Biofeedback — a bridge to bionics

Tom Benjamin

Machines to aid human motor functions, or to replace functions lost through birth defects or accidents, are now able to be linked to the brain using electronic biofeedback techniques — chief among these being the electromyogram, a sensor of the tiny bio-electrical impulses controlling muscle activity.

> **"Why should we offer you a pilot's job?", asked the interviewer.**
>
> *"In addition to my considerable private experience, I have superior reflexes", replied Geoff.*
>
> **"But surely a desk job would be more suited to your . . . uh . . . capabilities."**
>
> *"My 'handicap', you mean? . . . perhaps an old trick could help me make my point. Would you mind placing your thumb and finger on either side of this card? . . . Now see if you can catch it when I drop it . . . before it slips through . . . Ready?*
>
> Without warning, Geoff then dropped the card . . . the interviewer's fingers closed on empty space.
>
> *"Now you try it," said Geoff.*
>
> The interviewer dropped the card without warning . . . it fell about 10mm before Geoff caught it.
>
> *"Following my accident," said Geoff dispassionately, "the surgeons put me back together again . . . the engineers made some improvements . . . this is one of them. There are others . . ."*

THE short story above, imaginary though it is, may very well represent a real-life situation in the not too distant future.

Geoff, the bionic pilot, isn't flying yet but our minds have been prepared for his appearance years in advance thanks to 'The Six Million Dollar Man' and 'The Bionic Woman' — souped-up, sexed-up versions of last century's Frankenstein's Monster.

Today's handicapped person may sometimes feel like a "Six Dollar Man" compared with TV's Steve Austin. However, the stigma attached to prosthetic devices such as electric wheelchairs, artifical legs, and hearing aids may someday give way to the sort of intrigue and admiration we feel toward TV's growing bionic community.

From another direction, we have been increasingly prepared for the appearance of more human-like robots (see ETI July/Aug '78). The 'droids' of *Star Wars* are the only characters beside the noble Ben who show a selfless compassion — as when C3P0 offers to lend his own components to his comrade R2D2. (They are also the only characters refused entry to the pub!) Today's Sci-Fi robots are much more introspective and soul-searching than ever before.

Thus, the media has looked at the bridge between man and machine from both ends. The engineer who builds a more human 'droid' and the biologist who creates machine-like capabilities for the human are each working towards a new species. A quite believable example from *2001: A Space Odyssey* was the Jupiter space craft complex, with its combination of human crew and HAL, the computer, vying for control of the mission. An alien spacetraveller might well have had difficulty in figuring out "Who's in charge here?" in a close encounter with this craft.

Current progress in bionics

In November 1978, Dr. G. Shannon, of Queensland University, published an account of a "myoelectrically controlled hand" capable of providing sensory feedback about the strength of grip applied by its electric motor — possibly the first of its kind accepted and used for any length of time by its recipient.

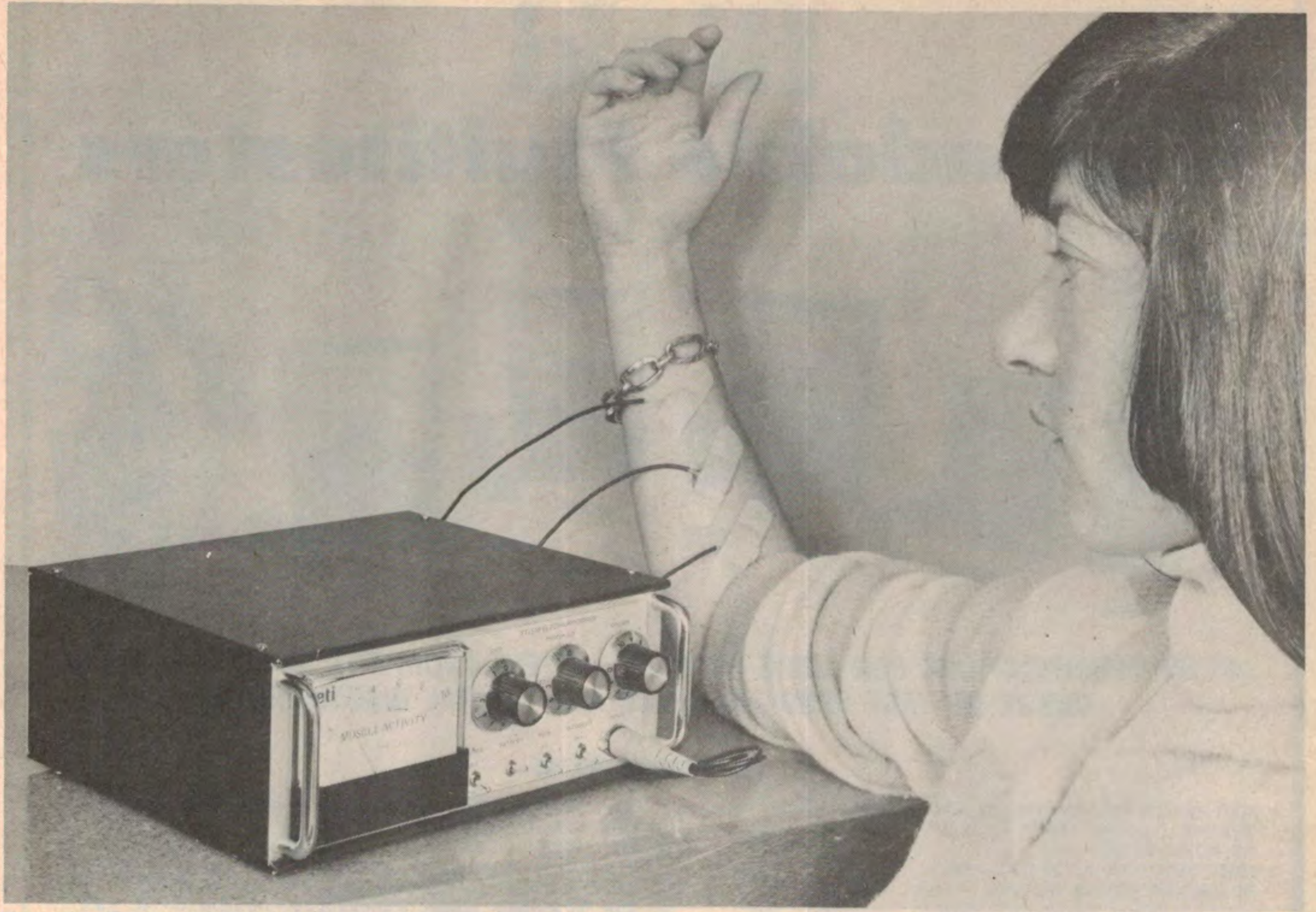
The mechanism used for providing a sense of "touch" was a pair of strain gauges attached to the mechanical fingers to register the slight bend which occurs when grasping. The sense of "force" was provided by an electromyograph (EMG) which amplifies the electrical activity of a muscle's nerves, converting this to a signal capable of controlling the motor. The EMG was attached to the forearm between the elbow and the patient's amputated stump. The muscles measured in this case normally control movement of the fingers — now they control an electric motor in an artificial hand.

