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BIOPIC HEARTBEAT MONITOR

JOHN BECKER

Take a peek at the rhythmic waveforms that keep you ticking!

BEFORE joining *EPE*, the author was on a short-term contract with a life-support equipment manufacturer. Of particular interest were the heartbeat waveforms displayed on the heart defibrillator screens, which had to match certain software criteria before electric shock treatment could be given to patients.

The various categories of waveform could be simulated electronically, but in active service the system would monitor a patient's heart via chest electrodes.

BEATING HISTORY

Inspired by the simplicity of the heart monitoring circuits, the author designed one for *EPE*. This was published in Feb/Mar '93 as the *Biomet* (which loosely translates as *Life Meter*).

PIC microcontrollers were unheard of to hobbyists at that time and the three-board design required 13 i.c.s. Heartbeats were monitored across the chest using simple electrodes. Pulse rates could be monitored separately by a handheld sensor that detected the opacity of the thumb, which changes as blood pulses through it.

A 3½ digit liquid crystal display (l.c.d.) showed the pulse rate. Data could also be output to a computer for waveform display.

MODERNISED MONITORING

Although heart monitoring techniques may not have changed fundamentally since that design, the methods for processing the data have moved on dramatically. The Biopic design presented here takes advantage of a PIC16F876 microcontroller's capabilities and uses an alphanumeric l.c.d. screen, plus an electrically-isolated serial data link to a PC-compatible computer. There are only five i.c.s.

The probes and contact pads used are those sold inexpensively by major chemists for use with proprietary TENS (pain relief) machines.

The design can be used as a handheld unit without using a PC. In this role it outputs heartbeat waveforms to the l.c.d., which is used in the same graphical fashion as with the author's *Micro-PICscope* (simple oscilloscope) of April '00. The display also shows the heartrate in beats per minute (BPM) and a real-time pulse beat via a flashing asterisk and l.e.d.

When used with a PC, the design switches off the l.c.d. waveform and outputs data as a 9600 baud serial stream to a program written for QB (QBasic or QuickBASIC). The Biopic software is self-contained and does not require QB itself to be installed.

The QB program can be run in DOS mode or under Windows 3.1, 95, 98 and ME (other Windows versions have not been tested with it and no advice can be offered for them).

Example of a thumb-monitored waveform on the Biopic.

PC WAVEFORM DISPLAY

A composite photo of several typical heart waveforms displayed on a PC screen is shown on the next page. Whilst the subject is believed to be in good health, a medical opinion of the waveforms has not been sought.

Normally a real-time waveform starts at top left (zone 1), continues to the right, recommences in zone 2, continues right, etc. At the end of zone 10, zone 1 is cleared and the display continues from the top again, each zone then clearing in sequence as the waveform starts at its beginning.

The BPM rate is calculated across each zone, and the value displayed at the screen's top right. This value is updated each time a zone line is completed. The BPM and a real-time calender/clock display are updated simultaneously.

At the bottom of the screen, details of the COM port in use are shown. The COM port address (shown here as COM 2) can be changed by pressing keyboard key <C> (more later). The baud rate and its format cannot be changed as this is set within the PIC software as well as in the QB program.

