Keep tabs on your ticker with this

Portable 3½-digit heart rate monitor

Here is a new heart rate monitor designed specifically for use by the dedicated fitness seeker. Small enough to carry when jogging or exercising, it features an optical sensor, no electrical connections to the body, an in-built calibration circuit, and direct readout on a large liquid crystal display (LCD).

by JEFF SKEEN

Our first Heart Rate Monitor was described back in April, 1981, and, within the constraints of components available at that time, was a very successful design. In fact, a version of it is still being used by a reader with a heart condition, who is under a strict medically prescribed training program. He uses it to monitor his heart rate while exercising, and hold it to a prescribed figure within close limits.

But the design had its limitations. It was mains operated and therefore had to be used within reach of a power point. It also had to use a relatively complicated circuit, with a large number of components, all housed in a large and rather expensive case, and was dependent on a specially programmed EPROM which was only available from a few sources.

More recently we realised that it might now be possible to design a very much smaller and simpler device. The thought was inspired by the DPM-200 module – already used in several projects – and which is, basically, a millivoltmeter with a large 3½-digit liquid crystal display.

The DPM-200 requires only a tiny fraction of the power needed by the LED display used in the previous design, and is well within the scope of battery operation. The implication was obvious; a monitor which would be light enough and small enough to carry, and use, anywhere.

Another advantage of the DPM-200 module is that it made possible a different, and simpler, approach to processing the heart pulse signals. The result is a monitor which is cheaper, simpler to build, and compact enough for the athlete and fitness enthusiast to use "on-the-job".

There are many potential uses for a heart rate monitor and a portable version makes many of these a lot more practical.

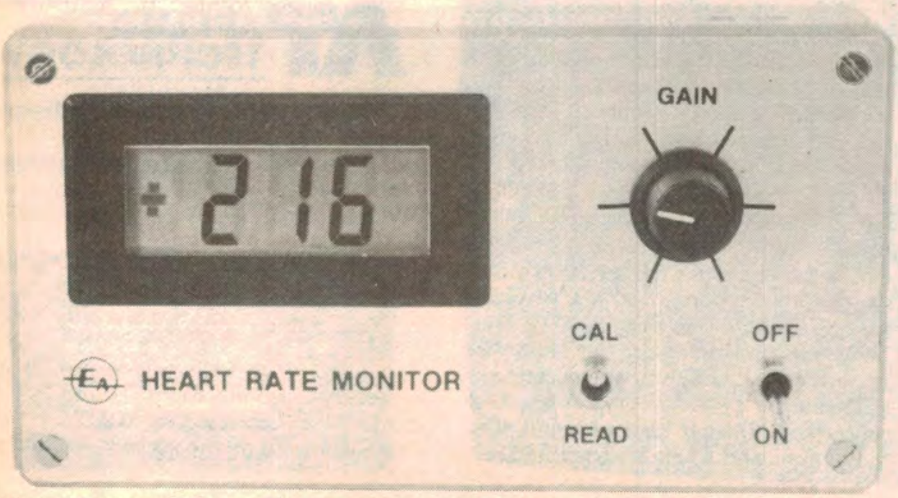
It is generally acknowledged that exercise is a valuable aid to physical fitness. Unfortunately, people often exercise for a while, then give it away because they can see no benefit for their effort. This is because the benefits are gradual and the individual cannot detect the small improvements resulting from each session.

Our Heart Rate Monitor can help solve this problem. By providing an instant display of the heart rate, measured before, during, and after exercise, it allows comparisons to be made on a day-to-day and week-to-week basis. A written record of such measurements will prove infinitely more valuable than mere subjective judgement.

