HEART-RATE MONITOR

An invaluable tool for the bio-feedback experimenter or for the assessment of athletes.

THERE ARE MANY METHODS of measuring heart rate ranging from feeling the pulse, to chart recordings via an electrocardiograph. Other methods include monitoring the electrical potential which triggers each heart best; resistance changes due to changes in blood flow; and change in the volume of blood in blood vessels with each beat.

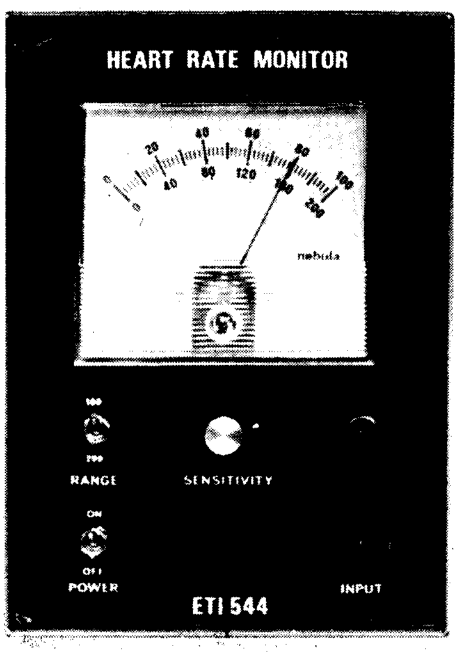
The detection of electrical signals associated with heart action is the best and most reliable method especially if the subject is exercising. However good connection must be made to the body by special electrodes and conductive paste to ensure very low contact resistance. The method is messy and requires skill in attaching the electrodes.

Similar electrodes are required to measure changes in body impedance and in addition the measurement is usually made by passing an electrical current through the body. This poses a considerable safety hazard as any fault in the insulation of mains-operated equipment can cause lethal currents to pass through the body. For this reason we did not use the method and we strongly recommend that experimenters do not either! With very well attached electrodes even small voltages can produce lethal currents.

LIGHTING UP TIME

This leaves us with the light-beam method, two variations of which are in common use. One is to pass light through flesh to a bone where it is reflected to a photo sensitive device adjacent to the lamp. This has the advantage that the sensor may be taped to any convenient part of the body, eg, the forehead, but the signal generated is very low. A second method still uses a light source and photo-sensor but the light is passed to the sensor through some thin section of flesh — the fleshy part of a finger or the ear lobe work very well. As there are no electrical contacts with the body this type of sensor is very safe to use and was therefore chosen for use in the ETI meter.

Specific Circuitry: While the detection and amplification of the signal due to heart action can be done with normal linear amplifiers the frequencies involved are very low. Measures must be taken to reject frequencies other than those of interest and to overcome dc offset problems due to differences in the path lengths depending on where the probe is attached.



Thought must also be given to the type of readout to be used. Were a digital readout to be used, counting of the rate would have to be performed for a full minute in order to obtain a one beat resolution and a new reading could only be taken at one minute intervals if normal frequency measurements are used. However, this problem may be overcome by measuring the period between the pulses and converting this to a frequency which can then be measured using digital logic to obtain a reading on every beat. This is quite valuable in a machine used for diagnostic work where information on the variations in regularity of the interval between adjacent beats can be quite meaningful. However, the method is complex, and expensive and requires some other type of sensor than the light beam type to obtain the accuracy required. As our meter is not intended for diagnosis the digital technique was rejected in favour of a simple analogue meter display.

CHOICE INTEGRATION

Even with an analogue readout we still have a choice of operating methods. We can measure the period between beats as previously discussed or we can use it as an integrating frequency meter. The latter method requires about 25 seconds for the reading to stabilise initially but thereafter it will follow variations in heart rate quite faithfully. The measurement of period between each beat is more rapid in its response but requires more

