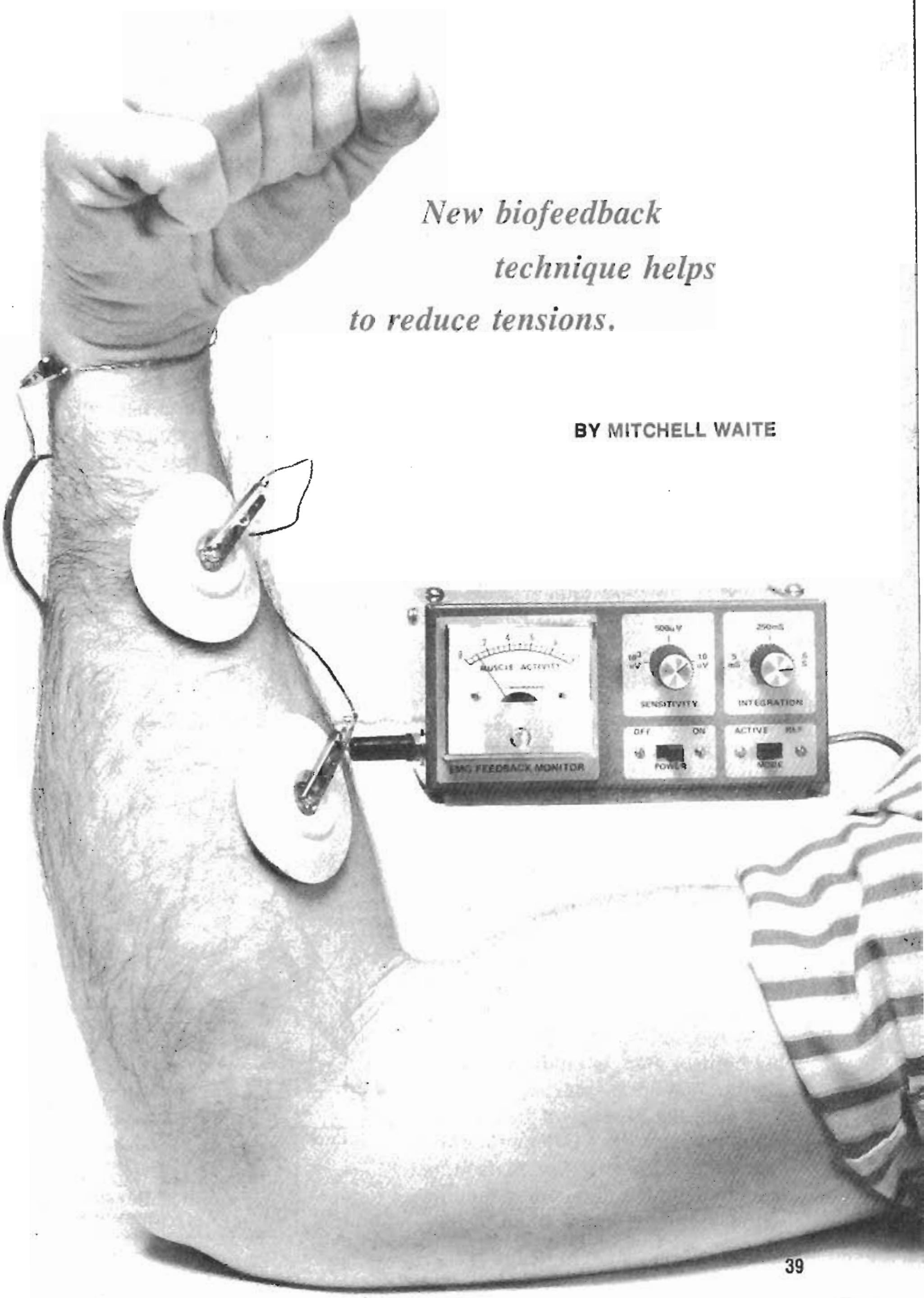
BUILD A

MUSCLE FEEDBACK MONITOR

New biofeedback technique helps to reduce tensions.

BY MITCHELL WAITE



UNNECESSARY muscular tension is known to be one of the contributing factors to psychosomatic illness. Unfortunately, much of this muscular tension is subconscious so many people can't relax because they aren't aware of the tension. Consequently, many methods have been devised to provide recognition of tension and encourage relaxation—including yoga and "autogenic training" (biofeedback techniques).