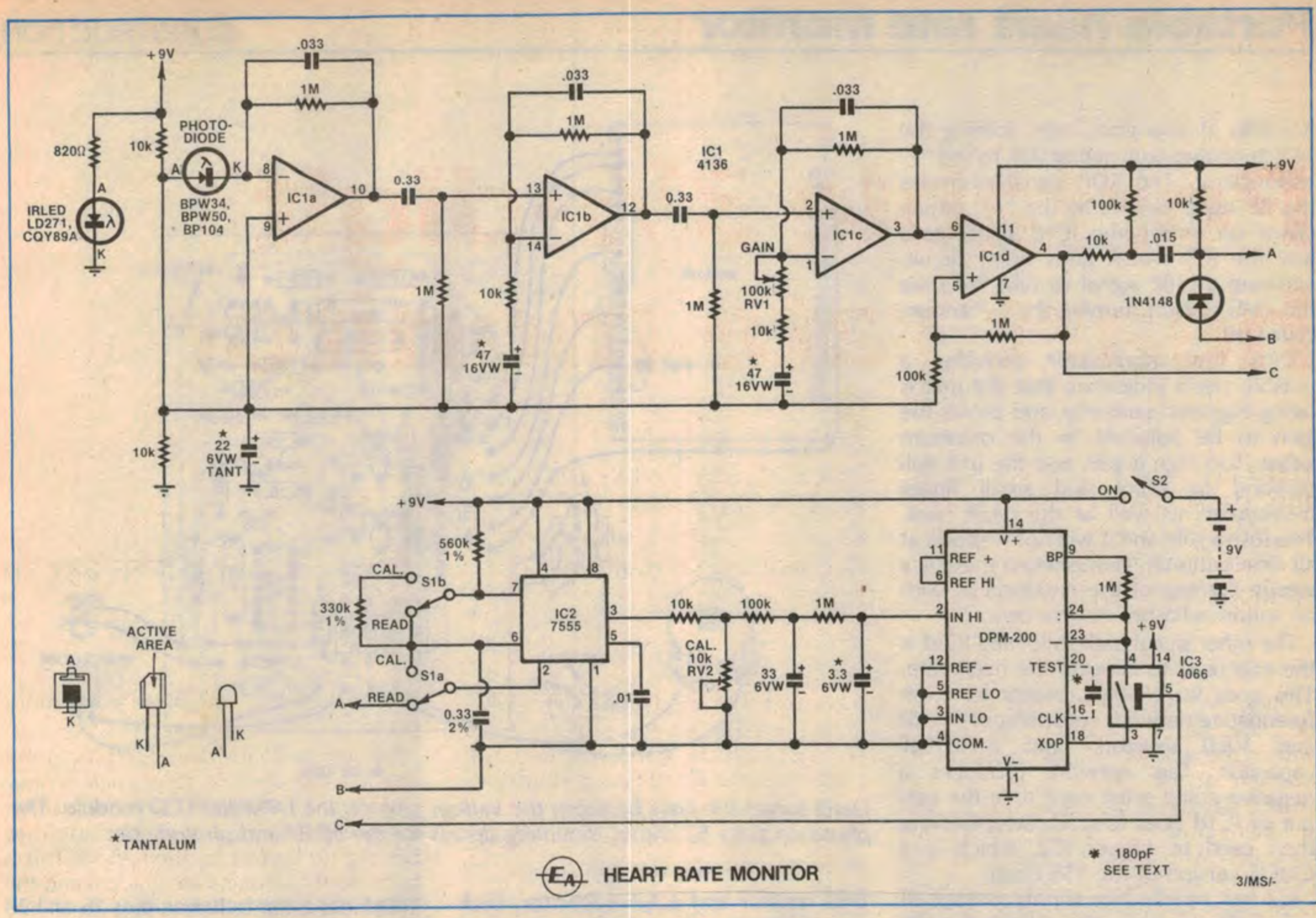
And what kind of readings should one expect? This is a very complex subject, and quite outside the scope of this article. A heart beat can vary from as low as 30 in a young highly trained athlete, at rest, to as high as 160 for an elderly person indulging in unaccustomed (and perhaps dangerous) exercise. Almost any figure in between may be good or bad, depending on the immediate circumstances and the person's medical history.

