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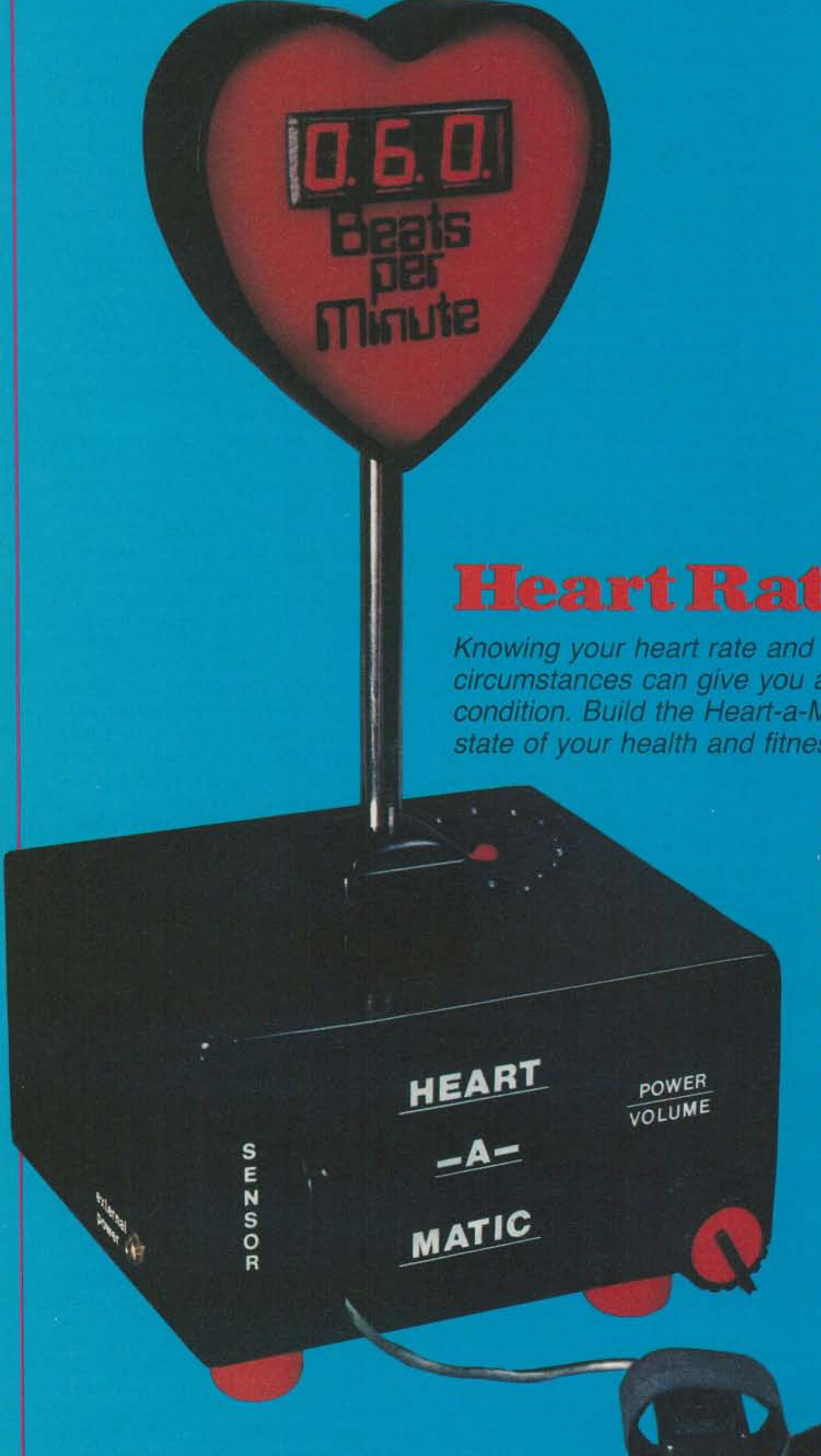

ROBERT GROSSBLATT

Heart Rate Monitor

Knowing your heart rate and how it varies under different circumstances can give you an idea of your physical condition. Build the Heart-a-Matic and keep track of the state of your health and fitness.

MEDICAL TECHNOLOGY HAS GROWN tremendously over the past 20 years. So much so that the consumer now has instruments available to him that at one time could only be found in hospitals. One such instrument, a machine to monitor a heart rate, used to occupy an entire room and required a sizeable endowment to buy; now you can build one that runs on batteries for under a hundred dollars.

The Heart-a-Matic described here gives a digital readout of your heart rate and can be built from readily available parts; it features both an audible and a visual heart-rate indication.

Design considerations

There are two basic problems that have to be overcome in designing a reliable heart-rate monitor. The first is that each heartbeat is actually made up of several beats; the second is that the heart is not crystal-controlled—even a healthy heart beats somewhat irregularly.

The heart is a four-chambered pump and consequently each heartbeat is composed of several parts (everyone is familiar with the "lub-dub" heard through a stethoscope). Figure 1 shows the various components of a heartbeat. The Heart-a-Matic is designed to integrate the "P" and "T" portions of the waveform with the "R" portion.

Even during rest, the rate at which the heart beats varies; irregularity between beats is a natural characteristic of the heart. Several beats have to be sampled and averaged to provide a result that has any useful meaning. The Heart-a-Matic heart-rate monitor uses an eight-beat sample to obtain an average reading. That number of beats was chosen as a good middle ground to minimize irregularity, on the one hand, and to provide reasonable response-time, on the other. Commercially available machines use multi-beat samples and update at the end of each sampling period. The Heart-a-Matic, however, gives a running average. In other words, whenever it adds a new beat to its sample,

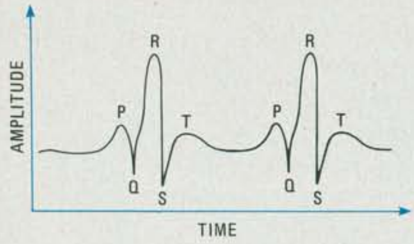

FIG. 1—THE PARTS OF A HEARTBEAT. The Heart-a-Matic integrates the P and T portions with the R portion.

it drops the first beat of the sample. Consequently, it's able to update with each beat and still give a meaningful readout.

How it works

As shown in Fig. 2, the Heart-a-Matic is composed of eight sections. A complete schematic of the device is shown in Fig. 3. The sensor, IC24, is an FPA104 infrared emitter-sensor combination in one housing. The two elements are side by side and there is no direct way for the radiation from the emitter to be seen by the detector, because they are separated by part of the case. The sensor is designed to be placed against a person's finger. The IR (*I*nfra*R*ed) radiation emitted by the LED in IC24 penetrates the outer skin-layer and is reflected back to the detector. As the heart beats, a new volume of blood is pumped into the finger and changes the amount of infrared light reflected back to the photo-transistor. That change in blood density (and, consequently, in reflected IR) is used by the Heart-a-Matic to determine the heart rate.

The input amplifier, composed of Q1 and IC1, has two main jobs. It amplifies the weak signal from the detector, and integrates the several components of the heartbeat into one pulse. The waveform emerging from the output of IC1, however, is far from being a clean single pulse. Even though the peaks and valleys of the heartbeat have been smoothed out, the pulse still has to be conditioned before it can meet the somewhat snobbish square-wave requirements of the digital circuitry that will process it later. That is a problem with *any* system that combines digital and analog techniques. While digital systems require strictly "yes" or "no" answers, the analog world usually provides just "maybes."

The conditioning circuit, consisting of Q2 and IC2, squares the wave presented to it by IC1 and raises its voltage level so it can be reliably detected by IC2, a 555 configured as a monostable multivibrator, or pulse generator. Capacitor C8 and resistor R9 give the output pulse of the 555 a width of about 100 milliseconds. That serves two purposes. First, it insures that the high level of the pulse will be seen as a logic one by the digital circuitry that follows and, second, it helps eliminate the "maybes" of the analog world. Once the 555 is triggered, it ignores all other signals for 100 milliseconds.

Should some signal ambiguity still manage to emerge from the analog portion of the heart-rate monitor, the first part of the digital portion should take care of it. Integrated circuit IC3-a is a Schmitt trigger set up as a half monostable with an output-pulse width of about 20 milliseconds. That signal is one of the two that control the interlock portion of the circuit made up of the three other NAND gates of IC3 and IC5. A set-reset latch formed by IC3-b and IC3-c controls the calculation of the heart rate started by each heartbeat detected.

When a positive pulse appears at the output of IC3-a it causes the output of the latch to go—and remain—high. That output is inverted by IC3-d and presented, through inverter IC22-f, to the clock input of IC21, a 4017 decade counter. Each pulse will make one of that IC's outputs go high in sequence.

We are sure of starting with number one because C18 performs a power-on-reset function. That means that IC21 will start with its first output at a logic-high and will then clock along with incoming heartbeats for eight beats, at which point it will reset back to one. That happens because the ninth output (which, coincidentally, is also pin 9) is also connected to the RESET pin. The outputs of the IC21 are connected in successive pairs to IC20's 2-input NOR gates. As a result, we have repeating sequential logic ones that are used in the section of the heart-rate meter that measures the period and calculates the heart-rate frequency.

Integrated circuit IC23 and its associated components provide an extremely accurate source of 60-Hz square waves that are counted by IC16-IC19, 4040 binary ripple counters. Each of the 4040's is connected to the "D" inputs of a 4508 (IC12-IC15) configured as 3-state eight-bit hold-and-follow latch.

When a heartbeat is detected, one of the outputs of IC20 goes high and causes two things to happen. The first is that its associated 4508 is enabled, and the data present at that moment at its "D" inputs is stored in the latch and presented at its "Q" outputs. The second thing that happens is that an inverter (a section of IC22) set up as a half-monostable outputs a positive pulse, lasting about 70 microseconds, that resets the 4040 to zero. The counter immediately starts counting again; but the latch is now disabled and it ignores the changing data at its inputs. The period of each heartbeat is counted at a 60-Hz rate and appears on the data bus.

Next comes a bit of arithmetic. Since the device knows the period of the heartbeat, it now has to calculate its frequency. Those are reciprocals of each other and the form of the calculation that has to be performed is also simple. Sixty Hz (cycles-per-second) times 60 (seconds-per-minute) equals 3600 cycles-per-minute. The number of beats per minute is therefore the number of cycles per minute divided by the number of cycles per beat. Since we are using a period of eight heartbeats, the magic number becomes 28,800 (8×3600). The division is carried out in two ways. The first way is sneaky and the second is interesting.

