Electronics + Fitness = Health

Heart Rate Monitor to

A quick and convenient way of measuring your heart rate can be useful in many circumstances. Our Heart Rate Monitor provides performances comparable to commercially available models at a much lower cost, and features a digital display in Beats Per Minute, a selection of two measurement periods and easy calibration. The sensor used to detect the heart beat slips quickly onto a finger or wrist for comfortable use, and the instrument incorporates some ingenious principles which could be put to use in many other applications.

by JOHN CLARKE

An accurate and reliable Heart Rate Monitor has many uses. Those undertaking exercise programs, practising relaxation or yoga, and anyone interested in their own state of health will find that a measurement of their heart rate is a valuable piece of information.

Interesting and useful information can be gained by checking the heart rate before and after exercising, or by continuously monitoring the pulse while using an exercise bike or similiar device. It is also interesting to note the change in heart rate after a cup of coffee or a glass of beer and in particular the slower "resting heart rate" which results from increased fitness after a sustained exercise program.

Generally the heart rate is related to a person's level of tension, anxiety or excitement, and can be used as a measure of the degree of stress or relaxation. Some readers may be interested in taking advantage of this fact to use the Monitor to measure and control their own degree of tension, or less seriously, as the basis for lie detection (stress monitoring equipment).

Many professional heart rate monitors use electrodes placed on the body to detect the electrical activity of the heart. This approach makes the equipment inconvenient to use, quite apart from the fact that $pecial (expensive) electrodes are necessary. Our monitor, however, is simple and convenient. It measures the tiny expansion and contraction of the arteries of the hand caused by pumping action of the heart. The monitor detects this variation using an optical pickup. An instrument of this type is commonly known as an "optical plethysmograph", from the Greek "plethysmos", an enlargement.

Before going on it might be best to mention that the equipment is completely safe. There is no electrical connection of any kind between the instrument and the person being monitored. A finger stall containing an infrared LED and a photodiode is slipped over the finger of the "patient" and the heart rate is read in beats per minute from the digital display.

The digital readout of the HRM will display heart rates from 30 to 240 Beats Per Minute (BPM), more than adequate for the heart beat variation of healthy people. The normal "rest heart rate" is generally taken to be 70 BPM for an adult. However, this can be much higher in the case of children and possibly down in the 30's for a really fit athlete. Any heart rate outside this range will result in an "E" on the display. This can also occur when first setting up the HRM.

Basically the monitor operates as a period meter which counts the number of clock pulses of a known frequency between heart beats. The faster the heart rate, the fewer clock pulses counted; the slower the heart rate the greater the number of clock pulses counted. This gives an inverse value to what we want to display. (A fast heart rate will give a low reading and a slow heart rate will give a high reading.)

Pictured above is the Heart Rate Monitor together with the wrist-strap sensor. It can be used during any stationary exercise such as pedalling an exercise bike, as pictured at top left (Photo courtesy of "Vital" magazine).

& Happiness!

Build

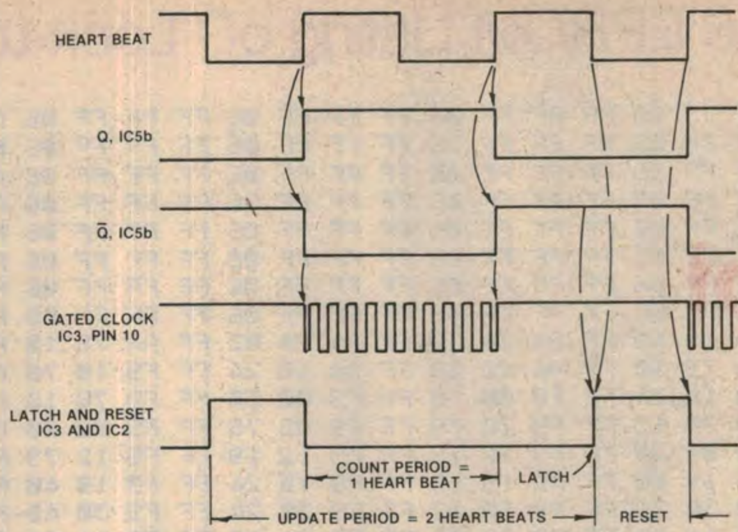

FIG. 1 : TIMING DIAGRAM FOR "TWO HEART BEAT" UPDATE PERIOD

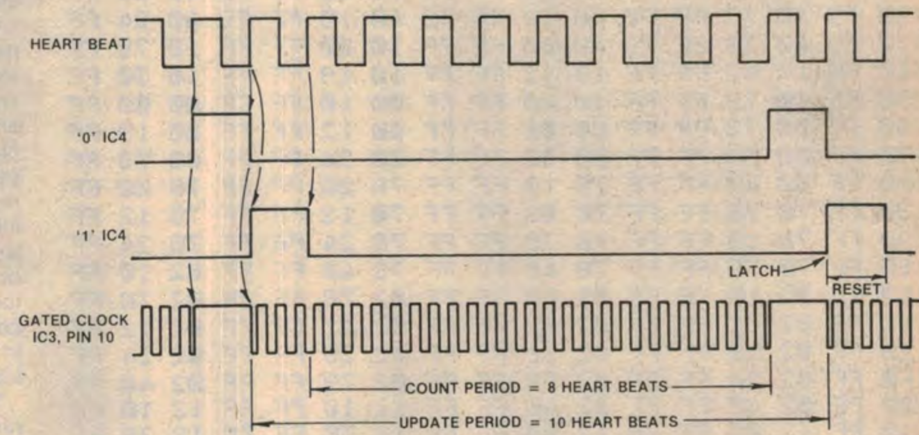

FIG. 2 : TIMING DIAGRAM FOR "TEN HEART BEAT" UPDATE PERIOD

To overcome this problem a look-up table, stored in non-volatile memory is used. The look-up table inverts the numerical value of the clock pulses counted between heart beats to give a true Beats Per Minute reading.

The circuit of the Heart Rate Monitor can be divided into four sections. These are the detector and amplifier, the counter, the look-up table and display, and the power supply section. We will look at each section in turn.

The optical detector consists of an infrared light emitting diode (IRLED) and a photodiode. The IRLED is run continuously at about 6mA. In operation the sensor assembly is arranged so that light from the IRLED penetrates the finger of the person being monitored and is reflected by the finger bone and received by the photodiode. The intensity of the reflected light will be modulated by the expansions and contraction of the arteries of the finger in response to heart beat pulsations, and this modulation will be detected by the photodiode and amplified by IC8c.

