a finger is placed in the tube (fingernail up), the clamp will force the finger down to bridge the *I1-PC1* gap. An alternative construction method is to use a piece of opaque, elasticized cloth attached to both sides of the opaque block. This cloth forms both a finger support and a light shield. Figure 4 illustrates both types of finger transducers.

The photocell, lamp, and ground plate are wired to a short length (three feet) of two-conductor shielded cable. This cable is terminated in a polarized three-pin plug.

Building The Bridge. The author built his bridge circuit in a 5" x 4" x 2" metal box, as shown in Fig. 5, although any other similar container would suffice. The bridge elements (*R1, R2,* and *R3*) are supported on a pair of three-terminal strip assemblies. The two batteries are mounted on the sides of the box, the on-off switch (*S1*) is on the upper surface of the box, and the three-pin polarized