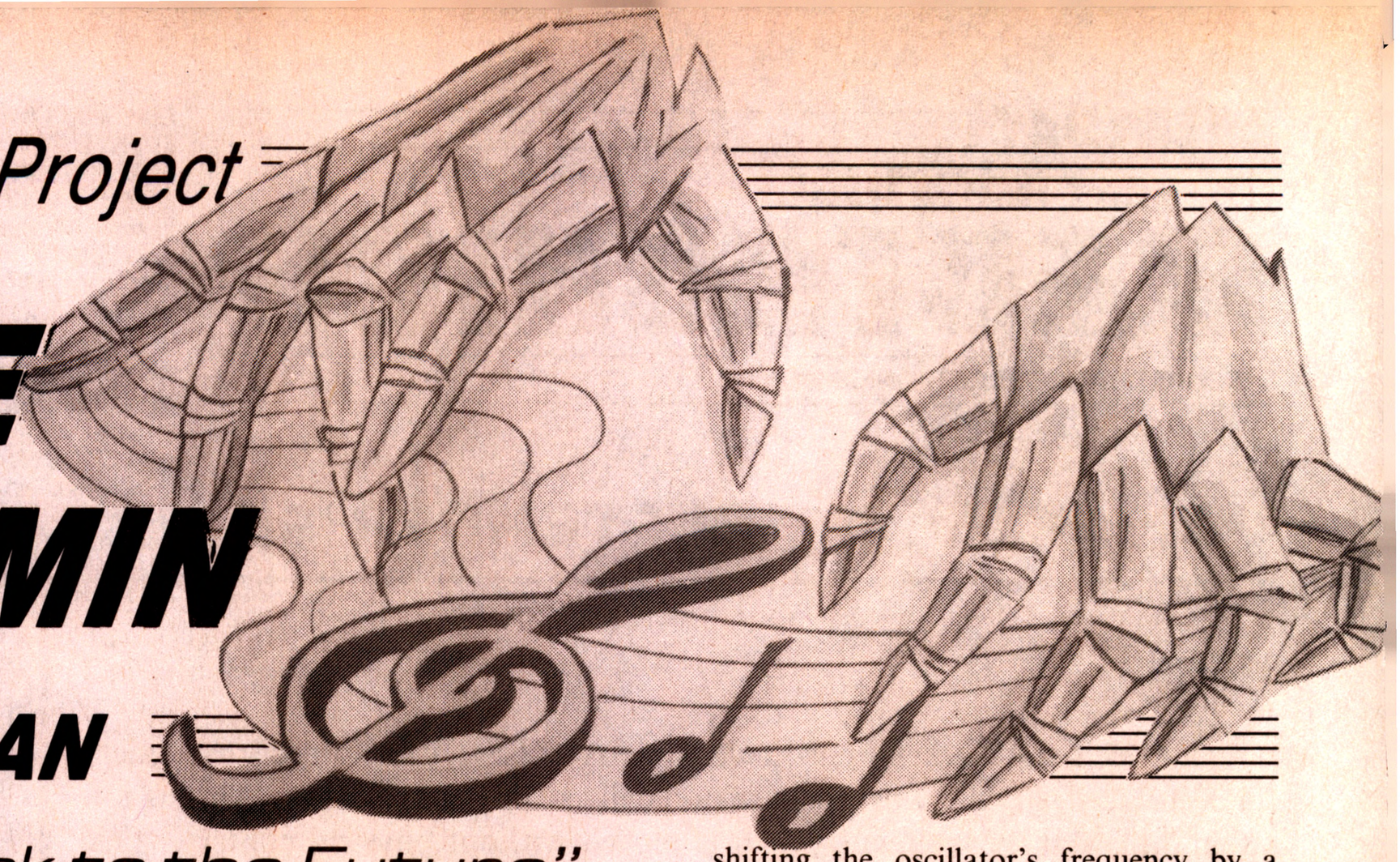
Constructional Project

SIMPLE THEREMIN



JAKE ROTHMAN

Take a trip "Back to the Future" and discover the fascinating world of "music and magic" that is the Theremin

FORGET inputting that formant data into your MIDI synthesis workstation via the Qwerty user interface for a limited time window (*enough of this techno-rubbish – Ed!*) and get back to those eerie tones of the good old Theremin.