The sneaky way is to ignore the two least-significant outputs of the 4040's. By doing that we immediately divide the count by four. That also gives us the advantage of smoothing out any "bobble" in the circuitry by dropping the two least-significant figures, which is where it would show up. All we have to do now is divide by 7200 ($28,800 \div 4$), and the way that is done is one of the most interesting features of the Heart-a-Matic. The secret lies in an often overlooked, frequently misunderstood, and extremely useful type of IC—the rate multiplier.

There are two types of rate multipliers—binary and decimal. The difference between them is much the same as

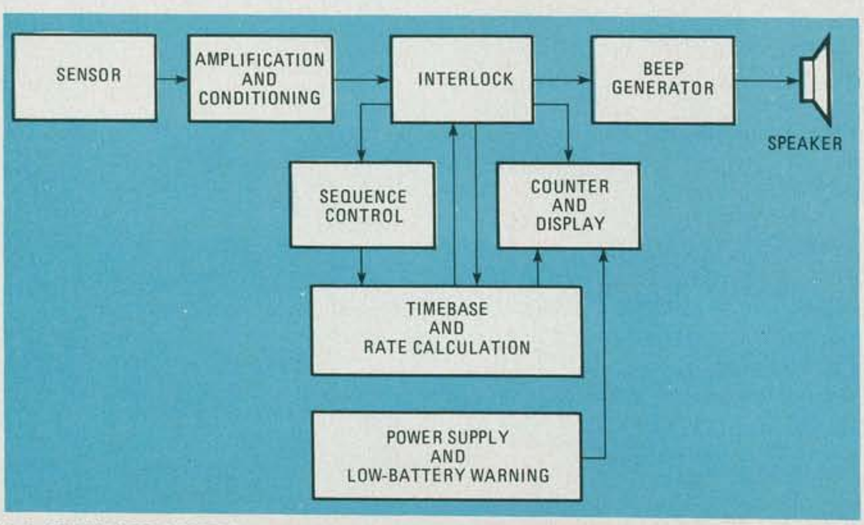

FIG. 2—THE HEART-A-MATIC is made up of eight main sections as shown in this block diagram of the device.

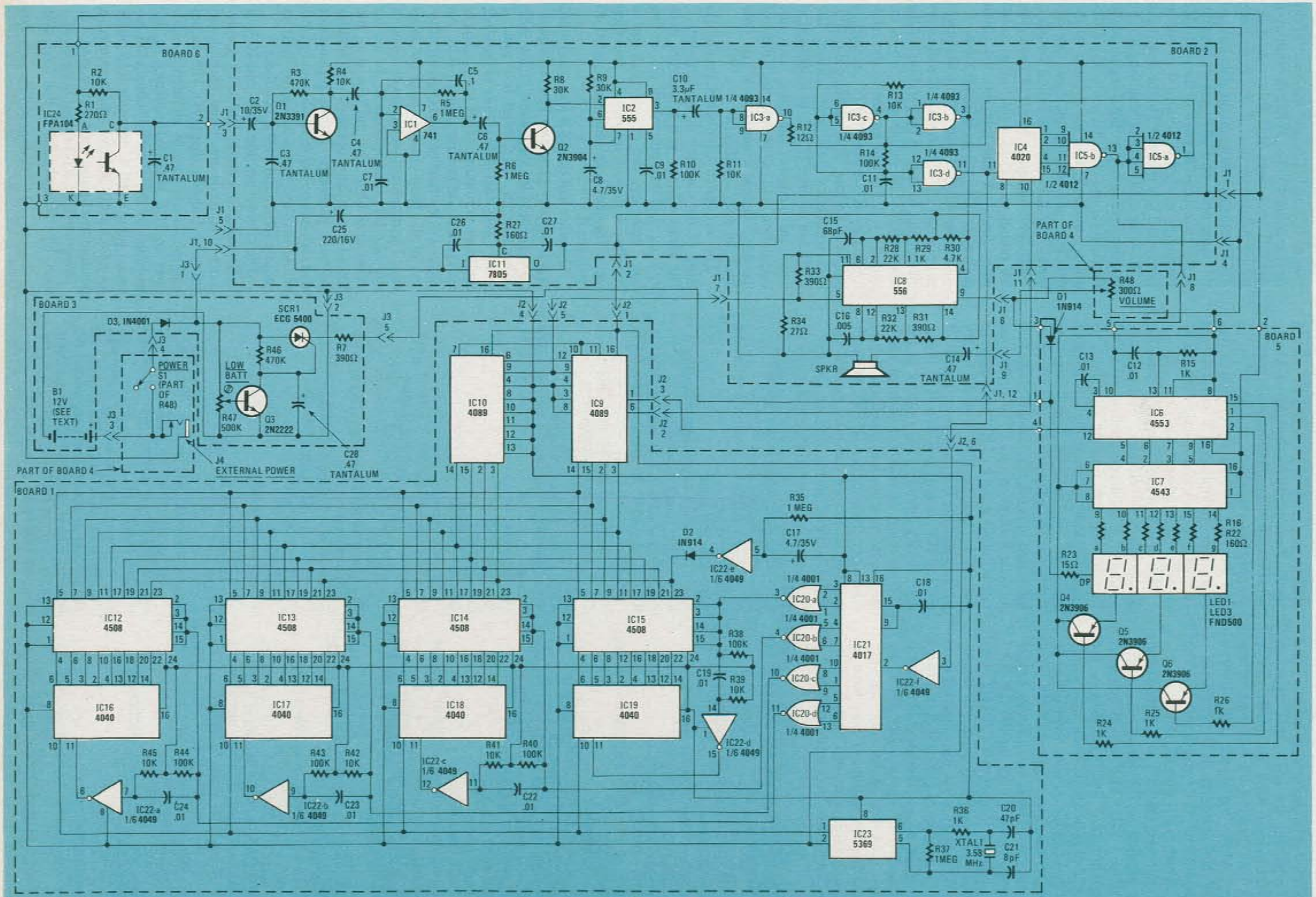

FIG. 3SCHEMATIC DIAGRAM of the Heart-a-Matic. The device is built on six separate PC boards.

the difference between a counter such as the 4520 that counts strictly in binary and its companion, the 4518, that counts in BCD (*B*inary-*C*oded *D*ecimal). Since BCD isn't needed by this part of the Heart-a-Matic, the choice is the 4089, a binary rate-multiplier (IC9 and IC10).

The 4089 has two types of outputs. The first, which we'll discuss shortly, is 1/16 the input frequency; if a 16-kHz signal were applied to the input, the output would be 1 kHz. The second output is "programmable" and is equal to 1/16 the frequency applied to its clock input *multiplied by* whatever number is applied to its binary inputs. For example, if the input frequency is 16 kHz, and a binary four is presented to the binary inputs, the 4089 will output a frequency of 4 kHz. Unfortunately, a rate multiplier will not always do exactly what you expect it to—output a number of pulses that is *always* an *average* of 1/16 the input frequency multiplied by the input number. While the example presented above works out very nicely, the rate multiplier may have to work with a frequency of 17 kHz as well. Since that figure is not evenly divisible by 2 (or multiples of two), the output pulse will be unevenly spaced and of uneven width. Fortunately for the Heart-a-Matic, however, that is unimportant because we are only interested in the number of pulses and not in a particularly smooth waveform. Rate-multipliers IC9 and IC10 are cascaded so they can handle division by an eight-bit number.

Half of IC8, a 556 dual timer, is used as an astable multivibrator, or frequency generator. With the component values indicated, the free-running frequency is about 400 kHz, although the actual figure is not critical. That's because the signal is fed to the cascaded 4089's and all we're interested in is the *ratio* of their base rate to their multiplied rate. The multiplied rate is output at pin 6 of IC9 and routed to the clock input of IC4, a 4020 binary ripple-counter. The base rate, output at pin 1 of IC9, is sent to IC6, a 4553 three-digit binary counter. The outputs of the 4020 that are decoded all go high when the counter reaches a number you should remember from earlier—7200. With all that behind us, we can now explain the device's operation much more simply.

The controlling key is the interlock section of IC3 and IC5, and the heart of the device is the 4089's. When the output of the IC3 latch goes high following a detected heartbeat, one of the octal-latch 4508's puts a number on the data bus. At the same time, two other things happen. A high is applied to pin 4 of the 400-kHz frequency generator, setting it in operation, and a low is applied to the RESET pin of IC4, the 4020 counter, enabling it. The rate multipliers begin outputting pulses to the 4020 at the rate of 1/16 the 556's frequency multiplied by the number on the data bus, and sending the base-rate frequency to IC6, the three-digit counter. When the count at the 4020 reaches 7200, the output of IC5-b, a four-input NAND gate, goes low and transfers the count present at IC6 into its internal latch.

The same signal also travels to the RESET pin, pin 13, of IC6 via C12 and clears the counter to zero in preparation for the next count. The output of IC5-b is inverted by IC5-a and returns to the latch formed by IC3-a and IC3-b, causing its output to go low. That disables the 400-kHz frequency generator, causes the 4020, via inverter IC3-d, to reset to zero and hold there for the next heart-rate calculation, and returns the clock input of the 4017 decade counter to a low state until the next heartbeat.

The sequence of events resembles those of the classic "do-nothing box." The Heart-a-Matic gets turned on, does its thing, and then turns itself off. In this case, however, the device performs a complex series of operations and then waits for the next incoming signal to retrigger it.

The other half of IC8 is also configured as a frequency generator and is frequency-modulated by the output of the 400-kHz generator. The result is a tone of about 1 kHz, that lasts as long as the other oscillator is running. That tone is fed to the speaker via volume-control R48. An unusual side-effect of that is that the duration of the beep changes with the heart rate. The reason is that the lower the heart rate, the less time it takes to do the internal arithmetic and the less time the 400-kHz oscillator operates and enables the beep generator. The beep generator also supplies power to the decimal points of the displays for a visual as well as audible indication of the heartbeat.

The counter section, IC6 and IC7, is fairly straightforward. The latter is a decoder that feeds the three multiplexed common-cathode displays. The actual multiplexing is done by an internal oscillator in IC6 whose frequency is determined by the capacitor connected between pins 3 and 4. Resistor R15 holds the RESET pin of IC6 low until it receives a positive reset-pulse from IC5-b via C12.