The brain is regarded as "the last defence perimeter" of a person's identity. Fears of electrical stimulation and control of the brain have been expressed in such works as *Brave New World* and *The Terminal Man*. However, it seems likely that many severely handicapped persons will gladly trade some amount of personal identity and privacy for increased abilities with which to contact and manipulate the outside world.

Today's multiply-handicapped person — quadraplegic or brain-damaged, can look forward to a pretty sedentary life. A number of complex switching circuits can put such amenities as a typewriter, TV, and intercom at the person's disposal. Currently, these circuits interface via a blow-tube on/off switch or, more recently, via a matrix system switched by photocells activated by a beam mounted on the head. Neither of these systems can provide the multichannel, simultaneous, analogue type of control required for complex movement and manipulation. A more direct interface is required.

In addition to artificial hands, there

BIONICS: *The emulation of biological components, 'body parts', with electromechanical ones with the object of their ultimate replacement.*



Illustrating muscle relaxation training using our own electromyogram project (see page 35). This project design is based on criteria given by the author of this article and compares very well with commercially made machines. Learning to relax is Jan Collins, our general secretary and office organizer. . . . note calm expression, unfurrowed brow and general aura of peace!

are a variety of aids being perfected to replace and assist the eyes, ears, and legs of those who are denied their use, either by birth or accident. Implantations in the visual cortex of an electronic grid which produces light sensations have brought artificial vision closer to reality than dream. Similar experiments with the auditory cortex have shown promise, although the frequency range perceived has thus far been limited.

Biofeedback

In 1901 the psychologist, J.H. Blair, sought to shed light upon "the nature of the will" by observing how subjects learned to direct muscles to serve a mental command. He taught his subjects to wiggle their ears by observing their efforts amplified via a system of pressure-filled drums onto a kymograph ▶

MAN VERSUS MACHINE: A COMPARISON

What are some of the strengths and weaknesses that each brings to an interface between man and machine? (see ETI July '78). The space programmes and the nuclear arms race have forced a perhaps premature look at these issues. The age of cloning and bionics may well force a further look. A shopper for bionic and cloned components might keep the following shopping list:

SPECIFICATIONS AND FEATURES

MAN	MACHINE
on-line processing and data reduction of multi-sensory input	reliance upon external sensors
large CPU capacity (10^{20}bits) relative to size	limited CPU dependent upon size
delicate components require an artificial environment	capable of operation in extremely hostile environments
reliability through redundancy; multiple back-up systems	reliability through strength of components
learning capability	very limited learning capability
direct interface difficult due to the body's rejection systems	modular construction allows limitless interface
indirect opto/mechanical interface with outputs	direct amplification of outputs
complex manipulative ability	strong but clumsy manipulative ability
flexibility in short-distance locomotion over rough terrain	capable of fast, extended travel over large distances — land, sea, air, space
low energy consumption: < 100 W	high energy requirements
low energy output: < 400W	high energy output
must be protected	disposable
must be maintained alive	can be switched off indefinitely

Well, shoppers which would you choose . . .

- if you wanted to move a 'fridge up two flights of stairs?
- if you wanted to turn out small components on an assembly line?
- if you were outfitting a craft bound for Alpha Centauri? . . . the Greek Isles?

(early chart recorder). A notched lever fitted to the wall of a drum transmitted small ear movements as pressure changes to a second drum to which was affixed a chart-pen. The subjects made efforts to wiggle these long-disused muscles and were rewarded by feedback from the pen tracing.

Today we know this principle as "Biofeedback" (see ETI Sept. '76). By monitoring the various activities of the body with today's sensitive electronic equipment, an average person can learn to control a variety of bodily functions as adeptly as many trained Yogi's. Such activities as heartrate (see ETI – 544, Sept. '76), skin temperature (ETI – 130), skin conductance (ETI – 546), blood pressure and brainwave synchrony can be readily measured and converted into an audio/visual signal suitable for providing feedback to the trainee.

In the early '60s, Dr. John Basmajian investigated the ability of persons to control the 'motor units', which are responsible for muscle contraction, using EMG biofeedback. He used needle electrodes 25 μm in diameter, inserted beneath the skin to contact a large number of the tiny motor units. The oscilloscope tracings of the combined rhythms of the motor unit firings resemble a noise signal. To the person observing the tracing, however, the effect is like that of an orchestra. From the assembled patterns, the traces of single rhythms could be discerned. With practise, Basmajian's subjects learned to be able to recognise and control single motor unit firings – *voluntary control over the action of a single body cell in isolation*!

The significance of the discovery was not lost upon orthotists, biomechanical engineers, and doctors. The electromyograph had been in use since the '20s as an expensive laboratory tool capable of measuring the activity of the nervous system in controlling the body's movements. By the '60s, however, the devices had become cigarette pack in size and capable of interface with a variety of electronic devices. The myo-electrically (muscle-electrically) controlled prosthesis was born.

From laboratory to rehabilitation centre

The human body is notorious for its ability to reject as "foreign matter" the finest creations of the best-intending implanter. The problems encountered in the kidney have long plagued pioneers in transplant and pacemaker research.

The courtship of medicine and engineering has been equally stormy. Outsiders such as physicists, psychologists and engineers who operate within the inner sanctum of medical care often complain publicly about their 'sidekick' status, minimal financial return from the great health 'pork barrel', and lack of reciprocity in learning the other's secrets.

