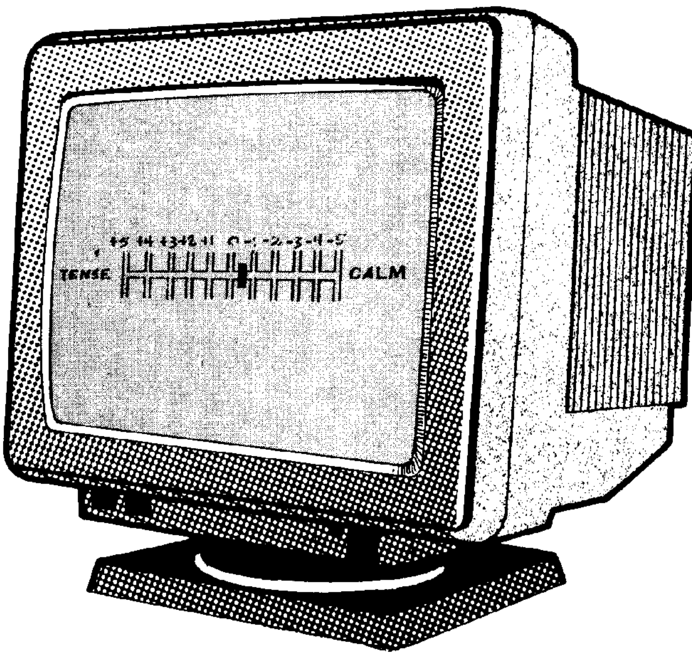
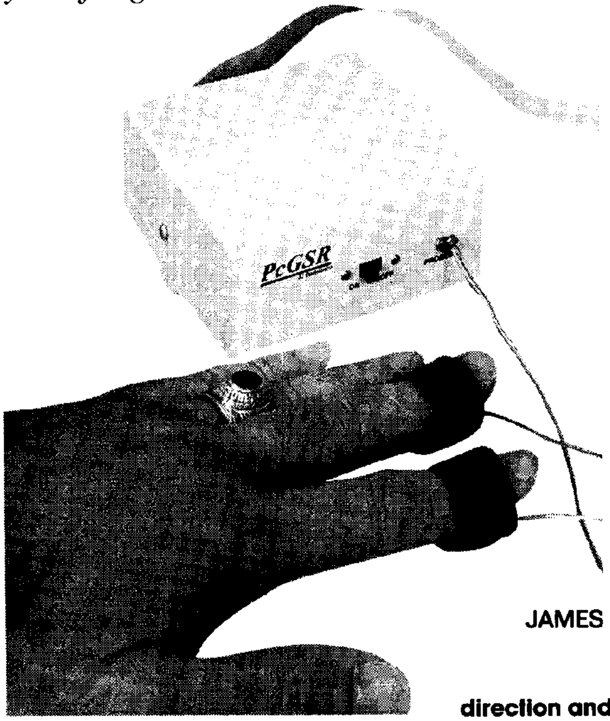
Stressed out from your job? Life's got you in a tizzy? Is your stomach in knots trying to find parts for that last **Electronics Now** *project? With this simple device and an IBM or compatible PC, you can use biofeedback techniques to smooth over some of life's rougher edges and calm your jangled nerves.*





BUILD A Biofeedback MONITOR

JAMES J. BARBARELLO

Stress reduction through biological feedback is a time-tested and relatively simple process. It consists of measuring a person's level of stress while thinking of various things. The current stress level is fed back to the person in real time, usually by some form of audio tone, lights, or other display. You can then discover the mental exercises that aid in reducing stress, and eventually use those exercises in everyday situations without biofeedback assistance. In a sense, biofeedback devices can be thought of as a set of mental training wheels. Once you get the hang of controlling your stress levels, you no longer need to rely on artificial support.

Note: If you have either a serious or medically-related stress problem, you should only attempt biofeedback or other types of treatment **under the direction and guidance of a doctor or other medical professional**. But for those of us who just want to reduce everyday tension, or simply relax, a self-administered biofeedback program is both safe and beneficial.

To make our monitor work, we obviously need a way to measure a person's stress level. Galvanic skin response (GSR), which is the measurement of the electrical resistance of the skin, changes with various levels of stress. Therefore, a GSR sensor whose output can be examined and fed back in real time would make an effective basis for a biofeedback system.

Over the years, there have been many such devices with a sensor based on a resistance-to-frequency conversion technique. The stress-level monitor was in the form of discrete circuitry, a microprocessor, or a computer of some type. In today's high-speed, Windows-based PC world, the computer-based resistance-to-frequency approach has a few drawbacks. First, that system depends on the microprocessor clock speed, and must be adjusted from computer to computer. Second, the sensor's frequency varies directly with the galvanic skin resistance. That causes an annoying disparity between the feedback rate at calm levels (very slow) and tense levels (very fast). Lastly, the sampling is interrupted periodically by the PC as it does "overhead" stuff (like keeping the clock updated). That is even more pronounced if you use it in an MS-DOS environment under Windows. The result is random variations in the sensor output that can cause shifts in the displayed stress level.