For more precise details consult some reliable literature on the subject first. One such reference is "Aussierobics", by Mr P. Russo of the Cumberland College of Health Sciences. This contains a lot of information on heart rates for various age groups and exercise conditions.

Above all, don't rush blindly into a bout of strenuous exercise, particularly after a long period of idleness; it could do more harm than good. We seriously recommend that anyone contemplating such a program should consult his doctor first, and be guided by his advice.



This photograph shows the new Heart Rate Monitor operating in the calibration mode. Note sensor cutouts on the top of the case.



HEART RATE MONITOR

How it works

Having said all that, let us look at our new Heart Rate Monitor in greater detail. Briefly, the circuit is a frequency to voltage converter that converts the heart beat frequency into a proportional voltage, in millivolts. This voltage is displayed by the DPM-200 panel meter in digital form, each millivolt corresponding to 10 beats per minute.

The circuit can be split into four basic sections. Three of these correspond to integrated circuits IC1, IC2 and IC3 and the fourth is the DPM-200 module. Section 1 (IC1) is an amplifier used to amplify the sensor output; section 2 (IC2) converts this output into constant length pulses, then averages these to form a DC voltage proportional to the heart beat rate; and (IC3) is an electronic switch that activates the "+" annunciator on the DPM-200 module.

Section 4, the DPM-200 module, was featured in the February, 1982 issue of "Electronics Australia", so we will not go into its internal operation here. Suffice to say that the DPM-200 is simply a high input impedance voltmeter with a full-scale reading of 199.9mV.

To begin the circuit description we start with the sensor, then follow the signal path through the circuit until we reach the meter.

The sensor consists of two parts: an infrared light source, and an infrared detector. The infrared light source is an infrared light emitting diode (IRLED) and the detector is an infrared photodiode. The diode appears as an open circuit when no infrared light reaches it and behaves as a normal diode under infrared light. The two devices are mounted side by side on the top of the case, and the IRLED run continuously at about 10mA.

When a finger is placed over the two devices, infrared light passes through the finger, is reflected off the bone, and passes back through the finger to the photodiode. On the way, the light is intensity modulated by the expansion and contraction of small arteries in response to the heart beat. This intensity modulated light is turned into an amplitude modulated electrical signal by the photodiode, and then amplified by IC1a.

IC1a is an inverting DC amplifier with a bandwidth limited to 4.8Hz by the .033μF capacitor across the 1MΩ feedback resistor. The output of IC1a then undergoes two stages of amplification, in IC1b and IC1c respectively. Both these stages have 0.48Hz high pass filters on their inputs and 4.8Hz low pass filters in the feedback paths, and are AC coupled with gains of about 100. IC1c, however, has a gain control which can reduce the gain of this stage from 100 to 10.

This allows the sensitivity of the detector to be varied, providing a means to control the effects of small finger movements, which could otherwise modulate the signal in the same way as a heart beat. The high and low pass filters around the amplifier stages allow only heart beat frequencies to be amplified, thus providing a large degree of immunity from external modulated infrared light sources, eg light bulbs, radiators etc.

Following the amplification stages is a Schmitt trigger formed by IC1d. This transforms the amplified sensor signal into a square wave with an amplitude approximately equal to the supply voltage.

From here the signal path is split, one path being used to trigger IC2 and the other to control the "+" annunciator on the module. The "+" annunciator is wired to flash each time the sensor detects a pulse. The user can thus determine when the unit is triggering correctly off his/her heart beat because the annunciator maintains a steady rhythmic flashing.

To enable the "+" annunciator, it is necessary to connect pins 23 and 24 of the DPM-200 module to XDP (pin 18). This is achieved by means of IC3, a 4066 CMOS switch.

Here's how it works. When the output of IC1d goes high the control input of

IC3 (pin 5) also goes high, turning the switch on and connecting SDP to the "+" annunciator. The XDP signal overrides the BP signal and turns the "+" annunciator on. When the IC1d signal goes low the IC3 switch goes open circuit, allowing the BP signal to take over via the 1MΩ resistor, turning the "+" annunciator off.

