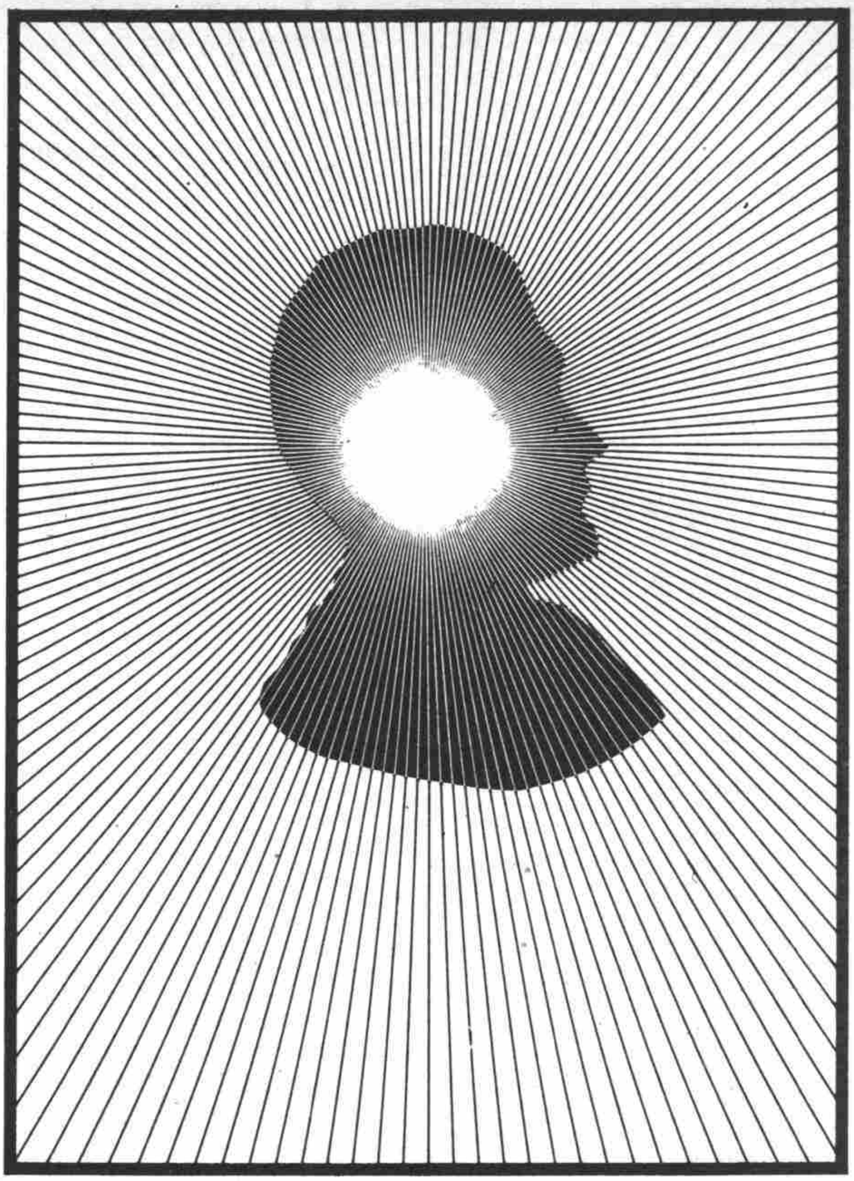


Biological Amplifier

This experimental project can demonstrate how neuro systems and electronics can be made to interact and influence certain muscular functions.

By D. BOLLEN

ELECTRICAL signals from the human body have been used for many years to diagnose certain illnesses and to monitor the condition of a patient during treatment. However, the possibility of using such signals for non-medical applications is a recent development.

The alphaphone, or electroencephalophone, is currently being used by mystics and others to achieve "instant" relaxation, by feeding back brain signals. A similar instrument can also serve as a lie detector monitoring the level of brain signals during interrogation.

Car drivers, athletes, and other people subject to stress, can learn to control their heart rate consciously with a cardiophone, which establishes an external feedback loop between heart and brain.

The biological pre-amplifier described in this article was designed as a general purpose module for detecting very low frequency signals from electrodes placed on the skin. Also described are a selection of output stages for specific projects, which include the alphaphone, lie detector, and cardiophone.

SKIN SIGNALS

Brain and nerve cells are similar to logic circuits in that they operate by emitting pulses of electrical energy. Under certain conditions, a group of cells will "fire" together in synchronism, to give a combined output either in the form of a large amplitude pulse (heartbeat) or slow sinusoidal waveform (brain rhythm). The nerve cells of a tensed muscle emit a stream of random pulses.

As a rough guide to signal levels from a pair of electrodes damped with salt water and placed on the skin, the chest will yield a heartbeat pulse of, say, 500 microvolts peak, the forehead an eyeblink pulse of 200 microvolts peak, and the crown of the head an alpha rhythm amplitude of around 50 microvolts r.m.s.

Other brain rhythms, with the exception of delta, tend to be of low amplitude, generally not more than 10 microvolts, and there is also a rapid, low voltage asynchronous activity when the subject is concentrating or excited.