IC8c forms a DC amplifier with its bandwidth restricted above 4.8Hz by the .033μF Capacitor across the 1MΩ biasing resistor. The output of IC8c is fed to two stages of amplification, IC8d and IC8a. Both these stages have 0.48Hz high pass filters at their inputs and 4.8Hz low pass filters across the feedback path, and are AC coupled with gains of about 100. The stage formed by IC8a however, has a gain control which can reduce the gain of that stage to 10.9. The high and low pass filters around these amplifiers allow only heart beat frequencies to be processed through the circuit, and heavily attenuate any other frequencies, preventing interference from other modulated light sources, the mains etc.

Following the amplification stages is a Schmitt trigger formed by IC8b. This transforms the amplified signal from the sensor into a square waveform. The output of the Schmitt trigger swings between zero and 12 volts, but is clamped to 5.1 volts by a zener diode to allow the signal to be fed to the following digital circuitry. The output of the Schmitt trigger also drives the righthand decimal point of the display directly, to indicate that a heart beat signal is being correctly received by the amplifier circuitry.

At this point we should mention that the power supply for the op amps of IC8 is derived in a somewhat unusual way. Since we have +5 volts already at the power supply it might be expected that we would use these for the op amp supply. However in doing this current loops can be formed which will upset the op amp circuitry. Remember that we have amplifier gains near one million! To prevent such problems, the positive 12 volt supply rail is regulated to 5.6 volts and filtered with a 22μF capacitor to supply the reference to the op amps. The positive supply is then 12 volts and a steady reference voltage is assured for the op amps.

From the output of the Schmitt trigger the heart beat signal is passed via switch S2 to counter IC4 and flipflop IC5b. Switch S2 selects either the heart beat signal or the calibration signal as the driving source for the counter. IC4 is a decade counter, so that the two outputs, pins 2 and 3, will go high every 10 heart beats. As shown by the timing diagram, Fig. 2, this will allow the clock output to be gated to counter IC3 for a time corresponding to eight heart beats.

Flipflop IC5b produces a pulse with a length of one heart-beat period and, as will be seen from Fig. 1, the output of the clock is gated to count IC3 for a counter period of a single heart beat. The count is latched and the counter reset every two heart beats.

This arrangement allows us a choice of two counting and update periods for the monitor, selected by the switch S1. With S1 in position one, the clock signal derived from the 555 timer, IC6, (set to 1024Hz by the 22kΩ trimpot and 68kΩ resistor) and counter IC3 will be driven by the output of IC5b.

1024Hz was chosen as the frequency for this count as it takes eight clock cycles to bring output Q4 of IC3 (the least significant bit of the count) high. Eight clock cycles multiplied by 256 are required to cycle through the whole of the look-up table of IC1 to reach the uppermost memory location, or 30 BPM. This corresponds to 2048 clock cycles in two seconds, or 1024Hz.

The clock signal to pin 10 of IC3 is gated by IC9a when the Q-bar output of IC5b or pin 3 of IC4 goes high. The ad-

2708 EPROM Listing of "Look-up" table for circuit

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0000 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0010 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0020 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0030 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0040 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0050 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0060 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0070 FF FF 06 FF FF FF 06 FF FF FF 06 FF FF FF 06 FF
0080 A4 19 40 FF A4 30 30 FF A4 24 02 FF A4 79 10 FF
0090 A4 79 30 FF A4 40 00 FF A4 40 24 FF F9 10 78 FF
00A0 F9 10 24 FF F9 00 78 FF F9 00 30 FF F9 78 10 FF
00B0 F9 78 12 FF F9 78 79 FF F9 02 78 FF F9 02 30 FF
00C0 F9 02 40 FF F9 12 78 FF F9 12 19 FF F9 12 79 FF
00D0 F9 19 00 FF F9 19 12 FF F9 19 24 FF F9 19 40 FF
00E0 F9 30 78 FF F9 30 12 FF F9 30 24 FF F9 30 40 FF
00F0 F9 24 00 FF F9 24 02 FF F9 24 19 FF F9 24 24 FF
0100 F9 24 40 FF F9 79 00 FF F9 79 02 FF F9 79 12 FF
0110 F9 79 30 FF F9 79 79 FF F9 79 40 FF F9 40 00 FF
0120 F9 40 78 FF F9 40 12 FF F9 40 19 FF F9 40 24 FF
0130 F9 40 79 FF F9 40 40 FF FF 10 00 FF FF 10 78 FF
0140 FF 10 02 FF FF 10 12 FF FF 10 19 FF FF 10 30 FF
0150 FF 10 79 FF FF 10 40 FF FF 00 10 FF FF 00 00 FF
0160 FF 00 78 FF FF 00 02 FF FF 00 12 FF FF 00 19 FF
0170 FF 00 30 FF FF 00 30 FF FF 00 24 FF FF 00 79 FF
0180 FF 00 40 FF FF 78 10 FF FF 78 00 FF FF 78 00 FF
0190 FF 78 78 FF FF 78 02 FF FF 78 12 FF FF 78 12 FF
01A0 FF 78 19 FF FF 78 30 FF FF 78 24 FF FF 78 24 FF
01B0 FF 78 79 FF FF 78 40 FF FF 78 40 FF FF 02 10 FF
01C0 FF 02 10 FF FF 02 00 FF FF 02 78 FF FF 02 78 FF
01D0 FF 02 02 FF FF 02 02 FF FF 02 12 FF FF 02 12 FF
01E0 FF 02 19 FF FF 02 30 FF FF 02 30 FF FF 02 24 FF
01F0 FF 02 24 FF FF 02 79 FF FF 02 79 FF FF 02 40 FF
0200 FF 02 40 FF FF 02 40 FF FF 12 10 FF FF 12 10 FF
0210 FF 12 00 FF FF 12 00 FF FF 12 78 FF FF 12 78 FF
0220 FF 12 02 FF FF 12 02 FF FF 12 02 FF FF 12 12 FF
0230 FF 12 12 FF FF 12 19 FF FF 12 19 FF FF 12 19 FF
0240 FF 12 30 FF FF 12 30 FF FF 12 30 FF FF 12 24 FF
0250 FF 12 24 FF FF 12 24 FF FF 12 79 FF FF 12 79 FF
0260 FF 12 79 FF FF 12 40 FF FF 12 40 FF FF 12 40 FF
0270 FF 19 10 FF FF 19 10 FF FF 19 10 FF FF 19 00 FF
0280 FF 19 00 FF FF 19 00 FF FF 19 78 FF FF 19 78 FF
0290 FF 19 78 FF FF 19 78 FF FF 19 02 FF FF 19 02 FF
02A0 FF 19 02 FF FF 19 12 FF FF 19 12 FF FF 19 12 FF
02B0 FF 19 12 FF FF 19 19 FF FF 19 19 FF FF 19 19 FF
02C0 FF 19 19 FF FF 19 30 FF FF 19 30 FF FF 19 30 FF
02D0 FF 19 30 FF FF 19 24 FF FF 19 24 FF FF 19 24 FF
02E0 FF 19 24 FF FF 19 24 FF FF 19 79 FF FF 19 79 FF
02F0 FF 19 79 FF FF 19 79 FF FF 19 40 FF FF 19 40 FF
0300 FF 19 40 FF FF 19 40 FF FF 19 40 FF FF 30 10 FF
0310 FF 30 10 FF FF 30 10 FF FF 30 10 FF FF 30 10 FF
0320 FF 30 00 FF FF 30 00 FF FF 30 00 FF FF 30 00 FF
0330 FF 30 00 FF FF 30 78 FF FF 30 78 FF FF 30 78 FF
0340 FF 30 78 FF FF 30 78 FF FF 30 78 FF FF 30 02 FF
0350 FF 30 02 FF FF 30 02 FF FF 30 02 FF FF 30 02 FF
0360 FF 30 02 FF FF 30 12 FF FF 30 12 FF FF 30 12 FF
0370 FF 30 12 FF FF 30 12 FF FF 30 12 FF FF 30 19 FF
0380 FF 30 19 FF FF 30 19 FF FF 30 19 FF FF 30 19 FF
0390 FF 30 19 FF FF 30 19 FF FF 30 30 FF FF 30 30 FF
03A0 FF 30 30 FF FF 30 30 FF FF 30 30 FF FF 30 30 FF
03B0 FF 30 30 FF FF 30 24 FF FF 30 24 FF FF 30 24 FF
03C0 FF 30 24 FF FF 30 24 FF FF 30 24 FF FF 30 24 FF
03D0 FF 30 79 FF FF 30 79 FF FF 30 79 FF FF 30 79 FF
03E0 FF 30 79 FF FF 30 79 FF FF 30 79 FF FF 30 79 FF
03F0 FF 30 40 FF FF 30 40 FF FF 30 40 FF FF 30 40 FF
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dress outputs of the ripple carry counter IC3 are given time to settle, then the count is latched into IC2 (an octal latch) by IC9b. The counter is reset at this time also, but the reset response time of IC3 is considerably longer than the time required to latch the previous count, so there is no conflict.