Thus the annunciator provides a reliable visual indication that the unit is being triggered correctly, and allows the gain to be adjusted to the optimum value. Too high a gain and the unit will respond to noise and small finger movements as well as the heart beat. Too low a gain and it will not respond at all. The optimum gain is when there is a steady flashing of the annunciator with no spurious flashes in between.

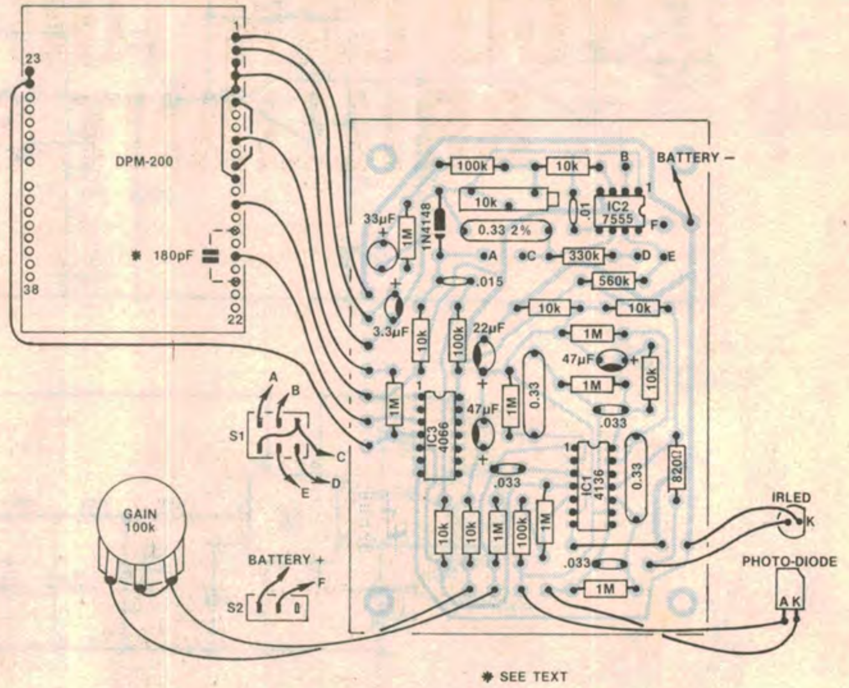
The other signal path following IC1d is the one used to indicate the heart rate. This goes via a 10kΩ resistor to a differentiating network consisting of 100kΩ and 10kΩ resistors, and a .015μF capacitor. This network produces a negative going spike each time the output of IC1d goes low. These spikes are then used to trigger IC2, which is a CMOS version of the 555 timer.

IC2 has an effective supply voltage of only 2.8V, this being the voltage that the DPM-200 module maintains between its V+ and COM pins. IC2 therefore has its ground floating at battery voltage minus 2.8V, or around 6.2V (assuming a 9V battery). Inputs to CMOS integrated circuits should not go below the negative supply voltage so a diode has been added to the circuit following the RC network to clip off the negative going spikes when they drop below the voltage maintained by the COM pin.

Under normal operational conditions (ie when the unit is measuring heart beat), switch S1 is in the "READ" position and IC2 is connected as a monostable. When a trigger pulse is applied to pin 2, the output of IC2 (pin 3) produces a 0.2s positive pulse as set by the 560kΩ timing resistor and 0.33μF timing capacitor.

The maximum pulse rate which can be measured is 300, this limitation being due to the 0.2s pulse length and the fact that the monostable cannot respond to an incoming pulse during this 0.2s period. (Any reader with a heart rate in excess of 300 will have more to worry about than this limitation of our Heart Rate Monitor!)

