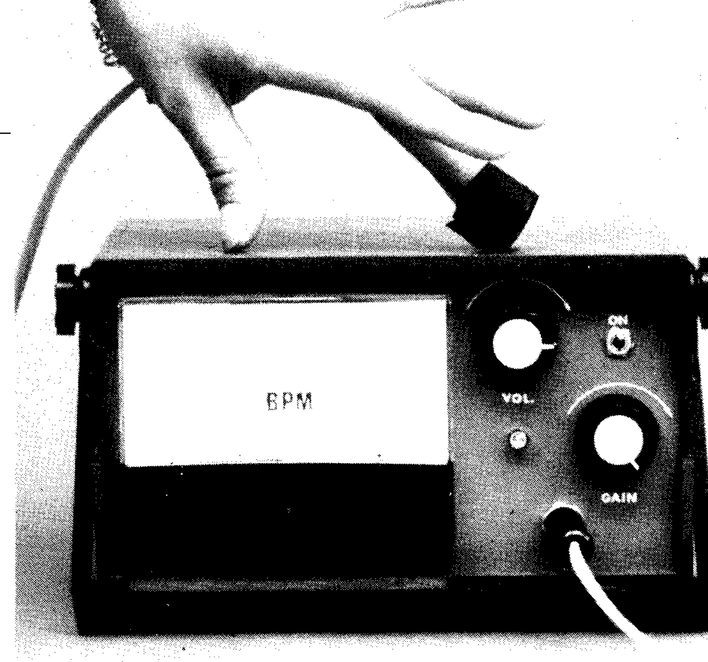

Heart Rate MONITOR

An instantenous check on heart-rate activity is essential when engaging in meditation, Yoga or an exercise program for health and physical fitness. This cardiotach provides a direct readout of your heart rate.

MARK C. WORLEY

THE CARDIOTACH IS AN ADVANCED, SOLID-state design useful for experimental or clinical monitoring of the human heart rate. The term "cardiotach" is derived from the Greek word *kardia*, meaning heart, and the Greek word *takhos*, meaning speed. Thus, *cardiotach* literally means heart speed or heart rate.

Research has shown that the heart rate is generally proportional to the body's level of tension, excitement or anxiety; therefore, a slower heart rate can be used as an indicator of the degree of relaxation. For those practicing various methods of meditation or tension-reducing relaxation, the Cardiotach can be useful for displaying the relative degree of calmness.

Experimenters and clinical technicians can use it as a response indicator of anxiety states or relaxation responses to such external stimuli as words, music, odors, visual displays, etc. The pulse rate increase is usually quite rapid in response to anxiety-producing stimuli and can be a more accurate indicator of the body's state than verbal responses. This is one reason why a heart rate monitor usually forms part of a polygraph or "lie detector."

Often, during relaxation-training sessions, an aural indicator can disturb the state of relaxation for the participants. The Cardiotach has a front panel meter that provides a visual indication of the heart rate.

For those physical fitness enthusiasts who might want to monitor heart rate in relation to physical stress, the Cardiotach could be useful, too. It is not, however, a portable (battery-operated) instrument, and is subject to false readings from muscle and sensor movements. Therefore, its best application might be as a before-and-after measurement while comfortably seated or otherwise stationary.

In addition, it's fun and satisfies your curiosity to know your heart rate and see the meter display it directly in BPM (*B*eats *P*er *M*inute).

Design objectives in devising the Cardiotach were to use inexpensive, readily available components, provide an accuracy of at least ±5% and avoid potential shock hazard. All these criteria were met far beyond expectations. The accuracy of the instrument, depending upon meter linearity, is better than 5%, the unit costs less than $100 to build, and all the components, except for the sensor, can be obtained from mail-order distributors.

Circuit description

The circuit senses each heartbeat via an infrared optocoupler/sensor and triggers on the "R"-wave, which is the largest-amplitude signal found in the heartbeat waveform (see Fig. 1). Because of this, it was decided to simply use amplitude discrimination in order to have the R-wave trigger the tachometer circuit. Thus, the circuit directly displays the R-wave repetition rate.

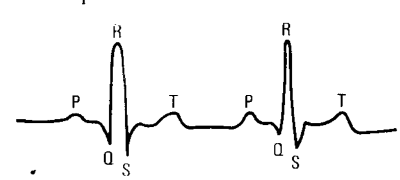

FIG. 1—HIGH AMPLITUDE PULSE of the heartbeat waveform.