It was Leon Theremin who first popularised electronic music with his electronic musical instrument the Theremin. His creation certainly followed Arthur C. Clark's assertion that good technology should appear like magic, since it was played with no physical contact. The "Thereminists" moved their hands in a controlled way around the antennas that controlled pitch and volume.

A motionless body was essential for pitch stability, but this merely enhanced the theatrical effect and mystery. Along with its eerie sounds, the instrument's strangeness led the Theremin to be used on the soundtrack of many 1950s science fiction movies, such as *The Day The Earth Stood Still.*

THEREMIN - END OF A LEGEND

The Theremin is surrounded by intrigue and legend and this was played upon a great deal in the *Channel 4* documentary, presented shortly after Leon Theremin's death in 1994. However, the role of a technical magazine like *EPE* is to demystify such things and explain their operation.

It is said that a lot has been discovered in electronics when things go wrong and this is very likely in the case of the Theremin, since the principle of the Theremin frequently arises by accident in electronics as a form of instability.

A classic case occurs in radios where there is a loud whistle accompanying the desired programme. If the tuning control is adjusted the whistle usually changes pitch. Combining this with another common fault, hand capacitance effects, the pitch will change if a hand is moved towards the receiver.

It is very likely that the old regenerative wireless sets popular in the twenties which were prone to these defects, inspired Theremin to analyse and exploit the effect to make a musical instrument. So there is no real mystery, the Theremin is in fact just a glorified audible capacitance meter!

BASIC OPERATION

The basis of all Theremins is two high frequency oscillators, of almost identical frequency, normally operating from 0·2MHz to 2MHz. One oscillator is fixed while the other is connected to a conductor which forms a variable capacitor with the player's hand. As the hand is moved, a minute change in capacitance occurs (in the order of fractions of a picofarad (pF) shifting the oscillator's frequency by a correspondingly small amount.

The oscillator outputs are then combined in a mixer as shown in Fig. 1 to produce a beat frequency as shown in Fig. 2. If the two original frequencies are close enough together, the beat frequency will be in the audio region.

Now here comes the clever bit: since the original frequencies are in the radio frequency (r.f.) region, it only requires a very small percentage shift to make a large difference to the beat frequency, giving a sensitive instrument with a wide pitch range.

The mixer output contains a lot of r.f. and is just like an a.m. radio signal. This then needs to be detected and filtered to obtain a clean audio signal. If the r.f. content is not removed the audio output amplifier may "overheat" and the signal may be radiated by the output wires causing instability.

ORIGINAL THEREMINS

Original Theremins built by RCA in the thirties were very large valve/wooden instruments with a vertical conductor for Pitch and a horizontal loop for Volume. (Basic Theremins, such as the one described here, do not usually have a volume control conductor.) The RCA's Volume control was quite unusual since it had a negative control characteristic, in that no tone was emitted until the hand was removed.

Since voltage controlled amplifiers were not effective at that time, the unique solution of varying the brightness of a directly heated valve filament was used. This filament was fed with r.f. generated by an oscillator that could be damped via the control conductor.