Even granted the smoothest of inter-professional relations, there is a lengthy process involved in fitting even the simplest of prosthetic devices to the most willing of recipients:

1. **Construction:** devices used in real life must be durable, simple to operate by someone not concentrating, "normal" in appearance, and cheap enough for the disadvantaged recipient to afford.
2. **Fitting:** an orthotic team must ensure that the device is precisely mated to the person's height, weight, shape of limb, and cosmetic needs.
3. **Training:** a team of physiotherapists and occupational therapists must put the recipient through a graduated series of tasks to allow practise in mastering the device. EMG biofeedback provides a bridge between the trainee and his new addition.

The myoelectronic prosthesis is currently only in experimental use. Many of the needs of the handicapped are better served with simpler mechanical limbs, spring-soled shoes and, of course, the ubiquitous wheelchair. But the day may not be far off when the first handicapped person opts for a myoelectric device which gives him abilities he lacked before his accident.

Current prosthetic hand 'replacements' are capable of quite a range of manipulative movement. With improved materials and electromechanical controls employing biofeedback, such prosthetics will improve markedly in appearance and performance.

The electromyogram (EMG)

The electrical output of a muscle derives from the *motor units* which entwine the contracting fibres of the muscles. As a number of motor units fire to contract a muscle, their asynchronous firings resemble a noise signal, modulated in amplitude. Numerous studies have attempted to describe the statistical properties of the complex EMG signal. It may be regarded for practical purposes as:

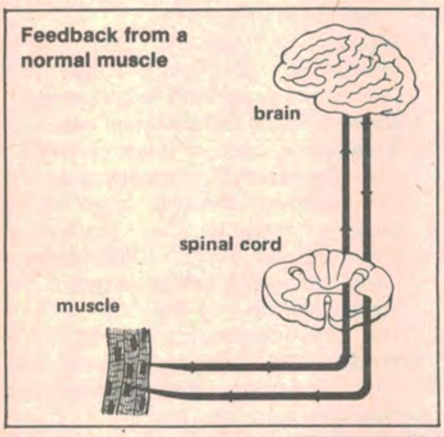
- amplitude modulation
- a weighted sum of the potentials of the motor units
- a function of the number of units, their rate of activation, and the quality of electrical contact

Amplification of the EMG signal presents problems to the amateur constructor. The output of a relaxed muscle is of the order of one or two microvolts ▶

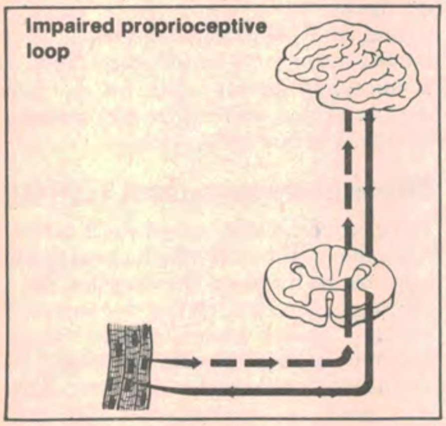
peak to peak. To tap this signal from the skin is no mean feat. The skin is itself a source of electrical activity, whose surface resistance changes with mood (see ETI – 546 galvanic skin response meter, March '77), and a source of a dc potential which can dwarf the feeble EMG signal from beneath.

An amplifier which meets the strict demands of electromyography will probably have some of the following specification:

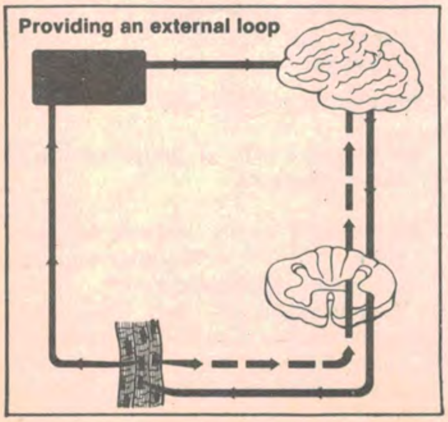
- common mode rejection of greater than 70 dB
- noise level less than 1 μV p-p
- sensitivity of at least 2 μV p-p
- linearity over the range 1 μV to 10 mV



Feedback from a normal muscle



Impaired proprioceptive loop



Providing an external loop

obtained through a combination of the following features:

- ac coupling,
- a high input impedance (100 K) or 'bootstrapped' differential pre-amp.
- a threshold for amplitude which chops the midportion of the signal, giving greater contrast to small changes in input.
- filtering for mains, radio, and heart-beat frequencies.
- a narrow bandwidth, centred around 200 Hz say 100 Hz to 500 Hz.
- provision for both direct and time-integrated readings to capture both transients and average levels of activity.
- audio and visual output for feedback.

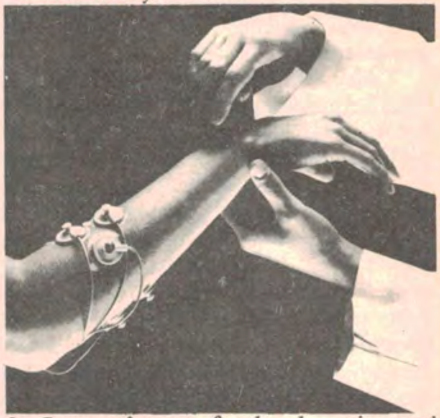
For practical use there are mechanical considerations as well. The electrodes are, of necessity, attached at some point in the system by flexible cable to allow movement by the user. But cable, however well shielded, presents its own problems of noise. One solution is to mount the electrodes, together with a compact preamplifier stage, into a single assembly worn directly on the user. The amplifier, integration, power, switching and output functions, built into a larger box, can then be connected by cable to this tiny system which rides on the body.

Uses of EMG

The object of training with an EMG is to begin to recognise the subtle sensations within the body which correspond to tiny variations in muscle activity level. One application is in learning to relax: the subject attempts to "switch off" his central nervous system from movement and sensation in specific areas of the body. This technique has shown promise with a variety of anxiety-based disorders and may benefit Yogi's and athletes who are learning to conserve their energy. At the other end of the spectrum is the need of the physically-handicapped to use the EMG as a sort of 'strength-ometer' for re-training weakened muscles.

Typically, the user applies a conductive gel to the electrode, tapes it to the skin and adjusts the sensitivity of the device, checking the noise level. A popular and practical training procedure is as follows:

1. **Connection to forearm** – flex the fingers and note the electrical activity which corresponds to fine movements; relax the arm by picking it up at the wrist and dropping it, allowing it to flop lifelessly onto the lap; note the sensations as the arm is allowed to become more and more "numb" and "heavy".