To detect muscular tension scientifically it is only necessary to measure the minute electrical signals generated by a muscle when it is working. This is done by an electromyograph (EMG). The EMG has electrodes which are placed in intimate contact with the skin over a given muscle. When the muscle is under tension, the EMG provides either a visual (meter) or audible indication of the muscle tension. The person to whom the electrodes are attached then becomes part of the feedback loop through his eyes or ears and can try to reduce the tension by mental or physical means. With this electronic aid, a person can learn to eliminate or greatly reduce the tension, thereby bringing about changes in general well-being.

Relaxation is not achieved instantaneously, and many training sessions may be required in difficult cases. Since emotions play a large role in the production of tension, unexpected feelings may be experienced when one becomes familiar with "letting go." The simple EMG feedback monitor described here can be used to practice muscle relaxation and also to explore the building up of muscles.

A block diagram of the monitor is shown in Fig. 1. The minute (microvolts) muscle signals detected by the skin electrodes are amplified and then applied to a rectifier/integrator stage. The pulses are averaged and either displayed on a meter or used to drive a voltage-controlled oscillator that generates a series of clicks for the audible signal. The amount of muscular tension—and the magnitude of the

EDITOR'S NOTE

This muscle monitor is intended for experimentation and entertainment only. It is not to be used as a substitute for professional clinical therapy. Persons with heart disease, high blood pressure, or any other tension-related illness should consult a physician. The monitor is *not* to be considered a home remedy for any illness.

voltage picked up by the electrodes —varies the reading on the meter and the frequency of the clicking sound.

How It Works. In a device of this type, the differential input preamplifier is the most important stage (*Q1, Q2,* and *IC1* in Fig. 2). This is because common-mode signals such as stray 60-Hz fields and associated line noises, put a limit on the signal resolution. The circuit's common-mode input impedance is compared to the source unbalance to determine the maximum common-mode rejection ratio.

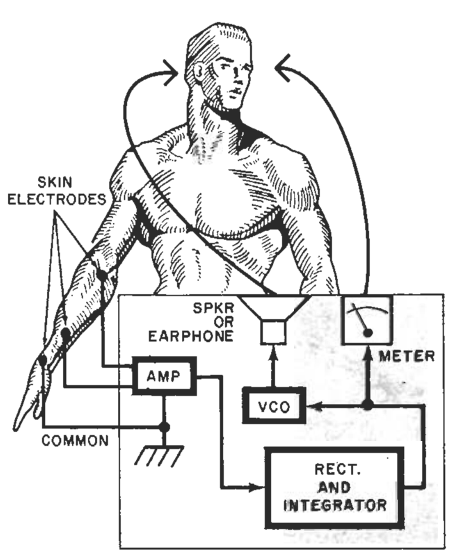
In the circuit, op amp *IC1* is used as a bootstrap element. The common-mode signal on the collector of current source *Q3* is fed back to the input through *R3, R4*, and *R5* so that the common-mode signal actually "sees" an impedance much higher than the values of these resistors. With this circuit, the balance between *C1-R1* and *C2-R2* and the impedance of the electrode determines the overall common-mode rejection. Making *C1* and *C2* larger in value improves common-mode rejection but also increases the recovery time due to transients at the electrodes. Input noise in the circuit is minimized by using low-noise transistors and designing the collector currents for low noise. R-f interference is drained off by capacitors *C3* and *C4*.

The output of the preamplifier is applied to *IC2*, a high-gain, noninverting amplifier. Associated with the amplifier are a low-pass filter (−3 dB at 1 kHz) made up of *C6* and *R11* and a high-pass filter (−3 dB at 200 Hz) made up of *C7* and *R12*. A second high-pass filter (*Q4*) further reduces low-frequency components. Sensitivity is set by *R25* and the signal is applied to a gain-of-30 noninverting amplifier (*IC3*), which also acts as a rectifier, integrator, and meter amplifier. Rectifier *D1* is located in the feedback circuit to reduce the effects of the diode voltage drop to a few millivolts. Transistor *Q5* acts as a buffer between the integrator and the meter.