Inverter IC22-e is present because of a basic law of mathematics that says that

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PARTS LIST

All resistors 1/4-watt, 5% unless otherwise noted

R1—270 ohms
R2, R4, R11, R13, R39, R41, R43, R45—10,000 ohms
R3, R46—470,000 ohms
R5, R6, R35—1 megohm
R7, R31, R33—390 ohms
R8, R9—30,000 ohms
R10, R14, R38, R40, R42, R44—100,000 ohms
R12—12 ohms
R15, R24-R26, R29, R36—1000 ohms
R16-R22, R27—160 ohms
R16-R22, R27—160 ohms
R23—15 ohms
R28, R32—22,000 ohms
R30—4700 ohms
R34—27 ohms
R37—10 megohms
R47—500,000 ohms, multiturn potentiometer, PC-mount
R48—300 ohms, potentiometer, panel-mount with switch (commonly used in TV receivers)

Capacitors

C1, C3, C4, C6, C14, C28—0.47 μF, 35 volts, tantalum
C2—10 μF, 35 volts, electrolytic
C5—0.1 μF, ceramic disc
C7, C9, C11-C13, C18, C19, C22-C24, C26, C27—0.01 μF, ceramic disc
C8, C17—4.7 μF, 35 volts, electrolytic
C10—3.3 μF, 35 volts, tantalum
C15—68 pF, ceramic disc
C16—.005 μF, ceramic disc
C20—47 pF, ceramic disc
C21—8 pF, ceramic disc
C25—2200 μF, 16 volts, electrolytic

Semiconductors

IC1—741 op-amp
IC2—555 timer
IC3—4093 quad 2-input NAND Schmitt trigger
IC4—4020 14-stage binary ripple counter
IC5—4012 dual 4-input NAND gate
IC6—4553 3-digit binary counter
IC7—4543 BCD-to-7-segment latch/decoder/driver
IC8—556 dual timer
IC9, IC10—4089 binary rate multiplier
IC11—7805 5-volt regulator
IC12-IC15—4508 dual 3-state 4-bit latch
IC16-IC19—4040 12-stage binary ripple counter
IC20—4001 quad 2-input NOR gate
IC21—4017 decade counter
IC22—4049 hex inverter
IC23—5369 60-Hz timebase
IC24—FPA104 infra-red emitter/sensor array
Q1—2N3391
Q2—2N3904
Q3—2N2222
Q4-Q6—2N3906
SCR1—ECG 5400
LED1-LED3—FND500 0.5-inch common-cathode 7-segment display
D1, D2—1N914 or 1N4148
D3—1N4001
XTAL1—3.579545 MHz color-burst reference crystal
SPKR—8 ohms, 2-inch diameter
S1—SPST switch (part of R48)
J1—12-contact edge connector
J2, J36-contact edge connector
J4—subminiature N.C., chassis-mount
B1-B8—1.5-volt "AA" cell

Miscellaneous: PC boards, two "AA" side-by-side battery holders, Velcro strip, plastic for cases, wire, shielded cable, solder, etc.

The following are available from Hal-Tronix, P.O. Box 1101, Southgate, MI 48195: Set of six etched and drilled PC boards, $29.95; Board 1 (double-sided), $19.95. Add $2.00 for shipping & handling; MI residents add 4% tax.

HEART RATE MONITOR

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you cannot divide by zero. When the Heart-a-Matic is first turned on, there is no guarantee as to what data will be present on the data bus. The 4508 that controls the bus at power-up will come up with data that seems to vary with the particular IC used. In a nutshell, there is no guarantee that there won't be all zeros on the data bus when the power is first supplied. The problem is resolved by IC22-e. It is configured as a half-monostable that outputs a pulse about one and a quarter seconds long. The IC is connected, via diode D2, to the most-significant-bit on the data bus.

When power is first turned on, the output pulse insures that there is some number greater than zero on the bus. Without that half-monostable and the "Mickey Mouse Logic" (M^2L) using D2, all zeros might appear and the Heart-a-Matic would try to divide by zero. If that happened, the batteries would give out before the answer showed up in the display.

The 12-volt power supply is made up of eight "AA" cells connected in series. Its output is fed to a standard 7805 regulator used in a slightly non-standard way. Be-

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HEART RATE MONITOR

continued from page 109

cause R27 is placed on the ground leg of the regulator, we are able to trick the device into putting out six volts instead of the standard five. That operating voltage was chosen for the Heart-a-Matic to provide a compromise between battery life and reliable operation. The monitor draws an average of 60 milliamps during operation allowing long battery life.

A low-battery warning is provided by R47, Q3, and SCR1. The voltage at the base of Q3 determines the voltage drop across R46. When it reaches a particular level, enough current will flow through the resistor to provide sufficient current to trigger SCR1. When the rectifier fires, the signal is routed to the decimal points of the display with the help of another bit of M^2L logic, causing them to remain lit constantly. Diode D1 allows the beep generator to continue operating, and resistor R7 was chosen to make the decimal points light up much more brightly than they do during the heartbeat—so there will be no mistaking that the batteries are getting low and should be replaced.

The trip point of SCR1 is set with R47, a 500 kilohm multi-turn potentiometer. Once the decimal points light, the SCR's latching action will keep them lit. Note that if the Heart-A-Matic is rapidly turned on, off, and back on again, the low-battery warning will appear. That's because C25 has not had time to discharge completely and the remaining charge fools the low-battery circuit into thinking that the batteries—not the capacitor—are not putting out enough voltage. A wait of about ten seconds is sufficient to prevent that from happening.

Now that we know how the Heart-a-Matic works, the next step is to build one. We will show you just how that is done in the next part of this article. **R-E**

Heart Rate Monitor

Keep track of your heart rate—and your health. This month we'll show you how to build your own Heart-a-Matic.

ROBERT GROSSBLATT

Part 2 THE HEART-RATE MONITOR WE DESCRIBED IN the September 1982 issue of **Radio-Electronics** is intended to give an audible and visible readout of your heart rate. In that previous part we described the theory behind the device, now its time to show you how to build your own.

Construction

The circuitry of the Heart-A-Matic is broken up to fit on six circuit boards (that has been indicated in the schematic in Fig. 3). Although wire-wrap techiques can be used, you're better off using the foil patterns in Figs. 4 through 10 to produce a set of PC boards (a set of boards is also available from the supplier indicated in the Parts List). That is particularly true of board 1, which is double-sided, has a high component density, and has a lot of interconnections. Also, unless you're the sort of person who does crossword puzzles in ink, the use of IC sockets is a must. Troubleshooting the boards is virtually impossible unless the IC's can be removed—and, more often than not, unsoldering an IC will ruin it, even if it was good to begin with. Note that if you are making your own boards, the dimensions provided for boards 1, 2, and 3, are solely for reproducing the foil patterns. Once those boards are etched and drilled, they should be cut to fit the case (more on that later).

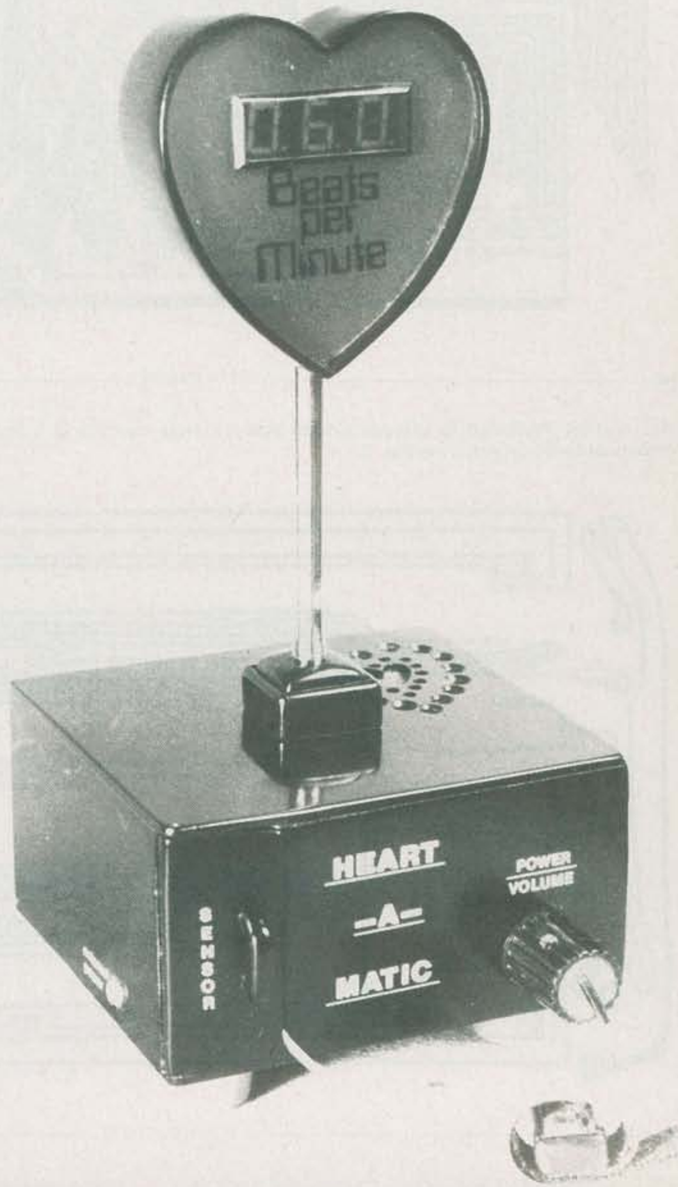
Assembly of the boards is straightforward. Refer to Figs. 11 through 16 for parts-placement diagrams. Be sure to observe the orientation of polarized components, such as electrolytic capacitors (and, of course, transistors, diodes, and IC's). Be especially careful in handling the CMOS IC's—they're sensitive to static electricity and can be "zapped," easily. If you made your own board 1 (the double-sided one) without plated-through holes, install all the feedthroughs—small pieces of wire such as resistor leads that connect one side of the board with the other—before doing anything else.

There are a few things that you should pay particular attention to. Diode D2 is tack-soldered to the component side of board 1, but holes should be drilled for its legs, anyway; it's not good practice to rely on the solder for strength. When the crystal is inserted in board 1, sufficient leg length should be left so it can be bent over at a 90-degree angle to lie parallel to the board, making its overall height the same as that of the IC's. The same goes for IC11, the voltage regulator on board 2. The speaker is mounted directly on board 2, and enough space has been left on the board to accommodate various-size speakers. Widen the hole just enough to allow the magnet of the speaker to fit snugly. Note also that there are two pins each for ground and +6-volts on the board's 12-pin edge connector.