The very approximate frequency range and psychological characteristics of some brain rhythms are as follows:

ALPHA Frequency 1-4Hz for infants, 4-7Hz for children and 8-12Hz for adults. This frequency can be modified by intake of certain drugs. Alpha is normally present when subject is relaxed with eyes closed, and signal is reduced or eliminated by seeing, sleep, unfamiliar sounds, anxiety, and mental concentration. A high level of alpha associated with deep meditation and pain immunity.

BETA Frequency 18-25Hz. Amplitude increased by anxiety and reduced during the initiation of movements and by muscular activity.

DELTA Frequency 2-3Hz. Strictly speaking, the name applies only to a type of rhythm associated with brain damage, but signals of similar frequency occur during sleep, accompanied by short bursts or "spindles" at around 14Hz.

THETA Frequency 4-7Hz. Thought to be related to creative thinking and problem solving activities, and with disappointment and frustration in young people.

BIO-FEEDBACK

Experiments currently being conducted in the U.S.A. seem to indicate that bio-feedback techniques can be used to alleviate symptoms arising from stress (of which there are many), to reduce heartrate and blood pressure, as well as provide a short-cut to the benefits arising from meditative practices such as Yoga.

The two most convenient ways of feeding signals back to the brain is via the ears or eyes. Fig. 1a shows the aural feedback alphaphone, which picks up subsonic alpha waves from the brain, uses them to modulate an audio signal, and feeds the resulting output to the ears.

The direct link between ear and brain is the feedback path, and the brain itself appears to be capable of adjusting a signal phase to positive or negative. With the alphaphone, the user quickly learns to reinforce his alpha waves, or reduce them, at will.

In the second example of bio-feedback (Fig. 1b), the heartbeat pulse is made to flash a light and the eye feeds this light pulse back to the brain. In time, the subject finds it possible to reduce or increase his heartrate by several beats per minute.

Visual feedback can also be achieved by watching an oscilloscope display, or meter readout of a biological signal.

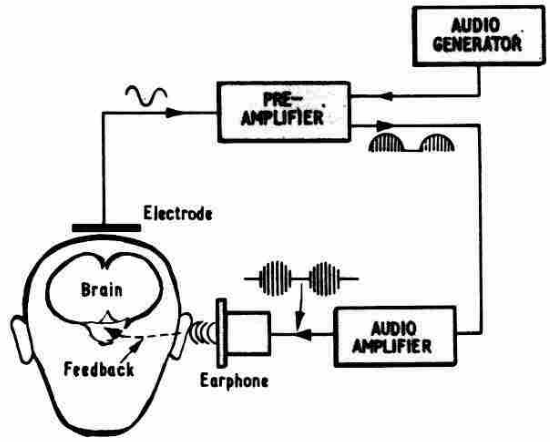


Fig. 1a. Graphical illustration showing the aural feedback path

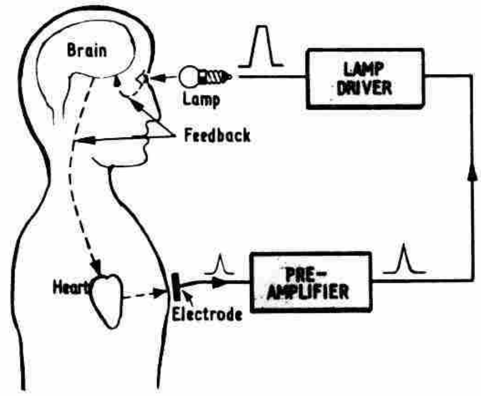


Fig. 1b. Graphical illustration showing the visual feedback path

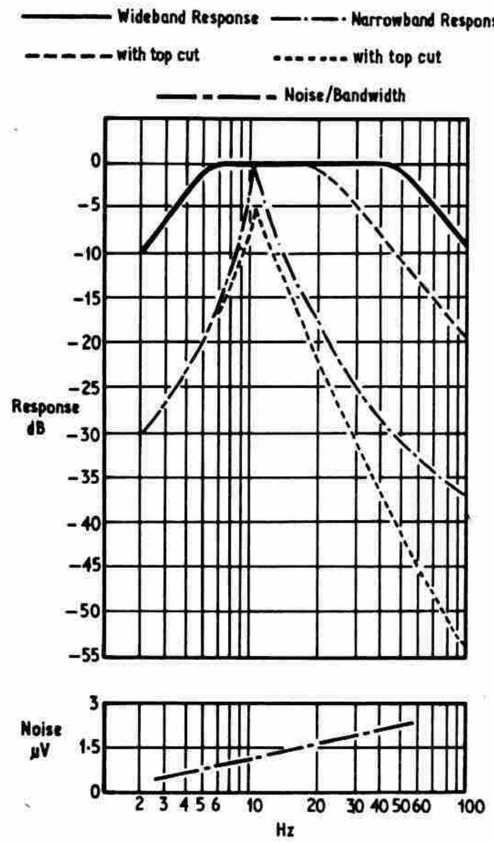


Fig. 2. Graphs of frequency response and noise of the biological pre-amplifier

Table 1. TUNED FILTER

	C5,C6 (μF)	C7 (μF)	Circuit tuned to
Alpha rhythms (muscle pulses)	0·47	1·0	10Hz
Beta rhythms	0·22	0.47	20Hz
Delta rhythms	2·2	4·7	2·5Hz
Theta rhythms	1·0	2·2	5Hz