Overall muscle activity can be averaged between 5 ms and 0.5 s, depending on the setting of *R26*. The sensitivity control, *R25*, is calibrated when integration is set at maximum.

The output frequency of the voltage-controlled oscillator (*IC4*) is a function of the voltage level applied to its input through *R22*. The timer is biased so that, at a certain low-voltage threshold, the oscillator automatically shuts off. The threshold is determined by the gain of the circuit and the value of *R24*. The turn-on threshold is approximately 2.5 microvolts at the skin electrodes with the sensitivity control set to maximum. Reducing the sensitivity raises the threshold point. The threshold was selected to make changes in muscle tension more apparent. The frequency range of the vco is approximately 5 to 30 pps.

Fig. 1. The EMG feedback loop.



Power for the circuit is provided by two 9-volt batteries. The power for the input stage is decoupled by *R20* and *C12* for the positive side and *R21* and *C13* for the negative.

Construction. Due to the high gain and complexity of the circuit, a pc board should be used. An actual-size foil pattern and component placement are shown in Fig. 3. When installing the components, be sure they are properly oriented with regard to terminals and polarities. Don't forget the single jumper on the component side. Note that some pads on the foil pattern have numbers corresponding to those on the schematic.

The pc board and the two batteries (preferably alkaline) are installed in a suitable metal enclosure. Metal is used to keep 60-Hz interference to a minimum. Mount the components on the front panel as shown in the photograph. The audio output jack is mounted on one side of the enclosure.

The SENSITIVITY control is marked for 10^3 μV in the full counterclockwise position, 500 μV at the center and 10 μV at the other end. Mark the

MUSCLE BIOFEEDBACK APPLICATIONS

Feedback Technique for Deep Muscle Relaxation. Experiments have shown that zero-firing of single motor units with EMG BFT can be achieved in less than twenty minutes. Most subjects report changes in body image. Further, work reveals that people can subjectively turn on and off, selected single-muscle motor units, even delicately controlling their firing patterns.

Paralyzed Muscles Retrained at Home. People recovering from cardiovascular accidents are often faced with the retraining of paralyzed limbs—a long and tedious job. Experiments are revealing now that much of the work load can be taken off the patient and also speeded up if biofeedback techniques are applied. An EMG monitor can sense minute muscle activity and inform the patient of the activities instantly.

"Talking" Muscles Help Scientists Design for Maximum Efficiency. A group of researchers at Eastman Kodak Co., known as the Human Factors Group, is looking into the activity of muscles in industry. Using the results of EMG data and performance tasks, they are able to design steps for a job to provide the least muscle discomfort, while obtaining maximum productivity of body movements.

EMG Signals Give Hams a Third Hand. Many who are physically handicapped are interested in amateur radio as a hobby. In a series of unique experiments, doctors have used the still-good EMG signals going to an amputee's missing limb to control a Morse code relay. Patients have, after brief training, learned to send up to 15 words per minute! By using a rectified EMG signal, 360-degree servo control for an antenna and tuning coils was achieved.

Learning to Control Tension Headaches. Experiments have shown that, by monitoring the "frontalis" or forehead muscle and using feedback, people can learn to reduce the occurrence of tension headaches. When presented this information, in a comfortable manner, patients have learned to abort the headaches without the biofeedback equipment.

Lowering Anxiety. EMG biofeedback has perhaps its greatest potential as an aid to anxiety reduction. By helping psychologists show their patients how to initiate self-induced calm and real relaxation, EMG monitors would be useful. Though still in its infancy, this application has vast potential and is the area of most interest for EMG at this time.