The *Stress-A-Bater* biofeedback monitor discussed here is a low-cost, PC-based home biofeedback system that eliminates the drawbacks of resistance-to-frequency GSR sensors. It uses an analog-to-digital (A/D) converter that measures GSR by referencing it to a fixed, known resistance. Common parts are used throughout, and no special construction techniques are required. The Stress-A-

LISTING 1

```
REM** GSR41.BAS -- V960220
REM** Galvanic Skin Response
          Biofeedback using ADC0831-
          Based Hardware
REM** (c) 1996, JJ Barbarello,
          Manalapan, NJ  07726 -- (908)
          536-5499
REM**
'
'******** Do Housekeeping (Variables,
          etc.) *************
'add is the parallel port address.  r() are
          all possible values of
'the four resistors switched in combination
          by the CD4066.
'xsupply1 produces 00000000.
          xsupply1+xsupply2 produces
          11111111
'
DEF SEG = 64: DEFINT A-T: add = 888:
          DIM a(7), r(15)
FOR i = 0 TO 7: a(i) = 2 ^ i: NEXT
disp$ = CHR$(204): d$ = STRING$(4,
          205) + CHR$(206)
FOR i = 1 TO 9: disp$ = disp$ + d$:
          NEXT i
disp$ = disp$ + STRING$(4, 205) +
          CHR$(185)
r(1) = 100: r(2) = 220: r(3) = 69: r(4) = 470
r(5) = 83: r(6) = 150: r(7) = 60: r(8) = 1000
r(9) = 91: r(10) = 180: r(11) = 64: r(12) =
          319
r(13) = 76: r(14) = 130: r(15) = 57
xsupply1 = 1.54: xsupply2 = 2.61
'
'******** Housekeeping Done, Program
          Starts Here *********
'
programloop:
COLOR 7, 1: CLS : LOCATE 1, 21:
          PRINT "PcGSR Biofeedback
          Monitor (Version 4.1)"
LOCATE 2, 1: PRINT STRING$(80, 223);
COLOR 7,0: FOR i= 8 TO 12: LOCATE i,
          6: PRINT SPACE$(69): NEXT i
LOCATE 8, 6: PRINT CHR$(218);
          STRING$(67, 196); CHR$(191)
FOR i = 9 TO 11: LOCATE i, 6: PRINT
          CHR$(179); TAB(74);
          CHR$(179): NEXT i
LOCATE 12, 6: PRINT CHR$(192);
          STRING$(67, 196); CHR$(217)
COLOR 2, 1: LOCATE 16, 26: PRINT
          "Press <Esc> To End
          Monitoring";
COLOR 7, 1
'
'******** Initialization Begins
          *************************
'Take a reference reading with the 100K
          resistor.  From that, calculate
'the probe resistance, rx.  From that, see
          which of the 15 ref resistor
'combinations come closest to start at mid
          range.  Set the mask as the
'resistor number * 16 (ex: r(4) mask is
          4*16 or 64) to be sent to port
'pins 6-9.  Use that resistor to take a
          baseline average of 5 readings.
'
baseline = 0: jsum = 0: delta = 9999:
          mask = 16: rref = 15
LOCATE 10, 28: PRINT "Initializing .";
OUT add, 1 + mask
start! = TIMER
WHILE (TIMER - start!) < .1: WEND
OUT add, 0 + mask: OUT add, 2 + mask:
          OUT add, 0 + mask: OUT add,
          2 + mask
 j = 7
  WHILE j > -1
   OUT add, 0 + mask: OUT add, 2 +
          mask
   jsum = jsum + (INP(add + 1) AND 64)
          * a(j)
   j = j - 1
  WEND
vx = ((jsum / 64) * xsupply2) / 255 +
          xsupply1: rx = vx * 100 / (5 - vx)
FOR i = 1 TO 15
 IF ABS(rx - r(i)) < delta THEN delta =
          ABS(rx - r(i)): rref = i
NEXT i
mask = rref * 16: jsum = 0
FOR i = 1 TO 5
 OUT add, 1 + mask: PRINT " .";
 start! = TIMER
  WHILE (TIMER - start!) < .04: WEND
 OUT add, 0 + mask: OUT add, 2 +
          mask: OUT add, 0 + mask:
          OUT add, 2 + mask
  j = 7
   WHILE j > -1
    OUT add, 0 + mask: OUT add, 2 +
          mask
    jsum = jsum + (INP(add + 1) AND 64)
          * a(j)
    j = j - 1
   WEND
 baseline = baseline + jsum / 64: jsum =
          0
NEXT i
baseline = baseline / 5: IF baseline = 0
          THEN baseline = 1
'
'******** Main Monitoring Starts Now
          ********************
'f is map for appropriate resistor(s).  1 +
          mask brings CS* high.
'2 + mask pulses Clk hi, with resistor
          selected and CS* low
          (enabled).
'0 + mask pulses Clk lo, with resistor
          selected and CS* low.
'jsum is 64 or 0.  At end, divide results by
          64 to get 1 or 0.
'
start:
jsum = 0: jsumtotal = 0
FOR i = 1 TO 5
 OUT add, 1 + mask
 start! = TIMER: WHILE (TIMER - start!) <
          .08: WEND
 OUT add, 0 + mask: OUT add, 2 + mask:
          OUT add, 0 + mask: OUT add,
          2 + mask
  j = 7
   WHILE j > -1
    OUT add, 0 + mask: OUT add, 2 +
          mask
    jsum = jsum + (INP(add + 1) AND 64)
          * a(j)
    j = j - 1
   WEND
 jsumtotal = jsumtotal + jsum / 64: jsum =
          0
NEXT i
jsum = jsumtotal / 5
'
'******** Print Results Of The Scan
          **********************
'
COLOR 8, 0
LOCATE 9, 15: PRINT "+5   +4   +3   +2
          +1    0   -1   -2   -3   -4   -5"
COLOR 7, 0: LOCATE 10, 9: PRINT
          "TENSE"; TAB(16); disp$;
          TAB(68); "CALM"
COLOR 9, 0: delta = ((jsum - baseline) /
          baseline) * 100 + 25
SELECT CASE delta
  CASE IS <= 0
   delta = 0: COLOR 4, 0
  CASE 0 TO 24
   COLOR 4, 0
  CASE IS > 49
   LOCATE 10, 66: PRINT CHR$(219); "
          CALM": GOTO donemonitoring
END SELECT
x$ = "t240l12n" + STR$(64 - delta): PLAY
          x$
LOCATE 10, 16 + delta: PRINT
          CHR$(219);
a$ = INKEY$: IF a$ = "" THEN GOTO
          start
IF ASC(RIGHT$(a$, 1)) <> 27 THEN
          GOTO start
'
'******** Done Monitoring.  Decide What
          To Do Next *******
'
donemonitoring:
COLOR 10, 1: LOCATE 16, 26
 PRINT SPACE$(3); "Monitoring Session
          Ended"; SPACE$(3)
COLOR 15, 1: LOCATE 18, 20
 PRINT "<Enter> for Another Session,
          <Esc> to End...";
optionselect:
a$ = INPUT$(1): a = ASC(a$)
SELECT CASE a
   CASE IS = 13
    GOTO programloop
   CASE IS = 27
    VIEW PRINT: CLS : LOCATE 18, 1:
          END
   CASE ELSE
    BEEP: GOTO optionselect
END SELECT
```