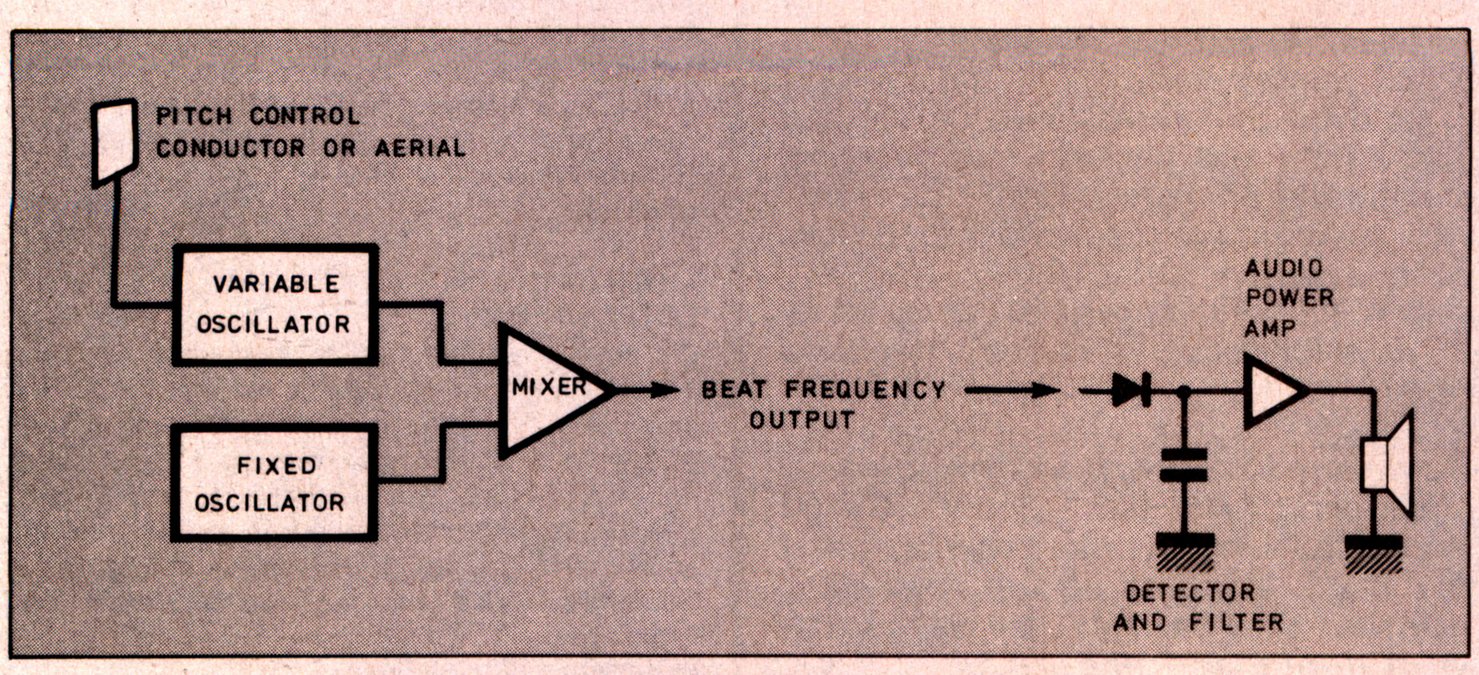


Fig. 1. Black diagram for the basic Theremin,

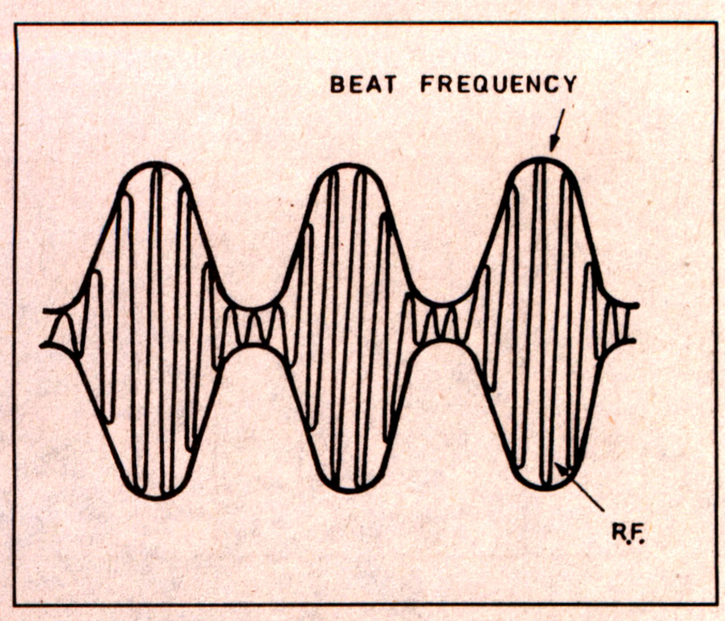


Fig. 2. Beat frequency output from the mixer stage.