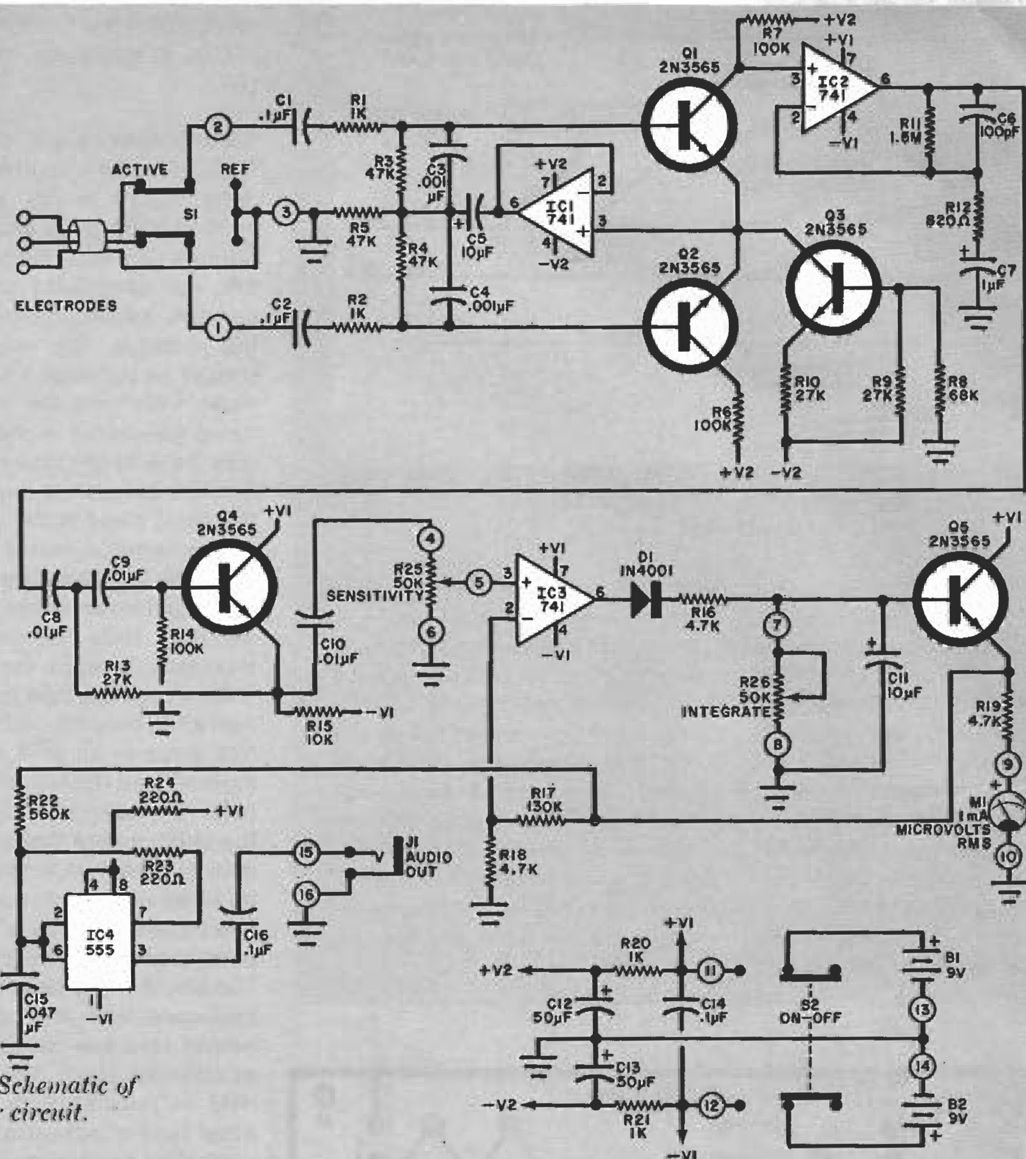


Fig. 2. Schematic of monitor circuit.