The span between screen data plotting points can be changed to vary the display detail, using the <+> and <−> keys. The
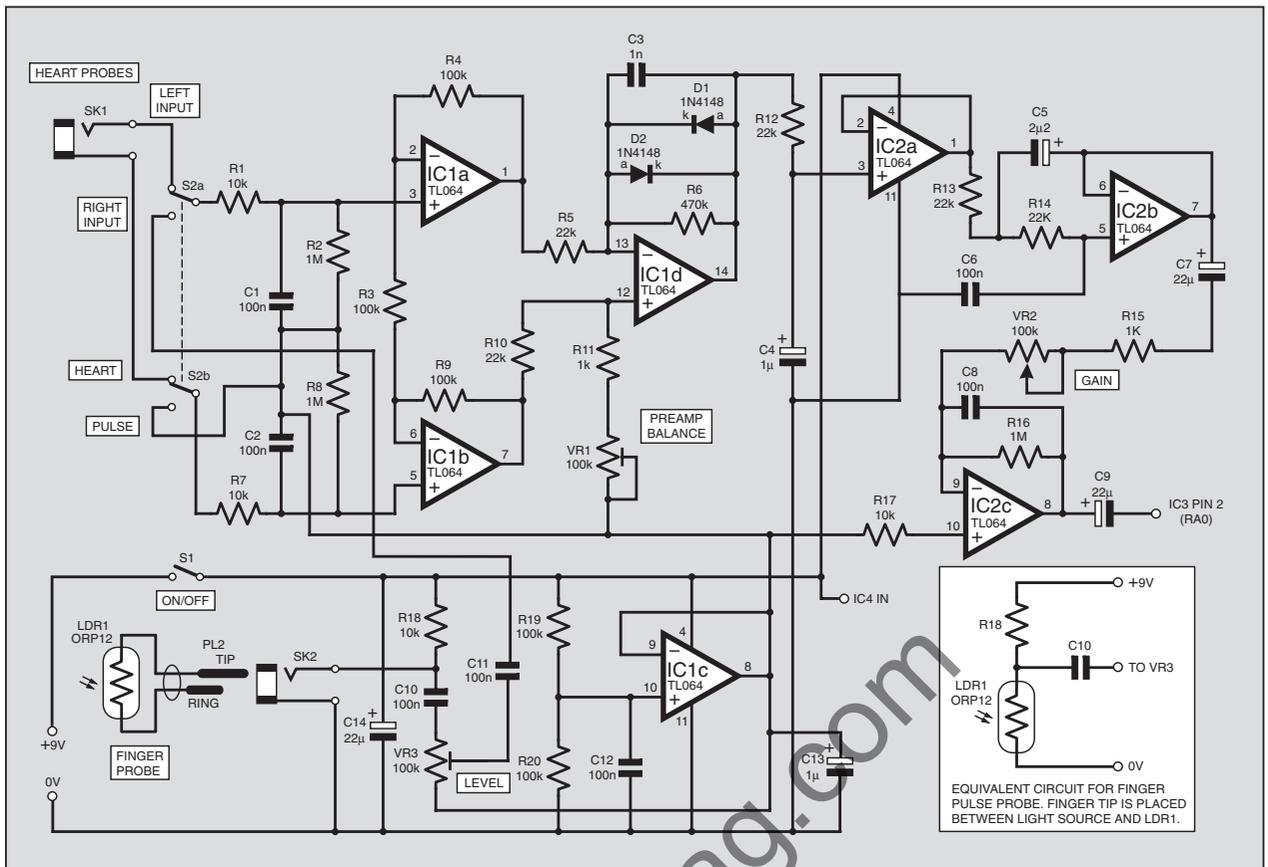
Fig.1. Circuit diagram for the analogue stages of the Biopic Heartbeat Monitor.

range is 1/1 to 1/50, the latter showing waveforms closer together. The sampling rate itself is not affected by these changes, the result is purely cosmetic on the PC's screen.

Pressing <H> turns on the "hold" function. The display then pauses when it reaches the far right of its current zone. Pressing any key then lets the display run again.

Pressing <Q> causes an exit from the program and a return to the screen from which it was first called.

Pressing <L> enlarges the display to cover just one nearly full-screen line. Pressing <L> again returns you to 10-line mode.

When run under Windows, waveforms can be "captured" for saving to disk and printing to paper (via Paint).

ANALOGUE CIRCUIT

The Biopic effectively has two circuits, the sensor input and signal pre-conditioning circuit, plus the PIC-controlled display and data output circuit.

Composite of several heart waveform traces as shown on the PC screen. In normal running the waveforms run continuously.