The level of the output pulses from the monostable is reduced by the variable potential divider formed by the 10kΩ resistor and RV2. From here the pulses pass to a two-pole filter, one pole being formed by the 100kΩ resistor and 33μF capacitor, and the other pole by the



Don't forget the links between the various pins on the DPM-200 LCD module. The photo on page 67 shows mounting details for the IRLED and photodiode.

1MΩ resistor and 3.3μF capacitor. Each pole in this filter has a time constant of 3.3 seconds giving a total time constant of 6.6 seconds.

The bandwidth of the filter is only 0.15Hz, which means that the voltage appearing at the input of the DPM-200 module is effectively DC. Due to the large time constant, this DC voltage takes a relatively long time to change, thus smoothing out the small voltage fluctuations that occur with the slight irregularities in a normal heart beat. Without the long time constant, these small fluctuations would cause the last digit of the display to jump around, making the display difficult to read.

If desired, the time constant can be shortened slightly to reduce the time needed for the reading to stabilise after a steady pulse rate is detected. To do this, reduce the 33μF and 3.3μF capacitors to 22μF and 2.2μF respectively.

At the same time it would be advisable to increase the readout update time of the DPM-200 in order to minimise last-digit jitter. This is done by connecting a 180pF capacitor between pins 16 and 20 of the DPM-200.

The output voltage from the filter is measured by the DPM-200 module which is connected as a 200mV voltmeter. The module contains all the necessary circuitry to drive the liquid crystal display direct, and only requires several shorting links to be placed across various module pins to enable the module to be used as a voltmeter.

Calibration of the Heart Rate Monitor is achieved by switching S1 to the "CAL" position. This converts IC2 from monostable operation to astable operation to produce a calibration frequency of 3.58Hz, or 215 pulses per minute.

These pulses have the same duration (0.2s) as those produced in the monostable configuration and so may be regarded in exactly the same way as a (fictious) heart rate of 215 beats per minute. On this basis, RV2 is simply adjusted until the display reads 215, and calibration is complete.

Note that RV2 is a multi-turn pot, this being chosen to provide the necessary precision during calibration.

We estimate the current cost of parts for this project is about

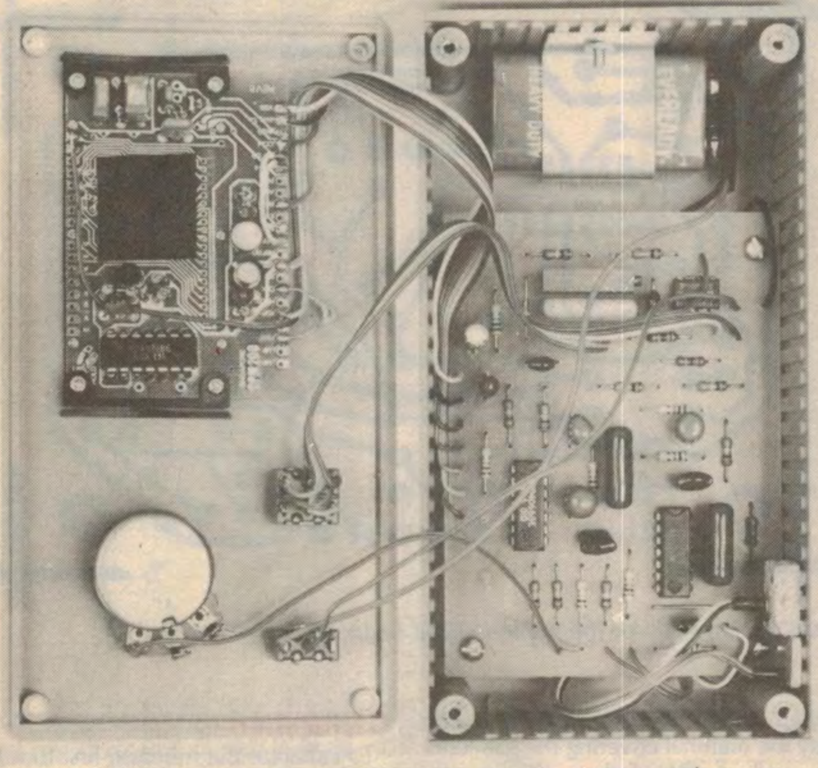
$70

including sales tax.