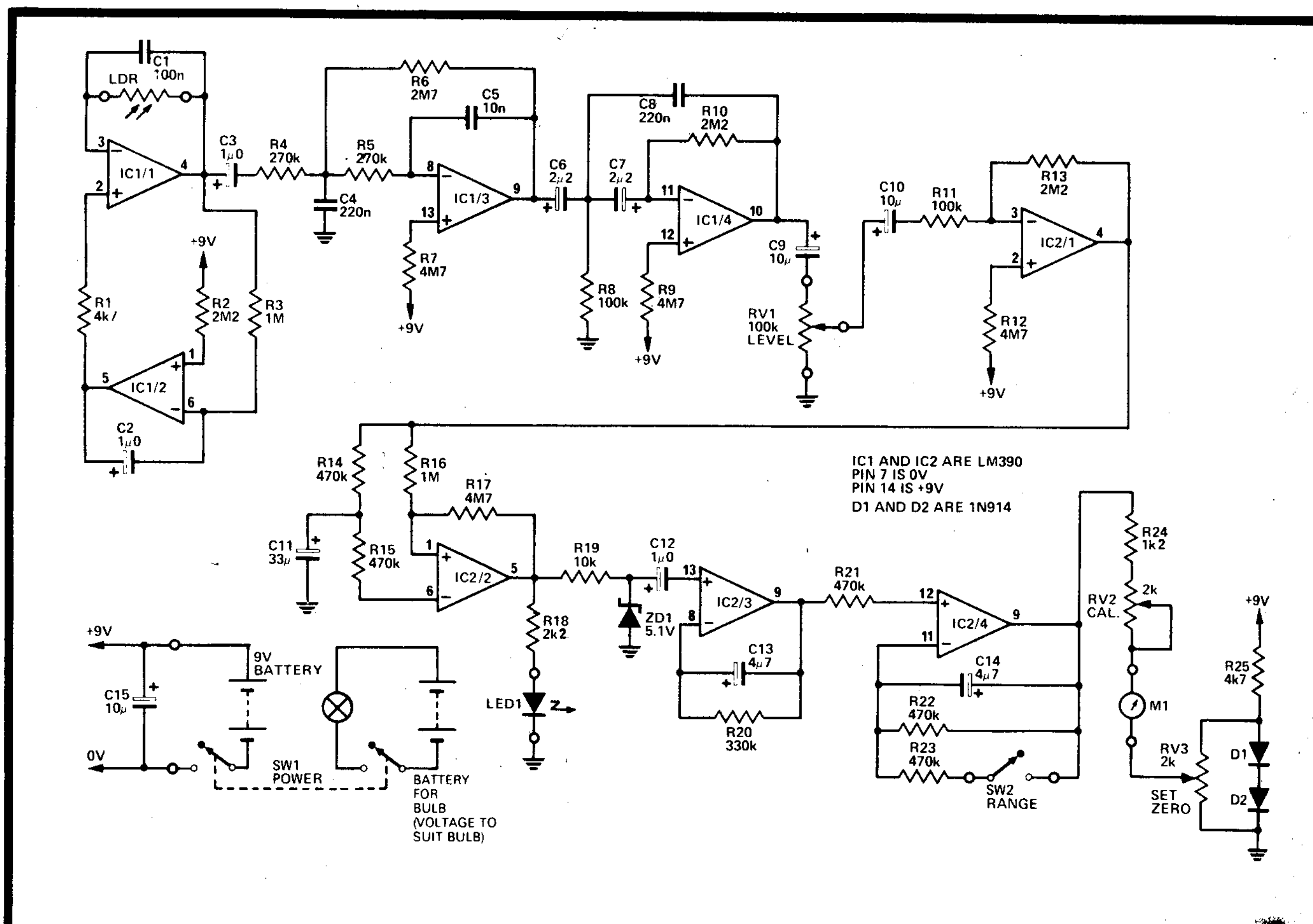


Fig. 1 Circuit diagram for heart-rate monitor.

How it works

The sensor consists of a light bulb and a light-dependant resistor mounted in a clothes peg in such a way that they may be positioned on opposite sides of a small section of flesh such as the ear lobe or a finger. As the heart beats it pumps blood through all the blood vessels of the body which swell. The density of the body therefore changes giving rise to a change in light transmission through the section of flesh to which the sensor is clipped. The LDR which is subject to this change of illumination therefore changes its resistance, and it is this change in resistance which eventually drives the meter. As the actual amount of light transmitted varies greatly from person to person and according to the thickness of flesh between the sensors, some method of stabilising the working base line is required.