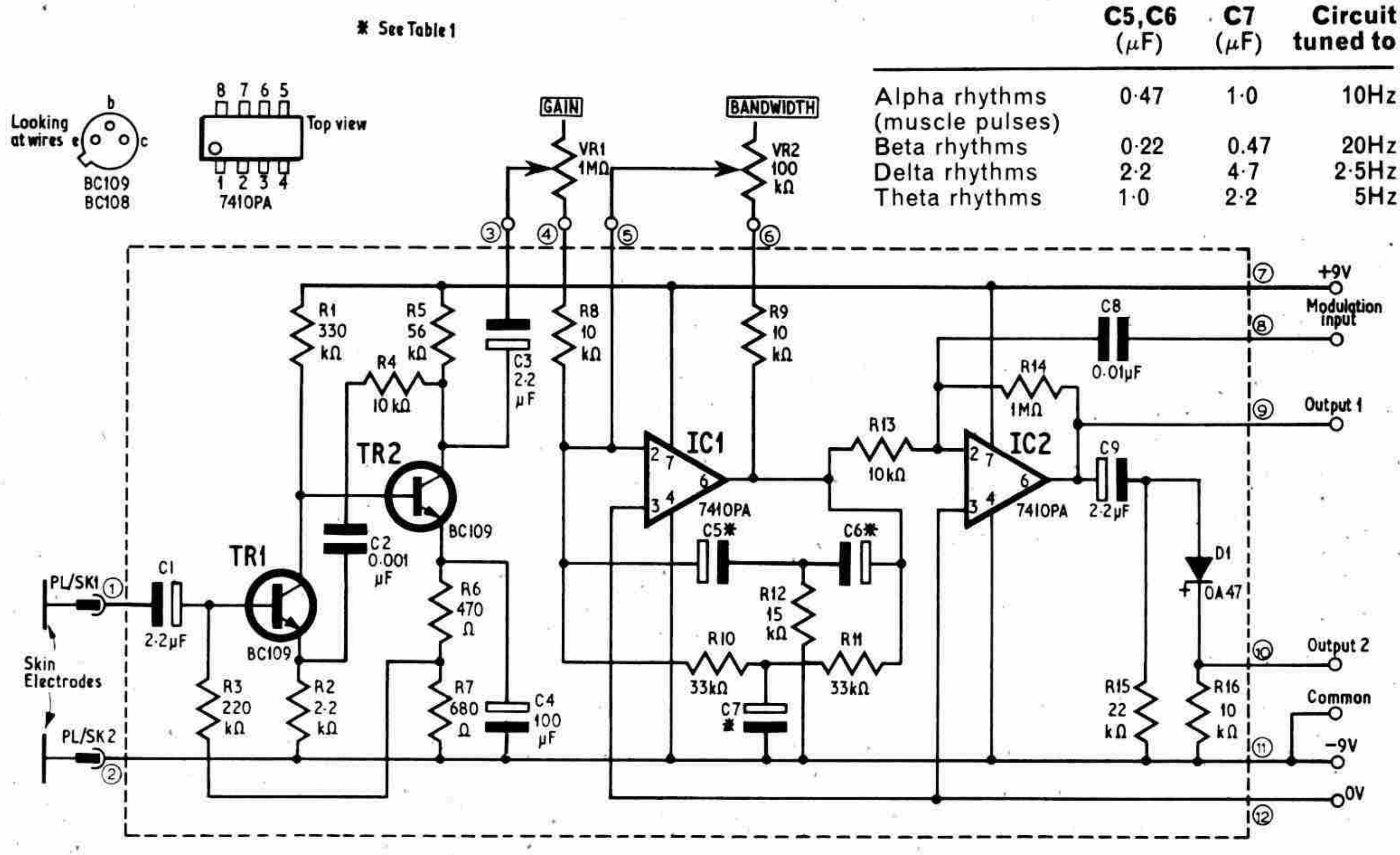


Fig. 3. Circuit of the biological pre-amplifier with component values of C5, C6 and C7 for different rhythms

CIRCUIT CONSIDERATIONS

Professional electroencephalographs (brain rhythm recorders) are carefully screened and operated under controlled conditions to achieve a typical noise-bandwidth performance of 2 microvolts at 0 to 75Hz. There is usually some provision for reducing bandwidth by means of switched filters to improve hum and noise rejection.

A noise performance only slightly inferior to that of a professional electroencephalograph is achieved with the biological pre-amplifier described here by sacrificing d.c. coupling. Flicker noise from transistors rises very steeply at sub-audio frequencies, and a considerable reduction in total noise can be obtained by giving the circuit a response roll-off below about 5Hz.

The pre-amplifier also incorporates a continuously variable bandwidth control which can be set to exclude mains interference in ordinary domestic environments and reduce amplifier noise.

Response and noise curves are shown in Fig. 2. At maximum bandwidth (−3dB at 4 and 60Hz) noise is less than 2·5μV, while at minimum bandwidth this figure is reduced to less than 0·5μV.

In its basic form, the pre-amplifier is tuned to 10Hz to give good resolution of alpha signals, but will also handle large amplitude beta, theta, and muscle pulses when set to wideband. However, the circuit can be modified quite easily for narrowband handling of beta, theta, delta, and low frequency alpha signals by altering the values of three capacitors.

All of the circuits given here are battery powered with outputs of less than 6 volts r.m.s., because it is potentially very dangerous to conduct electrode experiments with mains powered equipment. Even so, a mere 6 volts applied to the scalp is sufficient to cause visual strobing effects, twitching of facial muscles, an unpleasant tingling under the electrodes, and a mild headache if prolonged.