PARTS LIST

B1,B2—9-volt battery
C1,C2—0.1-µF, 10% Mylar capacitor
C3,C4—0.001-µF, 10% Mylar capacitor
C5,C11—10-µF, 10-V electrolytic capacitor
C6—100-pF, 10% silver-mica capacitor
C7—1-µF, 10-V electrolytic capacitor
C8 to C10—0.01-µF, 10% Mylar capacitor
C12,C13—50-µF, 10-V electrolytic capacitor
C14,C16—0.1-µF, 10% Mylar capacitor
C15—.047 µF 10% Mylar capacitor
D1—1N4001 diode
IC1 to IC3—741 op amp
IC4—555 timer
J1—Miniature earphone jack
M1—1-mA meter (Radio Shack 22-037 or similar)
Q1 to Q5—2N3565 transistor
Following resistors are ¼-watt, 5%:
R1,R2,R20,R21—1000 ohms
R3 to R5—47,000 ohms
R6,R7,R14—100,000 ohms
R8—68,000 ohms
R9,R10,R13—27,000 ohms
R11—1.5 megohms
R12—820 ohms
R15—10,000 ohms
R16,R18,R19—4700 ohms
R17—130,000 ohms
R22—560,000 ohms
R23,R24—220 ohms
R25,R26—50,000-ohm linear potentiometer
S1,S2—Dpdt subminiature switch
Misc.—Miniature crystal or magnetic earphone and plug; set of electrodes (½" stainless steel discs and electrode paste) or disposable Ag/Ag-Cl types; enclosure (LMB-778 or similar); knobs (2); two-conductor shielded cable (5 ft); miniature alligator clips (3); rubber grommet; mounting hardware. Disposable Ag/Ag-Cl electrodes are available from medical supply houses. Permanent Ag/Ag-Cl electrodes are preferred for ease of use. Small plastic containers of electrode cream are also available from medical supply houses.

Note—The following are available from EDC, P.O. Box 9161, Berkeley, CA 94709: complete kit of parts including two disposable Ag/Ag-Cl electrodes, stainless steel reference electrode, drilled and solder-plated pc board, drilled and painted enclosure, and 1-oz container of electrode gel (kit PE-22) at $54.50; separate drilled and solder-plated pc board (PE-23) at $3.98; drilled and painted enclosure (PE-24) at $4.50; set of three disposable Ag/Ag-Cl electrodes (PE-25) at $3.98; pair of permanent Ag/Ag-Cl electrodes (PE-26) at $15.95; 1-oz container of electrode gel (PE-9) at $0.75; 4-oz container of electrode gel (PE-9X) at $2.50. Orders for complete kits shipped postpaid and insured. Orders for components and accessories shipped postpaid, insurance extra. Add $1.00 for handling on orders less than $5.00. California residents, please add 6% sales tax (6½% for BART counties).

INTEGRATION control 5 ms on full CCW, 250 ms at the center, and 0.5 s for full CW.

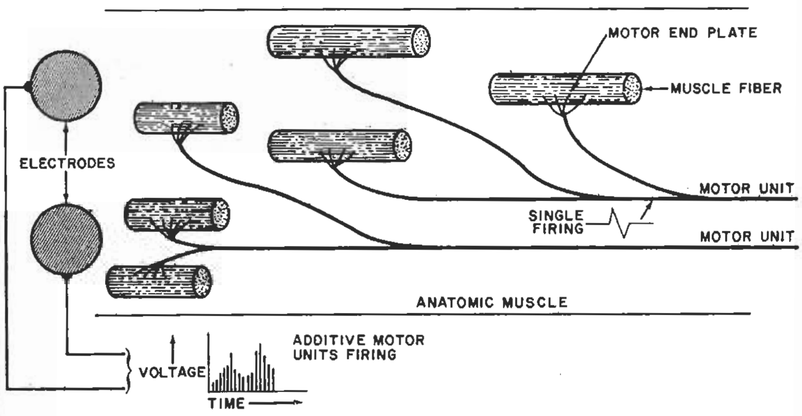
Circuit Checkout and Use. With fresh batteries installed, connect both "live" inputs across a resistance of 1000 to 5000 ohms and insert an earphone in *J1*. With the MODE switch ON REF, and SENSITIVITY and INTEGRATION controls maximum clockwise, turn on the monitor. The meter indication should be between 1/5 and 1/4 of full scale, indicating the maximum noise being generated in the circuit. There may be a slight delay (about half a second) before the meter deflects, as the input stage stabilizes.

Put the MODE switch on ACTIVE and note that the meter indication rises as the added noise of the resistor comes into play. Note also that the vco rate increases (through the earphone).

When you are sure that the circuit is operating properly, attach the two active leads to an area over a forearm muscle and attach the shield lead (with its electrode) to an area (such as the wrist) where there is little muscle activity. The two active leads should be attached to high-quality, low-noise electrodes such as a disposable or permanent silver/silver-chloride type. The shield of the electrode cable is the reference lead and should be connected to a low-cost electrode (such as stainless steel). The electrodes are held in position with tape or some other type of adhesive.