Resistor R48 and switch S1 are a single unit and are soldered directly to board 4 (see Fig. 17). That is done because the mounting hardware is used to secure the board to the case. The foil pattern for board 4 (Fig. 8) shows where the cutouts for the edge connectors are located as well as the holes for the bolts to hold them. It may be necessary to file down the ears of the edge connectors to make them fit properly in the space provided. Put ⅛-inch spacers between the ears and the board to make sure that the connectors don't stick too far out on the rear side of the board. The spacers can be small pieces of plastic. When the edge connectors are attached, use insulated hook-up wire between the eyelets on the back of the connectors and the appropriate pads on the board.

Checkout and troubleshooting

Connect the boards together as shown in Fig. 18 and turn on the power. Verify that the regulator is putting out about 6 volts to the circuit. When power is first applied, some number will appear in the display. What that number will be depends—as mentioned earlier—on the "temperament" of the particular 4508 used for IC15. Press your finger lightly on IC24 on board



6. The Heart-a-Matic should start beeping in time with your pulse. After the ninth beat it will start displaying your heart rate. If the device fails to operate, there are several checks you can make.

It goes without saying that you should look for cold-solder joints, bad or unsoldered connections, broken traces, and other mechanical problems. Assuming that nothing is wrong there, each individual section of the unit can be checked separately.

The input section can be checked by connecting an LED from the output of IC2 through a 1K resistor to ground. If you have a logic probe, so much the better. Shine a small light on the top of IC24 on the sensor board. As you blink it on and off you should see corresponding pulses at the IC. If you don't, do the same thing and monitor the output of IC1. If the problem isn't there, connect a jumper from the regulated supply-voltage through a 10K resistor to the positive side of C2. Every time you touch C2 with the jumper you should see a corresponding pulse at the output of IC2. If you do, then the problem is with the sensor board. If you don't, check the output of IC1 again. That method should help you to find a defective IC and, if your IC's are in sockets, you should be able to replace it easily.

Board 1 is the most complex part of the Heart-a-Matic but, fortunately, it's also the easiest to check. Remove the board from its edge connector and solder a piece of hook-up wire to pin 3 of any one of 4040's. Replace the board in the edge connector and remove IC1 on board 2. Insert the other end of the wire into pin 6 of IC1's socket and turn the monitor on. If the digital circuits of the Heart-a-Matic are operating properly, you will get a display of 120 that will be updated every half-second. If that doesn't happen, make the same sort of checks you would for any digital circuit: Is the clock clocking? Is IC21 advancing with each incoming pulse? Is IC23 putting out 60 Hz? And so on. Most of the problems on the board will be found to be due to "mechanical error." Bad IC's should be way down near the bottom of your list of suspects.

After building three Heart-a-Matics, the only problems I ever encountered were mechanical ones. In any event, none of the three worked the first time I applied power, and the problem always turned out to be in the construction of the boards, not the design or the condition of the components. As far as troubleshooting the boards goes, all that can be said is that careful work always pays off...and that you'll always find the source of the problem in the last place you look.

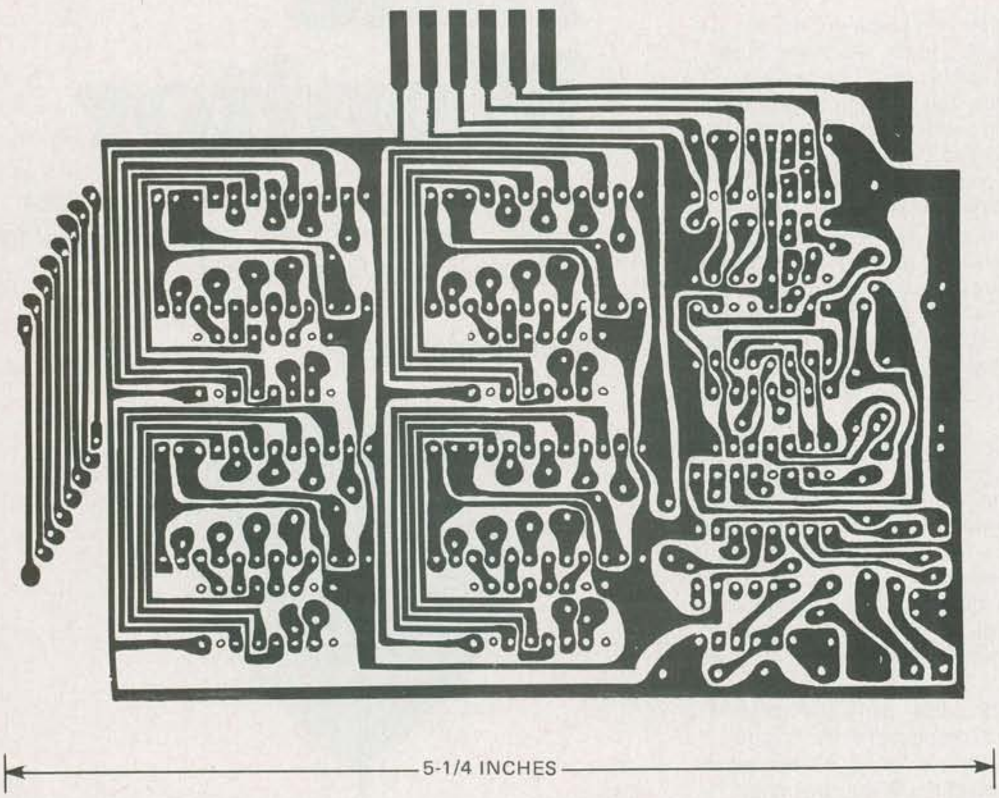


FIG. 4—FOIL PATTERN for the foil side of board 1. Note that this is a double-sided board. The component side as shown in Fig. 5.

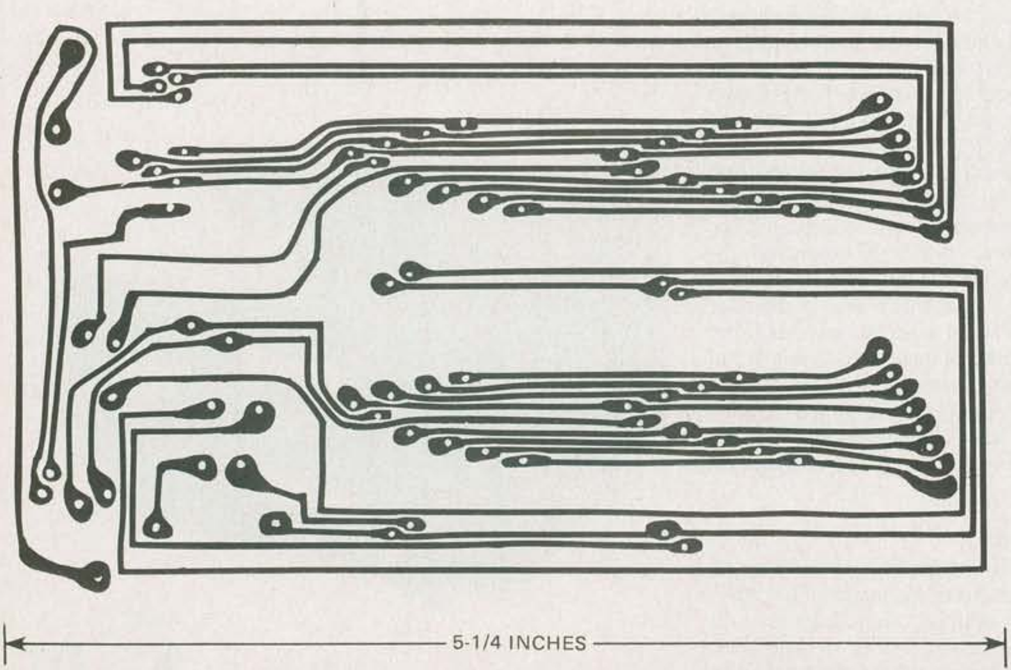


FIG. 5—COMPONENT SIDE of board 1. Note that if you etch your own boards plated-through holes or jumpers are needed (see text and Fig. 11 for more information).

Bottom case

The Heart-a-Matic's case is made entirely of ⅛-inch acrylic plastic, which can be cut and shaped using ordinary woodworking tools. Solvent-type cement (available where you buy the plastic) is used throughout to hold it together. When you're assembling the case, be sure to keep your fingers off the areas of the plastic where you apply the cement. The cement softens the plastic and nothing ruins the appearance of a project more than a fingerprint etched into the case. There are more elegant, if not quite so personal, ways of signing your work.

Figure 19 shows an exploded view of the bottom case of the Heart-a-Matic. The easiest way to assemble it is to cut the base to the exact size indicated in Table 1. The sides and front can be cut larger and then attached to it. When the cement has dried they can be sanded down to fit exactly. The top of the case is one of the last parts to be attached, and it will be discussed shortly. Make sure that the slots for the circuit boards line up correctly with the edge connectors on board 4 and that the boards can slide easily in and out of the case.

The dimensions given for the base assume that slots will be routed in the sides as shown. If you decide to use card guides instead, you will have to make the base, rear door, and other pieces larger than indicated.

There are two doors in the unit; they should be installed last (their installation will be described below). One door is at the rear to allow access to the boards and the other is in front to close the storage compartment for the sensor assembly and the shielded cable that connects it to board 4. The pieces should fit snugly enough so that friction will hold the doors closed. Cut them slightly larger than needed and then carefully sand them to the correct fit.