Bater is powered by a single 9-volt battery and connects to an IBM or compatible PC through any available parallel port.

How It Works. The schematic in Fig. 1 shows how simple the Stress-A-Bater's hardware is. There are only three integrated circuits: an ADC0831 A/D converter (IC1), a CD4066 quad analog switch (IC2), and a 78L05 5-volt regulator (IC3).

Let's begin with a quick description of the A/D converter. (For more information on A/D converters in general, see "Build an 8-Channel A/D Converter" in the June, 1995 issue of **Popular Electronics**.) Integrated circuit IC1 converts an analog voltage into an 8-bit binary number between 0 and 11111111 (255 decimal). The reading is zero when the input voltage on pin 2 ($V_{IN}+$) is equal to the voltage on pin 3 ($V_{IN}-$). A value of 255 is reached when the input voltage is equal to the sum of the voltages on pin 3 and pin 5 (V_{REF}). That arrangement allows IC1 to measure input voltages that span a range less than 5 volts. In order to convert an input voltage to a digital number, pin 1 (CHIP SELECT) is brought low and a clocking signal is supplied to pin 7. The most significant bit (D7) appears on pin 6 (DATA OUT) on the falling edge of the second clock pulse. Each following bit (D6, D5, etc.) appears on pin 6 with the falling edge of each additional clock pulse. When all eight bits have been read, pin 1 should again be brought high to prepare for the next conversion.

The input to IC1 is a two-resistance voltage divider. Resistors R5–R8 form the upper part of the divider. Those resistors are selected by IC2, a quad bilateral-analog switch. That device contains four identical switches, each with an input, an output, and a control. When a switch's control signal is low, a low-resistance connection (about 50 ohms) is made between the input and output. Thus, any single or parallel combination of the four resistors (R5–R8) can be selected with the appropriate control signals to IC2 pin 5, 6, 12, or 13. By selecting one of the 16 possible on/off combinations for the switches, the resistance in the top portion of the voltage divider can be adjusted between about 56,000 ohms and 1 megohm.