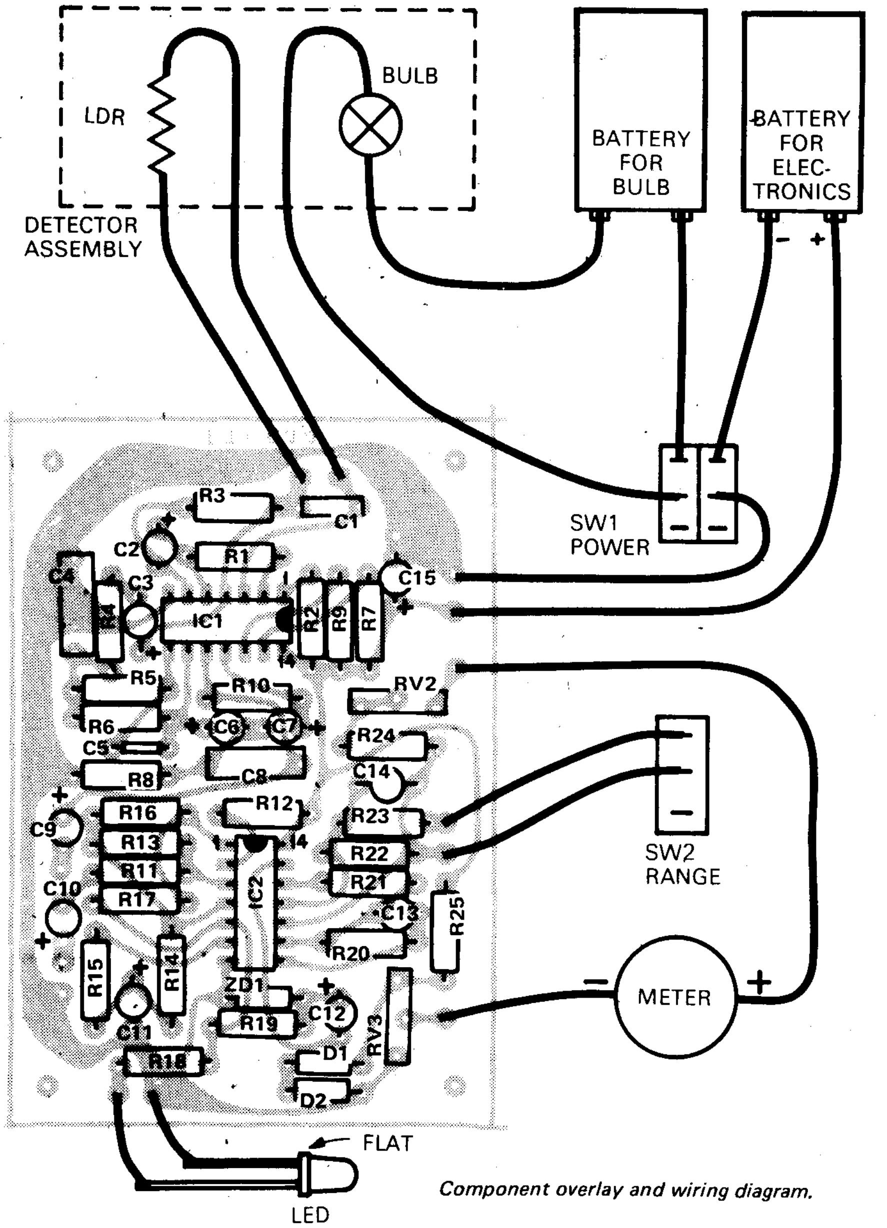
The stabilising function is performed by IC1/1 and IC1/2. Due to the operating mode of IC1/1 the current through the LDR is always equal to the current through R1. The current in R1 is automatically adjusted by IC1/2 such that the output of IC1/1 sits at about four volts (as the current in R2 must equal the current in R3). Capacitor C2 prevents the current in R1 from changing quickly and hence, relatively fast changes due to heart-beat (which cause changes in LDR resistance) are detected.

As the output of IC1/1 is at a very low level this signal must be amplified by IC1/3 and IC1/4 by about 40 dB. A low-pass filter which limits the rate, which can be detected to about 250 beats per minute, is also formed by IC3/3; and a low-pass filter which cuts off all frequencies below 30 beats per minute is formed by IC1/4. These filters eliminate 50 Hz pickup and any other signals generated by slow movement of the body which could also interfere with the measurement. As the actual signal can vary over a range of 20 dB with different people a level control is incorporated, after IC1/4, and the output from this control is amplified by 26 dB in IC2/1.

The output of IC2/1 has now to be squared up before it can be used. This is performed by a Schmitt trigger formed by IC2/2 where the necessary positive feedback is supplied by R17. Both inputs are biased from the output of IC2/1 but the ac signal is prevented from reaching the negative input by capacitor C11. An LED driven by the output of IC2/1 is incorporated to give a visual indication that heart beat is actually being detected.