The analogue circuit diagram is shown in Fig.1. Probes from the subject whose heart is to be monitored are connected into socket SK1. The circuit is not "earthed" for safety reasons and a differential amplification technique is used.
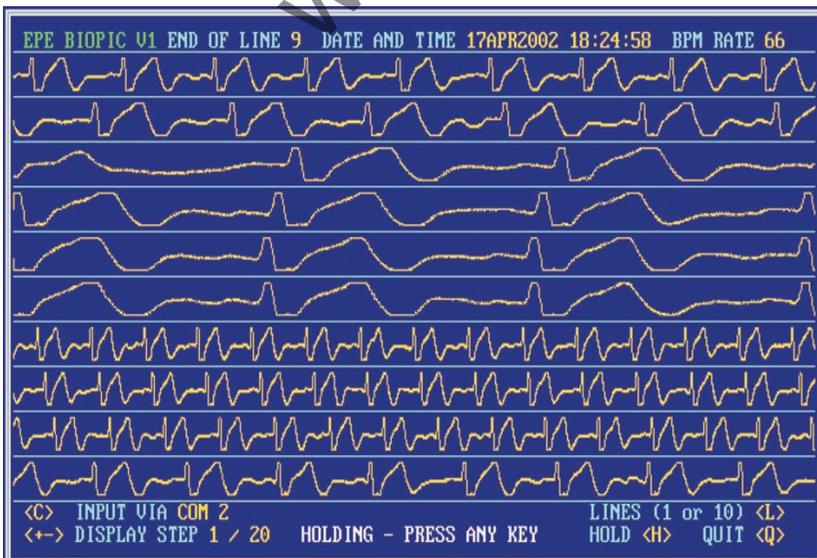
The probes are each connected separately to the non-inverting inputs of two op.amps, IC1a and IC1b, via resistors R1 and R7. Both inputs are biassed at about 4·5V (half the nominal 9V supplied by a PP3 battery) via resistors R2 and R3, which have a high value to minimise the voltage drop across R1 and R7.

A pumping heart is accompanied by a small electrical field across the chest. This can be detected by using two electrical contact pads and probes. One pad is placed below the heart, near the bottom left of the subject's rib cage. The other is placed on the subject's right towards the top of the chest. It is worth experimenting to find the best position.

The self-adhesive pads have terminals to which the commercially purchased probe leads are clipped. As the heart beats, the electrical field is detected as a voltage difference between the probes, and thus by their amplifiers. The difference in potential between the probes is extremely small and needs a considerable amount of amplification.

Initially, the difference is d.c. amplified by a factor of two, as set by resistors R4, R3 and R9, although this is complicated by the intercoupling between IC1a and IC1b via R3 (see *Teach-In 2002* Part 5 (Mar '02) for an explanation).

Further amplification of about ×21 is given when combining both paths via differential op.amp IC1d. The balance between the two signals can be set by
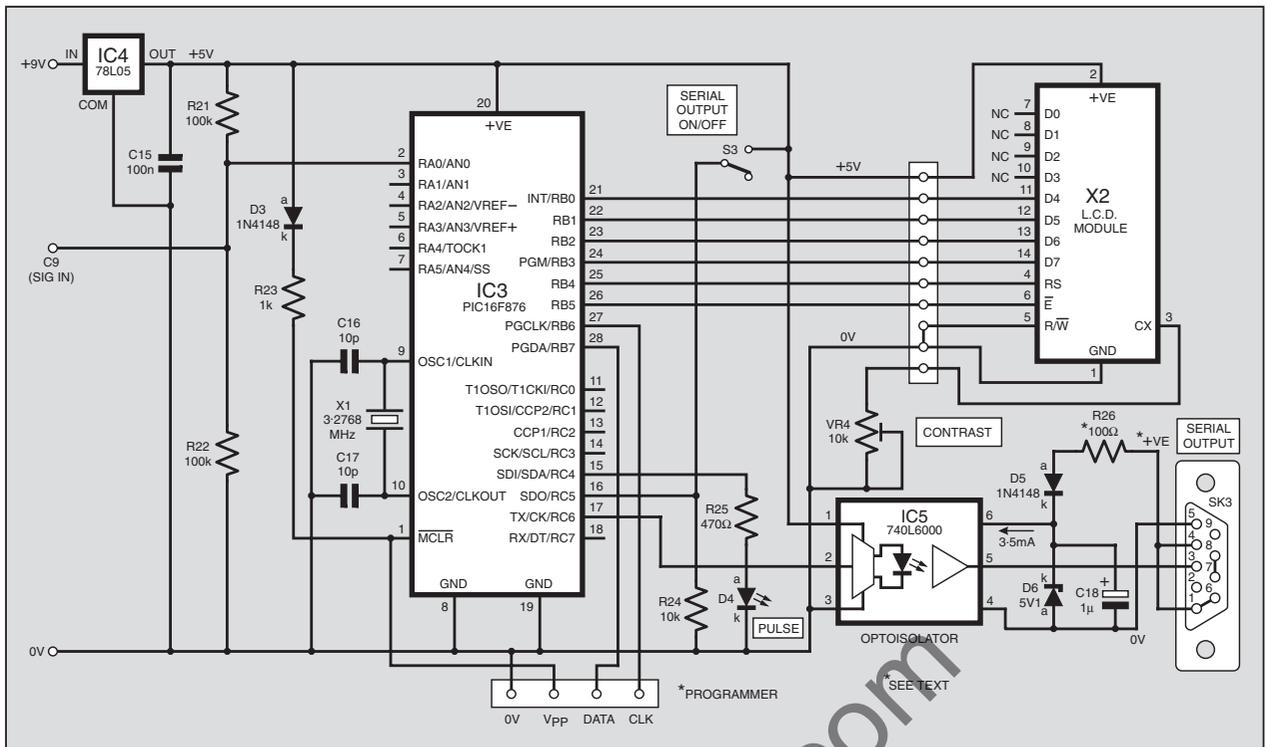
Fig.2. The Biopic's control circuit details.