As a general policy, therefore, it is inadvisable to touch any circuit wiring while wearing head electrodes, and the temptation to couple bio-amplifiers to, say, audio amplifiers or flashing light systems, should be strictly avoided.

PRE-AMPLIFIER CIRCUIT

The circuit of the biological pre-amplifier is shown in Fig. 3. Input transistor TR1 has a collector current of 50μA for low noise working with typical skin electrode impedances of around 5 kilohms.

A proportion of TR2 emitter voltage is fed back to TR1 base via R3, to set the d.c. operating points of TR1 and TR2. C2 and R4 reduce the gain of the input stage above 100Hz to combat noise and instability. At 10Hz, the combined voltage gains of TR1 and TR2 is approximately 300.

A resistance placed between the inverting input and output of an operational amplifier will determine its gain. In the circuit in Fig. 3, an operational amplifier (IC1) uses a twin-T filter between input and output (C5-C7, and R10-R12) to offer a near infinite impedance at the frequency to which it is tuned; a low impedance is presented at other frequencies. Hence, the gain of IC1 is very high at the centre frequency and the amplifier behaves like a high-Q tuned circuit.

The bandwidth of IC1 is controlled by a variable resistance VR2 placed in parallel with the twin-T filter. With VR1 at minimum and VR2 at maximum resistance, stage gain is eleven, and can be reduced

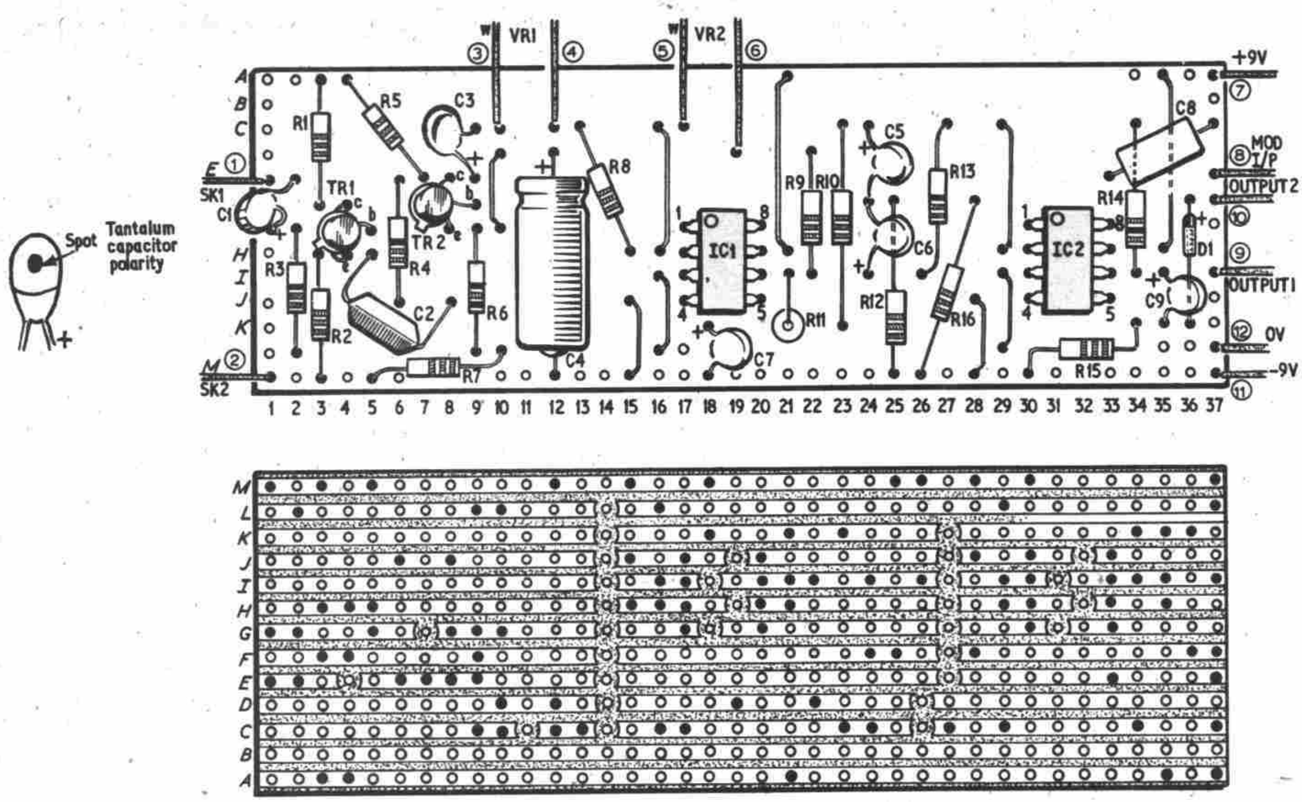


Fig. 4. Layout and wiring of the pre-amplifier board

to less than unity when VR1 is at maximum resistance.

The values listed for C5–C7 in Table 1 with Fig. 3 will give centre frequencies to suit different brain rhythms, but a frequency of 10Hz will serve for general purpose use, including muscle activity.