Figure 2 is the block diagram of the Cardiotach circuit; Fig. 3 is the complete schematic diagram. The circuit is divided into eight basic sections: sensor, bandpass amplifier, Schmitt trigger, charge pump, meter circuit, beep-tone generator, calibrator and power supply. We'll consider the operation of each section in turn and see how they all combine into one instrument.

1. The sensor is an infrared reflective sensor (manufactured by Optron, Inc., 1201 Tappan Circle, Carrollton, TX 75006) containing an infrared emitting diode and an infrared sensitive phototransistor that are shielded from each other

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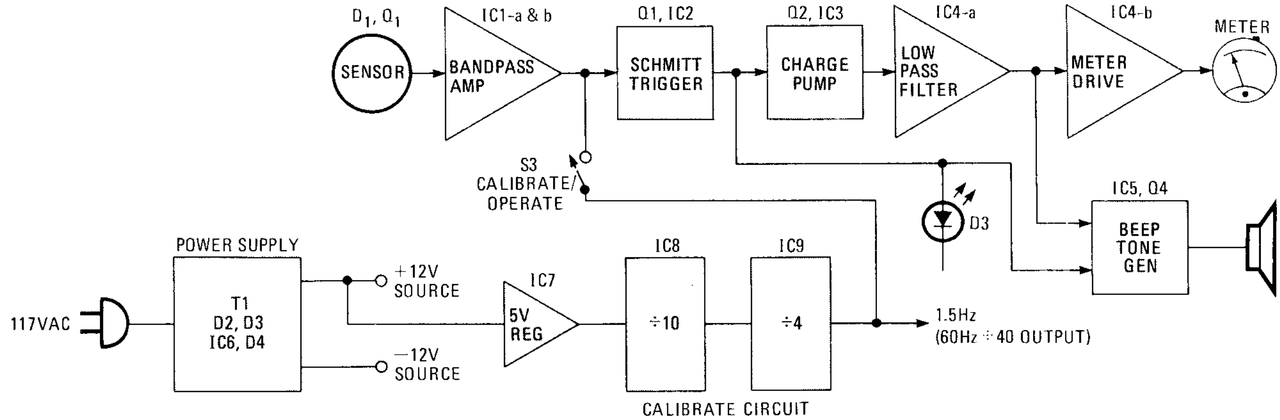

FIG. 2—BLOCK DIAGRAM of the cardiotach. Infrared optoelectronic sensor detects pulses in blood flowing close to the skin surface and interprets each pulse as a heartbeat.

by a barrier (see Fig. 4). The transparent cover allows the infrared emission to be coupled back to the transistor via reflection or conduction from a nearby surface. In this application the transparent face of the optocoupler is held against the skin. As blood pulses through the body, the infrared-sensitive phototransistor responds to the varying levels of infrared skin transmissivity caused by the changing blood volume with each heartbeat. The phototransistor, Q1, senses and amplifies the signal for further amplification by IC1.

2. The bandpass amplifier, IC1, amplifies the signal within the range of about 0.5 Hz to 6 Hz to reduce 60-Hz hum and other noise-source problems. It is a non-inverting amplifier with the variable gain controlled by sensitivity potentiometer R9. Resistor R10 is an end-mounted resistor that is used as a scope test point for the electrocardiogram signal.