The heart rate monitor is constructed on a single printed board (PCB) coded 82hb6 and measuring 102 x 71mm. A small plastic box measuring 152 x 80 x 47mm is used to house the project.

Begin construction by mounting all the

Heart rate monitor



This internal view shows the prototype with wiring complete.

components on the PCB according to the overlay diagram. Note that there is a wire link to be fitted near IC1. When soldering the CMOS devices make sure that the power supply pins are soldered first, and connect the soldering iron barrel to the negative supply rail using a small clip lead.

When all components have been mounted on the PCB, you can begin assembling the electronics into the case. It is a good idea to start by trimming the Scotchcal front panel, since this can serve as a drilling and cutting template. Using a sharp pair of scissors, trim the panel along the inside of the black border which surrounds it. This done, cut out the opening for the DPM-200 display module, cutting along the black rectangular border marking out this area.

Temporarily locate the Scotchcal panel on the lid of the box (do not remove the backing paper) and push a sharp pin through the centre of the targets mark-

PARTS LIST

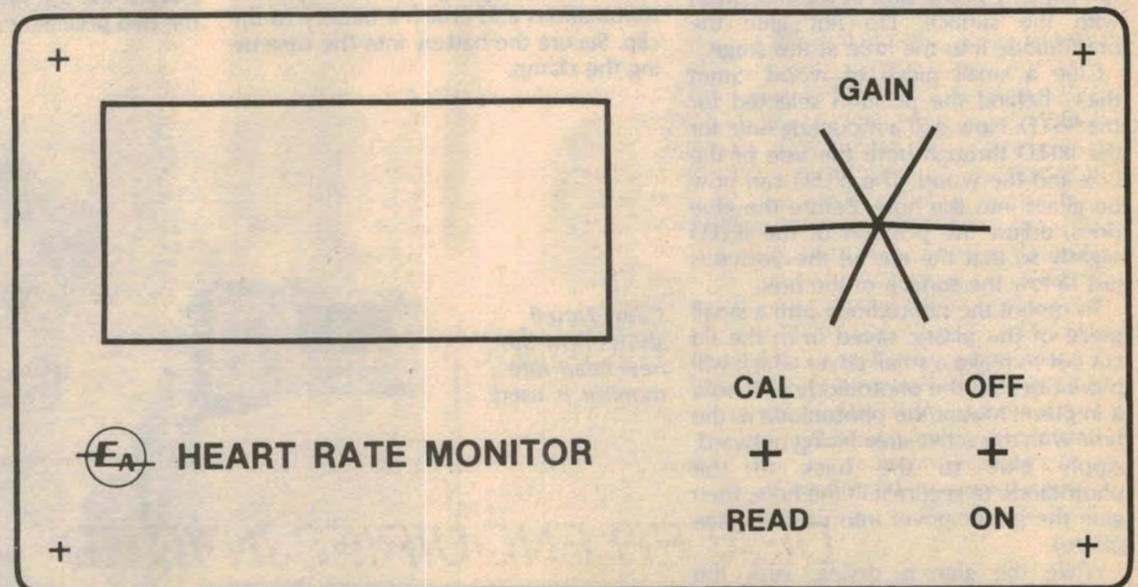
1 printed circuit board, code 82hb6, 102 x 71mm
1 plastic case, measuring 152 x 80 x 47mm
1 SPDT toggle switch
1 DPDT toggle switch
1 DPM-200 panel meter module
1 Scotchcal front panel, 149 x 79mm
1 9V battery, Eveready 216
1 9V battery clip
4 12mm PC board spacers
1 ½-metre length 10-way ribbon cable