preset VR1. High-frequency cut-off is provided by capacitor C3.

Still as a d.c. voltage, the signal is fed to the first stage of a low-pass filter via resistor R12, with capacitor C4 providing some preliminary upper-frequency cut. Heartbeats normally take place at around one per second, and seldom above two per second except under extreme conditions.

Whereas the previous *Biomet* used a switched-mode filter (MF10), Biopic uses a purely analogue filter. This is a variant of the Third Order Chebyshev low-pass filter from the *Filter Handbook* by Stefan Niewiadomski. It is formed around op.amps IC2a and IC2b and removes practically all frequencies above those that are to be expected from a heartbeat waveform.

Its output is a.c. coupled by capacitor C7 to the final gain stage, formed around IC2c. Here the gain can be varied between about ×10 and ×1000 by potentiometer VR2. Capacitor C9 gives stability to IC2c at high gain levels.

The final output is a.c. coupled by capacitor C9 to one of the ADC inputs (RA0/AN0) of the PIC microcontroller (Fig.2).

THUMB PULSE

Still referring to Fig.1. The circuit can be switched to monitor a pulse beat detected via a thumb probe, detecting blood flow as mentioned earlier.

The familiar ORP12 light dependent resistor (l.d.r.) is used. This is biassed across the 9V/0V power rails via resistor R18. An equivalent circuit of the sensor configuration is shown in the inset of Fig.1.

As the blood pulses, the amount of light passing to the l.d.r. through the thumb varies. This cause the resistance across the l.d.r. to change minutely. The resulting fluctuating voltage at the l.d.r./R18 junction is a.c. coupled via C10 to

potentiometer VR3. This sets the amplitude that is fed via C11 to op.amp IC1a and switch S2a. Amplification takes place as before, but with IC1b not used.

CONTROL CIRCUIT

In the control circuit of Fig.2, the principal component is the PIC16F876 microcontroller IC3. This is clocked at 3·2768MHz as set by crystal X1.

The amplified and a.c. coupled signal from IC2c is fed to the PIC's RA0/AN0 analogue-to-digital converter (ADC) input. The input is biassed to about 2·5V (half the PIC's nominal 5V supply), by resistors R21 and R22.

When no signal is present, the ADC conversion value read by the PIC is about decimal 128, out of a possible 8-bit range of 0 to 255 (the PIC's full 10-bit range is not needed in this design).

From the incoming values, the PIC calculates the BPM rate according to an internal clock. It does not attempt to determine which pulses are truly heart-generated and which have been caused, for example, by movement of the thumb on the l.d.r. The twin heart-probe path is less prone to extraneous conditions.

The pulse beats are displayed by l.e.d. D4, which is buffered by resistor R25 and controlled by PIC output RC4. The calculated BPM rate is output to the l.c.d. via lines RB0 to RB5, the display being operated in conventional 4-bit mode. Preset VR4 adjusts the l.c.d. screen contrast.

The software also outputs graphics data to the l.c.d. for display on line 1 in cells 1 to 8 as a simple waveform (as shown earlier and on the final page). The technique was first used by the author in the l.c.d. display for his *Micro-PICscope*.

Readers familiar with alphanumeric l.c.d.s will be aware that the display has several internal character generator registers that can

be programmed by the user. Data is written from the PIC into these registers such that the pixels show a moving display of the heartbeat waveforms.

It has to be emphasised, though, that the l.c.d. shows less detail than can be displayed on the PC screen. Nonetheless, for simple handheld use of the unit, the l.c.d. can produce informative results.