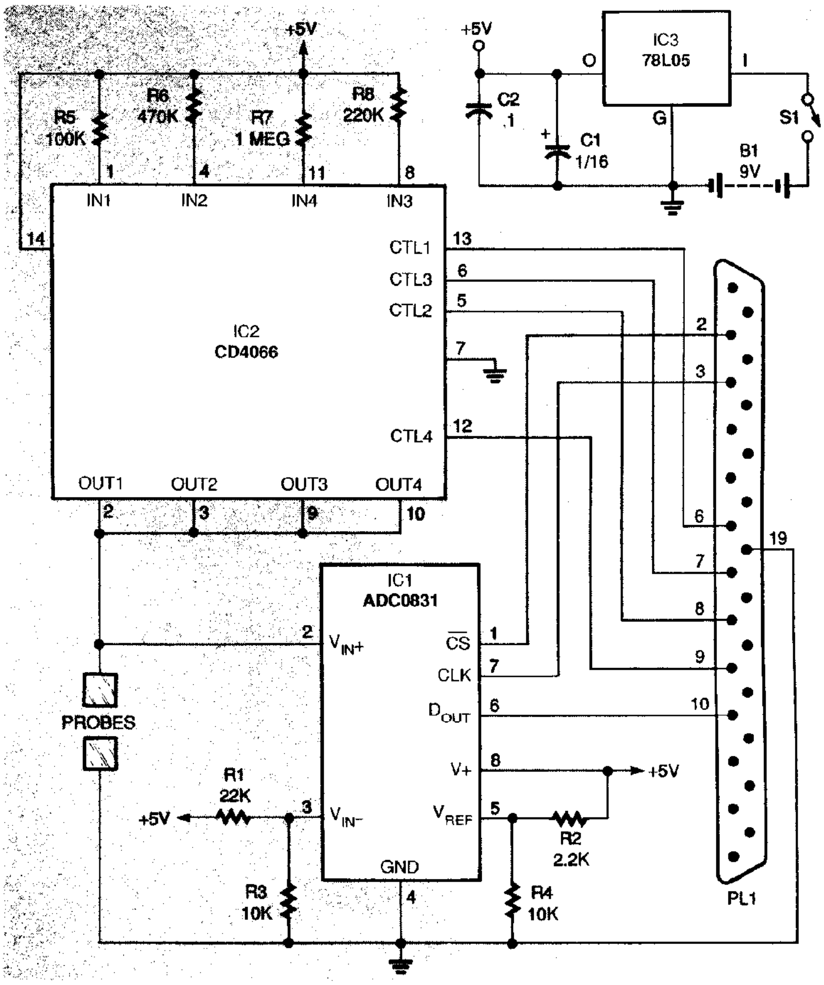


Fig. 1. The circuit for the Stress-A-Bater's hardware is very simple. The 3-wire output of the ADC0831 makes it very easy to interface the A/D converter to many different types of computers.

The lower part of the voltage divider is the resistance of a person's skin. One of the GSR probes connects to the input of the A/D converter, and the other probe is connected to ground. When the probes are attached to a person's fingers, a resistance (GSR) is seen between pin 2 of IC1 and ground. Since the selected resistors and the GSR probe together form the voltage divider, the input voltage at IC1 generated by the voltage-divider circuit is directly proportional to the galvanic skin resistance across the probes.

The V_{IN-} and V_{REF} voltages are generated by voltage-divider resistor pairs R1/R3 and R2/R4. Using the values shown in Fig. 1 for R1-R4, the reference voltage are approximately 1.6 volts for V_{IN-}, and 2.6 volts for V_{REF}. With those voltage levels, IC1 provides a 0 output at 1.6 volts, and a 255 output at 4.2 volts (1.6 + 2.6). The resolution of IC1 is the input voltage range divided by the number of possible binary output steps. That is , or about 10-mv/step. As an example, with only R5 selected and a GSR of 100,000 ohms, the input to IC1 will be:

$$V_{IN+}=5\times(R_{select}/(R_{select}+R_{probe}))$$
$$=5\times(100{,}000/(100{,}000+100{,}000))$$
$$=2.5v$$