3. The Schmitt trigger, IC2, is trig-

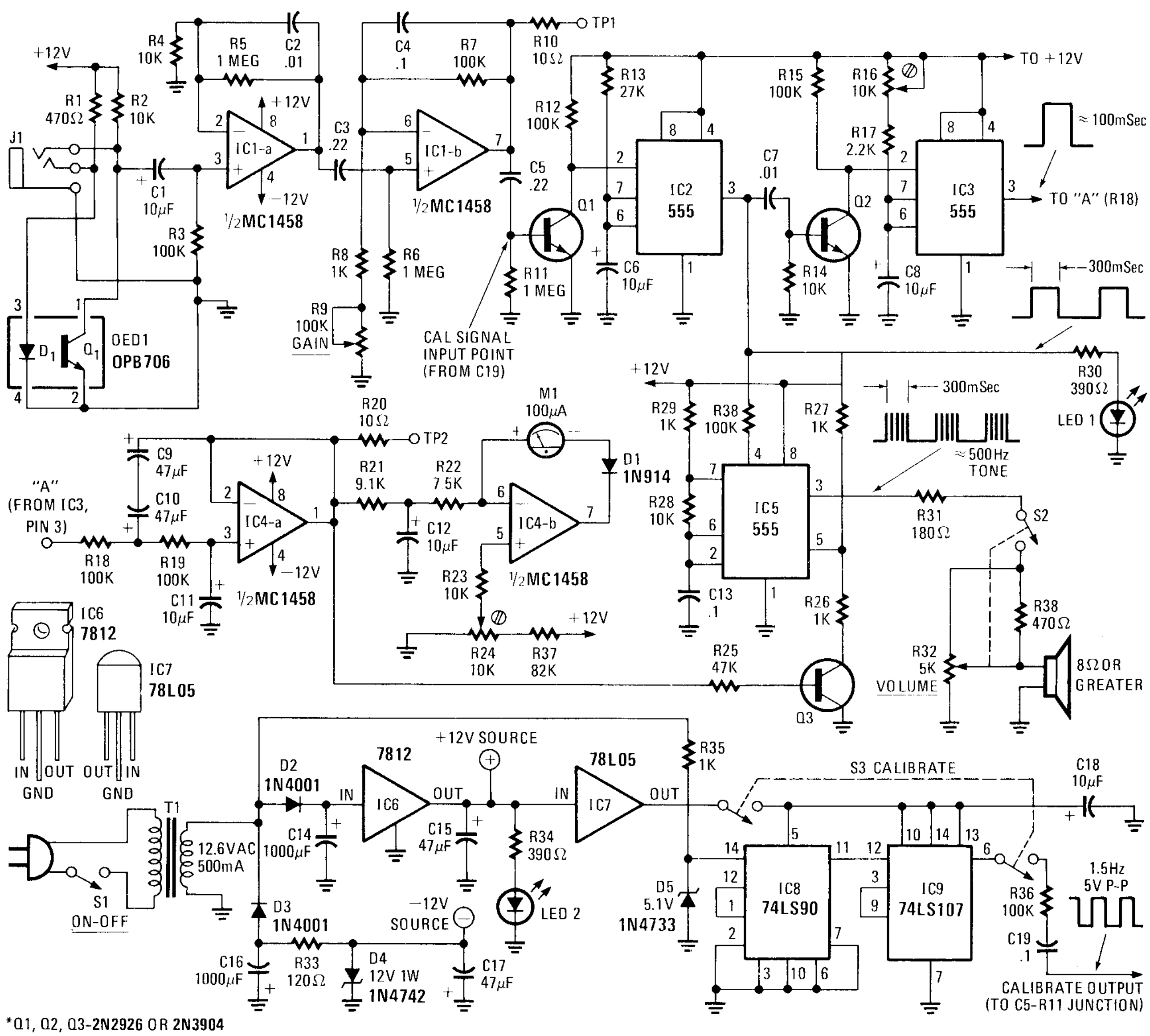

FIG. 3—SCHEMATIC of the Heart Rate Monitor. If you desire, rather than hardwiring opto-sensor OED1 to front-panel jack J1 as shown in the diagram, you can add a male plug to the opto-sensor cable and plug it into J1. If you opt to leave the cable hardwired, you can eliminate jack J1.

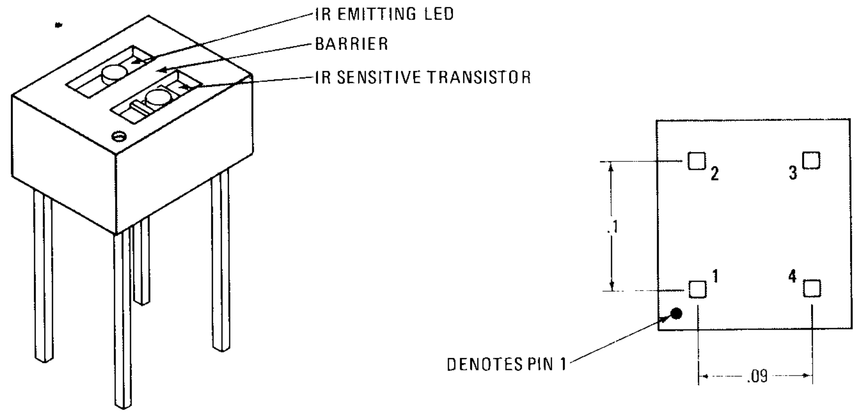

FIG. 4—CONSTRUCTION and pinout for the OPB-706 infrared reflective sensor.