It is now necessary to convert the square wave from the output of IC2/2 into a voltage proportional to heart rate and this is the purpose of IC2/3. Each time the output of IC2/2 goes high, capacitor C12 is charged up via R19 and the positive input from IC2/3. By the nature of the IC this current has to be balanced by a corresponding current in the negative input. This current can only be supplied by the output going high and supplying current via C13. This charges C13 up a little. On the negative edge of the output from IC2/2 the capacitor is discharged via the protection diodes on the input of IC2/3. If R20 was not present C13 would continue to charge up on each input pulse, however R20 bleeds a little current from C13 and the charging stops when it reaches a voltage where the amounts of charge and discharge become equal. The voltage reached will of course now be proportional to the heart rate. The amount of ripple on this voltage is determined by the time constant of R20 and C13 and this is selected as a compromise between response time and ripple. The zener diode is used to stabilise the output of IC2/2 against any changes in supply voltage.

The last section of IC2 is used as a b... amplifier which provides the two r... required along with an extra st... filtering. The output of IC2/4 is mete... give a direct readout of heart r... resistor and trimpot in series with th... allow the instrument to be cali... the potentiometer RV3 provides a ... correction (as the output of IC2/4 is ... zero volts but at about 0.8 volts). Dio... and D2 stabilise this against s... variations.



Component overlay and wiring diagram.

Parts List

Resistors all ½w 5%

R1	4 k7
R2	2 M2
R3	1 M
R4,5	270 k
R6	2 M7
R7	4 M7
R8	100 k
R9	4 M7
R10	2 M2
R11	100 k
R12	4 M7
R13	2 M2
R14,15	470 k
R16	1 M
R17	4 M7
R18	2 k2
R19	10 k
R20	330 k
R21-R23	470 k
R24	1 k2
R25	4 k7

Potentiometers

RV1 100 k log rotary
RV2 2 k Trim.
RV3 2 k Trim.

Capacitors

C1	1 µF 35V electrolytic
C2	100 n polyester
C3	1 µF 35V electrolytic
C4	220 n polyester
C5	10 n "
C6,7	2 µ 2 25V electrolytic
C8	220 n polyester
C9,10	10 µ 35V electrolytic
C13,14	4 µ7 25V electrolytic
C15	10 µ 16V electrolytic

Semiconductors

IC1,2	LM3900
D1,2	1N914
ZD1	5.1V Zener 400mW
LED1	

Miscellaneous

Meter 1mA FSD
PC board ETI 544
Box to suit
9V battery
2 x 9V batteries
One single pole switch
One double pole switch
LDR ORP12 or similar
12V 30mA bulb

complex circuitry and is very responsive to noise 'glitches' or to phenomena other than heart beat. Furthermore the scale for such an instrument is non-linear and wrong reading. That is high readings are at the left of the scale and vice versa. For these reasons the integrating frequency meter was chosen as the cheapest and most effective method for our particular application.

PROTOTYPE PROBLEMS

Our original prototype was built with 741 type operational amplifiers but in the final version we used the LM3900 which contains four Norton type operational amplifiers in the one package. This is a very economical solution as although the circuit is quite complex in concept, the whole device only uses two inexpensive ICs.