SERIAL OUTPUT

When the PIC detects that its RC5 pin has been set high via switch S3, it switches from l.c.d. output mode to serial output mode via pin RC6, feeding to opto-isolator IC5. This has an integral l.e.d. that is controlled by RC5 and buffered internally. The l.e.d.'s behaviour controls an opto-sensor coupled to IC5's internal buffer. The resulting logic level changes are output from pin 5 to the serial connector SK3, and thence to the PC.

The buffer within IC5 draws its power directly from the PC. The positive supply is passed via ballast resistor R26 and diode D5 to IC5 pin 6. Zener diode D6 ensures that the voltage across the buffer cannot exceed 5·1V and capacitor C18 smooths this supply. As a result, the data logic levels output to the PC stays within its acceptable range of nominally 0V to 5V.

The PIC16F87x series all have serial communications routines built into them, and the protocol (e.g. Baud rate etc.) can be changed as detailed in this PIC family's data sheets. The rate has been set at 9600 baud, 8-bit, 0 parity, 1 stop bit. This configuration data is also set into the Biopic's QB software that controls the PC's serial reception mode.

Each PIC-generated ADC conversion is sent to the PIC's serial data output register and then to the PC, which receives each data byte and processes it as discussed later. The l.e.d., D4, is not active in this mode.
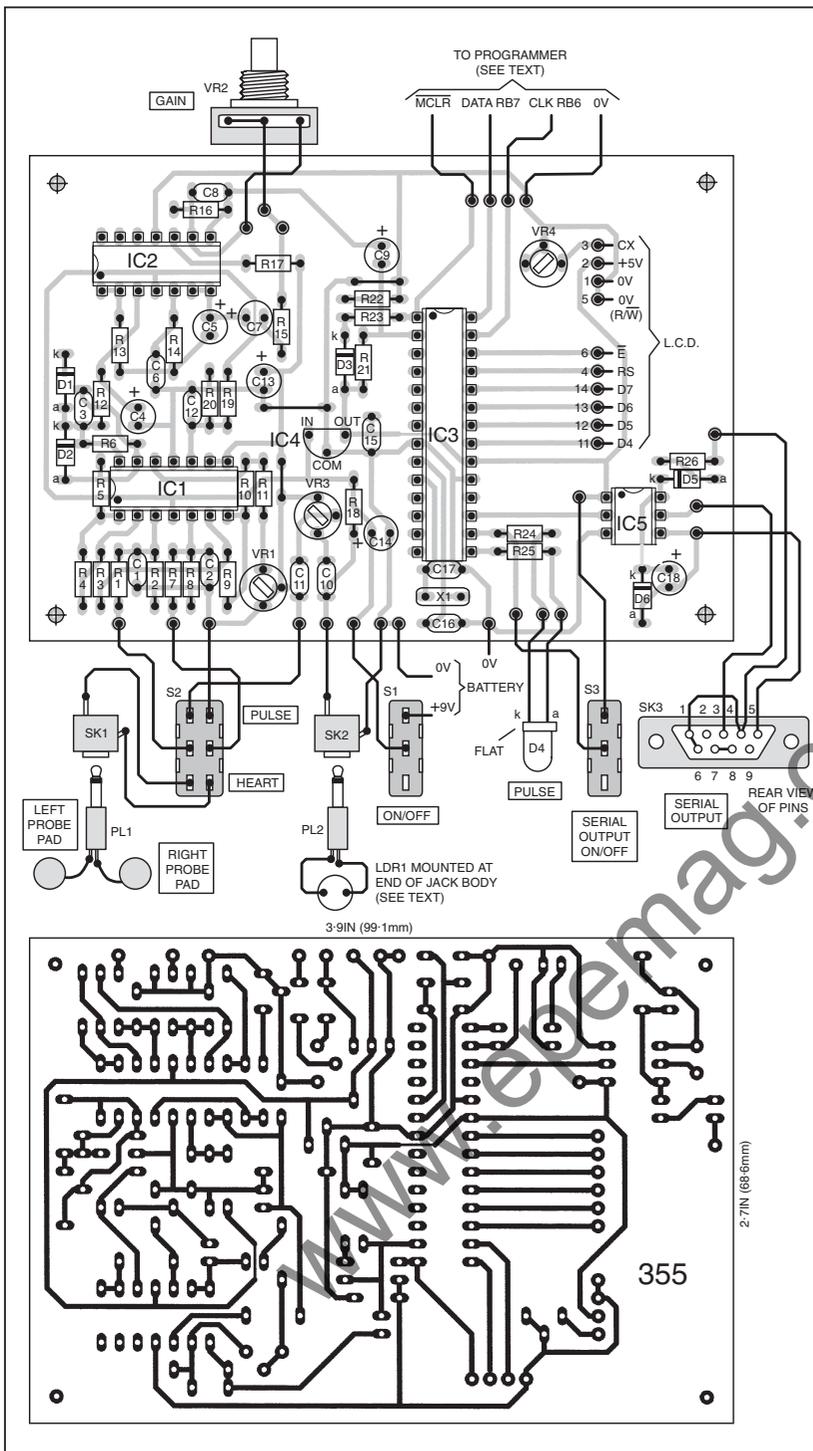
Fig.3. Printed circuit board component layout and full-size master track pattern, plus off-board connection details.