2. **Connection to forehead** – raise and lower the eyebrows, frown, squeeze the eyes shut, bite hard: note how all of the facial muscles interconnect; close the eyes and allow the face to become "smooth", listening to the audio feedback as the muscles lose their tightness.
3. **Connection to neck** (cervical or trapezius) – shrug the shoulders, move the head from side to side: note the postures in which the muscle output becomes lowest – slightly drooped shoulders, head balanced vertically; lose that tight feeling in the neck which often accompanies typing or driving.

Having practised the above, the trainee can then strive for more complete mastery of the nervous system: causing tinier and tinier voluntary flickers of movement while remaining relaxed; relaxing quickly after muscular strain; relaxing one portion of the body while tensing another.

Biofeedback is an educational and athletic discipline – there are no unbreakable records, no unbeatable performances, no lack of goals and challenges. No matter how powerful and sophisticated a man's bionic body may become, the challenge of mastery will remain.

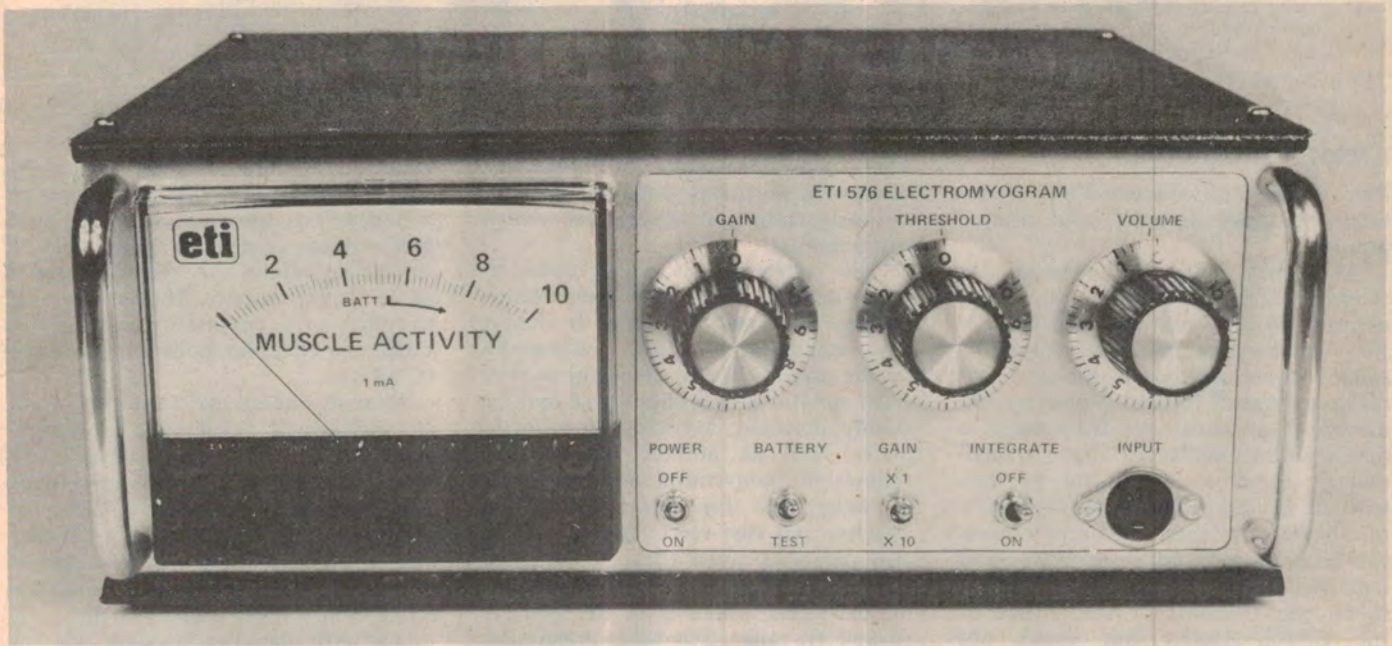
Biofeedback will continue to form a bridge between man's mind and his body. ●

Project 576

Electromyogram for biofeedback use

David Tilbrook

This unit senses the tiny electrical impulses associated with muscle activity and provides an indication of this activity via a meter and a sound output. The latter is a series of pulses, the repetition rate increasing with increased muscle activity, decreasing as muscle activity declines. It may be used to 'train' particular muscles or to learn effective relaxation.



AT THE SUGGESTION of Tom Benjamin, author of the biofeedback feature immediately preceding this article, an electromyogram project was investigated to go hand in hand with the feature on the premise that it's frustrating to read about something that you can't follow up with some practical experiments!

I tackled this project with some enthusiasm as it presented a range of interesting design problems as well as having some pretty tough specifications to meet if the unit was to be at all useful. There's nothing like a challenge to stimulate a little creativity!

We have published two biofeedback projects in the past – the Heart Rate Monitor (ETI 544) in September 1976 and the Galvanic Skin Response Monitor (ETI 546) in March 1977 – but this is the most complex instrument to date. In an article on biofeedback in the September 1977 issue (pages 68 to 72), in discussing EMG devices, the writer said: "This type of instrument is not really suitable for home designing or building".

That little charmer was the first hurdle I had to face.

Before going on to the construction and setting up of the instrument, you may be interested in seeing how this design evolved and why particular circuit techniques were used.