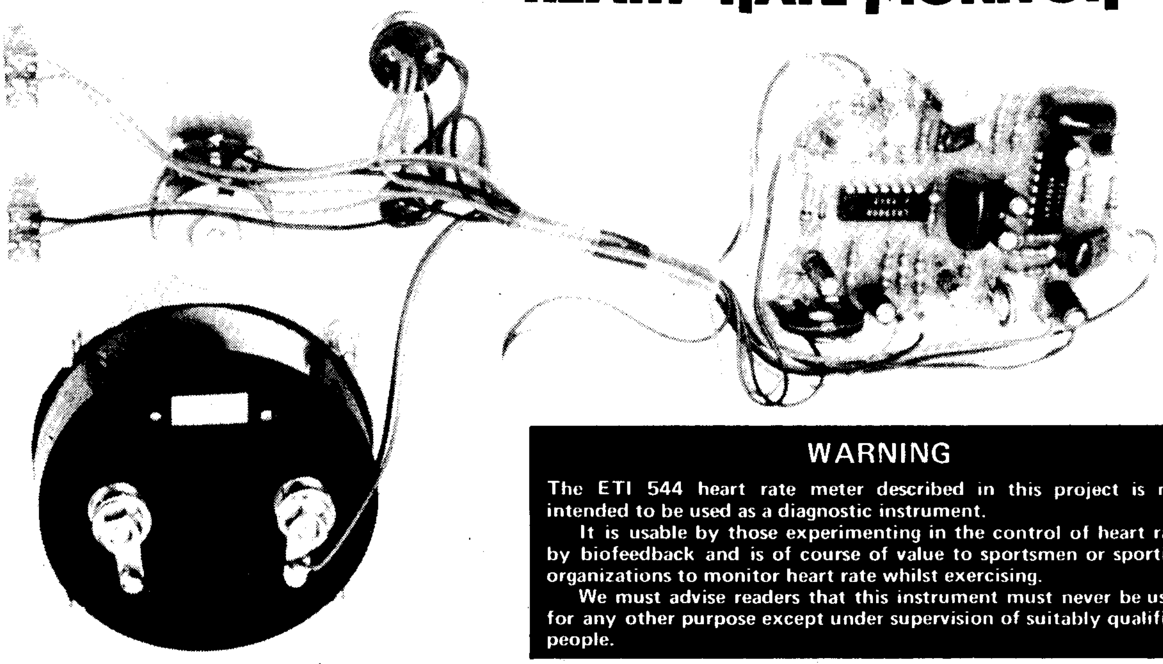
In the development of the circuit for this instrument a laboratory power supply was used. However, when the completed board was mounted into its case and run from batteries it worked alright until the battéries had been used for a while and then problems were encountered. The unit would just not count correctly. After much experimentation it was discovered that when the Schmitt trigger operated the power rail changed by about 10 millivolts or so and this modulated the bulb thus generating a spurious pulse.

Having located the problem it was a simple matter to cure it — just run the bulb from a separate battery.

CONSTRUCTION

There is no need to use the box that we used either — any suitable one will do. Just use the wiring diagram supplied to connect up the unit.

The sensor was made from a spring clip type of clothes peg, by mounting the bulb on one leg of the peg and the LDR on the other. Holes must be provided in the peg so that the light can pass through to the LDR. Fix the bulb and LDR into position with a little epoxy cement. The area around the rear of the LDR should be painted black or covered with tape to prevent all light other than that from the bulb reaching it.



WARNING

The ETI 544 heart rate meter described in this project is not intended to be used as a diagnostic instrument.

It is usable by those experimenting in the control of heart rate by biofeedback and is of course of value to sportsmen or sporting organizations to monitor heart rate whilst exercising.

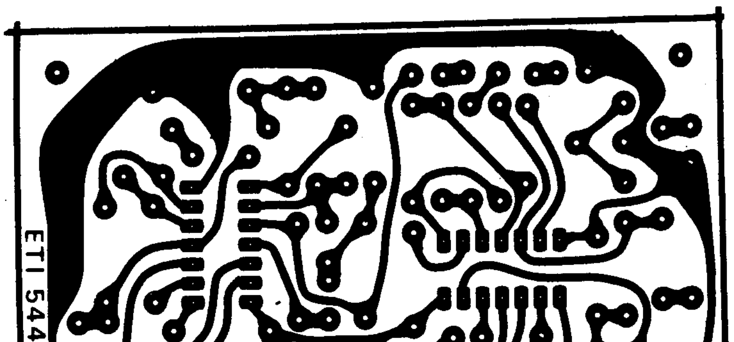
We must advise readers that this instrument must never be used for any other purpose except under supervision of suitably qualified people.

USING THE MONITOR

To use the monitor simply clip the sensor to the ear lobe or to the fleshy part of the finger or thumb. Now adjust the sensitivity upward until the LED justs starts to flash regularly — indicating that heart beat is being detected reliably. The reading on the meter will start to rise and will become stable after about 25 seconds. Hereafter the reading will faithfully follow variations in heart rate.

Note that the finger or thumb should not be moved whilst taking a reading as this will cause a change in the flesh — which can be interpreted as a spurious heart beat thus giving an erroneous change in the indicated rate. ●

BOARDING PARTY



Full size 91 x 64mm.

This is the PCB track pattern for the Heart-Rate Monitor, ETI Project Number 544, which was omitted from last month's article. Copies of the board were sent to our regular PCB supplier advertisers, and so should be available from them in the usual manner. See the Mini-Ads section in this issue