When switch S1 is in position two the clock frequency is 128Hz, determined by the 100kΩ trimpot and 560kΩ resistor. From Fig. 2, it can be seen that the clock signal to IC3 is gated off when the "0" output of IC4 goes high. Latching of the count and resetting of the counter occurs when the "1" output goes high, and the count begins again after the "1" output goes low again, removing the reset. Thus the clock is gated to IC3 for a period of eight heart beats, and the count is updated every 10 heart beats.

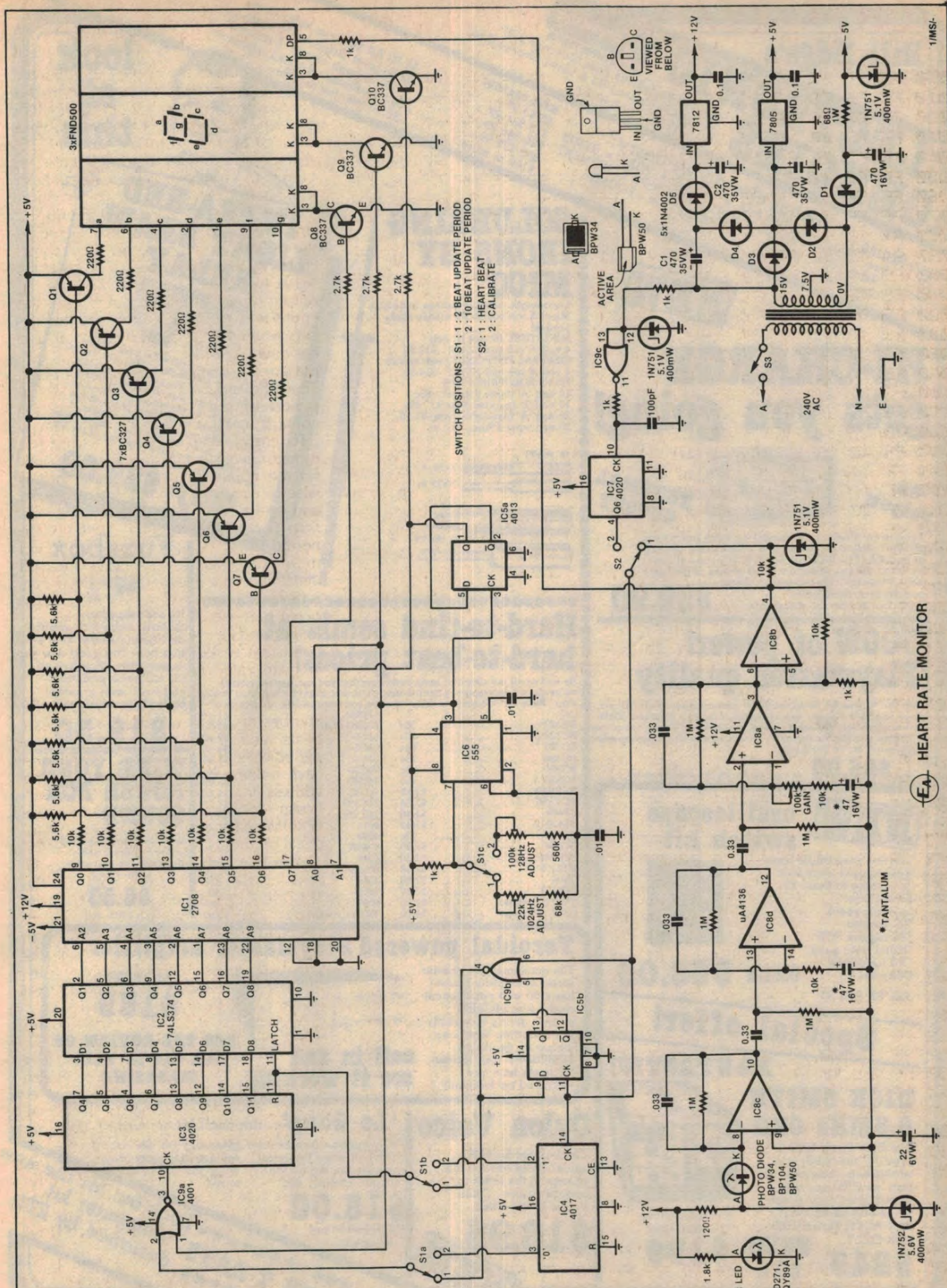
To ensure that the reading from the monitor is correct it is necessary to wait for the count to be updated, and it is wise to wait for a second update period and take a second reading to check the first. For this reason the short update period (S1 in position 1) will be found more convenient for quick readings and initial checking. However the heart rate is never constant and some variation will occur between beats. Consequently the longer update per period will give more consistent readings since the variations in heart rate will be averaged over a longer period.