OPTO-ISOLATION

The importance of using an opto-isolator cannot be over-emphasised. The most dangerous route that an electrical current can take across the human body is via the chest. The voltages and currents that can be lethal can vary between subjects, but can be as low as 50V and 10mA.

It is therefore imperative that any unit which requires a pair of electrodes to be secured across the chest when that unit is also connected to a mains powered piece of equipment, such as a PC, must provide *total electrical isolation* **between them.**

Any designer must ensure that his units and their users cannot be harmed by mains power faults. The opto-isolator specified for the Biopic is stated by the manufacturer to provide isolation up to 2500V, well in excess of the 230V a.c. present on a normal UK a.c. mains supply.

The reason for using a serial connection between the PC and the Biopic was to simplify the isolation circuit. To have used the parallel port as the connection path (easier in some respects) would have required using an isolator for each data line.

Also for electrical safety reasons, the Biopic MUST NOT be powered from a

mains operated power supply of any type. Only battery power must be used. The safety of the person to whom the probes are connected must be the prime consideration. **DO NOT IGNORE THIS SAFETY ADVICE.**

CONSTRUCTION

The component and track layout details for the Biopic, plus the off-board wiring, are shown in Fig.3. This board is available from the *EPE PCB Service*, code 355.

Sockets must be used for all d.i.l. (dual-in-line) i.c.s, but do not insert the i.c.s until the correctness of the power supply regulator has been proved. Assemble the other components in any order you prefer, but it is recommended that they should be inserted and soldered in order of ascending size.

It is up to you whether you use preset potentiometers for VR2 and VR3, mounting them on the p.c.b. in the holes provided. The alternative is to use panel mounted rotary potentiometers with knobs. The former is neater, but the latter provides easy external control of signal amplitudes. On consideration, the author opted for VR2 as a rotary pot.

If you do not intend to use a PC with the Biopic, connect the lead that would otherwise go to the pole of switch S2 to the 0V connection.

A plastic case measuring 150mm × 80mm × 50mm was used for the prototype. A viewing slot for the l.c.d. was cut in its lid, and holes drilled for the controls and sockets.

PROBES

The ORP12 l.d.r. for thumb pulse monitoring conveniently has a diameter that allows it to be inserted in the plastic "cap" of a 6·35mm (¼in) jack plug. Solder a suitable length (say half a metre) of twin low-voltage cable to the l.d.r.'s pins, pass the cable through the hole at the end of the cap and gently push the device into the cap until it is flush with the rim.

Secure the l.d.r. with a suitable glue or adhesive-backed tape, such as insulating tape (as was done with the prototype). Connect a 3·5mm plug to the other end of the cable. Polarity does not matter.

The heart monitoring pads are likely to be sold in multi-packs – two pairs in the pack bought by the author. They are intended as replacements for use with proprietary TENS machines and their

Interior details of the Biopic enclosure.

existing cables. Spare cables can be purchased, however. Two were in the pack supplied for the prototype, having press-studs that clip onto the pads at one end, and a 2-pin female plug at the other.

The author made no attempt to buy a suitable male connector for use with the Biopic. Instead, the plug was cut off and the twin wires soldered to a 3·5mm jack plug. Again polarity does not matter.