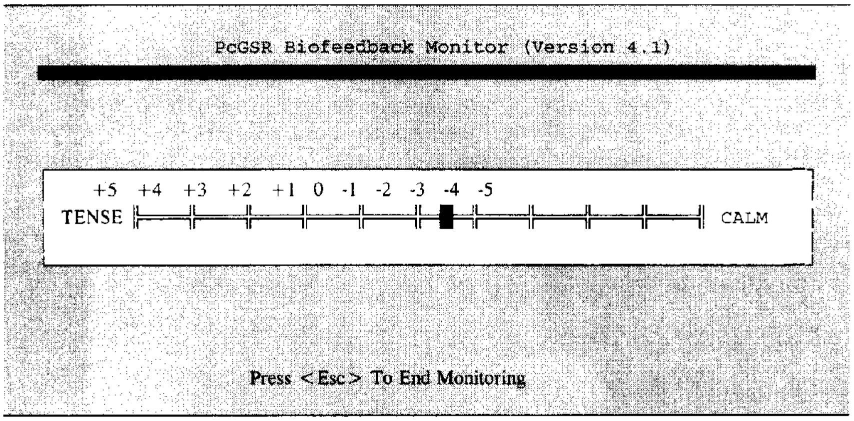
The V_{IN+} equation can be rearranged to:

$$R_{probe}=5\times(R_{select}/V_{IN+})-R_{select}$$

Using the 10-mv (0.1-volt) resolution we previously calculated, we can see that the next change in output will be when the input voltage changes to either 2.49 volts or 2.51 volts. Using 2.51 volts in the R_{probe} formula above gives us a GSR of:

$$R_{probe}=5\times({}^{100{,}000}/_{2.51})-100{,}000$$
$$=99{,}200 \text{ ohms}$$

The resistor values chosen for R5–R8 let us see changes in GSR of about 1%. The Stress-A-Bater can operate at that


PcGSR Biofeedback Monitor (Version 4.1)

Press <Esc> To End Monitoring

Fig. 2. The QBasic program for the Stress-A-Bater displays this moving dot across a horizontal scale showing how much stress a person is under. A beeping also sounds from the computer's speaker; the more tense you are, the higher the pitch of the beeping.

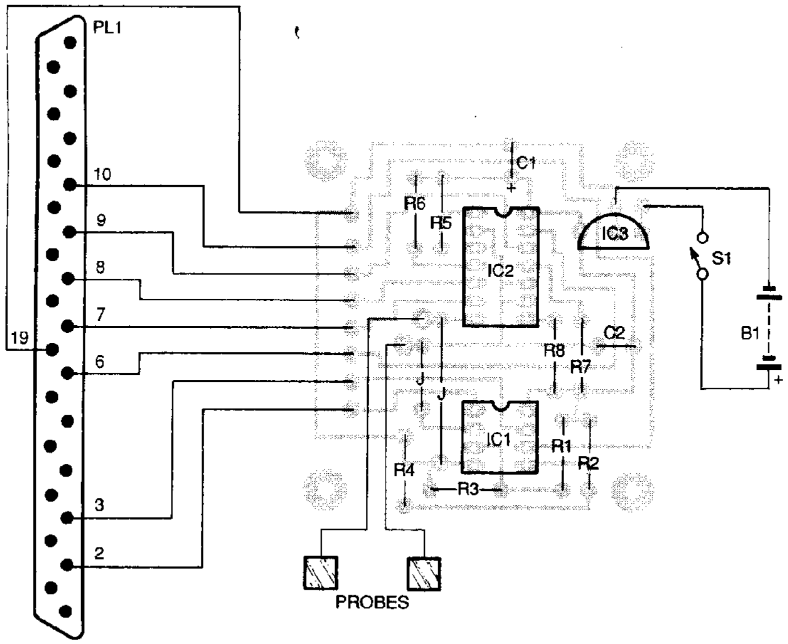


Fig. 3. Here's where the components are located on the PC board. Single-sided board design makes assembly easy—there is no worry about placed-through holes or solder connections on the top side of the board.

good a level of resolution because of IC1's ability to operate over an input range smaller than 5 volts, and the ability of IC2 to selectively set the fixed resistance in the input-voltage divider.

The control lines from IC2 for selecting the voltage-divider resistors, along with the control and data lines from the A/D converter, are connected with a length of ribbon or round cable to a male DB-25 connector. That allows the Stress-A-Bater to be hooked up to the printer port of an IBM or compatible PC for computer control and monitoring of biofeedback sessions.

Power from a 9-volt battery is regulated by IC3 to 5 volts. That 5-volt source powers IC1 and IC2, and also connects to all the voltage dividers (R1, R2, and R5–R8). It is very important to include C2 in the circuit. If C2 is left out, electrical noise will interfere with the A/D converter, causing erratic and unstable readings.