Original RCA Theremins were very highly developed pieces of electronics, having excellent stability and range. They have often been used in conjunction with an orchestra and can be considered true concert instruments. Of course this is reflected, along with their scarcity, in the price, which is in the order of £12,000.

SIMPLE THEREMIN

Being £11,980 cheaper than the RCA model, the design presented here is harder to play in tune because of a more compressed range, but when plugged into a loudspeaker with decent bass response and some sound processing gear, the results can be quite acceptable.

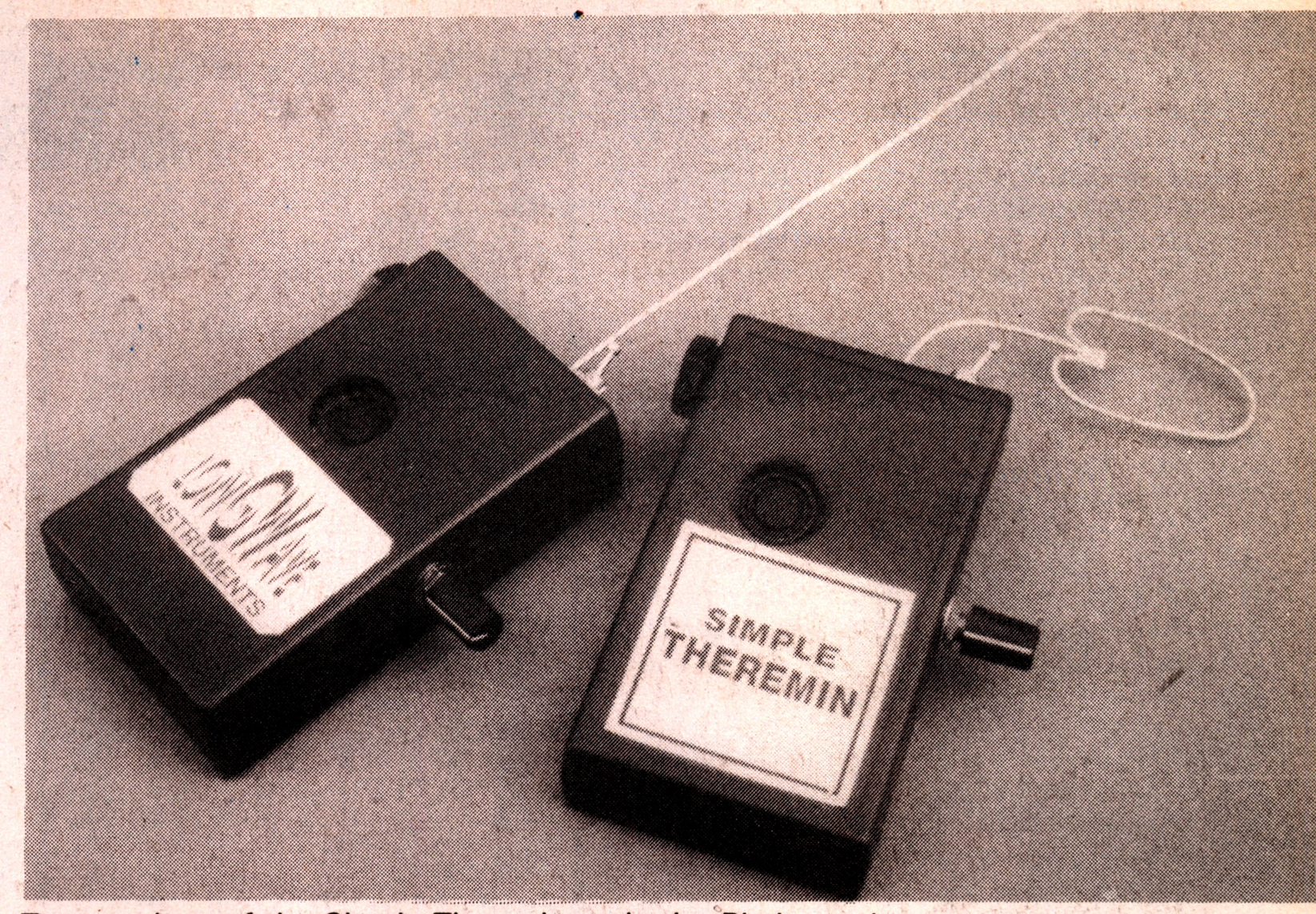
To obtain a range comparable with the original necessitates the use of expensive specially made coils, whereas this design uses standard 100µH coils available from most of the main distributors.