Output stage IC2 is another operational amplifier set for a voltage gain of 100, making the total gain of the pre-amplifier 330,000. Capacitor C8 has a dual purpose role, firstly as a modulation input whereby the subsonic bio-frequencies can be rendered audible after demodulation by diode D1, and secondly to act as an additional top-cut filter when connected to output 1, depending on the type of output circuit used with the pre-amplifier.

As it is not practicable to use conventional de-coupling techniques with very high gain low frequency circuits, owing to the large values of coupling capacitance required, the pre-amplifier is independently powered by two miniature 9 volt batteries, with output circuits separately powered to avoid interaction.

CONSTRUCTING THE PRE-AMPLIFIER

Pre-amplifier components can be assembled on a 3·7in by 1·3in piece of 0·1in matrix Veroboard, see Fig. 4. Having cut the circuit board to size, cut the copper strips where shown with a spot face cutter or sharp knife, then proceed to mount and solder components in position.

Take care not to let solder bridge the gaps between copper strips (a miniature soldering iron is essential here) and ensure that capacitor and diode polarities are correctly observed. To complete the panel, solder 3in lengths of 20 s.w.g. tinned copper wire as circuit board leads, in positions numbered 1 to 12 in Fig. 4.

For preliminary testing of the pre-amplifier module, join leads 3 and 4, and also leads 5 and 6. Spread out the remaining leads so that they do not touch, and connect leads 7, 12, and 11 to two 9 volt batteries. Polarity is shown in Fig. 3.

COMPONENTS . . .

PRE-AMPLIFIER

Resistors

R1	330kΩ ½ watt metal oxide.	R9	10kΩ
R2	2·2kΩ	R10	33kΩ
R3	220kΩ	R11	33kΩ
R4	10kΩ	R12	15kΩ
R5	5·6kΩ	R13	10kΩ
R6	470Ω	R14	1MΩ
R7	680Ω	R15	22kΩ
R8	10kΩ	R16	10kΩ

All ±10% ½W carbon except R1

Potentiometers

VR1 1MΩ preset knob trimmer
VR2 100kΩ preset knob trimmer

Transistors

TR1, TR2 BC109 (2 off)

Integrated circuits

IC1, IC2 741OPA or equivalent (2 off)

Diode

D1 OA47 or 1B40

Capacitors

C1	2·2μF tantalum 35V
C2	1,000pF polystyrene
C3	2·2μF tantalum 35V
C4	100μF elect. 6V
C5, C6, C7	35V tantalum (see text and Fig. 3)
C8	0·01μF polyester
C9	2·2μF tantalum 35V

Miscellaneous

Veroboard 0·1in matrix, 3·7in × 1·3in. Two 2mm plugs and sockets.

Now, with a 20 kilohms-per-volt testmeter, measure the voltage relative to lead 11 of the following: TR1 case (1·9V), TR2 case (11V), IC1 pin 6 (9V), IC2 pin 6 (9V). A variation of about ±0·5V can be allowed on the above voltages.

Disconnect the batteries and place the pre-amplifier on one side for use with the projects to be described next.

ALPHAPHONE

The purpose of the alphaphone is to apply bio-feedback to the brain to increase the level of alpha rhythms and thus promote those "good feelings" which, for some people, are associated with alpha.

Commercial versions of the alphaphone retail in the U.S.A. for £100 or more, but the version shown in Fig. 5 can probably be built for under £10 if a pair of headphones are already available.

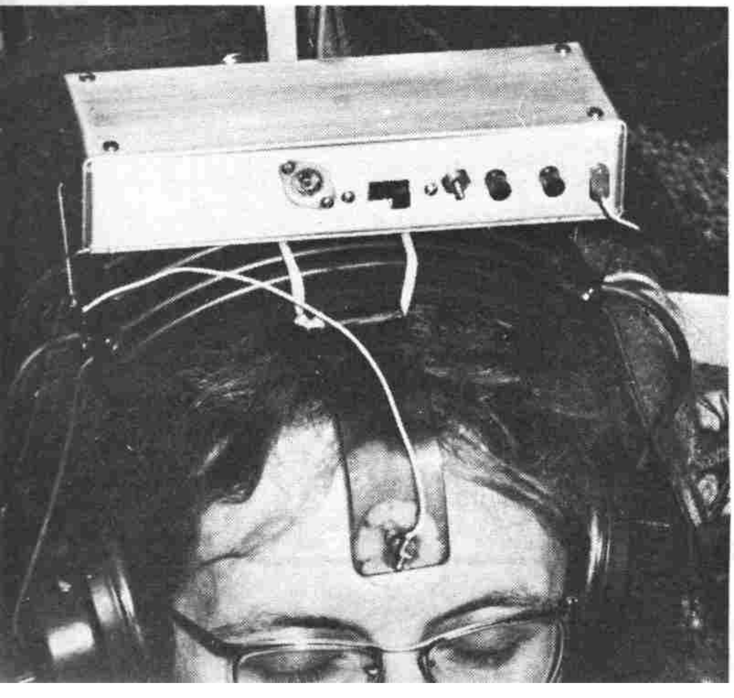
It is important that the sound heard by the alphaphone user should not be harsh, otherwise this will tend to interfere with relaxation. Another important point is that the alpha signal may have to compete with a background of external, domestic sounds which tend to distract the user and "block" his alpha. Ordinary stereophones, with their soft ear cushions, are excellent for attenuating noise, and a pair may be to hand. Alternatively, cheap mono phones with good sound insulation can be purchased for use with the alphaphone.