The circuit-board assembly is held in the case by the nut on R48 and a nut-and-bolt assembly that goes in a hole drilled

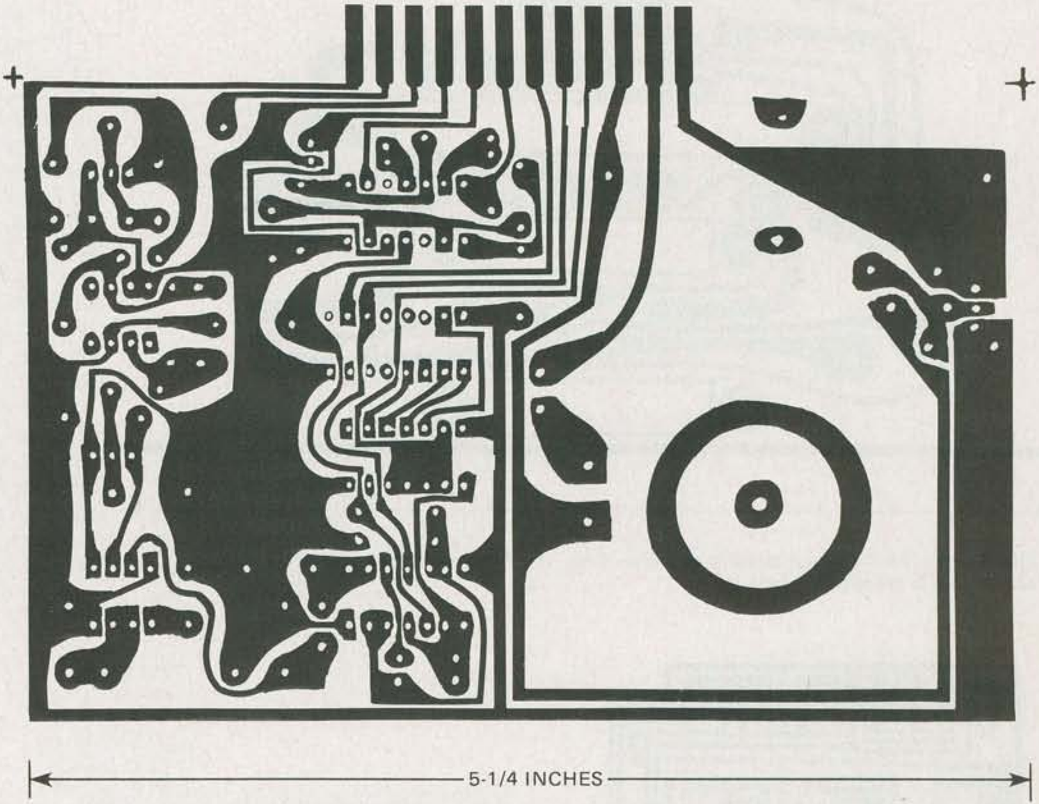


FIG. 6—FOIL PATTERN for board 2 of the Heart-a-Matic. Note that enough space has been left to accommodate a speaker (see text).

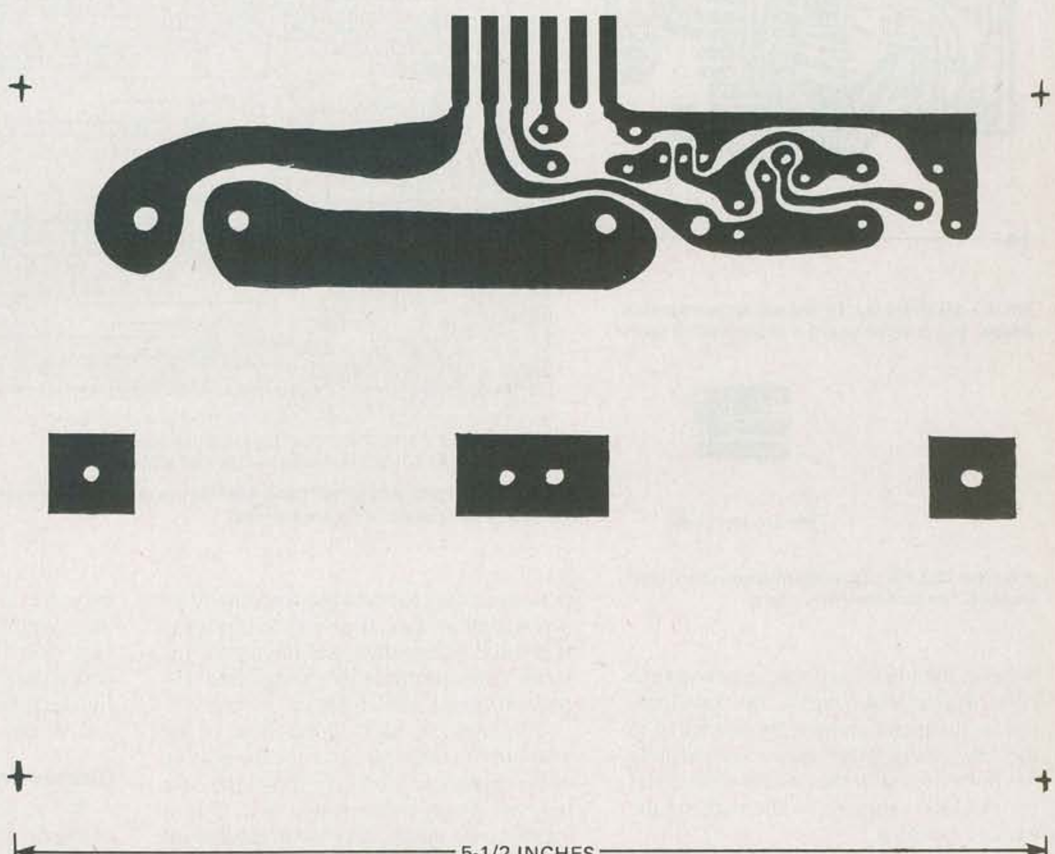


FIG. 7—MOST OF BOARD 3 is taken up by battery holders. The foil pattern for that board is shown here.

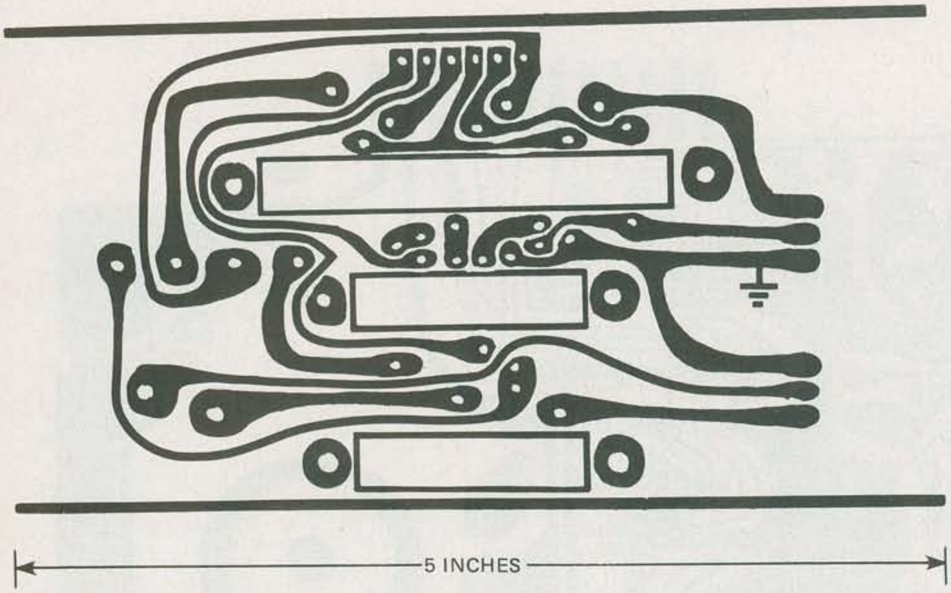


FIG. 8—FOIL PATTERN for board 4 is shown here. The three rectangles should be cut out to accommodate the edge connectors.

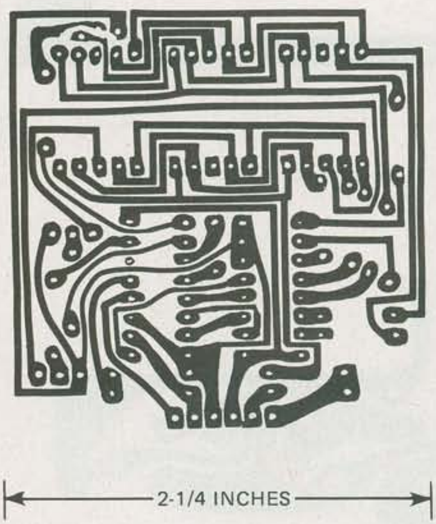


FIG. 9—AS WITH ALL OF the foil patterns in this article, this one for board 5 is shown full size.

FIG. 10—THE TINY foil pattern shown here is for board 6, the small sensor board.

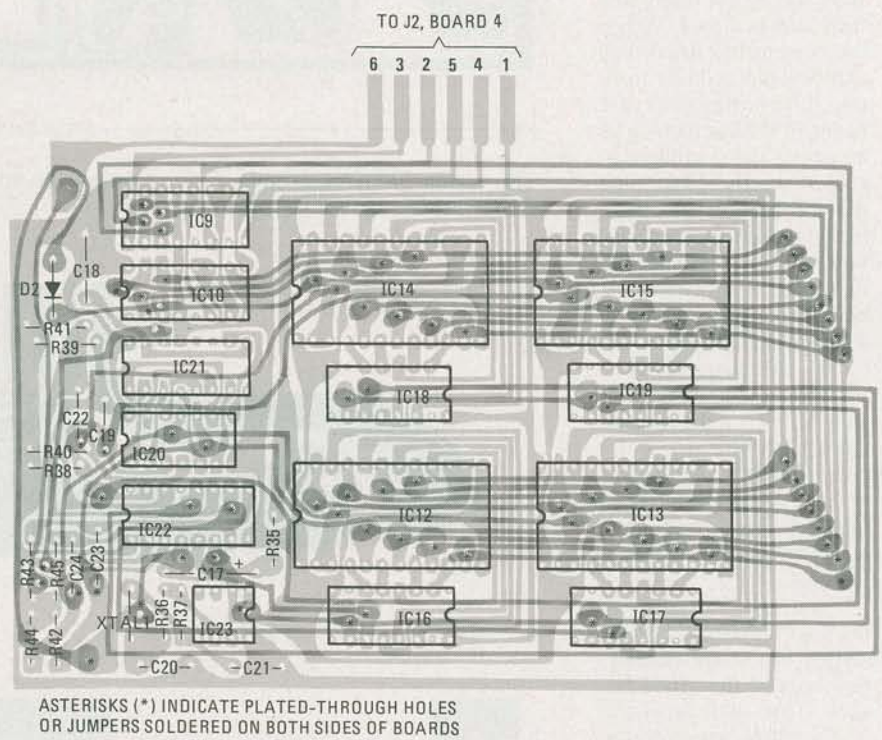


FIG. 11—PARTS PLACEMENT DIAGRAM for the main board (board 1). To prevent problems later on, the use of IC sockets is recommended.

through the top rear of the sensor storage compartment and board 4. Its exact location will depend on how the boards fit in the case. Remember that a second hole has to be drilled in the case as well, to let the shielded cable get to the pads on the back of board 4.