With the MODE switch on ACTIVE, adjust the INTEGRATION control to 0.5 s and set the SENSITIVITY control to its minimum. Slowly increase the latter while flexing the forearm muscles. Observe the change in indication on the meter and in the frequency of the audible signal. Make a note of the SENSITIVITY setting when the arm is relaxed. Try the approach once more, this time trying for a lower relaxed reading by changing your thoughts and mental attitude.

Move the SENSITIVITY control up slightly and try again to relax the forearm to reduce the indications to zero. Repeat this operation with the SENSITIVITY increased again. A regular daily routine works best, practicing between 15 and 30 minutes a day on muscle areas that give you a particular problem—such as the forehead if yo have tension headaches. Keep a record of sensitivity readings, and in a period of a week you should see some sign of improvement. ◈



THE SOURCE OF MUSCLE SIGNALS

The signals picked up by the muscle monitor originate in large motor nerves, each of which supplies pulses to any of 25 to 2000 motor end plates. (Only three end plates are shown in the diagram for simplicity.) Each set of end plates makes up a "motor unit." The motor units are not clumped together, but are interlaced to give the muscle its smoothness in movement. The electrical signal associated with the tensing of a muscle is made up of thousands of randomly additive microvolt pulses. Each pulse is associated with a motor unit, and each motor unit may drive many hundreds of muscle cells.

For medium tension (with Ag/Ag-Cl skin electrodes), the EMG energy is at a frequency between 200 and 2000 Hz and an amplitude between 500 µV and 1 mV. It is noise-like in appearance. However, at low tension levels, individual motor units may be differentiated with pulse rates of 25 to 100 pps. Amplitudes are between 5 and 25 µV, depending on the physical distance between the motor units and the skin electrode.

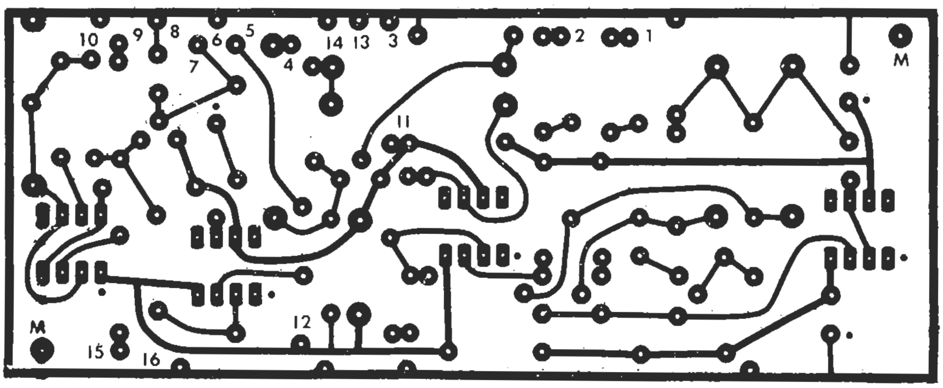
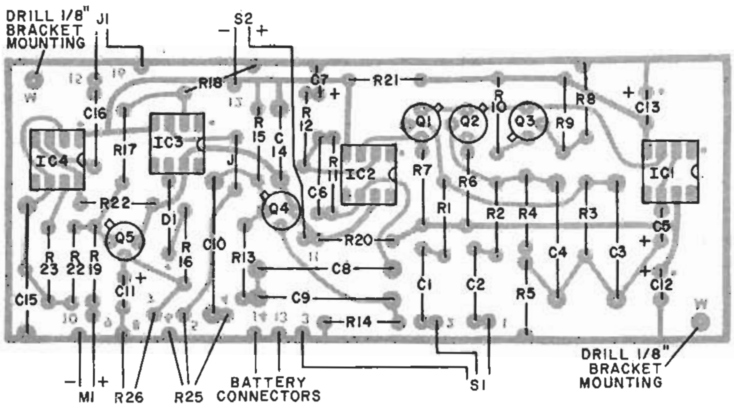


Fig. 3. Etching and drilling guide (above) and component layout.



Out of Tune

In "Build a Muscle Feedback Monitor" (May 1975), the polarity of *B2* in Fig. 2 should be revers