CIRCUIT DESCRIPTION

The complete circuit diagram of the Simple Theremin is shown in Fig. 3. The two oscillators are of the Colpitts configuration which avoids the need for a tapped coil by using two capacitors to form a "tapped" capacitance. This allows ordinary off-the-shelf inductors to be used.

The frequency of the fixed oscillator, built around transistor TR1, is around 1·33MHz. The variable frequency oscillator, built around TR2, is connected to the Pitch aerial (note that this is at positive potential since current can flow through coil L2). Trimming for ambient conditions is provided by trimmer capacitor VC1.

Mixing of the two oscillator outputs is accomplished by transistor TR3. To prevent the oscillators locking together at low frequencies the mix resistors R9 and R10 are of high value. Note R10 is about half the value of R9 to ensure the amplitude of the resulting waveform does not fall to zero at the dips of the beat frequency. This ensures there is always some carrier frequency which reduces the distortion produced by the detector.



Two versions of the Simple Theremin, only the Pitch conductor shape has been changed.

The mixer stage is simply a collector biased common emitter stage. If a different transistor is used, resistor R11 may need altering to get lowest distortion. To prevent low frequency oscillation the mixer stage is decoupled by resistor R13 and capacitor C13. Note that the two oscillators have their own decoupling, provided by ceramic capacitors C1 and C6.

Demodulation of the mixer output is provided by diode D2. Capacitor C14 is used to block the half-rail d.c. bias present on TR3 collector. To prevent a d.c. offset building up, diode D1 provides an equivalent d.c. path.

First stage r.f. filtering to recover the audio is provided by capacitor C15. A second stage of r.f. filtering is provided by R15 and capacitor C16 before the signal is fed into load resistor R17.

To prevent the Volume control VR1 from scratching due to d.c., the signal is a.c. coupled via capacitor C20. Unusually for a Volume control, it is acceptable for VR1 to be a "linear" type, although a log. type gives a smoother change at low levels.

A final stage of filtering, built around resistor R16 and capacitor C17, is applied just before the input to IC1, an LM386 power amplifier i.c. The LM386 was chosen since it is less prone to r.f. oscillation than a lot of monolithic power amps and provides an adequate output of 250mW.

A Zobel network consisting of resistor R18 and capacitor C21 is used to prevent any h.f. oscillation due to the voice-coil inductance of the loudspeaker. Capacitor C22 is used to block the half-rail d.c. bias voltage from entering the loudspeaker. Finally, decoupling for the power-amp is achieved by capacitor C18, with high frequency bypassing provided by C19.