SEMICONDUCTORS
1 4066 quad analog switch
1 7555 timer IC
1 4136 quad op amp
1 1N4148 diode
1 CQY89A infrared light emitting diode
1 BPW50 infrared photodiode

CAPACITORS
2 47μF 16VW tantalum
1 33μF 6VW PC electrolytic
1 22μF 6VW tantalum
1 3.3μF 6VW tantalum
2 0.33μF greencaps
1 0.33μF 2% greencap
3 .033μF greencaps
1 .015μF greencap
1 .01μF greencap

RESISTORS (¼W, 5% unless stated)
8 x 1MΩ, 1 x 560kΩ 1%, 1 x 330kΩ 1%, 3 x 100kΩ, 7 x 10kΩ, 1 x 820Ω, 1 x 100kΩ linear potentiometer, 1 x 10kΩ multiturn potentiometer.

MISCELLANEOUS
Machine screws and nuts, small piece of scrap aluminium sheet, small piece of wood, solder, etc.



Actual size artwork for the front panel. Finished Scotchcal panels will be available from the usual retail outlets.

ing the gain control and switch positions. The resulting "dents" in the plastic will provide an accurate drilling guide. Before removing the Scotchcal, use a pencil to trace around the outline of the cutout for the DPM-200 display.

Remove the Scotchcal, drill the gain control and switch holes, then cut out the section for the DPM-200 display. Note that the latter should neatly accommodate the bezel supplied with the DPM-200. Save the scrap plastic from this cut-out. Next, place the PCB in the bottom of the box, towards one end, and use it as a template to drill its mounting holes.

The battery clamp is made from a small piece of scrap aluminium bent into an S shape so that it fits snugly over the battery (see photo). Drill a hole in one end of the clamp, then place the battery and clamp in position in the box. Mark the correct position for the battery clamp mounting hole, remove the battery and clamp, then drill the hole through the side of the box.

Mount standoffs on the PCB, and sit the PCB in position in the box. Select a suitable location in which to mount the sensor components that is both comfortable to reach and does not foul the PCB. The best location is at the top right hand corner of the box so that the fleshy end of a finger can lie comfortably across the sensor while the hand is holding the box.

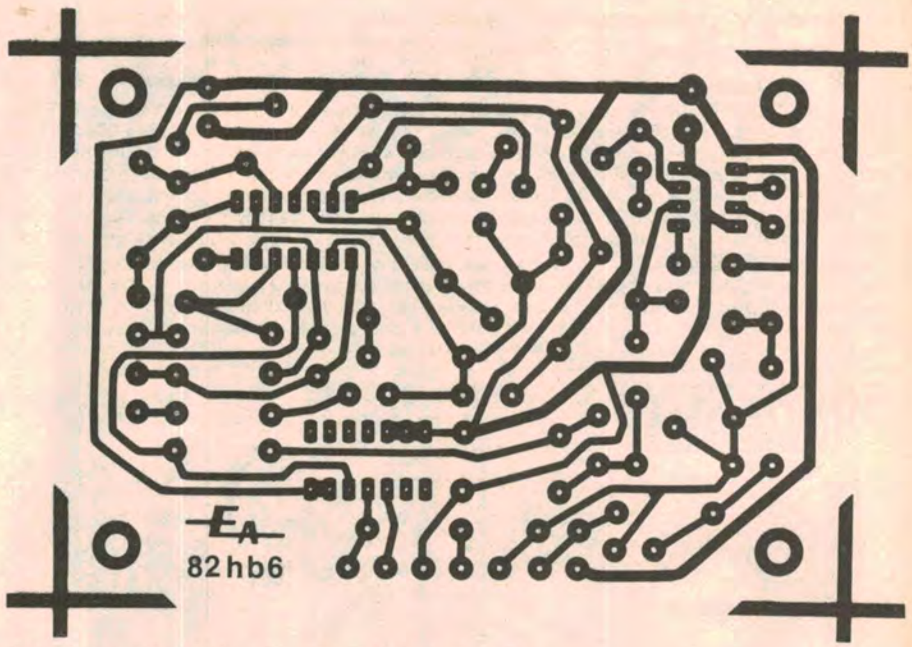
Once the sensor location is selected, remove the PCB from the box and mark out positions for the IRLED and photodiode. The distance between the centres of the two devices should be about 8 to 9mm. Drill a small hole for the photodiode, then enlarge this with a small file to fit the shape of the photodiode. The photodiode mounts horizontally in the side of the box, flush with the surface. Do not glue the photodiode into the hole at this stage.