The binary counter IC3, counts the number of clock pulses between heart beats, and the most recent count is periodically latched into IC2. With the latch holding the counted value on the address lines of the EPROM 1C1, a particular location is accessed in the EPROM and the data at this location appears on the data lines Q0 to Q7 of IC1.

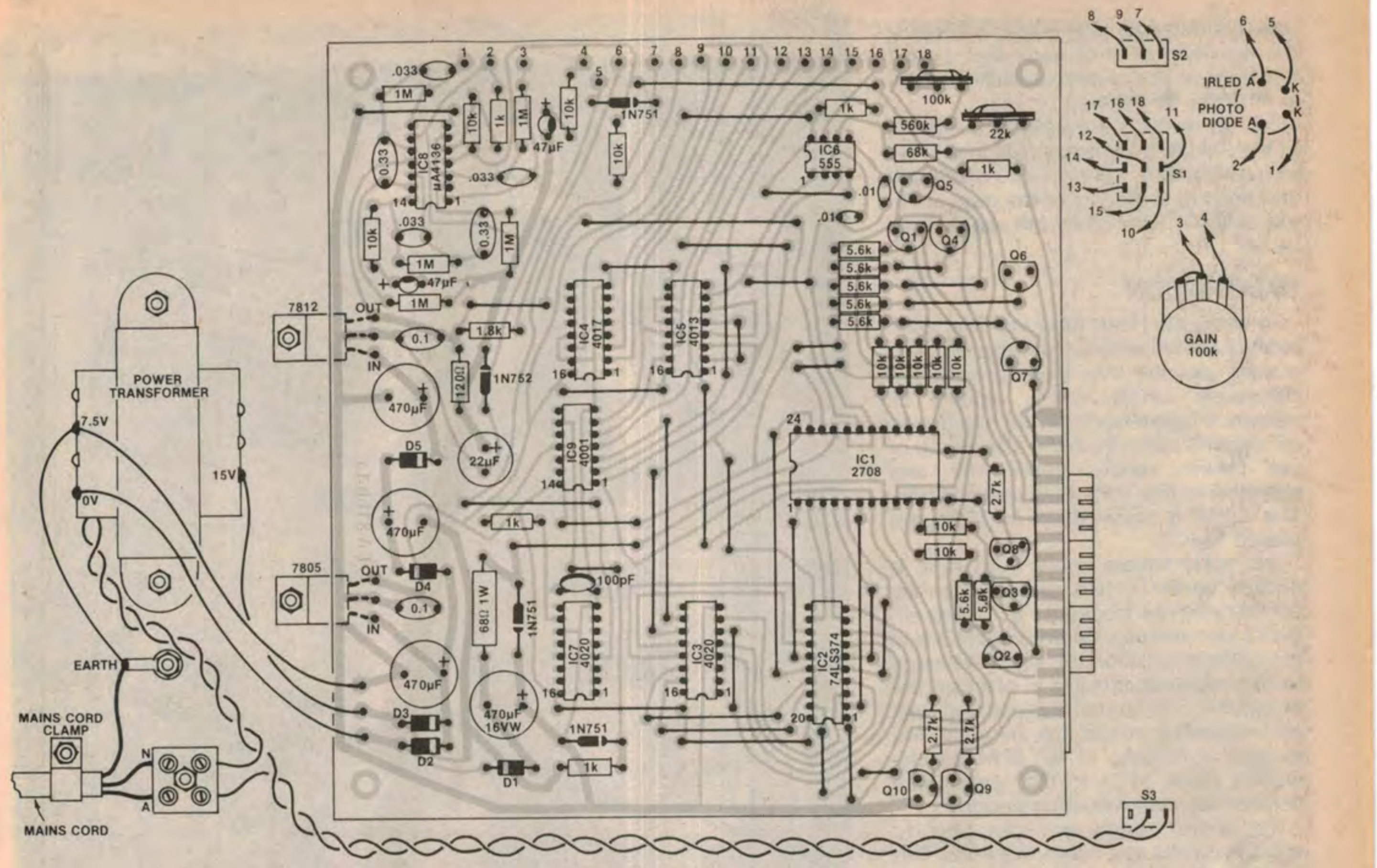
Note that only the eight most significant of the 10 address lines of the EPROM, A2 to A9, are connected to the latch. This means that the binary counter, IC3, accesses the memory in 4-byte blocks, with a total of 256 blocks provided by the 1K EPROM. Of the remaining address lines, AO is connected to the clock frequency (IC6) and A1 is connected to IC5a, a D-type flipflop wired as a divider, with an output at half the clock frequency. This means that these two address lines cycle between zero and three (in binary) at the clock frequency, allowing each byte of the 4 byte block addressed by the counter to be accessed sequentially at the clock rate.

This method allows us to multiplex the displays with the required data by driving each of the seven segments of the displays from the data lines of the EPROM, via switching transistors Q1 to

At left is the Hex listing of the "look-up" table for the 2708 EPROM. At right is the full circuit of the Heart Rate Monitor.



HEART RATE MONITOR



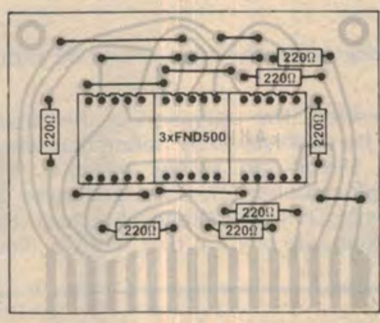
These two PC boards are soldered together at right angles to form one assembly.

Q7, and enabling each digit of the display in turn. The most significant digit of the display is enabled by data line Q7 from IC1, the next significant digit by A0 and the least significant digit by A1.

Each display digit is assigned to one of the bytes of a 4-byte block, and as each digit of the display is enabled, the corresponding byte of the data block is accessed and used to drive the seven segments of the display. For example when A1 and A0 are both low the most significant digit can be accessed and the most significant display digit enabled when data output Q7 of the EPROM is taken high. A1 low and A0 high will access the next most significant digit and enable the appropriate display, while A0 high and A1 low will access the least significant digit and enable that display. When A0 and A1 are both high no information is sent to the segments.