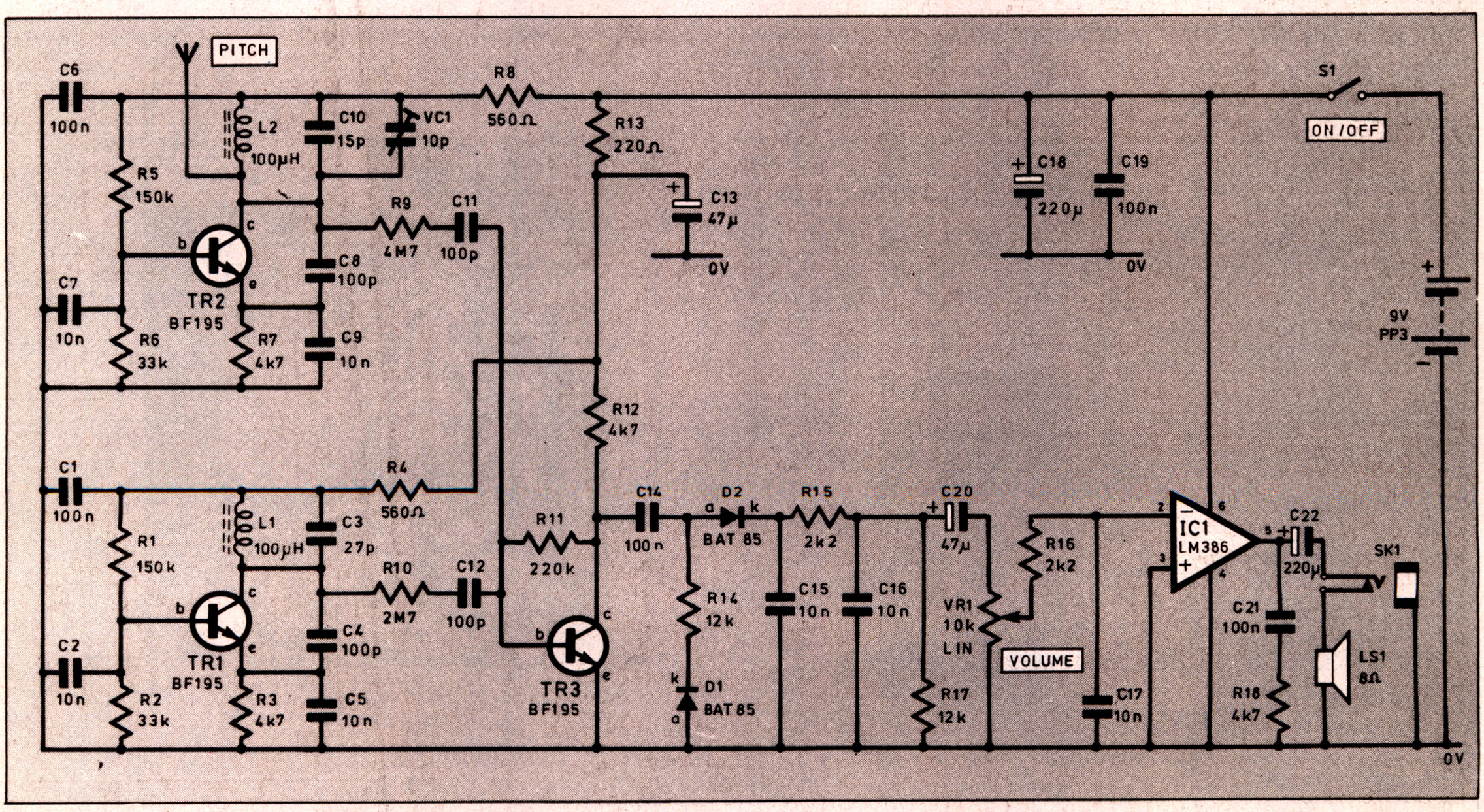


Fig. 3. Complete circuit diagram for the handheld Simple Theremin.

COMPONENTS

All the *frequency* determining capacitors should be zero temperature coefficient NP0 ceramic, or better still, negative temperature coefficient, such as N150 ceramic types. The use of N150 capacitors helps compensate for the positive temperature coefficient of the ferrite cored inductors used.

Most N150 ceramic capacitors can be identified by a band of orange paint across the top. However, aiming for high stability in a Theremin can be a pointless exercise since they will tend to drift according to air temperature, humidity and the proximity of any objects.

All the other capacitors are used for coupling and decoupling and cheap poor-tolerance ceramics and electrolytics can be used. None of the resistors are critical and standard five per cent carbon-film types can be used.

The transistors are cheap r.f. types as used in a.m. radios; it is possible to use l.f. types such as BC182s although it may be necessary to alter the value of the emitter components to get a clean sine wave. Although Schottky diodes are specified for the detector, old germanium types, such as the OA91, work almost as well.

CONSTRUCTION

The Theremin printed circuit board (p.c.b.) topside component layout and full size underside copper foil master pattern are shown in Fig. 4. Construction should not present any problems provided the circuit is built on the recommended p.c.b. The board is available from the *EPE PCB Service*, code 952.

To minimise the magnetic coupling between the two oscillators the inductors L1 and L2 are mounted on almost opposite corners of the p.c.b. They are also at right angles to each other, with L1 being horizontally mounted whereas L2 is in a vertical orientation.