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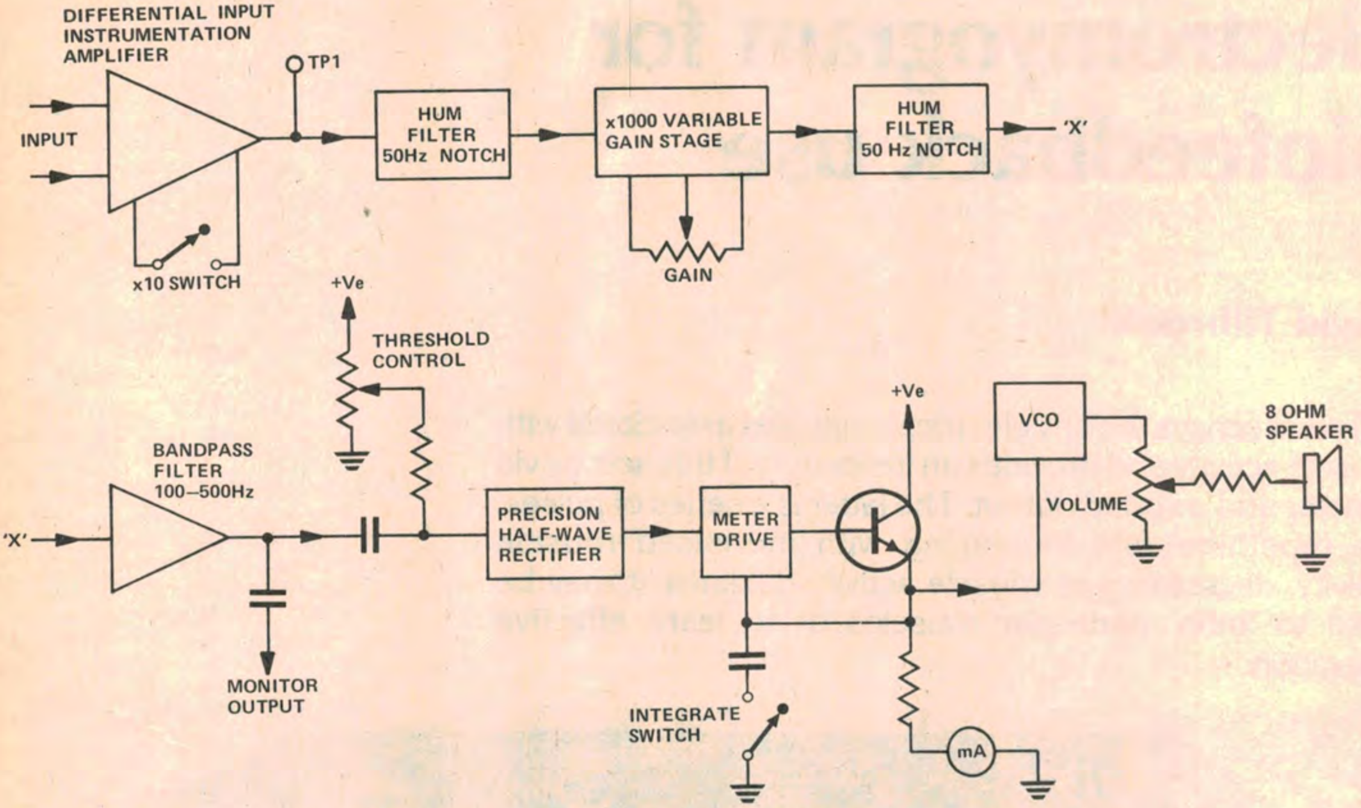


Design problems

The design and construction of an electromyogram presents some unique problems.

The object is to detect the minute electrical signals produced by the 'firing' of muscle fibres in a particular muscle. For our purpose metal electrodes of some sort are attached to the skin over the muscle(s) of interest. For a relaxed muscle, these signals are fractions of a microvolt in amplitude. That's a small enough signal to detect on its own without having to find it amongst *volts* of 50 Hz hum that will be present in the body – induced from power and light wiring. Of course, you could do these measurements in the middle of the Gibson Desert but that's not always convenient! You only have to touch your finger to the input of an oscilloscope to get an idea of the magnitude of the hum induced onto the body.

When the body is grounded, this hum will drop to typically one volt peak-to-peak, but trying to see one microvolt in one volt of unwanted noise (50 Hz hum here) sure isn't easy.

The overall block diagram of the unit is shown in the drawing here.

Battery operation is essential as, with any device connected directly to the body, the possibility of accidental contact with mains potential from a mains-operated unit is very real – with lethal results.

The instrument is called upon to detect quite small signals in the presence of large amounts of noise. It should have variable gain control – adjustable by the user, a threshold control so that small variations of a large signal may be readily detected, a visual indication (a meter) and an audible output that follows the convention of rising pitch or pulse rate for increasing muscle activity, and vice versa. Tom Benjamin also mentions some form of bandpass filtering to sort out the predominant muscle signal which is in the 100 Hz to 500 Hz range. Selectable integration of the feedback response is also considered desirable.

First thing was to tackle the hum problem. To overcome this, a number of techniques have been employed. Firstly, I have used a differential amplifier for the input stage. This type of circuit has two input terminals. Signals on the inputs that are *out of phase* will be amplified and passed to the output, while signals that are *in phase* (called common mode signals) will be rejected. The amount of rejection is determined by the amplitude of each in-phase signal. As, in this application, the two inputs are connected to the skin, they will each receive hum signals in phase and of similar amplitude and thus be rejected to a large extent. The amount of rejection of a common mode signal is called the common mode rejection ratio (CMRR).

Most IC operational amplifiers are of the differential input type. A typical op-amp IC has a CMRR of about 90 dB – which means that any common-mode signal will be reduced by a factor of about 30,000. This is good in theory but, in practise, the use of 5% resistors in circuits results in a CMRR of around 60 dB, which is not good enough.

The differential input stage was the most difficult portion of the circuit to design as it was required to have a very high CMRR, a high input impedance and very low noise. Naturally, the home constructor should be able to reproduce the performance of our prototype, preferably without going to a lot of trouble selecting special components or through elaborate set-up procedures. I managed to achieve all these design goals – after discarding several circuits!

The need for a high input impedance is a much-debated subject. Some commercial EMG's boast input

ETI 576 ELECTROMYOGRAM SPECIFICATIONS

Equivalent input noise	150 nV (0.15 uV)
Minimum 50 Hz rejection	80 dB (irrespective of common mode rejection)
Common Mode Rejection Ratio	100 dB or better
Input impedance	220 k
Bandwidth	100 Hz to 500 Hz
Audio output	Variable repetition rate pulse output from inbuilt loudspeaker.
Power source	two 9 V batteries
Power consumption	20 mA per battery
Battery check	battery check switch indicates condition of batteries on meter

impedances as high as 1000 M! The reason is to reduce the effect of poor electrical contact between the electrodes and the skin. In a 1000 M input impedance a few thousand ohms difference between the electrode input impedances (that is, from each electrode to the instrument common or 'ground') goes unnoticed as it represents such a small percentage of the unit's input impedance. Input impedances in this order necessitate MOSFET devices which are relatively noisy in comparison with bipolar transistors at these frequencies.

I elected to use a much lower input impedance and to optimise the noise figure. This has the added advantage that readily available transistors could be used for the input stage.