So each display digit will be enabled in turn and driven with the required seven segment display code for that digit. Of course, with only three displays the fourth location of the 4-byte block of memory holding each reading will not be required to supply information to the display, and can be left unprogrammed.

Once we can access each memory location for each reading we need to devise the code for each digit we want to display, remembering that a "0" will activate a segment via the associated switching transistor. To display an "8" for



example, we need to light all the segments, so the code is 00000000, or 00 in hexadecimal. A "1" is 01111001, or 79 in hex. The leading zero in both these cases indicates that the number will be displayed in the least or middle digit position. To enable the most significant digit requires a 1 in the leading position, so that the code for a "1" in the most significant digit position would be 11111001.

Now that we know how to program the EPROM, the next question is what numbers are required to be placed in the EPROM? We have 256 blocks of information to fill and we know that the highest count or address (256) is the slowest heart rate to be measured. We have chosen 30 BPM to be the slowest heart rate, so location 256 should contain 30. At the 128th location, then, the value should be 60; the 64th location, 120; the 32nd location, 240. Below this we have placed the letter E to signify overrange.

TWO-FIGURE ACCURACY

Note that the numbers from 30 to 60 are placed in 128 locations, meaning that the same number is repeated in several locations, whereas the numbers from 120 to 240 have to fit in 32 locations. This gives two figure accuracy for all values of heart beat. The resolution below 90 BPM is one BPM and falls to seven BPM resolution at close to 240 BPM.

The switching transistors driving the segments of the displays are chosen for their low saturation voltage to ensure that all the segments will be of equal brightness when activated. The output of the clock circuit, IC6, which drives the least significant and middle digits, is made as close to a square wave as possible by making the resistor from pin 7 to the 5V rail small in comparison with the resistors between pins 6 and 7, keeping the activated time of each digit almost equal, again to ensure that each segment is of similar brightness.

Pull up resistors are used at the bases of the switching transistors Q1 to Q7, ensuring that they will turn off completely and prevent segments of the display being dimly lit when they are required to be off.

CALIBRATION

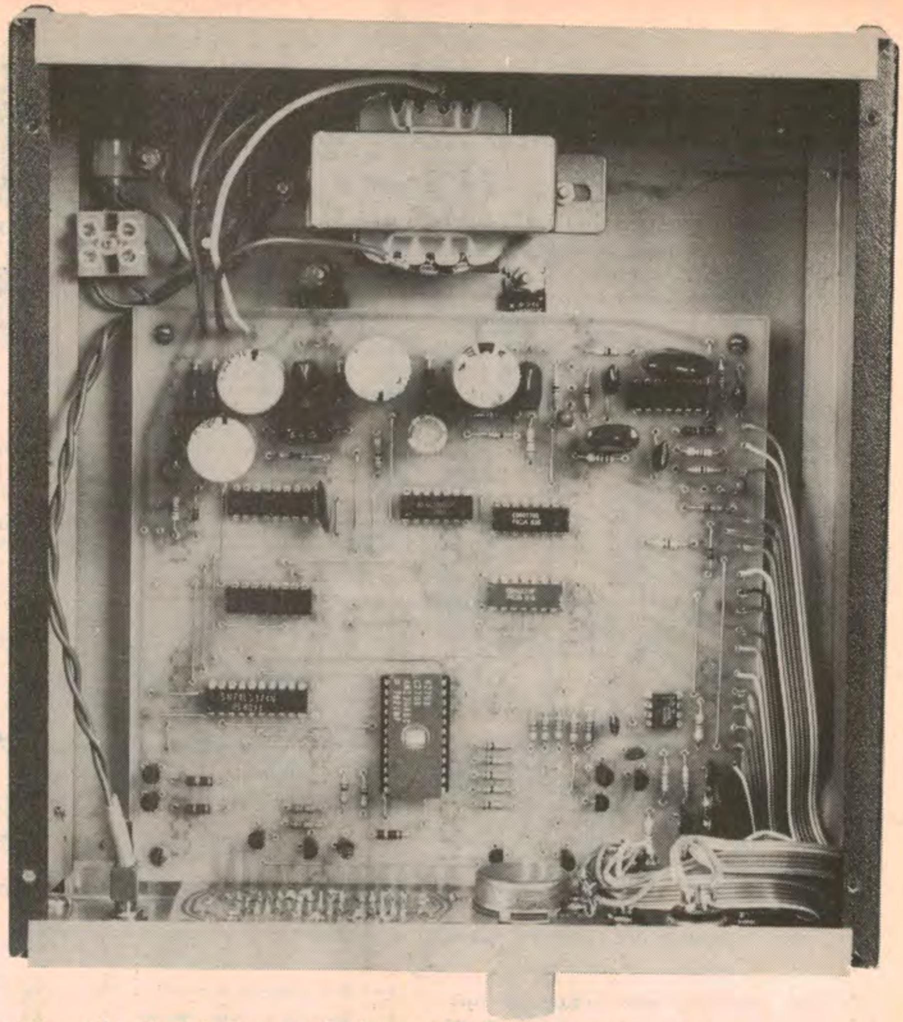
To allow the Heart Rate Monitor to be easily adjusted without the use of a frequency counter we have provided a calibration circuit which derives its reference frequency from the mains. An AC signal is taken from the 15-volt tap of the power supply transformer and clamped to five volts by a zener diode. This signal is squared up by IC9c and passed to IC7.

The 50Hz square wave from IC9c is divided by 64 by IC7, providing an accurate reference frequency of 0.78Hz (47 cycles per minute). When switch S2 is in the calibrate position this signal is passed to the counting circuitry in place of the heart beat. The trimpots associated with each sampling period are then adjusted to give a reading of 47 BPM on the display when S1 is in the appropriate position for each counting period.

The power supply provides plus 12 volts, five volts and minus five volts. This is achieved with a centre-tapped 15-volt transformer. Full-wave rectification and filtering with a 470μF capacitor provides 10 volts which is regulated with a five volt regulator. The minus five volts is provided by a half-wave rectification circuit clamped at five volts with a zener diode. A 470μF capacitor filters this supply.

About 30V DC is generated by a tripler circuit consisting of bodies D4, D5 and 470μF capacitors, C1 and C2 together with the full-wave rectifier already described. The operation of the circuit can be understood by noting that when the 15-volt tap swings negative, the 470μF capacitor C1, is charged up to 20 volts by D4 which effectively clamps the positive side of C1 at plus 10 volts. Now when the 15-volt tap swings positive D4 is reverse biased and the charge on C1 is dumped onto C2 by D5. This voltage is then regulated with a 12-volt regulator.