CORNFIELD

Back in the early eighties as a young electronics undergraduate one of my lecturers said, "no more cornfields laddie" referring to a recently constructed mixer channel I had designed with all the resistors mounted vertically. However, no apologies are made for this being a "cornfield" design since it is the only way, apart from surface-mount techniques, the Theremin could be made pocket-sized without having to use one of those awful mini-jacks. Only full-size jack sockets are reliable enough, as users of Walkman type cassette players will testify.

Assembling the board should follow the normal rule of "lowest components first" although this will contradict the other general rule of "resistors first" which cannot apply to vertical mount boards. It is a good idea to mount IC1 in a socket and care should be taken bending the leads of the diodes and coils. The transistors are "lock fit" and so despite being of low profile, they can be fitted last, in accordance with good practice.

Trimmer capacitor VC1 ***MUST*** be mounted on the copper side of the board. This is quite a tricky soldering job necessitating a fine pointed iron, since the

COMPONENTS

Approx cost guidance only **£20**

Resistors

R1, R5	150k (2 off)
R2, R6	33k (2 off)
R3, R7, R12	4k7 (3 off)
R4, R8	560Ω (2 off)
R9	4M7
R10	2M7
R11	220k
R13	220Ω
R14, R17	12k (2 off)
R15, R16	2k2 (2 off)
R18	4Ω7

All 0·25W 5% carbon film

See SHOP TALK Page

Capacitors

C1, C6, C18, C21	100n ceramic, +80 −20% (4 off)
C2, C5, C7, C9, C15, C16, C17	10n ceramic 20% (7 off)
C3	27p ceramic 2% NP0 or N150
C4, C8, C12, C10	100p ceramic, NP0 or N150 (4 off)
C10	15p ceramic, NP0 or N150
C13, C20	47µ radial elect. 10V
C19, C22	220µ radial elect. 10V
VC1	10p Philips trimmer

Note
This design is offered as a project for home construction only and no licence for commercial manufacture is implied.

Semiconductors

D1, D2	BAT85 small signal Schottky diode (2 off)
TR1, TR2, TR3	BF195 *npn* silicon r.f. transistor (3 off)
IC1	LM386 low voltage power-amp.

Miscellaneous

L1, L2	100µH axial inductor (2 off)
B1	9V alkaline battery (PP3), with clip
SK1	6·3mm (¼in.) mono switched jack socket
S1	s.p.s.t. min. toggle switch
LS1	8ohm 1·5in. diameter loudspeaker, with alnico magnet

Plastic case, with battery compartment, size 105mm x 60mm x 28mm; printed circuit board available from *EPE PCB Service*, code 952; 8-pin d.i.l. socket; 10mm dia., 3mm shaft, collet knob plus end cap; single-ended solder pins (8 off); 16s.w.g. tinned copper wire, approx. 150mm length, for Pitch aerial; multistrand connecting wire; solder etc.

Note that the p.c.b. design and circuit is copyright of Longwave Instruments and many not be manufactured by commercial companies.