Glue a small piece of wood, 5mm thick, behind the position selected for the IRLED. Now drill a mounting hole for the IRLED through both the side of the box and the wood. The IRLED can now be glued into the hole. Before the glue dries, adjust the position of the IRLED slightly so that the end of the device is just below the surface of the box.

To mount the photodiode trim a small piece of the plastic saved from the lid cut-out to make a small cover which will mount behind the photodiode and hold it in place. Mount the photodiode in the hole with the active area facing outward. Apply glue to the back of the photodiode to secure it in the hole, then glue the plastic cover into position (see photo).

While the glue is drying, stick the Scotchcal panel into position on the lid of the box and use a sharp knife to trim away the material covering the gain control and switch holes. Mount the DPM-200 module, the switches, and the gain control on the lid of the box, and complete the wiring that runs between these components and the PCB. Do not forget to wire in the shorting links between the various module pins.

When the glue holding the sensor assembly is dry, trim the IRLED and photodiode leads to about 6mm and solder on wires to run between both devices and the PCB. Place some short lengths of spaghetti tubing over the bare leads to prevent shorts. Solder the leads from the battery clip to their respective terminations and attach a battery to the clip. Secure the battery into the case using the clamp.



Actual size artwork for the printed circuit board.

Calibration

To calibrate the monitor, first turn RV2 fully clockwise. As already mentioned, this is a multi-turn pot and the extremes of travel are indicated by a series of clicks as the shaft is turned beyond this point. Adjustments to the pot are most conveniently made before the PCB is mounted in the box.

Prop up the lid of the heart rate monitor so that you can see the display, then turn the monitor on. The display should read 000 with the "+" annunciator flashing on and off sporadically. Switch S1 to the CAL position and slowly adjust RV2 until the display reads 215. Due to the 6.6 second time constant of the two pole filter section there is a con-

Continued on page 105

Cathy Farrell shows how the new heart rate monitor is used.

. . . ctd from p86

siderable delay between adjustment of RV2 and its effect upon the display, so adjust RV2 slowly.

With the meter display now reading 215, the heart rate monitor is fully calibrated and ready to use. Switch S1 to the READ position and place a finger across the sensor so that the fleshy pad on the end of the finger just covers the two sensor components. Do not press too hard or the blood flow will be reduced to the point where the sensor will not pick up any pulses. A light finger pressure is sufficient.

Now adjust the gain control until a regular on-off flashing of the "+" annunciator is obtained. If a double flash of the "+" annunciator occurs for each heart beat it means that there is too much gain and the gain control should be reduced.

In some cases, it may not be possible to completely remove the double flash effect, particularly from strong signals. However, this usually does not affect the display reading since the second pulse occurs while the monostable output is still high from the first pulse and, during this time, the monostable cannot be retriggered. Once a steady flashing of the "+" annunciator is achieved, it is necessary to wait several seconds until the display reaches a stable value. Some small variations in the reading will occur due to slight variations in the heart rate, however these should only be about 1 or 2% of the reading.

Two points to watch when taking a reading are that you don't hold your breath, and that you don't concentrate too hard on making the "+" annunciator appear. Both these actions will increase your heart beat above the normal resting value.

Finally, some readers may wish to use a remote sensor to monitor their heart rate while exercising. Full constructional details for three different remote sensors were published in the April 1981 issue of "Electronics Australia".