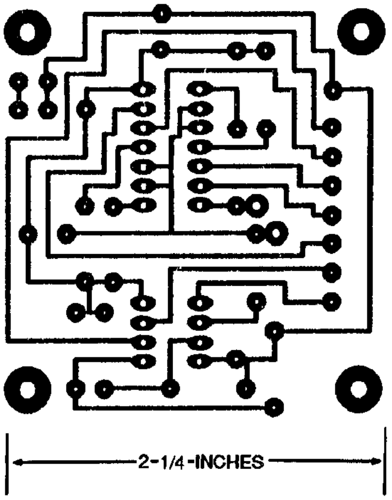
The Computer Program. Listing 1 is the source code for a simple biofeedback program that can be run under Microsoft QBasic. An enhanced version of the program, with better resolution, data logging, and results graphing is available from the source given in the Parts List. Each of the lines beginning with an apostrophe (') is a remark line. They have no program function—merely documenting certain aspects of the program. If you are typing in the program, you do not need to enter the remark lines.

The "Do Housekeeping" and "Housekeeping Done . . ." sections set up program variables and do initial formatting of the screen. Of special interest are the following statements:

```
add = 888
xsupply1 = 1.54
xsupply2 = 2.61
```

The variable *add* specifies the address of the parallel port you intend to use. The program listing sets that variable to 888, which is the decimal address number for LPT1. If you are going to use a different parallel port, you must change the value for the *add* variable to the proper address of the port to be used. The variables *xsupply1* and *xsupply2* are the voltages present at pins 3 and 5, respectively, of IC1. Based on the actual values of the resistors you use in the device, the voltage values will most likely be slightly different than what is mentioned here. You will need to measure those values, change the values assigned to *xsupply1* and *xsupply2*, and re-save the program before using it.

The "Initialization Begins" section uses the starting GSR of the person attached to the Stress-A-Bater to establish an initialization "baseline". As mentioned in the remarks lines for that section, an initial reading is taken after the 100,000-ohm resistor is



Here's the foil pattern for the Stress-A-Bater. Only 2 jumper wires are needed on this single-sided board.

switched into the circuit. That reading is used to calculate the person's current GSR across the probes. The program then figures out which of the available resistor combinations come closest to the person's current GSR. Finding the person's current GSR resistance reading will set the input voltage to IC1 at about mid range. Once that has been done, five readings are taken within a quarter second to obtain an average. That average is then used as the starting baseline. That approach minimizes any instantaneous GSR variations such as hand movement or changes in position of the probe's contact surfaces against the skin.

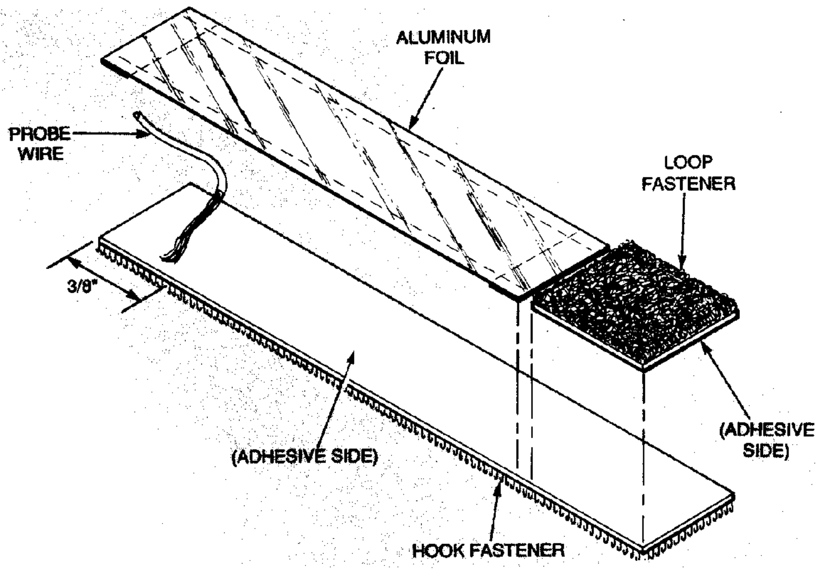


Fig. 4. Self-adesive Velcro-style hook-and-loop fasteners make assembly of the skin probes very simple. You could substitute a single layer of heavy-duty aluminum foil for the 2 layers of regular aluminum foil for the contact itself. With either type of foil, be sure to fold over the edges for added resistance to wear and tear on the probes.