PRELIMINARY CHECKS

Having completed the board assembly, thoroughly check that all components are in the right place and that their polarity has been correctly observed as appropriate. Pay great attention to the soldering, especially for those components in the physical region of opto-isolator IC5.

It is imperative to ensure that no solder bridges or "hairs" occur in that area. The isolation value quoted earlier only holds true if the manufacturer's pin separation distance is maintained. The board area in that region (above and below) must be scrupulously clean to maintain its own electrical isolation qualities.

With d.i.l. i.c.s and the l.c.d. omitted, apply battery power to the board. Check that +5V exists at the output of regulator IC4 and at strategic points around the board. If the voltage is not correct, within about five per cent or so, switch off and investigate the reason.

When satisfied, and with the battery disconnected, insert the remaining i.c.s., ensuring their correct orientation in the sockets. Connect the l.c.d. Apply power
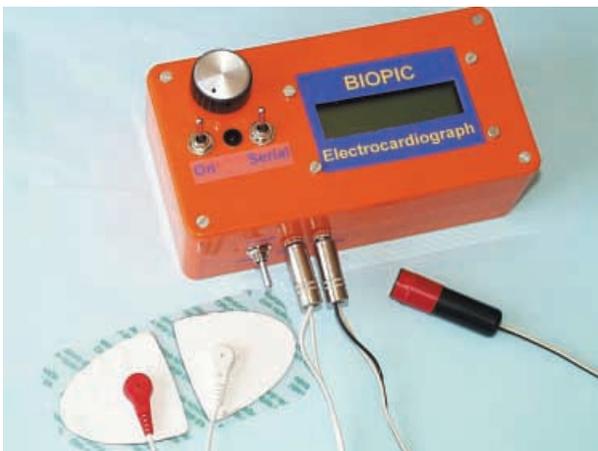
Completed Biopic, plus heart monitoring probe pads, and thumb pulse detector.
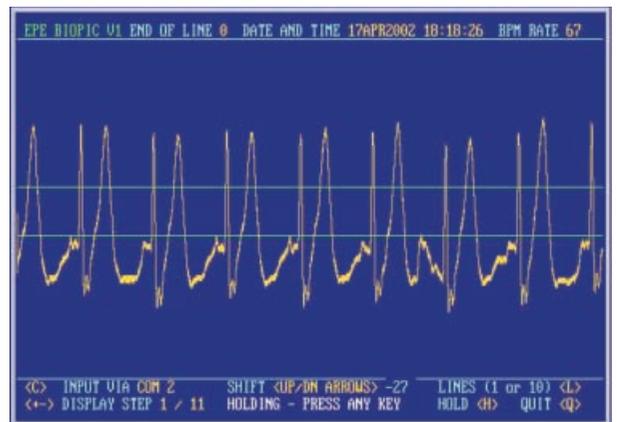
Typical example of a heart waveform shown on the PC when the program is in "enlarge" mode. The two horizontal lines indicate the "trigger" zone used for assessing beat rate.

again and recheck that the regulator still outputs +5V.

If you have *Toolkit Mk2* or *Mk3 (TK3)* you can now program your PIC while *in situ*, making the required connections via the connections provided. The PIC configuration is for crystal XS, POR on, WDT off.

For those who do not have programming facilities, pre-programmed PICs can be obtained as stated on this month's *Shoptalk* page, which also gives details of obtaining the software itself..

ACTIVE TESTS

Once the programmed PIC is running, adjust preset VR4 until a message is visible on the l.c.d. With mode switch S2 in the Pulse setting, line 1 should show the word BIOPIC on the right, to its left nothing recognisable is likely to be displayed. Line 2 should read PULSE RATE followed by a

Example of a heart waveform monitored across a subject's chest.

Another example of a pulse being monitored via the thumb probe (the lack of uniformity is due to the subject's slight agitation!).

The Biopic's screen while it outputs pulse waveform data to the PC.

numerical value and perhaps an asterisk.

It is best to check the unit while using the "thumb-pulse" detector, with the first message on display. Plug the l.d.r. assembly into socket SK2 and switch S2 to "Pulse" mode.

Set preset VR1 midway and potentiometers VR2 and VR3 for maximum signal gain. Move your hand back and forth across the l.d.r.'s face in a reasonably well-lit room, so putting the l.d.r. in and out of shadow. Observe l.e.d. D4 while you do so. It should flash on and off in response. If it does not, check that you have set VR2 and VR3 in the correct direction.