Referring back to the pre-amplifier circuit (Fig. 3) if white noise or an audio note is fed to the modulation input (lead 8) it will be mixed with the subsonic alpha signal at the input of IC2, and the intensity of this noise or note will vary in sympathy with the alpha signal after being passed through a non-linear diode D1.

In preference to an audio note, which is tedious to listen to for long periods, the alphaphone circuit (Fig. 5) uses a simple white noise generator (D2, R17, R18) to supply a restful "chuff-chuff" sound in the headphones, rather like a distant steam locomotive.

An output taken from the pre-amplifier demodulator diode (lead 10) is taken by way of R19 and C10 to a standard type of pre-built audio amplifier. The low alpha frequency is removed by C10 to leave only the higher frequency white noise, which is then amplified and fed to the phones.

The alphaphone fitted to the headband



LISTENING AMPLIFIER

Almost any small 9V amplifier, of about 50mV sensitivity and ½ watt output into 8 ohms, will serve. The author used a Newmarket module PC7+. The value of R17 (Fig. 5) can be adjusted to raise or lower the sound output in the phones, and it may be necessary to reduce the value of C10 with audio amplifiers of high input impedance, to give the required alpha frequency rejection.

The output socket, SK3 in Fig. 5, is shown wired for mono and stereo phones, to drive mono earpieces in parallel, and stereo earpieces in parallel.

The alphaphone should be well screened to minimise interference and instability. A suggested layout, inside a metal box, is included in Fig. 5, and this will give an instrument small enough to fit in a large pocket, and light enough to be carried by a stereophone headband.

The pre-amplifier module can be supported on its stiff wire leads, with a rectangle of s.r.b.p. under the Veroboard copper strips to prevent contact with the base of the metal box.

The PC7+ amplifier can be held in place with two screws, on stand off spacers. VR1 and VR2 may be glued to the front panel with a semi-flexible adhesive, which is easy to prise apart if one of the sub-miniature potentiometers needs to be replaced.

HEAD ELECTRODES

Electrodes held in place with sticky tape tend to pull at hair and leave adhesive behind on the skin, so the arrangement adopted here was to use spring loaded electrodes mounted on a shaped headband; see Fig. 6.

The electrode configuration shown, with one on the forehead and one on the crown of the head, is suitable for all brain rhythms except beta, and will pick up a good eyeblink pulse. A couple of layers of lint covering the electrode discs will retain the salt water conductive liquid for long periods without attention.

The electrode headband is a strip of $\frac{3}{16}$in sheet Perspex measuring approximately 10in by 1¼in and shaped in a steam jet or boiling water to be a loose fit on the top of the head. Holes are drilled at each end of the strip to take the spring loaded electrodes.

The eyeblink pulse is useful to test that equipment is in working order, but it may interfere with brain rhythm experiments, in which case the forehead electrode can be resited near the top of the head by drilling another hole in the Perspex strip. The complete electrode assembly is held in place on the head either with an elastic strap under the chin, or when mounted on a stereophone headband.

Electrode leads should preferably be of twisted or "side-by-side" insulated wire, as ordinary screened cable generates several microvolts of low frequency noise when bent or pulled. Even so, some amount of electrode lead noise is unavoidable if the alphaphone user moves his head around or touches the leads with his hands.

When using the electrodes, the lint covering is first soaked in salt water, and good contact is made with the crown of the head by soaking the patch of intervening hair with salt water. Natural skin grease acts as an insulator and should be removed with hair shampoo or surgical spirit.