PARTS LIST FOR THE STRESS-A-BATER BIOFEEDBACK MONITOR

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1—22,000-ohm
R2—2,200-ohm
R3, R4—10,000-ohm
R5—100,000-ohm
R6—470,000-ohm
R7—1-megohm
R8—220,000-ohm

CAPACITORS

C1—1µF, 16-WVDC, electrolytic
C2—0.1-µF, ceramic-disc

SEMICONDUCTORS

IC1–ADC0831 analog/digital converter, integrated circuit
IC2—CD4066 CMOS quad bilateral switch, integrated circuit
IC3—78L05 5-volt regulator, integrated circuit

ADDITIONAL PARTS AND MATERIALS

B1—9V battery
PL1—DB25 male connector and hood
S1—SPST switch
9-volt battery snap, printed-circuit board, hook-and-loop fasteners, household aluminum foil, 24-gauge two-conductor cable, 9-conductor multi-conductor or ribbon cable (see text)

NOTE: The following items are available from: James J. Barbarello, 817 Tennent Road, Manalapan, NJ 07726: Printed circuit board (GSR-PC), $10; Enhanced software with source code and executable file on 3.5-inch disk (GSR-S), $12; Complete kit includes printed-circuit board, all parts, case, wire, and enhanced software (GSR-K), $35. NJ residents must add appropiate sales tax.

The "Main Monitoring" section uses a similar approach to obtaining monitoring samples. The variable *mask*, set during the "Initialization Begins" section, is the value that selects the appropriate resistor combination. To repeat what the remarks in the program listing say, that value is added to whatever data is to be sent out each time to the Stress-A-Bater to make sure that those resistors stay connected in the proper configuration. Just like in the initialization section, five samples are taken and averaged to minimize excess variations.

The averaged GSR value is displayed in the "Print Results Of The Scan" section. A typical screen display in Fig. 2 shows the stress measurement cursor positioned midway between 0 and -1 (moving towards the calm portion of the scale). In addition to the visual display, there is a continuous audio tone whose pitch is directly proportional to the displayed stress level. Lower stress levels lower the pitch of the tone, and higher stress levels raise the pitch. After the tone pitch is played, the following two lines check to see if you want to end the monitoring session:

```
a$ = INKEY$: IF a$ = "" THEN GOTO
                start
IF ASC(RIGHT$(a$, 1)) <> 27 THEN
              GOTO start
```

If no key, or a key other than the escape key (whose ASCII value is 27) is pressed, the program loops back to the label *start:* (in the main monitoring section) for the next sample. If the escape key was pressed (or the CALM level has been reached), the program goes to the "Done Monitoring" section. Here, you can press the enter key to start another monitoring session, or press the escape key to end the program.

Construction. Building the Stress-A-Bater is simple when using a single-sided PC board. After fabricating the board or obtaining one from the source mentioned in the Parts List, follow the placement diagram in Fig. 3 for location of the components. The orientation of polarized components C1 and IC1–IC3 should be followed carefully. Attach the black lead of a 9-volt battery clip to the hole marked "–", and the red lead to one lug of S1. The other lug of S1 is connected to the hole marked "+". The two jumper wires may be formed from two excess capacitor or resistor leads. Solder all the parts into place.

Before connecting PL1 and the probes, decide what type of case you will be using to house the Stress-A-Bater. One inexpensive alternative is a case for holding 3½-inch floppy disks. Such cases can be found almost anywhere for around a dollar and are just the right size to house the PC board

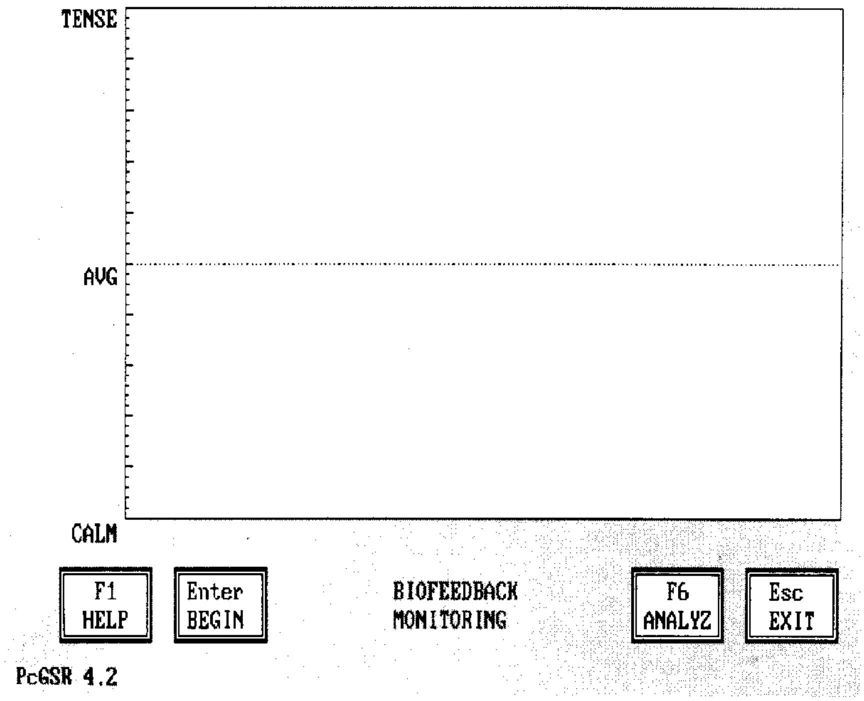
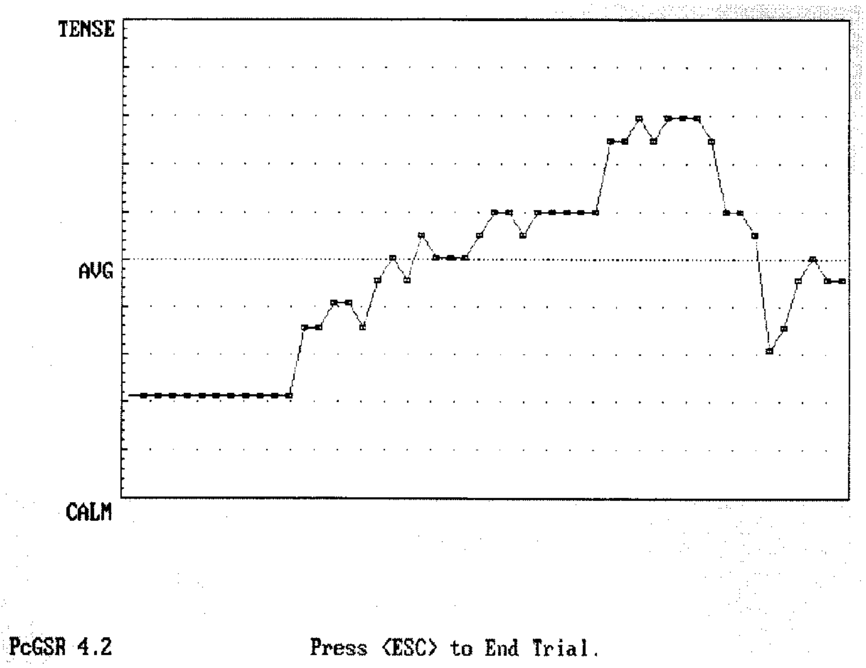