The last piece of advice for this part of the case concerns the rubber feet. Small pieces of plastic should be glued to the bottom of the case and the feet should be screwed into them. If you try to screw the feet directly into the case, the tips of the screws may protrude far enough into it to prevent board 3 from fitting properly.

The trickiest part of the case is the assembly of the connector for the bottom of the display section. The top of the case has two sets of holes drilled in it. One is located over the speaker located on board 2 to allow the beeps to be heard. The other is a set of six holes drilled in the center of the top for the connections that have to be made between the main case and the one that contains the display.

The six leads from the top of board 4 go to the display and are routed along the underside of the case top and inserted through the holes. The holes themselves are drilled in a pattern to accommodate the six solder tails of a piece of edge connector. The details for that are shown in Fig. 19. The wires should be soldered to the tails of the edge connector and then the edge connector should be glued to the case top using epoxy. The six edge-connector pins that protrude into the case can then be bent over flat. Once that is done, the top can be glued to the rest of the case with the solvent cement.

The doors can now be fit into place and the hinges installed. The hinges are small wire brads that are pushed into holes drilled in the doors and case as shown in Fig. 19. Don't force the brads in too far because it is easy to crack the plastic. Once they are in securely, grind the ends down so they are flush with the case. If they are too loose in the holes, secure them with a small drop of epoxy, making sure you don't inadvertantly glue the doors shut in the process. When you're finished, you can put the assembly aside and let the epoxy harden.

Display case

We've given you a choice of two types of display case—plain or fancy. The plain case is a simple box, assembled more or less in the same way as the bottom case. The fancy version, shown in Fig. 20, is

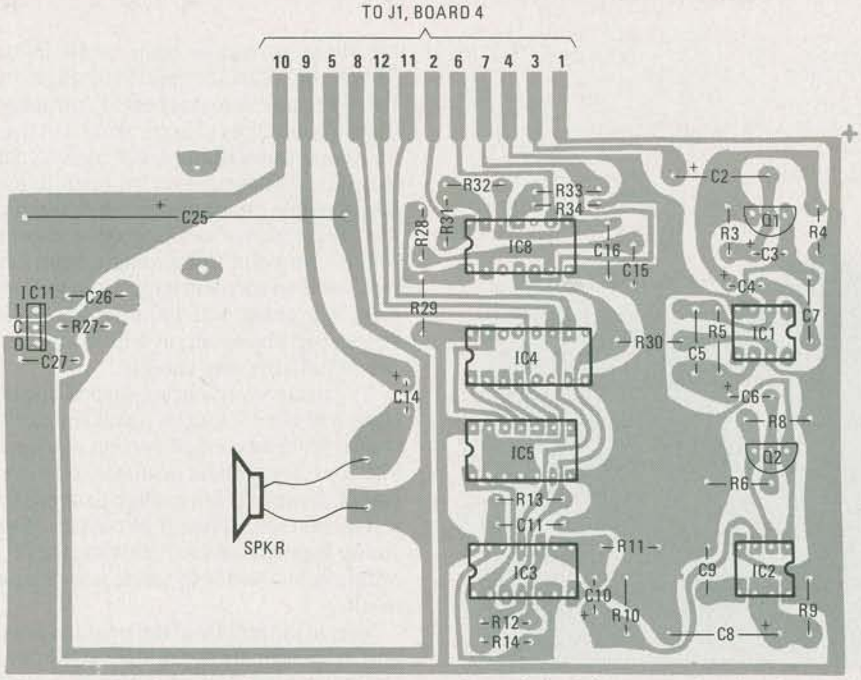


FIG. 12—WHEN MOUNTING IC11 on board 2, be sure to leave the leads long enough so that they can be bent to allow the device to lie flat.

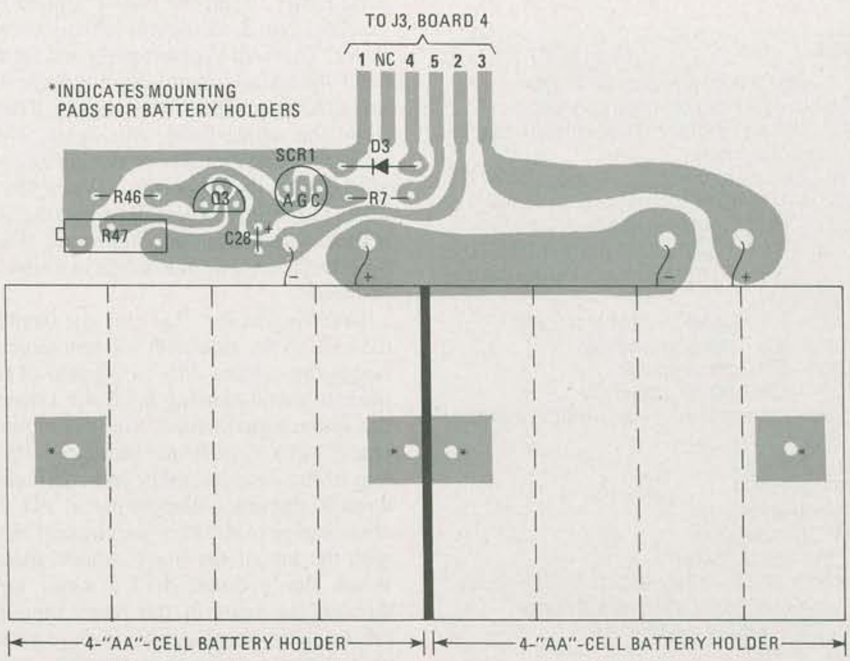


FIG. 13—THE BATTERY HOLDERS are mounted to the pads indicated by asterisks in this parts-placement diagram for board 3.

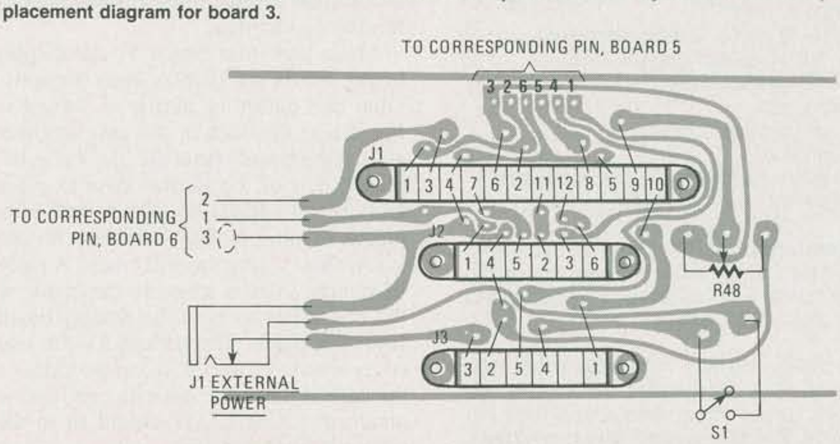


FIG. 14—IF NECESSARY, file down the "ears" of J1-J3 to allow them to fit in the space provided on board 4.

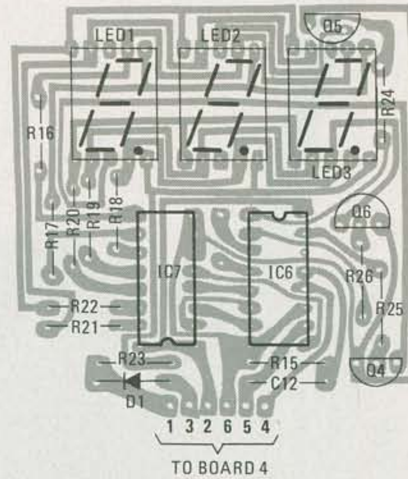


FIG. 15—PARTS-PLACEMENT DIAGRAM for board 5 is shown here.

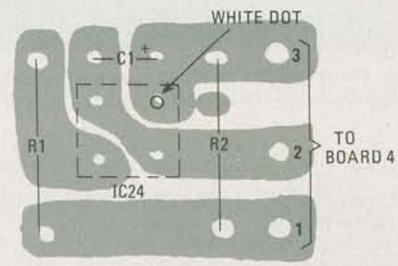


FIG. 16—BE SURE that IC24 is aligned as shown when mounting it on board 6, the sensor board.

the one that will be described here. With the exception of forming the plastic for the heart-shaped case, construction details for both types are essentially the same. If you build the plain case, be sure it is large enough to hold the display board comfortably; dimensions for the heart-shaped case are given in Table 2.

Like the bottom part of the case, the display case is made of acrylic plastic. A short piece of ⅜-inch diameter chrome-plated copper tubing is used to connect the two cases. Figure 21 is a template for the front of the heart, which is made from a piece of ¼-inch opaque red plastic. A rectangular piece of ¼-inch *transparent* red plastic is used as a lens; it is cut as indicated and glued in the display cutout. Be careful to get none of the solvent cement on the surface of the lens. The lens should stick out in front about ⅛-inch so small strips of black plastic can be glued to the edges to form a bezel. The lettering is standard dry-transfer type; I have found that it is much easier to apply before the lens is glued to the case. After the lettering is applied, spray the case with clear lacquer to protect the type.

The side of the heart-shaped display case is made from a single piece of black acrylic plastic. **Being very careful and wearing protective gloves,** heat the strip and bend it to fit around the heart. **The plastic gets very hot,** so protective gloves are a must. The easiest way to heat

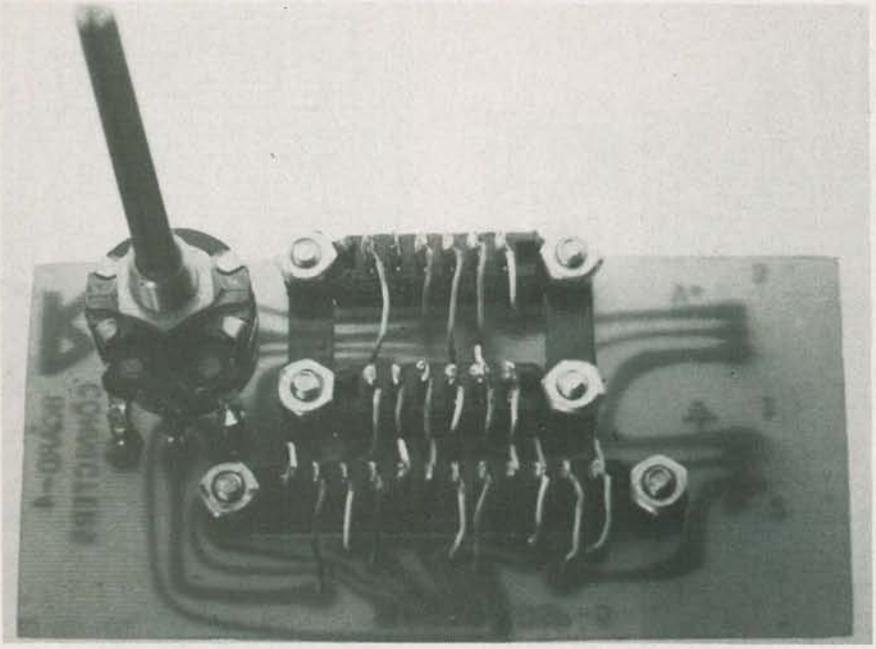


FIG. 17—RESISTOR R48 and switch S1, a single unit, are soldered directly to board 4. That unit's mounting hardware is used to secure the board to the case.