The input impedance is limited by the base bias resistors of the input stage — in this case, 220 k for each input. At this input impedance, differences in electrode contact resistance with the skin are important, so care should be exercised to minimise this when attaching them.

Biasing the differential input stage is important and this is discussed in the "How it Works" section. One trimpot is used to set up the input stage for correct operation. Once set up, any of the component values may be varied by +/— 10% without affecting the CMRR.

Gain of the input stage is about 1000 (60 dB). Common mode signals will be reduced by the CMRR (about 100 dB, or better), the exact amount of reduction depending on the electrode attachment, as just mentioned, but the CMRR can be degraded quite a bit by this before it becomes a real problem. We experienced little difficulty attaching dry electrodes to dry skin on the forearm.

The choice of this type of first stage has resulted in a very low noise figure. The prototypes (we built two) had measured noise figures close to 150 nV (0.15 uV) at the input. This equals the performance of the best commerical units we have seen.

Immediately following the input stage is a 50 Hz notch filter to offset any increase in hum pickup due to contact resistance variations. This uses the same circuit as our Hum Filter (ETI 451), described in July, but omitting the preset adjustment.

There are two hum filters, we'll get around to the second shortly.

From the first hum filter the signal goes to a variable gain stage. This employs a 741 op-amp, the gain of which is controlled by a potentiometer mounted on the front panel. Gain is variable between 10 and 1000. This stage is fairly straightforward, although the circuit is a little unusual. See "How it Works" for a complete description.

Following this stage is the second hum filter, immediately preceeding the bandpass filter. Signal levels at this stage are around one volt, excess hum on top of this can cause clipping and severe distortion in the succeeding stages.

The bandpass filter is centred at 250 Hz, around the middle of the frequency range of interest. Output from the firing muscle fibres consist of a broad 'noise' signal extending from a little below 100 Hz to about 1 kHz, although the largest amplitude portion of the muscle signal spectrum is between 100 Hz and 500 Hz. The bandpass filter attenuates noise and other signals outside the main area of interest, improving the signal to noise ratio of the instrument.

The output of the bandpass filter is available as a 'monitor output', via a coax socket on the rear panel of the instrument. This enables you to monitor the signal directly using an oscilloscope or via an audio amplifier.

To provide the required audible and visual feedback indications, the signals must undergo some processing to control the appropriate outputs.

From the bandpass filter the signal is mixed with a dc voltage that is varied by means of the Threshold control on the front panel, then fed to a precision half-wave rectifier. This stage rectifies any (ac) signal above the dc voltage set by the Threshold control. By setting the threshold just above the level of noise present, very small changes in muscle activity are made readily apparent. The output of this stage is a series of positive-going pulses from the muscle fibre signal.

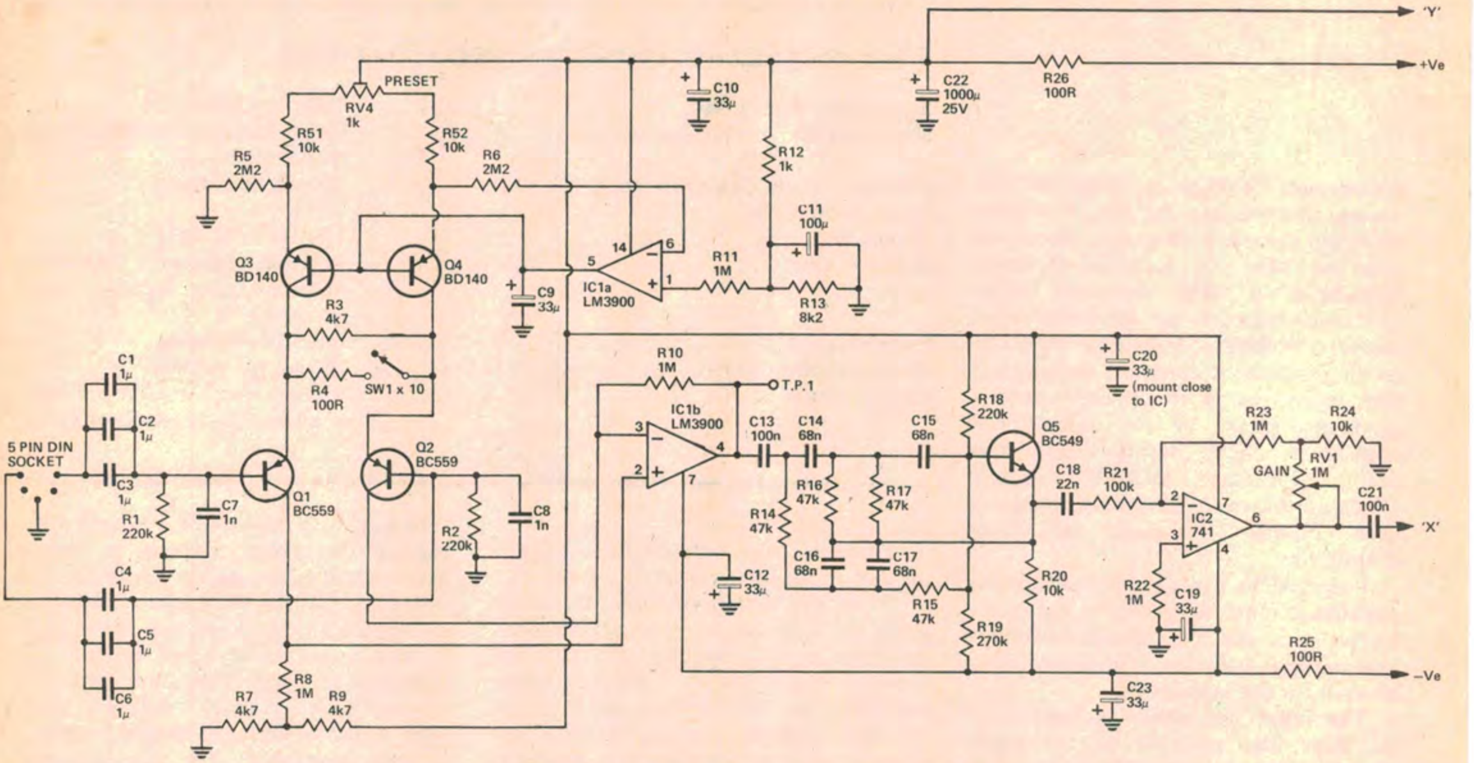
The meter drive stage follows the precision rectifier. This employs a 741 op-amp and an emitter follower stage with negative feedback from the emitter of the transistor. The positive-going pulses from the rectifier stage charge a capacitor, the voltage on this being a measure of the muscle activity as the signal varies above the threshold while the muscle is active.