We constructed the Heart Rate Monitor on two printed circuit boards.



Wiring within the Monitor can be kept neat by using rainbow cable.

PARTS LIST

- 1 PC board coded 81hb4a and measuring 159 × 150mm
- 1 PC board coded 81hb4b and measuring 72 × 59mm
- 1 Scotchcal front panel
- 1 2155 power transformer
- 1 100kΩ linear potentiometer
- 1 3-pole 2-way toggle switch
- 2 single pole, 2-way toggle switches
- 1 Horwood case measuring 203mm × 76mm × 228mm (W × H × D)
- 1 knob
- 1 24-pin socket DIL socket
- 1 4-pin DIN plug and socket
- 1 mains cord and plug
- 4 10mm PC tapped standoffs
- 4 rubber feet
- 1 grommet
- 1 cord clamp
- 1 2-way terminal strip
- 1 earth lug

INTEGRATED CIRCUITS
- 1 2708 1K EPROM (programmed with Heart Rate Monitor Listing)
- 1 74S374 Tri-state octal D flipflop
- 2 4020 ripple-carry binary counters
- 1 4017 decade counter/divider
- 1 4013 dual flipflop
- 1 4001 quad 2-input NOR gate
- 1 4136 quad operational amplifier
- 1 555 timer
- 1 7812 12V regulator
- 1 7805 5V regulator

SEMICONDUCTORS
- 1 LD271/CQY89A infrared LED
- 1 BPW34/BP104/BPW50 photodiode
- 3 1N751 5.1volt 400mW zener diodes
- 1 1N752 5.6volt 400mW zener diode
- 5 1N4002 100PIV rectifier diodes
- 7 BC327 PNP transistors
- 3 BC337 NPN transistors
- 3 FND500 common-cathode displays

CAPACITORS
- 3 470uF/35VW PC electrolytics
- 1 470uF/16VW PC electrolytic
- 2 47uF/6.3VW tantalum electrolytics
- 1 22uF/6VW PC electrolytic
- 2 0.33uF metallised polyester
- 2 0.1uF metallised polyester
- 3 .033uF metallised polyester
- 2 .01uF metallised polyester
- 1 100pF disc ceramic

RESISTORS (¼W 10%)
5 × 1MΩ, 1 × 560kΩ, 1 × 68kΩ, 11 × 10kΩ, 7 × 5.6kΩ, 3 × 2.7kΩ, 1 × 1.8kΩ, 5 × 1kΩ, 7 × 220Ω, 1 × 120Ω, 1 × 68Ω 1W, 1 × 100kΩ vertical trimpot, 1 × 22kΩ vertical trimpot

MISCELLANEOUS
Hook-up wire, four-way wire for sensor, nuts, bolts, washers, solder, copper wire etc.

one coded 81hb4a, measuring 159 × 150mm, and the other coded 81hb4b and measuring 72 × 59mm. The smaller board is used for the display and associated resistors. The complete PCB assembly was contained in a Horwood case measuring 203 × 76 × 228mm (W × H × D).

On the large 81kb4a PC board there is a bus which brings out the connections for the display board. This edge should be filed until the coppper track is flush with the edge of the PC board. This allows the small display PC board 81hb4b to be soldered to the larger board.

Start construction by placing the wire links, the resistors and the socket for the EPROM on the PCB. Position the capacitors, trimpots, diodes and transistors and solder them, using the PC board overlay diagram as a guide and taking care with the orientation of the diodes and transistors. When soldering the CMOS ICs make sure that the power supply pins are soldered first, and have the barrel of your soldering iron connected to the negative supply rail.

The voltage regulators should be soldered to the underside of the PCB, with their leads just proturding through to the top of the board. The regulators can then later be bolted to the base of the case for heatsinking.

Solder the links and resistors to the small display PCB and when soldering the displays make sure that they are not upside down. Do not solder this PC board to the main PC board yet.

Using the Scotchcal front panel as a guide, drill the holes for the potentiometer, switches, DIN socket and a row of holes around the required rectangular hole for the display. File this rectangular hole until the display fits squarely and snugly.

Use tapped 10mm spacers for mounting the large PC board. Screw these spacers to the PC board with short screws so that the PC board can stand securely on the spacers. The Horwood case at this stage will have to be drilled for the self tapper screws and the base plate secured to the sides. With the front panel bolted as well to make a complete case except for the lid, place the large PC board in the case.

The small display PC board should be secured in the rectangular cut out on the front panel. Slide the large PC board up to and in line with the display PC board. Mark with a pencil on the back of the display PC board the point where the top of the large PC board meets the display PC board. Remove both PC boards from the case and solder tack the two end copper bus tracks of the display board to the large PC board.

Make sure that the PC boards are at right angles to one another and that when the display PC board is in position the standoffs on the large PC board are seated on the base of the case. When the two boards are correctly positioned the remainder of tracks can be soldered.

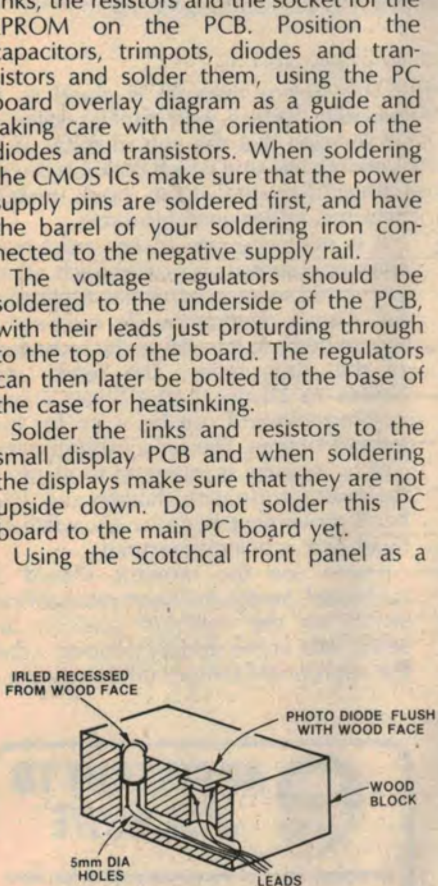
At this stage the holes for the PC board standoffs can be drilled in the base of the case, as well as the holes for the regulators, transformer, terminal block, earth lug, cable clamp and grommet. We used ribbon cable for the wiring of the PC board to the front controls making a neater appearance than with separate hookup wire. Follow the wiring diagram and make all of the connections to the switches, potentiometer and socket which can now be positioned on the front panel.