gered by a negative pulse from Q2 to produce a 300-μs squarewave that helps eliminate multiple triggering on both the R- and T-waveforms. The pulse is also used to light LED1 and trigger the beep generator IC.

4. The charge pump, IC3, produces a 100-μs pulse each time it's triggered by a heartbeat signal from IC2. Resistor R17 is an internal calibration potentiometer that adjusts the width of the pulse. The actual pulse width is dependent upon the circuit values and tolerances in the low-pass filter circuit. Quality components are a must in this part of the circuit in order to maintain stability.

5. The low-pass filter, IC4, is used to smooth the 100-ms pulses into a DC voltage that is proportional to the heart rate. This voltage can be measured at R20, which is an end-mounted resistor used as a test point during calibration. Integrated circuit 4-b is a voltage-to-current converter used to drive meter M1. Input resistors R21 and R22 filter and scale the meter drive circuit to produce a 60-μA current for a 1-volt input. Since the meter is in the feedback path of IC4-b, its internal resistance and any thermal resistance changes will have no effect upon the current through it. Diode D1 prevents reverse meter current, and since it also is in the feedback path, it has no other effect on the meter. Resistor R24 is used to cancel offset voltages and to position the meter needle during calibration. Resistors R21 and R22 are selected for a series resistance of 16,660 ohms, resulting in a 60-μA-per-volt scaling of IC4-b's meter drive circuit. (The meter is intended to be calibrated with 0μA as 50 BPM, 20 μA as 70 BPM and so on, with 100 μA as 150 BPM. If a 50-μA meter is used, R21 and R22 must be doubled in value to equal a total resistance of 33, 330 ohms.)

The charge pump and filter circuit are designed to provide 1-volt DC to IC4-b at 60 BPM (or 1 Hz) and to increase that voltage linearly with an increase in frequency. This results in a 60-μA change through the meter when the heart rate increases from 60 BPM to 120 BPM.

6. The beep-tone generator, IC5, produces a 300-ms beep with each heartbeat. The generator operates in a keyed and modulated mode controlled by IC2 and Q3. As long as pin 4 is kept low, IC5 does not oscillate. When IC2 pin 3 goes high, it allows IC5 to produce a tone for the duration of the pulse of IC2. The frequency, or pitch, of the tone from IC5 increases with an increased heart rate and vice versa. The voltage on pin 1 of IC4-a varies the conduction of Q3, which, in turn, varies the trip point of IC5 and its operating frequency. The response of Q3 is not linear, but it does vary noticeably with the heart rate. If this feature is not desired, eliminate R25–R27 and Q3. No jumper connections are needed; just leave IC5 pin 5 disconnected.

7. The calibrator circuit, IC7–IC9, generates a 1.5-Hz (or 90-BPM) squarewave that is derived from the 60-Hz line frequency. It is used to initially calibrate the Cardiotach and for later recalibration

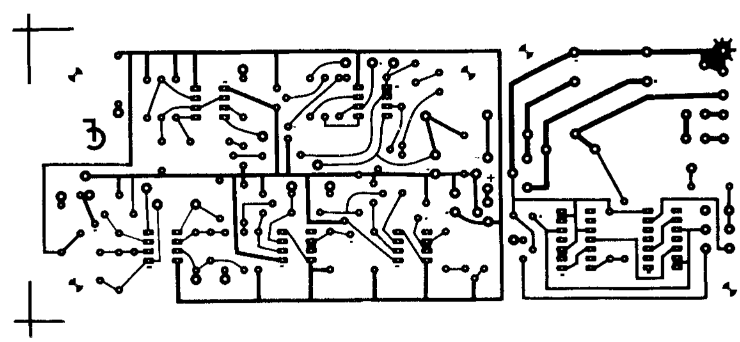

FIG. 5—FOIL PATTERN for the printed-circuit board used in making the cardiotach. The board may be cut in two and the pieces wired separately. Pattern is shown half-size.