To provide some integration of the muscle activity level, so that the meter and audible responses are not too rapid (as researchers have found undesirable in some instances), switched capacitors are provided at this point to provide integration times of about 0.5 second and 4 seconds — selected by a front panel switch.

The audible output is derived from the meter drive so that it corresponds with the visual feedback response provided by the meter. This consists of a voltage-controlled oscillator (VCO) that provides a series of pulses to drive a speaker. The VCO employs a 555 timer ic.

Originally, it was intended to use a tone for the audio output. However, battery consumption on the prototype was almost 150 mA — at best! Battery life would be very limited at this consumption. A class A audio output stage is necessary to provide a tone output, and these are quite inefficient. Using a pulse output enabled me to reduce the total current consumption to 20 mA. ▶

Construction details and how to use the machine will appear next issue . . . acts of God, gremlins and the fairies at the bottom of the darkroom permitting!



HOW IT WORKS – ETI 576

Since the circuit is fairly complex, a detailed analysis of its operation is best tackled by looking at the individual stages in turn, from input to output.

Differential input stage

Input signals from sensors on the body drive Q2 and Q1 which are arranged as a differential pair. Emitter current, and thus collector current, for Q1 and Q2 is derived from a precision constant-current source comprised of Q3, Q4 and IC1a. Transistors Q1 and Q2 share the current supplied by the constant-current source. If Q1 (for example) is driven harder, by an input signal, than Q2 then, while the collector current of Q1 increases, there will be a corresponding decrease in the collector current of Q2.

Now, the collectors of Q1 and Q2 are each connected to the input of IC1b, one amplifier in an LM3900 (a quad op-amp package). The amplifiers in the LM3900 package have the special feature that they amplify current **differences** applied to the inputs.

To ensure a high common-mode rejection ratio, the quiescent (no signal) collector currents of Q1 and Q2 must be held very close to a fixed amount. Hence, the precision constant-current source.

To derive this constant current source for Q1 and Q2 the two bases of Q3 and Q4 are driven by the output of IC1a. The non-inverting input (marked +) of IC1a is driven by a fixed voltage derived from a voltage divider (R12, R13) from the positive supply rail. C11 is a bypass capacitor to prevent supply rail variations modulating this reference voltage.

The inverting input (–) of IC1a is coupled to the emitter of Q4 placing this transistor in the feedback loop of IC1a. The op-amp (IC1a) will attempt to maintain the current flowing through its inputs at a constant level, thus maintaining the base-emitter current through Q4, and therefore the collector current, constant at nominally, 100 mA. Assuming Q3 has similar gain to Q4, its collector current will be the same. The 1k preset, RV4, allows adjustment of the two collector currents to offset any slight differences in gain.

The input stage gain is determined by the value of the resistance between the emitters of Q1 and Q2. The lower this resistance, the higher the gain. The 'x 10' switch simply connects a 100 ohm resistor in parallel with R3, increasing the gain.

Capacitors C7 and C8 ensure high frequency stability through bypassing the bases of Q1 and Q2 at frequencies above the range of interest.

To ensure good common-mode rejection ratio, it is essential that the bases of Q1 and Q2 each receive the *same* level of input signal. As the input is ac-coupled the characteristics of the input coupling capacitors must closely match each other. If stranded 10% capacitors are used the slightly different impedances of each will limit the common mode rejection. The solution we adopted was to use several capacitors in parallel so that the slight capacitance variations, and corresponding impedance variations, average out. It is important therefore that these six capacitors, C1-C6, are all the same type.

Supply rail decoupling for the input stages is provided by R25, R26 and C22, C23.

The hum filters

Two 50 Hz hum filters are employed, as can be seen in the block diagram, one immediately following the differential input stage, the other between the variable gain stage and the band-pass filter.

Both 50 Hz filters employ a 'twin-T' circuit – as used in our Hum Filter project, ETI 451, in the July issue. A detailed discussion of this circuit can be found in that article.

In the first hum filter, Q5 is connected as an emitter follower, the twin-T components connected to provide feedback at 50 Hz. In order to obtain a high circuit Q and thus good rejection at 50 Hz, the value of the resistance formed by R16 and R17 (parallelled) must be as close as possible to half the value of R14 and R15. As the latter are 47k resistors, the best way to obtain a value of half that is to connect two 47 k resistors in parallel.