Fig. 5. The enhanced software from the source listed in the Parts List gives you greater detail in analyzing your indididual stress-reduction sessions. Several different people can use the same program to store their individual sessions on disk for future reference.



Press <ESC> to End Trial.

Fig. 6. After a session is done, the enhanced software graphs shows how you did. Time runs right to left, with the first reading of the session to the right, and the last reading of the session to the left. You can see in the example that the person started calming right away, but then tensed up and took a while to relax again. That may have been caused by readusting the sitting position.

and battery. One example is a Radio Shack 26-273 disk case. The PC board is mounted in the case with #4-40 × ½-inch machine screws and nuts. To hold the battery in place, a "Z" shaped bracket is bent from light aluminum and secured to the case with another #4-40 × ½-inch machine screw and nut. Two more #4-40 × ¼-inch machine screws are force-threaded into a pair of ³⁄₃₂-inch diameter holes drilled in either side of the case to hold the two case-halves together. Choose where the computer and probe cables will exit the case and cut the appropriate openings. Pick a spot on the case where the on-off switch will be mounted and drill the needed holes.

You'll need a male DB-25 connector, along with a suitable length (4 to 6 feet) of seven conductor cable with ground wire, or a 9-conductor cable for PL1. You could also use a ribbon cable with a DB-25 male insulation-displacement connector (IDC) on one end as an alternative. The individual conductors on the free end of the ribbon cable can be separated for connection to the PC board. Thread the cable through the opening you made for it in the case, and wire the corresponding pads on the PC board to the cable wires using Figs. 1 and 3 as a guide.

Thread 4 to 6 feet of two-conductor cable for the probe cable through the appropriate opening in the case; 22-gauge or 24-gauge stranded audio-speaker "zip-cord" wire works well. If you're using that size zip-cord wire, a ⅛-inch diameter hole in the case will fit the wire just fine. Make sure there is sufficient wire in the case to allow it to be opened and closed easily when it comes time to change the battery. Tie two knots in the wire, one on either side of the case wall. Slip the knots snugly towards the case wall to form a strain relief. Solder the wire's conductors to the probe pads on the PC board. Either conductor may be soldered to either pad. Mount the PC board, the battery, and the switch to the case. Make sure the switch is in the off position.

The final construction step is to build the two skin probes and attach them to the unconnected end of the two-conductor wire. Get a piece of adhesive-backed hook-and-loop fastener. The hook portion contains evenly spaced rows of hooks, while the loop portion appears fuzzy. Cut one hook piece to 3 by ¾ inches, and one loop piece to ⅝ by ¾ inches. If you have large fingers, you might want to make the hook piece a bit longer than 3 inches. Remove the paper backing on both pieces, and following the layout in Fig. 4, stick the adhesive-backed sides of the loop piece onto one end of the adhesive-backed side of the hook piece. Separate the two