PARTS LIST

Resistors ¼ watt, 10%, unless otherwise specified

Resistors
R1—470 ohms, ½ watt
R2,R4,R14,R23,R28—10,000 ohms
R3,R7,R12,R15,R18,R19,R36,R38—100,000 ohms
R5,R6,R11—1 megohm
R8,R26,R27,R29,R35—1000 ohms
R9—100,000-ohm linear pot (sensitivity control)
R10,R20—10 ohms, ½ watt (test points 1 & 2)
R13—27,000 ohms
R16,R24—10,000-ohm trimmer
R17—2200 ohms
R21—9100 ohms, 1%
R22—7500 ohms, 1%
R25—47,000 ohms
R30—390 ohms
R31—180 ohms
R32—5000-ohm, audio taper pot with switch
R33—120 ohms, ½ watt
R34—390 ohms, ½ watt
R37—82,000 ohms
R38—470 ohms

Capacitors
C1,C6,C11,C12,C18—10 μF, 16 volts, electrolytic
C2, C7—.01 μF, ceramic
C3, C5—.22 μF, 50 volts, Mylar
C4, C13, C19—0.1 μF, 50 volts, Mylar
C8—10 μF, tantalum
C9,C10,C15,C17—47 μF, 16 volts, electrolytic
C14, C16—1000 μF, 16 volts, electrolytic

Miscellaneous
OED1—OPB706 (Optron)
D1—1N914
D2, D3—1N4001
D4—1N4742, 12-volt, 1-watt Zener diode
LED1, LED2—Visible red LED (LED 2 not used in prototype)
D5—1N4733, 5.1-volt, 1-watt Zener diode
Q1, Q2, Q3—2N2926, 2N3904, or equal
IC1, IC4—MC1458 or 5558
IC2, IC3, IC5—NE555
IC6—7812 or LM340T-12
IC7—78L05
IC8—74LS90
IC9—74LS107
S1—SPST toggle on/off switch
S2—SPST switch (forms part of R32)
S3—DPDT mini PC-mount slide switch
M1—100-μA, 4¼-inch meter
T1—12.6 VAC at 500 mA, or greater
Cabinet plus assorted hardward, knobs, etc.

The author, Mark C. Worley, 3504 Minerva, Flint, MI 48504, has the following available: Meter with separate dial overlay $22.50; G-10 etched and drilled PC board $12.00; Optron type OPB706 sensor only, not complete assembly, $6.50. A kit of the three items listed here is $37.50. All prices are postpaid.

The enclosure is available from Tracewell Enclosures, Inc., 7032 Worthington-Galena Road, Columbus, OH 43058. Model H457, $18.95 plus $2.00 shipping and handling. Will be shipped UPS collect upon request. For further details call 1-800-848-4525.