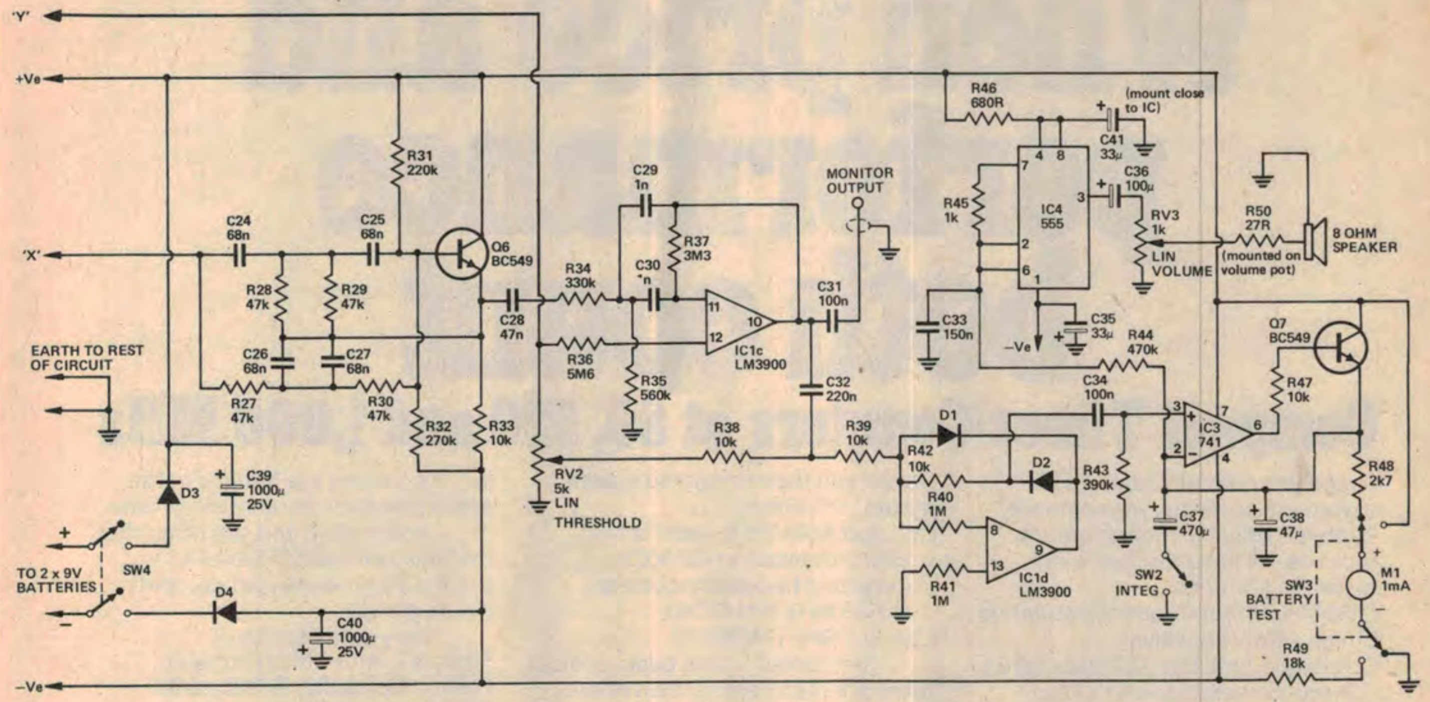
Similarly, for the second hum filter, Q6 is the active component and the filter consists of C24, 25, 26, 27 and R27, 28, 29 and 30. Resistors R28 and 29 form a resistance half that of R27 and 30 to provide good rejection at the notch frequency.

These stages provide a total of 20 dB rejection at 50 Hz.

Variable gain stage

Following the first hum filter is a variable gain stage employing a 741 op-amp. This is quite a conventional amplifier, gain variation being provided by RV1, a 1M potentiometer connected in the feedback path of the 741. RV1 is a front panel control. Gain is variable between 10 and 1000.

To avoid problems arising from large output offset voltages and unstable gain settings, the feedback for the 741 has been arranged via a voltage divider consisting of R23 and R24, the gain potentiometer being connected between the op-amp



output and the junction of these two resistors.

The gain of the circuits is given by the equation:

$$\text{GAIN} = \frac{R_{23} + \dfrac{R_{23}\,RV1}{R_{24}} + RV1}{R_{21}}$$

Bandpass filter

Signal levels at the output of the variable gain stage are around 1 V. Any hum exceeding this level could easily cause clipping in succeeding stages and the purpose of the second hum filter is to prevent this.

The bandpass filter employs one op-amp from the LM3900 package, IC1c. A filter network, consisting of R34, R35 and R37 and C29 and C30, is connected around a feedback path between the op-amp output and its inverting input. This provides a bandpass extending from 100 Hz to 500 Hz which encompasses the range of interest for the muscle fibre signals. At midband (250 Hz), the gain of this stage is roughly four.

A monitor output is taken from the output of IC1c so that the muscle activity waveforms (filtered) may be viewed on an oscilloscope if desired.

Threshold control

This consists of a precision rectifier that passes only the positive peaks of the signal that are greater than a preset dc voltage — determined by potentiometer, the threshold control on the front panel.

The output of the bandpass filter is mixed with a dc voltage derived via the positive supply rail by the potentiometer RV2. The resultant signal — the ac muscle activity signal superimposed on a dc voltage — is then applied to the input of the precision rectifier. This involves IC1d, D1 and D2 and resistors R39, 40, 41 and R42. The latter two resistors convert the current-differencing input of the LM3900 into a conventional voltage-input op-amp.

Positive-going signals of less than 0.6 V above the voltage present on the junction of R39 and R40 will be amplified by the full open-loop gain of IC1d. The output of this stage increases rapidly until D2 conducts, the stage then has only unity gain (x 1), determined by the ratio of R42 and R39.

Output from the precision rectifier is taken from the cathode of D2 and will consist of the amplified, positive-going part of the muscle fibre signals that are above the positive voltage set by the threshold potentiometer, RV2.

Diode D1 ensures that the gain of the stage remains at unity gain for the negative-going portions of the muscle fibre signals from the output of IC1c.

Meter drive

This consists of an op-amp (IC3) with an emitter-follower stage (Q7) connected in the negative feedback path. The emitter of Q7 drives the meter.

The threshold stage output is coupled to the input of IC3, a 741, via a 100n capacitor, C34. Resistor R47 limits the base current of Q7 to a safe value as the 741 will provide much more current than the transistor will stand! A signal from the output of the threshold circuit will be amplified by IC3, causing Q7 to turn on, charging C38. The meter is connected to 'read' the charge on C38, via R48. The more signal that appears above the threshold, the longer Q7 will be turned on, increasing the charge in C38, thus increasing the meter reading. The circuit will respond quickly to increasing input signals, showing a corresponding increase in the meter reading. As the signal decreases, with decreasing muscle activity, the meter reading decays at a rate depending on the capacitance between the emitter of Q7 and ground. This provides for some integration of the signal level variations.

The integrate switch, SW2, connects a 470 μF capacitor C37) in parallel with C38 (47 μF). With this in circuit (integrate switch 'on'), the meter takes some four seconds to drop from full scale to zero.

Voltage-controlled pulse generator

This provides an audio output, consisting of a series of pulses, the repetition rate being an indication of muscle activity.

The emitter of Q7 is coupled to IC4, a 555 timer, via R44. Current through this resistor charges C33 until the voltage on pin 6 of IC4 reaches 2/3 of the voltage on pins 4 and 8. At this point, pin 7 of the 555, previously appearing as an open circuit, will conduct discharging C33 via R45. Once the voltage on pin 2 drops below 1/3 of that on pins 4 and 8, pin 7 returns to an open circuit condition, allowing C33 to charge again. In this manner, the 555 oscillates providing pulses on pin 3 to the speaker, via RV1 which serve as a volume control. As the voltage at the emitter of Q7 varies according to the variation in muscle activity signals, the rate at which C33 charges will vary. This varies the pulse repetition rate of the 555 oscillator in sympathy with the variations in muscle activity.