Use 250VAC rated insulated wire to run from the on/off switch to the terminal block and use sleeving on the mains switch lugs, including the unused lug. Clean away the paint around the earth lug and bolt the earth lug to the case. Keep the earth lead from the mains cable long enough to ensure that if the active and/or neutral wire is pulled from the terminal block the earth wire will remain intact.

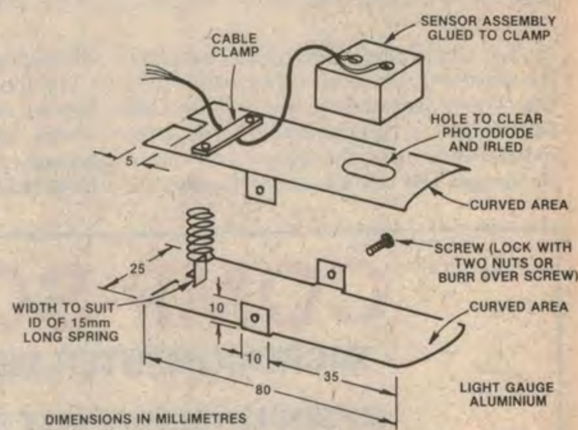
Make sure that the mains cable is grommetted at the rear cable entry and that the cable clamp secures the lead tightly.

Constructing the sensor involves some handyman work but is not difficult. We have provided diagrams to demonstrate how we made our sensors. We constructed three different sensors, all of which consist of the IRLED and photo diode mounted in a small block of

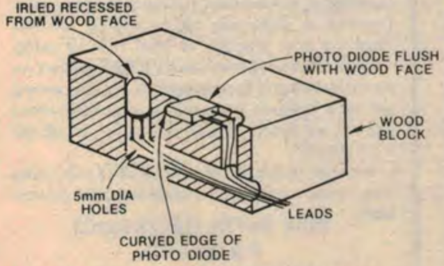
These diagrams show details of construction of the sensors.



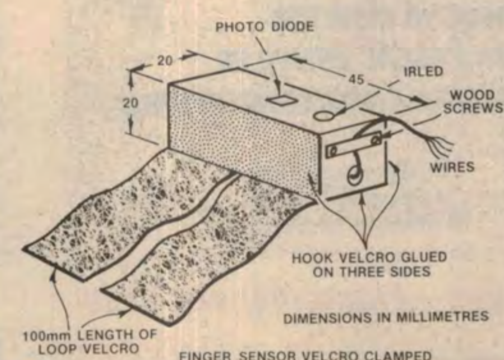
CROSS SECTIONAL VIEW OF SENSOR ASSEMBLY WHEN USING BPW34/BP104 PHOTO DIODE



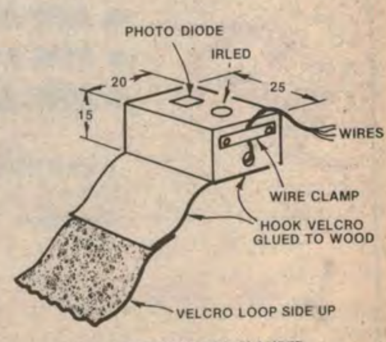
FINGER SENSOR USING CLIP



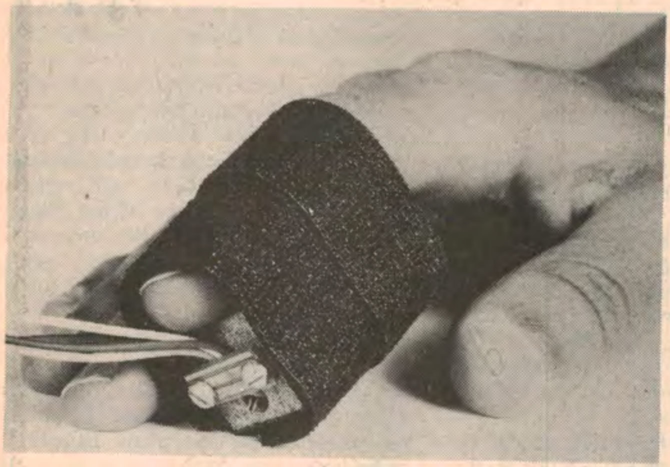
CROSS SECTIONAL VIEW OF SENSOR ASSEMBLY WHEN USING BPW50 PHOTO DIODE

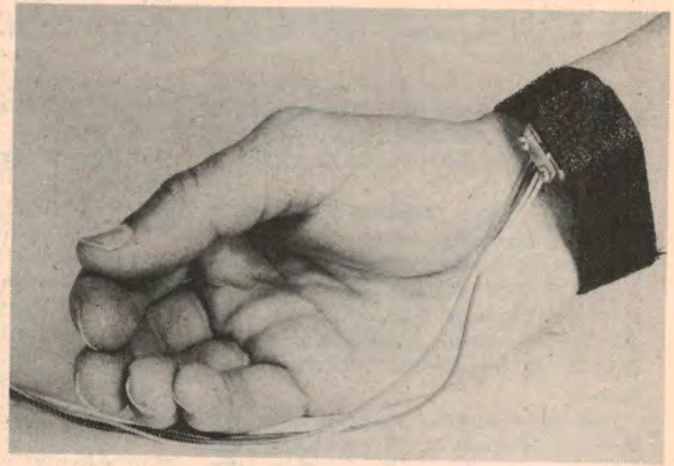


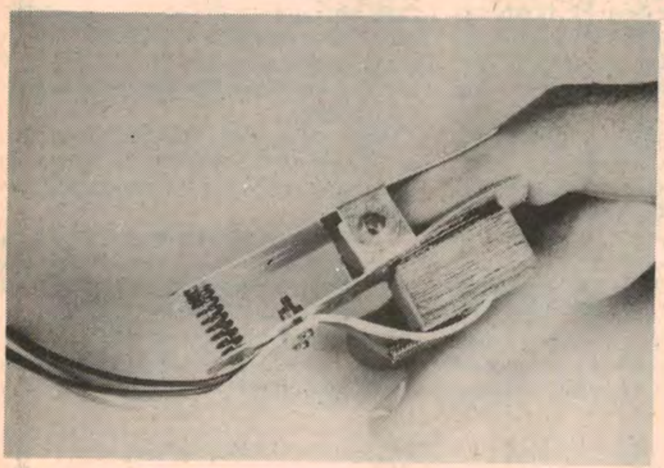
FINGER SENSOR VELCRO CLAMPED



WRIST SENSOR VELCRO CLAMPED







These three photos show how the sensors are worn. They should not be strapped on too tightly otherwise blood circulation will be impeded.