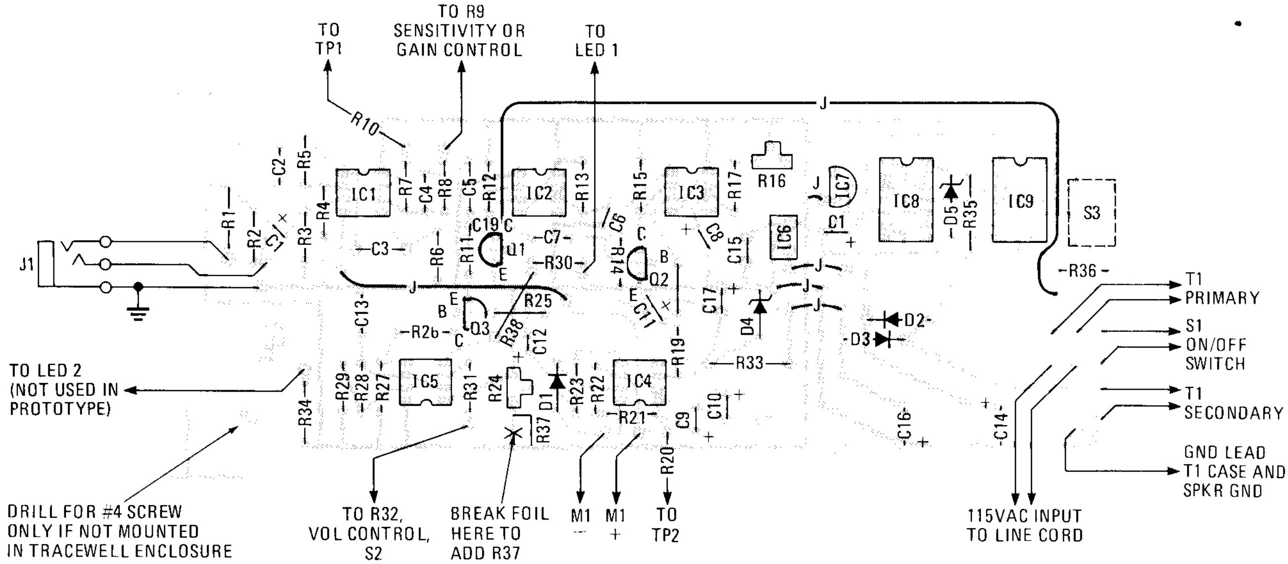

FIG. 6—HOW PARTS ARE PLACED on the PC board. Note pads that are used for making connections to meter and other parts that are not mounted directly on the board.

checks. Regulator IC7 is a low-current 5-volt regulator used to power the circuit; IC8 and IC9 together divide the 60-Hz frequency by 40 to yield a 1.5-Hz output; and R35 and D5 limit and square the 60-Hz sinewave into suitable digital levels for TTL IC's. Standard TTL IC's can be used instead of L or LS TTL types, but at an increased current drain from the nominal 10 to 12 mA.

8. The power supply is a straightforward, half-wave, dual-polarity supply. The +12-volt current drain is less than 100 mA, while the −12-volt drain is less than 10 mA, thus eliminating the need for more elaborate rectification or filtering. Voltage regulator IC6 is a standard, three-terminal unit, and D6 is a 500-mW or 1-watt, 12-volt Zener diode.

Circuit assembly

Assembling the Cardiotach is straightforward and easy with a printed-circuit board. Assembly can be done on perforated board, but it is not recommended because of the numerous circuit connections to be made. Figure 5 shows the foil pattern of the PC board. Figure 6 shows where parts are positioned.

The PC board is designed to be versatile. It can be left at its full size of 7½ × 3 inches, or cut into two boards, 5 × 3 inches and 2½ × 3 inches. The larger size is designed to fit into an enclosure that has built-in PC board slots to hold the board. I used the case manufactured by Tracewell Enclosures, Inc., described in the Parts List, but any enclosure that can accommodate the PC boards and transformer should work all right.

Begin by installing the two jumpers located near the middle of the board (so you won't forget them). The remainder of the components can be installed in any order you prefer. IC sockets are optional but a good idea. Make sure to install all diodes, capacitors, etc., with the proper polarity. A dot on the PC board is adjacent to pin 1 of the IC's and the positive end of all polarized capacitors. If you use the full-sized board, also install short jumpers from positive to positive (+ to +), from negative to negative (− to −), and the ground between the main board and the calibrator/power-supply board. If the PC board is cut in two and mounted separately, the jumpers will of course have to be longer. Additionally, run a jumper between the output of the calibrator, R36, and the junction of C5 and R11.

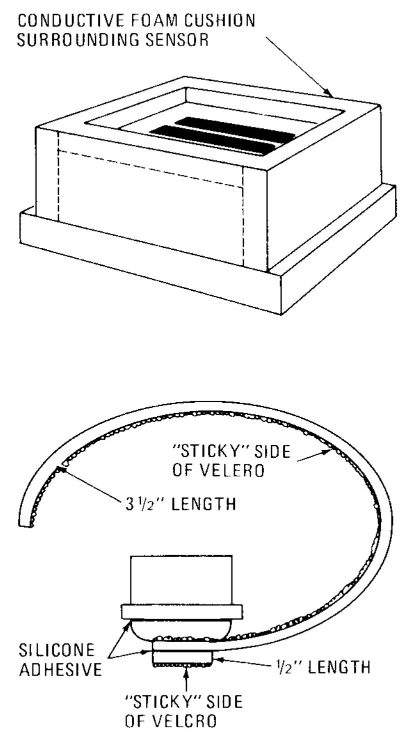

FIG. 7—HOW THE SENSOR IS ASSEMBLED. Connecting circuit leads are not shown.