Looking at the l.c.d. screen, the asterisk at the right of line 2 should also go on and off in response to light changes. On line 1 a pulsed waveform should now be seen, corresponding to the high and low light levels as the shadow crosses the l.d.r.

Gently place your thumb across the l.d.r. face and point the top of your thumb towards the light. As your blood pulses, so the l.e.d. should flash, accompanied by meaningful detail on the l.c.d. screen.

You must keep your hold of the l.d.r. gentle and steady to avoid false triggering. It may either be necessary to come closer to the light or to reduce the setting of VR3 until an even l.c.d. waveform is shown,

Another "enlarged" waveform, displayed horizontally on a wider scale.

together with a reasonable BPM value on line 2. A certain amount of practice is needed to get the technique right.

CHEST PROBES TESTING

To check the chest probes mode, switch S2 to Heart. Plug the heart sensor cable into its socket.

Attach the TENS monitoring pads to your chest, as described earlier, and clip the cable to them. Next, stop moving, relax and observe the l.c.d. screen. If you have positioned the pads on your chest correctly, you should see your heart waveform begin to appear on the l.c.d. It may take a few seconds to stabilise.

Adjust potentiometer VR2 until distinct pulses are seen. Your pulse rate should again be indicated numerically, together with a flashing asterisk, and the l.e.d. flashing in sympathy.

Again, it takes a bit of practice to remain in a sufficiently passive state for the display and BPM rate to remain stable.

Having set VR2 for what appears to be a reasonable gain setting, return to using the thumb monitor and if necessary readjust VR3 to compensate for the change in VR2's setting.

If you have an oscilloscope, preset VR1 can be adjusted to balance the gain between the two input signal paths. If not, leave VR1 set midway.

PC MONITORING

Instructions for loading the PC with its program for monitoring the Biopic are to be found in the text file BIOPIC.TXT that accompanies the software. This file may be read via a text editor such as Notepad or MS-DOS Edit. Follow the instructions,
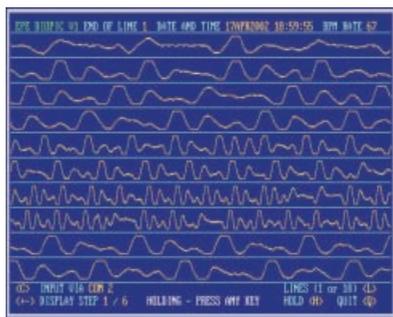
Composite of several typical pulse displays when the thumb pulse monitor is used. Slight involuntary movement of the patient causes unevenness.

connect a serial cable between the PC and Biopic, using the type required by standard modems.

Set the Biopic for thumb monitoring and switch S2 for serial output. Then run the program.

On first running, it may be that the software and PC have different ideas on which COM port to use. If the PC screen does not show a series of waveforms such as appear in the screen photos, press key <C> to change the COM address used by the Biopic's PC software.

Pressing <C> again reverts to the previous COM port address, of which there are two, COM1 and COM2. It is not known if PCs can have more than two COM ports – if yours has, consult its Help file for more information.

Do not change any of the settings within the Biopic's PC program unless you know what you are doing.

SCREEN "DUMPING"

When the program is run from within Windows, the display can at any time be "captured" and pasted into the Windows Paint program, from where it can be saved to disk or sent to a printer (i.e. a "screen dump" – such as shown in on this page). Screen dumps cannot be created from within DOS, nor can other forms of screen output to disk or printer (there are methods to do so, but discussing these is beyond the scope of this article).

To capture a screen, press the Print Screen function key. Now press the Windows-symbol key, and select the route Programs > Accessories > Paint > Edit > Paste > Save As. If you are not familiar with Paint, explore its range of options.

MEDICAL GUIDANCE

Biopic should not be used as a substitute for seeing your medical practitioner. It is not claimed that the waveforms it displays accurately mimic those that would be displayed by fully professional heart monitors. The displays are purely for interest. They should not be taken as an indication of anyone's true state of health.

If you have any reason to believe that anyone's heart is not behaving as it should, seek prompt medical advice. □

REFERENCE

Filter Handbook – a practical design guide. Stefan Niewiadomski. Heinemann Professional Publishing. ISBN 0 434 91378 2.