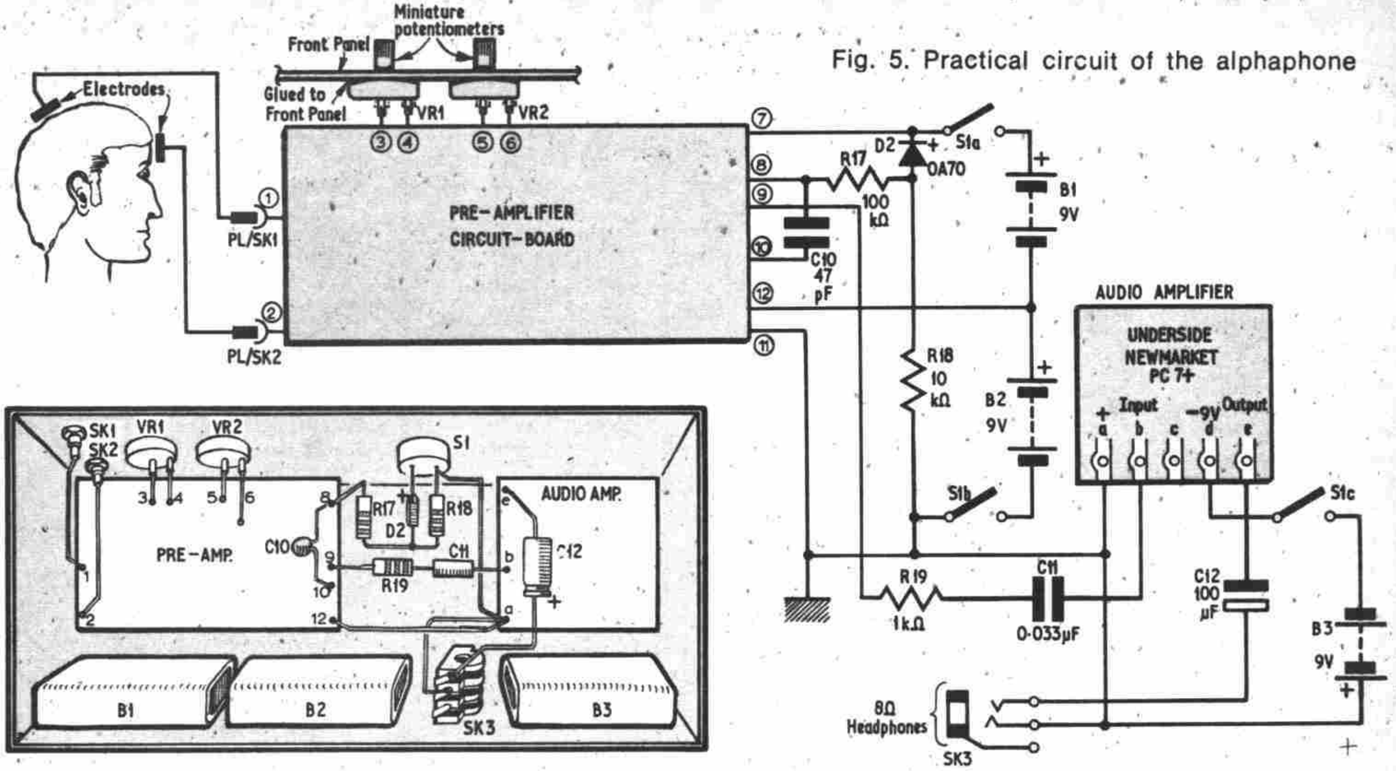


Fig. 5. Practical circuit of the alphaphone

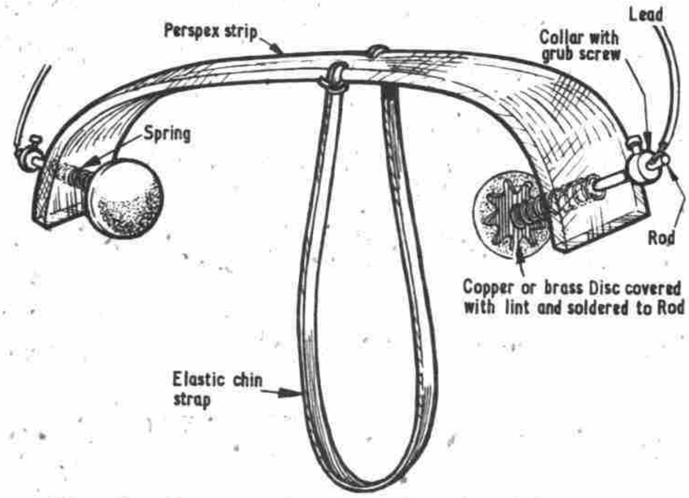


Fig 6. Construction of the head electrode assembly

USING THE ALPHAPHONE

When ready to use the alphaphone, insert the headphone jack in SK3, but leave the head electrodes disconnected from SK1 and SK2. Set VR1 to mid-resistance and VR2 to minimum resistance (wide-band) and switch on. A low, steady hiss should just be audible in the headphones. If there is humming, or buzzing sounds, this will probably be mains interference, so try resiting the alphaphone away from house wiring.

Advance VR1 to the point where low frequency noise from the pre-amplifier is just audible. When a 4·7 kilohm resistor is inserted across SK1 and SK2, pre-amplifier noise should disappear.

Wet the electrodes and place them on the head, and connect to SK1 and SK2. A sharp sound should now be heard every time the eyes are blinked, and a crackling noise from jaw muscles when the teeth are clenched, against a background of random brain noise.

Relax with the eyes closed and listen for the "chuff chuff" alpha signal; initially this will tend to come and go in short bursts, but with practice the alpha can be maintained at a steady, high level.

COMPONENTS . . .