PARTS LIST

All resistors ¼-watt, 5% unless otherwise noted
R1—270 ohms
R2, R4, R11, R13, R39, R41, R43, R45—10,000 ohms
R3, R46—470,000 ohms
R5, R6, R35—1 megohm
R7, R31, R33—390 ohms
R8, R9—30,000 ohms
R10, R14, R38, R40, R42, R44—100,000 ohms
R12—12 ohms
R15, R24-R26, R29, R36—1000 ohms
R16-R22, R27—160 ohms
R16-R22, R27—160 ohms
R23—15 ohms
R28, R32—22,000 ohms
R30—4700 ohms
R34—27 ohms
R37—10 megohms
R47—500,000 ohms, multiturn potentiometer, PC-mount
R48—300 ohms, potentiometer, panel-mount with switch (commonly used in TV receivers)

Capacitors
C1, C3, C4, C6, C14, C28—0.47 µF, 35 volts, tantalum
C2—10 µF, 35 volts, electrolytic
C5—0.1 µF, ceramic disc
C7, C9, C11-C13, C18, C19, C22-C24, C26, C27—0.01 µF, ceramic disc
C8, C17—4.7 µF, 35 volts, electrolytic
C10—3.3 µF, 35 volts, tantalum
C15—68 pF, ceramic disc
C16—.005 µF, ceramic disc
C20—47 pF, ceramic disc
C21—8 pF, ceramic disc
C25—2200 µF, 16 volts, electrolytic

Semiconductors
IC1—741 op-amp
IC2—555 timer
IC3—4093 quad 2-input NAND Schmitt trigger
IC4—4020 14-stage binary ripple counter
IC5—4012 dual 4-input NAND gate
IC6—4553 3-digit binary counter
IC7—4543 BCD-to-7-segment latch/decoder/driver
IC8—556 dual timer
IC9, IC10—4089 binary rate multiplier
IC11—7805 5-volt regulator
IC12-IC15—4508 dual 3-state 4-bit latch
IC16-IC19—4040 12-stage binary ripple counter
IC20—4001 quad 2-input NOR gate
IC21—4017 decade counter
IC22—4049 hex inverter
IC23—5369 60-Hz timebase
IC24—FPA104 infra-red emitter/sensor array
Q1—2N3391
Q2—2N3904
Q3—2N2222
Q4-Q6—2N3906
SCR1—ECG 5400
LED1-LED3—FND500 0.5-inch common-cathode 7-segment display
D1, D2—1N914 or 1N4148
D3—1N4001
XTAL1—3.579545 MHz color-burst reference crystal
SPKR—8 ohms, 2-inch diameter
S1—SPST switch (part of R48)
J1—12-contact edge connector
J2, J36-contact edge connector
J4—subminiature N.C., chassis-mount
B1-B8—1.5-volt "AA" cell

Miscellaneous: PC boards, two "AA" side-by-side battery holders. Velcro strip, plastic for cases, wire, shielded cable, solder, etc.

The following are available from Hal-Tronix, P.O. Box 1101, Southgate, MI 48195: Set of six etched and drilled PC boards, $39.95; Board 1 (double-sided), $19.95. Add $2.00 for shipping & handling; MI residents add 4% tax.

the plastic is over an open candle flame. Move the plastic rapidly through the flame to make sure it is heated uniformly. If the plastic starts to burn, remove it from the flame **immediately** and blow it out. Whenever working over an open flame, take sensible precautions such as wearing the correct gloves and protective glasses. There's no point to building a heart-rate monitor if an accident happens to you and there's nothing left to monitor. In all seriousness, however, as with any project you should be very careful.

I've made several heart-shaped display cases and have found its much simpler to create the bend a small portion at a time. Plastic is an excellent insulator so while a part of the strip is hot enough to bend, the rest remains cool enough to hold its shape and be handled safely. Following the procedure below will help assure you of good results.

Start in the middle of the strip and make the first bend in the top middle of the case. Don't force the plastic to bend, because it will snap; when it's hot enough it will bend easily. Bend the plastic around the case and then dunk the whole thing in cold water. That will cool it rapidly and set the bend. Keep holding it until the shape has set or the strip will deform and you'll have to do the whole thing over again. Now make the bend around one side of the case all the way to the bottom. When that's done, cut off the excess plastic so the end is flush with the bottom of the case. Then form the other side of the case in a similar fashion.

Referring to Fig. 21, glue the front of the case to the side with solvent cement. Apply the cement only to the rear of the piece to avoid marring the front. Glue in the inner support-piece for the chrome pipe. Drill a ⅜-inch hole through the bottom of the case assembly and continue it through the inner support-piece. Put the chrome pipe in and keep the end of it flush with the top of the inner support-piece. When that's done, drill a small hole through the back of the inner support-piece and the chrome pipe. Push in a wire brad that has been covered with epoxy and set the assembly aside so the epoxy has time to harden.

Make sure that board 5, the display board, fits in the display case correctly. Glue two pieces of plastic as shown in Fig. 21 to the back of the case at either side of the board. Hold the black acrylic-plastic rear of the display case in place and drill two holes through it into those pieces of plastic. The holes are for the screws that secure the rear cover. A piece of sponge foam is glued to the inside of the rear cover to hold the display board firmly in place. The pattern for the rear cover should be traced, using the sides of the case as a pattern, once the red heart is attached. LED1-LED3 should fit in the cutout behind the lens.

Drill a ⅜-inch hole in the center of a

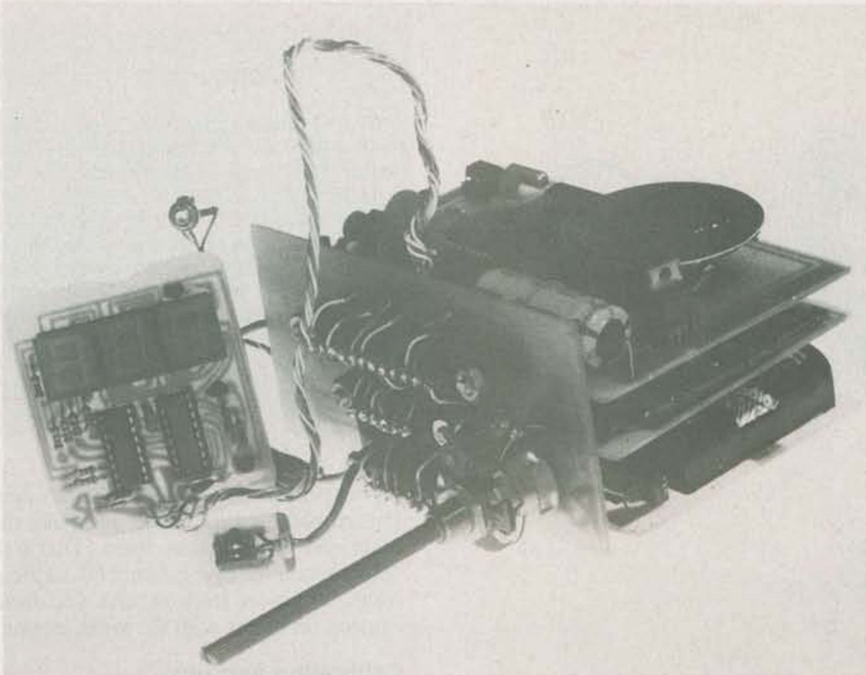


FIG. 18—WHEN ALL OF THE BOARDS are completed, they are connected together as shown here.

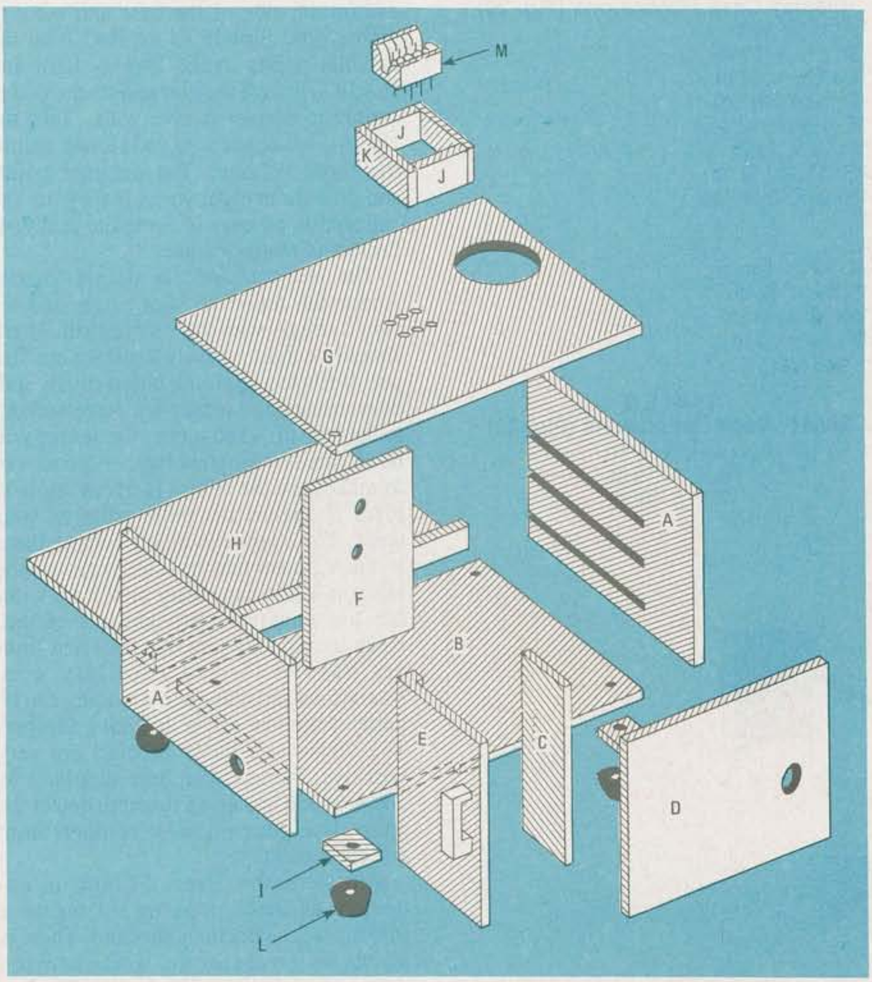


FIG. 19—EXPLODED VIEW of the Heart-a-Matic's bottom case. The dimensions for that case are given in Table 1.