Install the board (or boards) with the necessary connections to the input jack, gain potentiometer, meter, etc., in the enclosure.

Assemble the sensor as shown in Fig. 7, using a small piece of perforated board measuring ¼ × ⅜ inch. Note that pins 2 and 4 (Fig. 4) of the sensor are jumpered. Use shielded two-conductor cable or jacketed, flexible three-conductor cable; a 3- to 4-foot-long section is sufficient. Connect a stereo phone plug to one end of the piece of cable and the sensor assembly to the other end. A piece of conductive foam plastic of the type used to protect MOS devices can act as a cushion and as a

continued on page 82

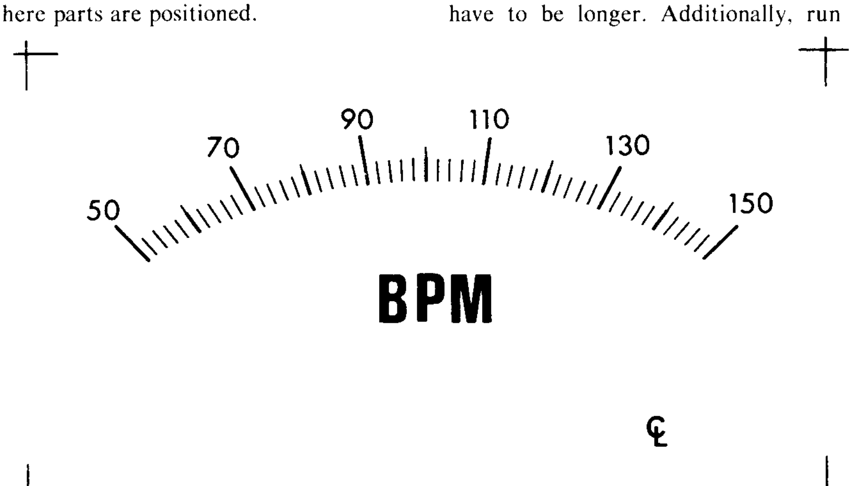

FIG. 8—METER SCALE can be photographed full-size or cut from the pages of this magazine and cemented directly onto the face of a 4½-inch 100μA meter.

HEART RATE MONITOR
continued from page 38

convenient means of grounding your finger to circuit ground. This is accomplished by connecting a short, bare wire to pins 2 and 4, bending it around and pushing it into the conductive foam after it has been glued to the perforated board. This ground connection will considerably reduce the capacitive coupling of AC hum into the sensor assembly. Now attach some self-stick *Velcro* material as shown in Fig. 7 with silicone adhesive and allow to dry thoroughly.

If you use a 4¼-inch meter as suggested, the meter overlay (Fig. 8) can be cut out and glued with rubber cement to the face of the meter. This will result in a neat, professional-appearing project. Use extreme care when disassembling the meter to prevent damage to the delicate meter movement and needle.

In the prototype Cardiotach, the on/off indicator LED, D7, was not used; this LED is optional and can be omitted if you wish. If the LED is not used, eliminate R34 from the PC board.

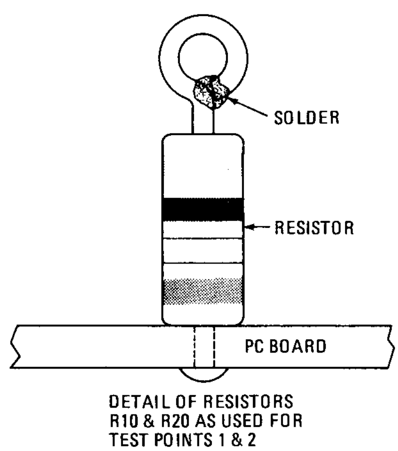

FIG. 9—TEST POINTS consist of 10-ohm, ½-watt resistors soldered upright on the board.

(An experienced builder NEVER marks or covers a meter scale. Instead, he turns the dial plate over and cements the new scale on the back.—*Editor*)

Resistors R10 and R20 are end-mounted, ½-watt resistors at test points 1 and 2. Cut the lead on one end of each resistor to ½ inch and form it into a loop, then solder the other end of the resistor snugly against the PC board as in Fig. 9. Any low-value resistor can be used or even a piece of bare wire; however, a resistor tends to be a sturdier test point.