ADDITIONAL COMPONENTS FOR ALPHAPHONE

Resistors
R17 100kΩ
R18 10kΩ
R19 1kΩ
All ±10% ½W carbon

Capacitors
C10 47pF polystyrene
C11 0·033μF polyester
C12 100μF elect. 12V

Diode
D2 OA70

Switch
S1A, B, C 3-pole, 2-way miniature wafer

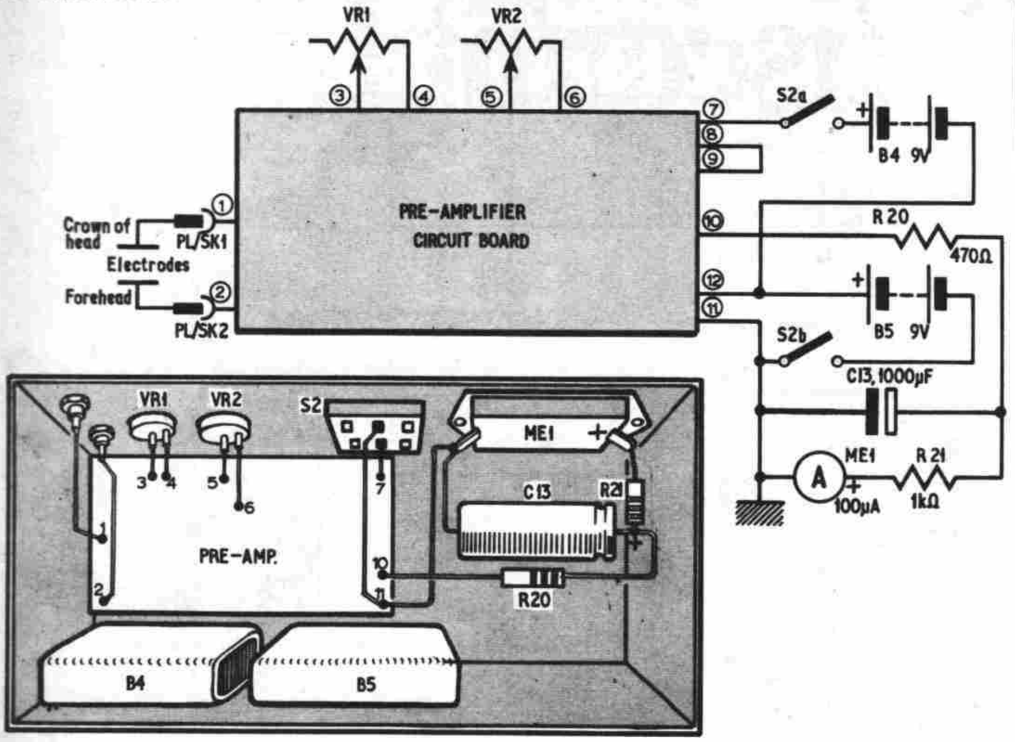
Socket
SK3 3-pole jack

Batteries
B1, B2, B3 9 volt style PP3 (3 off)

Audio amplifier
Newmarket PC7+ or similar (see text)

Miscellaneous
8 ohm mono or stereo headphones
Electrodes (see text)
Battery connectors
Metal box (see text)

Fig. 7. Suggested wiring of the pre-amplifier for an alphameter



COMPONENTS . . .

ADDITIONAL COMPONENTS FOR ALPHAMETER

Resistors
R20 470Ω
R21 1kΩ
Both ±10% ½W carbon

Capacitor
C13 1,000µF elect. 3V

Meter
ME1 100µA edgewise type level indicator

Switch
S2 Double-pole change-over slide

Batteries
B4, B5 9 volt style PP3 (2 off)

Miscellaneous
Battery connectors
Electrodes (see text)
Metal box (see text)

If mains interference is impossible to avoid, decrease gain (VR1) and reduce bandwidth (VR2) until a satisfactory signal is obtained. The tendency of the pre-amplifier to oscillate at 10Hz when VR2 is near minimum bandwidth can be checked by blinking the eyes. If there is appreciable ringing after an eyeblink (several cycles of 10Hz oscillation) increase bandwidth.

ALPHAMETER

The circuit in Fig. 7 can be variously employed as a relaxation meter, lie detector, and sleep threshold monitor, on the principle that alpha rhythm amplitude varies inversely with anxiety, and is reduced to zero by sleep.

Diode D1 in the pre-amplifier module here acts as a meter rectifier, to feed ME1 in Fig. 7 via series resistors R20 and R21, while C13 provides a time constant of 2-3 seconds to smooth out signal fluctuations. C8 in the pre-amplifier module is linked to output 1 (leads 8 and 9) for additional top-cut (see Fig. 2) to reduce interference and unwanted brain noise. Low frequency roll off is also increased by the meter load placed on output capacitor C9 in the pre-amplifier circuit, to remove delta type sleep rhythms.

CONSTRUCTING AND USING THE ALPHAMETER

If ME1 is a miniature edgewise meter, small enough to mount on the front panel, the alphameter can be housed in a metal box of the same dimensions as that used for the alphaphone. A suggested layout is shown in Fig. 7, with ME1 and C13 taking up the space previously occupied by the packaged amplifier.

To use the alphameter as a relaxation meter, set VR1 to maximum gain and VR2 to wideband. Place the electrode assembly on the head, after wetting with salt water, and switch on. When the subject's eyes are open, a reading of about 5% of full scale should be obtained, assuming that there is little or no mains interference.

Now ask the subject to close his eyes and relax, whereupon the meter reading should rise to about half full scale, indicating a state of moderate relaxation. A gentle tap on a door will cause the meter reading to fall back towards zero, by alerting the subject out of his relaxed state, and the same applies if the subject is asked to do mental arithmetic.

It is interesting to note the increase of meter reading when the subject's eyes are open and he becomes excited, caused by a rise in "brain noise" and theta.

LIE DETECTION

A similar technique to the above is employed for lie detection, with the virtue that the instrument cannot be misused against the will of the person being interrogated because nervousness or tension obliterates the alpha signal, and renders the lie detector inoperative.

With the subject relaxed and showing a consistently high meter reading, interrogate with a series of simple, undemanding questions, with a short pause allowed between question and answer. If a significant question is suddenly interposed, which calls for a devious answer, the meter reading will fall dramatically towards zero, despite the apparent outward calm of the subject.

To use the alphameter as a sleep threshold detector, the subject is asked to compose himself for sleep, and when the eyes are closed alpha rhythms will initially be generated, causing the meter to read. Just before sleep, the alphameter reading will start to become erratic, and will fall to near zero at the onset of unconsciousness.

Part 2 will describe a brain rhythm frequency meter and cardiophone.