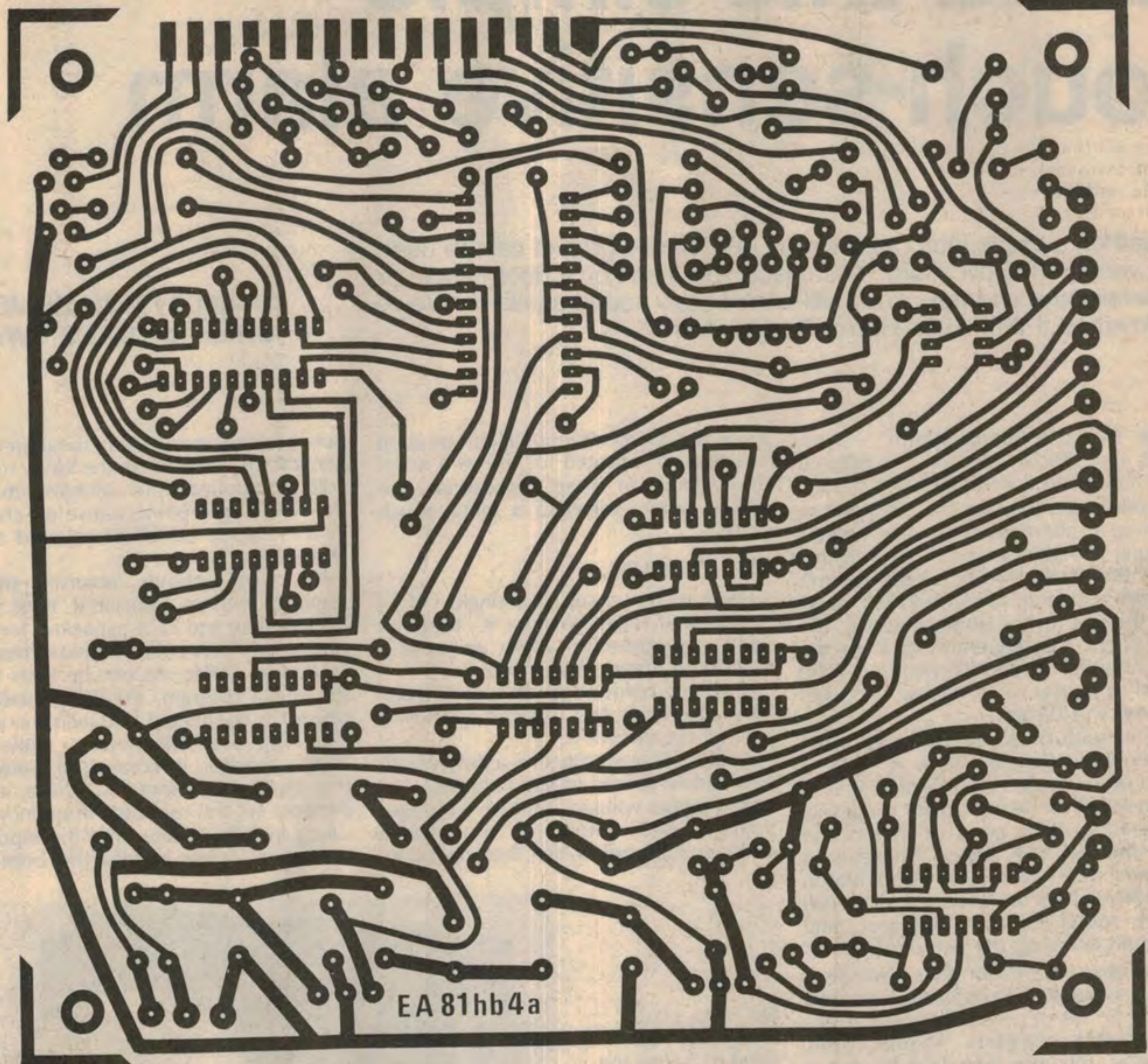
wood. The major difference between the devices is the method of connecting the sensor assembly to the person. One sensor uses a clip fashioned from scrap aluminium so that the sensor can clip to the finger. The other two involve the use of Velcro material to secure the sensor.

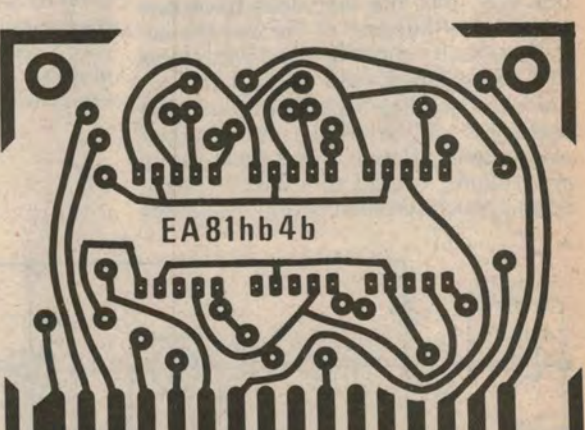
For those who have not come across Velcro material, it consists of two different types of fabric that when contacted to one another form a gripping longitudinal bond but which can be easily torn apart.

The Velcro material is glued to the wooden surface with contact adhesive. Make sure that the soft material of the Velcro is the one which contacts the skin rather than the nylon hook material which is rather uncomfortable.

It is not necessary to construct more than one sensor, however each sensor presented serves a particular application. For a quick reading the clip type sensor would be best. It involves the most work of the three types. The sensor with Velcro to clamp to the finger is very comfortable and can be worn for long periods of time. The sensor with the long Velcro material is intended to clamp to the wrist for use with children and when hand movement is necessary while the heart rate is being measured.

Before use the monitor should be calibrated. Switch the heart rate/calibrate switch to the calibrate position and select one of the update periods. Adjust the appropriate trimpot until a reading of





Here is the full-size artwork of the PC boards.

47 is obtained on the display, then switch to the other update period and adjust the other trimpot for the same reading. Make sure that the EPROM is in place at this point! After calibration the Heart Rate Monitor is ready to be used.

To operate the HRM, the sensor is clipped to the finger or wrist making sure the sensor is not too tight. The sensor should be located over the pad of the finger. Overtightening the sensor on the finger will reduce the blood flow and prevent the sensor from receiving the blood pulses. Starting with the gain control at minimum, the gain should be turned up until there is a steady pulse reading as indicated by the flashing decimal point on the display. Too high a setting of the gain control can result in a "double beating" effect which should be avoided.

Once a constant heart beat is detected wait for an update period before taking the heart beat reading.

Velcro material can be obtained from the haberdashery sections of department stores. We expect that at the time of printing preprogrammed EPROMs will be available from the usual component suppliers. Alternatively we have provided a complete 1K listing for those who have access to an EPROM programmer.