Resistor R37 was added after the PC board was designed. You will have to break the foil between the +12V supply and trimmer R24 to add the resistor. You can omit R37, but then it becomes a little tricky to adjust R24 properly.

A DPDT switch and calibration resistor could be added to the meter to connect it to test point 2 during calibration. This would eliminate the need for a separate meter during calibration. An 18K resistor, plus the internal meter resistance, would roughly allow the meter to read 2 volts full scale. Using an additional meter, you could determine where to place the calibration mark on the meter face.

After assembly is complete and all connections are carefully checked, the unit can be calibrated.

Calibration and check-out

With the cover off, apply power to the Cardiotach, but don't plug in the sensor assembly. Place switch S3 in the calibrate position. LED1 should start flashing, and the beep tone should be heard if it is turned on. Connect a voltmeter to TP2 and adjust R16 to exactly 1.5 volts DC. The filtering action of IC4-a will slow down the action of R16. Adjust the control a little at a time and wait for the meter to reach its final value before readjusting the control. Now adjust R24 so that the meter reads 90 BPM. The Cardiotach is now calibrated. Set S3 back into the operate position and plug in the sensor assembly.

Attach the sensor to your index or middle finger, placing it against the finger pad, and wrap the self-stick straps around your finger moderately tightly. Your finger should not feel uncomfortable or cold due to excessive tightness, nor should the sensor be loose enough to slip around. Adjust the sensitivity control upward from the minimum until the LED starts flashing and beep tones are heard, then set the control a little beyond that point. After from four to six heartbeats, the meter should begin to move upward. It will overshoot, then settle back down to the correct measurement. Double triggering, and the resulting high meter reading, is usually caused by the excessive gain that results from an improperly set sensitivity control and from 60-Hz hum. If the sensitivity control doesn't seem to be causing the problem, shield the sensor from any direct AC-operated light source. Multiple triggering can also result if the power supply goes out of regulation. This can be caused by an underrated transformer or too much beep-tone volume. The beep tone is intended to be low in volume so it won't be obtrusive. Changing the value of R31 for higher volume may result in too much current drain from the +12V supply and feedback into the rest of the circuitry.

Some people with chronically cold, dry fingers may have difficulty using the Cardiotach. In these cases the sensor can be used on the earlobe, or on the back of the hand, arm or other surface that has better circulation. Adhesive tape can be used to hold the sensor in place.

One final word. The Cardiotach is a useful instrument for biofeedback and simple heart-rate monitoring. It is *NOT* a diagnostic device, nor is it designed to effect any cures. Medical problems are best left to the professionals. **R-E**

HEART RATE MONITOR

Usually, I don't read **Radio-Electronics**, but your July 1979 cover showing the Heart Rate Monitor prompted me to buy that issue. I didn't build your circuit, either, but my interest in it derives from having designed a similar circuit (digital readout) that I submitted to a design contest, and which won me the first prize! (See EDN September 5, 1977 and EDN October 20, 1977, page 79 for the circuit.) Since that circuit aroused great and unexpected interest, I am passing along the following information to your readers:

The only criticism I have of M. C. Worley's circuit is the rather slow response time (6+ seconds) because of the output filter. Also, the physical size of the circuit could be reduced by using a quad op-amp (LM324) in place of IC1 and IC4; in addition, that allows low voltage and a single supply (battery) operation. IC2 and IC3 might also be replaced by a 556 dual timer. IC5, Q3, and the speaker can also be simplified to one "Sonalert" beeper. A comparator with histeresis in front of Q1 also greatly improves noise (muscular, etc.) immunity.

My circuit updates the rate at every pulse using frequency multiplication with F/V, V/F converters, runs on one 9-volt battery, and has digital LCD display—all for less than $60. The sensor I use is a Monsanto MCA-7 ($3.95).

Since the originally published circuit turned out to have some problems, I developed an improved version obtaining $f = 1/t$ by analog division.

A copy can be obtained from Intech Function Modules (the sponsor of the contest), 282 Brokaw Road, Santa Clara, CA 95050 or directly from me. Good luck.

GERO TIMMERMANN
Multitech, P.O. Box 2277, Santiago, Chile