¾-inch-square piece of black plastic and slide it onto the bottom of the chrome pipe. That is the top of the assembly that connects the display case to the base. Route the wires from board 5 through the pipe and solder them to a small piece of double-sided circuit board with three "fingers" on each side as shown in Fig. 20. Cut the wires from board 5 about six inches longer than necessary for a tight fit; they will be pulled up inside the display case when the assembly is finished and will allow the board to be removed from the case without your having to unsolder anything. Make sure you solder the wires in the same order you did on the matching piece of edge connector mounted on the top of the bottom case. Use an ohmmeter to verify that the wires go to the proper places. Assemble the rest of the display base, making sure that the ears on the circuit board fit snugly in the slots you have cut in the side pieces. The plastic parts can be assembled with solvent cement but the slots will have to be filled with epoxy. When the whole assembly has set, sand it down smooth for best appearance.

The dimensions of the plug retaining walls on the top of the case should be measured with the display case plugged into its connector. It is important that they be high enough to provide support. Once they are cut and glued into place, you're almost finished. All that's left is the small case for the sensor board.

TABLE 1
Bottom Case Dimensions (Fig. 19)

A: 4¾ × 2¾ in.
B: 5⅛ × 4¾ in.
C: 1 × 2⅝ in.
D: 4⅛ × 2¾ in.
E: 2¾ × 1¼ in.
F: 2⅝ × 4¼ in.
G: 5⅜ × 4⅞ in.
H: 4¾ × 2¾ in.
I: 1 × 1 in.
J: ⅜ × 1 in.
K: ⅜ × 1¼ in.
L: 1-in diameter
M: 6-connect double-sided .156 in. center edge connector

Sensor case

The sensor board is housed in the case as shown in Fig. 22. Dimensions are given in Table 3. Use about two feet of shielded cable to connect the sensor board to board 3. To assemble the sensor, attach a strip of Velcro to the bottom of the case with epoxy. The strip should be long enough to wrap around your finger and attach to the bottom of the case. Use one part of the Velcro material (it comes in two parts) for the strip and attach a small piece of the other part to the strip on the bottom of the case. Cut a piece of conductive foam to fit inside the case and slit it so the sensor, IC24, can poke through. Sol-

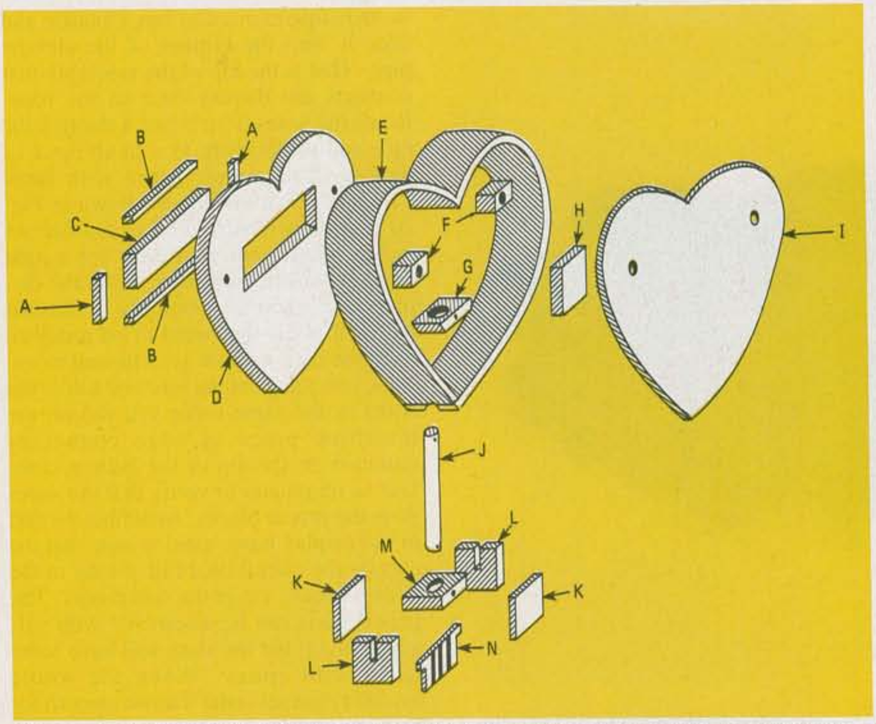


FIG. 20—EXPLODED VIEW of the heart-shaped display case and its connector. The dimensions are given in Table 2.

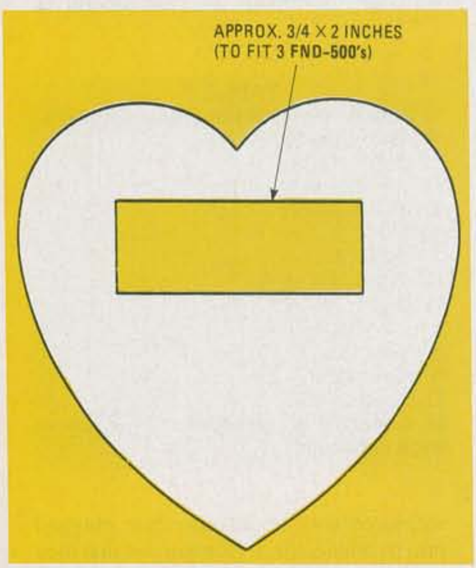


FIG. 21—USE THIS TEMPLATE for the front of the heart-shaped display case.

TABLE 2
Display Case Dimensions (Fig. 20)

A: ¾ × ⅛ in.
B: 2⅛ × ⅛ in.
C: 1⅞ × ¾ in.
D: See Fig. 20
*E: 1⅜ × 12¼ in.
*F: ½ × ⅜ in.
*G: 1⅛ × ¾ in.
*H: 2 × 2 in. foam
*I:
*J:
K: ¾ × 1 in.
*L: ¾ × ¾ in.
*M: ¾ × ¾ in.
*N: ¾ × ½ in.
*: See text

TABLE 3
Sensor Case Dimensions (Fig. 22)

A: ½ × 1 in.
B: ½ × ½ in.
C: 1 × ¾ in.

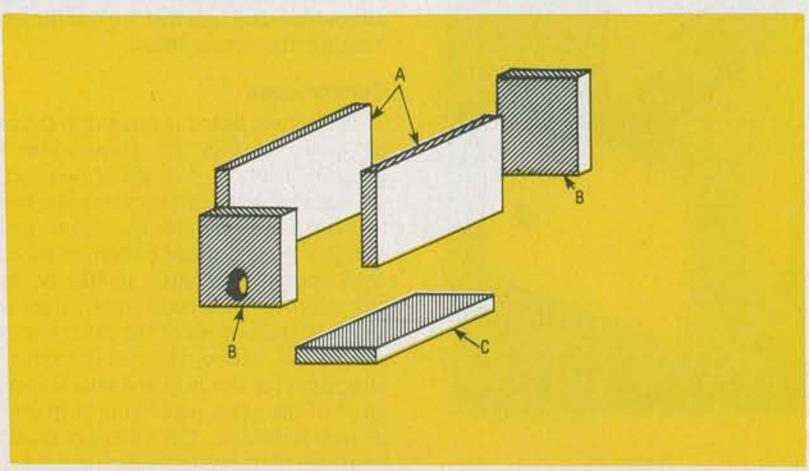


FIG. 22—THE DIMENSIONS for the small sensor case shown here are given in Table 3. Be sure to drill a hole for the connecting cable.

OOOOOOPS

Several errors appeared in Part 1 of the Heart-a-Matic construction article in the September 1982 issue. The correct value for capacitor C25 is 2200μF, 16 volts—not 2200μF. Jack J4 should be wired so that the battery is out of the circuit when a plug carrying external power is inserted. The sentence on page 48 that reads in part..."a rate multiplier will not...output a number of pulses that is *always* an *average*..." is wrong—it will. Finally, the correct price for the set of six PC boards is $39.95.

der a small piece of hook-up wire to the ground plane on the board and poke the other end of it into the foam. That will help prevent the ever-present 60-Hz field from the power lines around you from causing problems with the input section.

Calibration and use

The Heart-a-Matic needs no calibration other than setting the low-battery-warning trip-point by adjusting R47 on board 3. Connect a variable power-supply to the unit at J1 (EXTERNAL POWER) on the side of the case and set it to eight volts. Slowly adjust R47 until the decimal points in the display light and stay lit. Turn off the unit and set the power supply to deliver twelve volts. Turn the Heart-a-Matic back on and slowly reduce the input voltage. The decimal points should light at eight volts. If they do, the calibration process is complete and your project is ready for use.

The Heart-a-Matic is simple to use. Attach the sensor to your finger and secure it snugly with the Velcro strip. There should be light pressure against your finger. If it's too tight, the blood supply will be restricted and the sensor will have nothing to detect; if it's too loose, the sensor will be affected by ambient light. A good way to make sure the sensor is operating is to place it against the pulse-point in your wrist. The change in blood volume there is much greater than in your finger and the Heart-a-Matic can easily pick it up without too much concern about pressure. Keep in mind the fact that different fingers have different capillary configurations and that often a reading can be gotten from one finger and not a another. The sensor and input circuitry are very sensitive, though, and there shouldn't be any problem in using a finger to detect the pulse. I've gotten reliable readings from my cat's paws!

Although the Heart-a-Matic is extremely accurate, it is by no means a substitute for a doctor's checkup. There is all the difference in the world between data and diagnosis. While the Heart-a-Matic can tell you what your heart rate is, only your doctor can tell you what it means. **R-E**