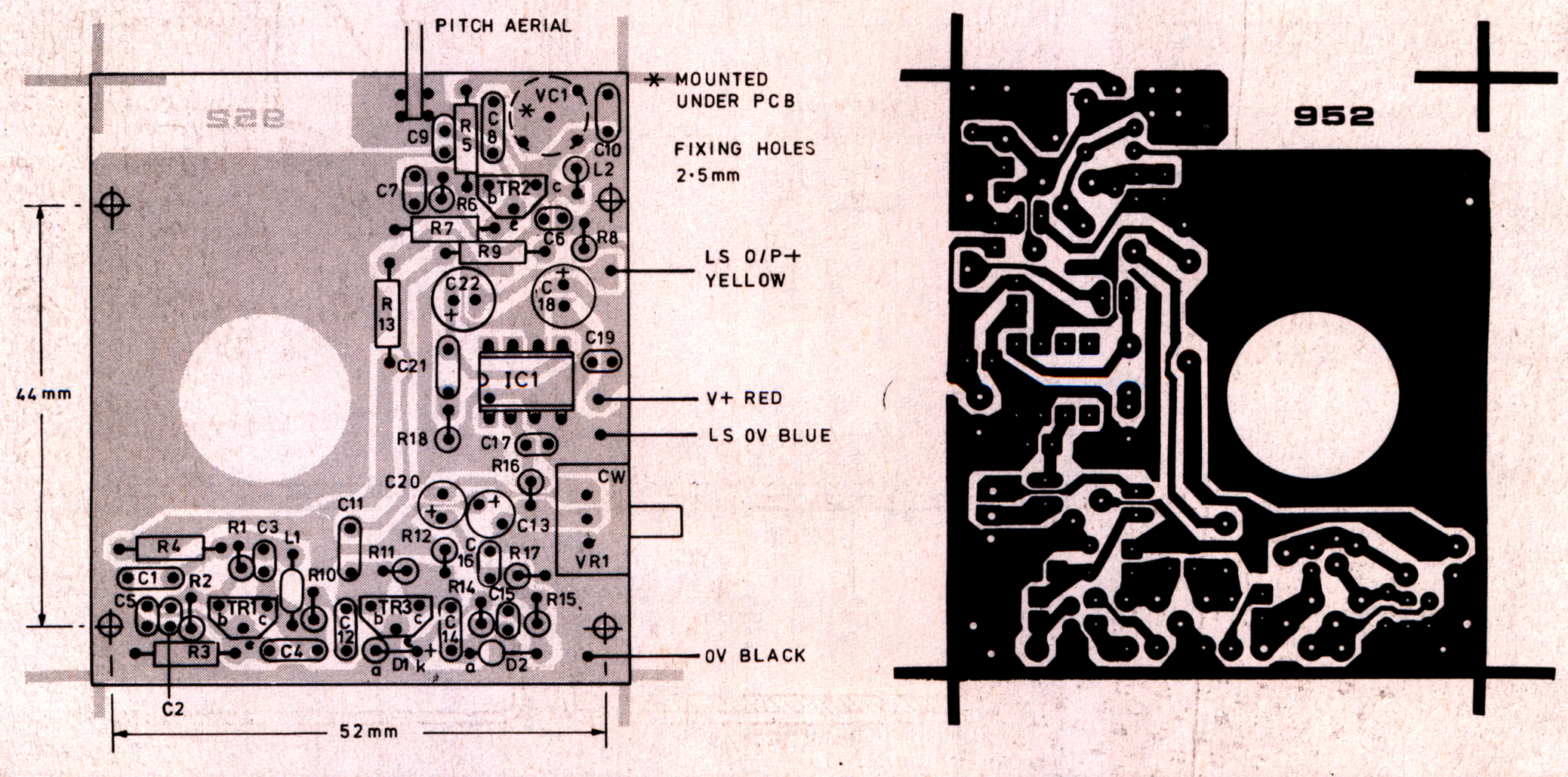


Fig. 4. Printed circuit board component layout and full size underside copper foil master pattern for the Simple Theremin. The size of the speaker cutout may need to be enlarged to suit the size of magnet on the speaker used.

iron has to go under the component to reach the tags. When mounting the potentiometer VR1 it is essential that the tags are firmly bent over before being soldered, since the soldered joins on all p.c.b. mounted pots are subject to considerable mechanical stress.

CASE

Being a compact unit, the drilling and mounting details are more critical than for most units. In particular the 2·5mm mounting holes for the p.c.b. are very tight, as is the actual size of the p.c.b.

Some judicious filing of the board will be needed to ensure an accurate fit inside the case. This is best accomplished before the p.c.b. has been soldered up, since the trimmer capacitor is sensitive to dust and abrasion.

The loudspeaker is mounted with Evostik impact adhesive (the brown stuff). It is essential that the speaker used has a colmnar or alnico magnet, the more common ferrite magnets will be too wide and will foul the components on the p.c.b.

Since the speaker does not have to handle the full range, a single hole sufficient to clear the voice coil will suffice. This provides protection without the need for a covering grille. Fig. 5 shows the drilling details for the box.

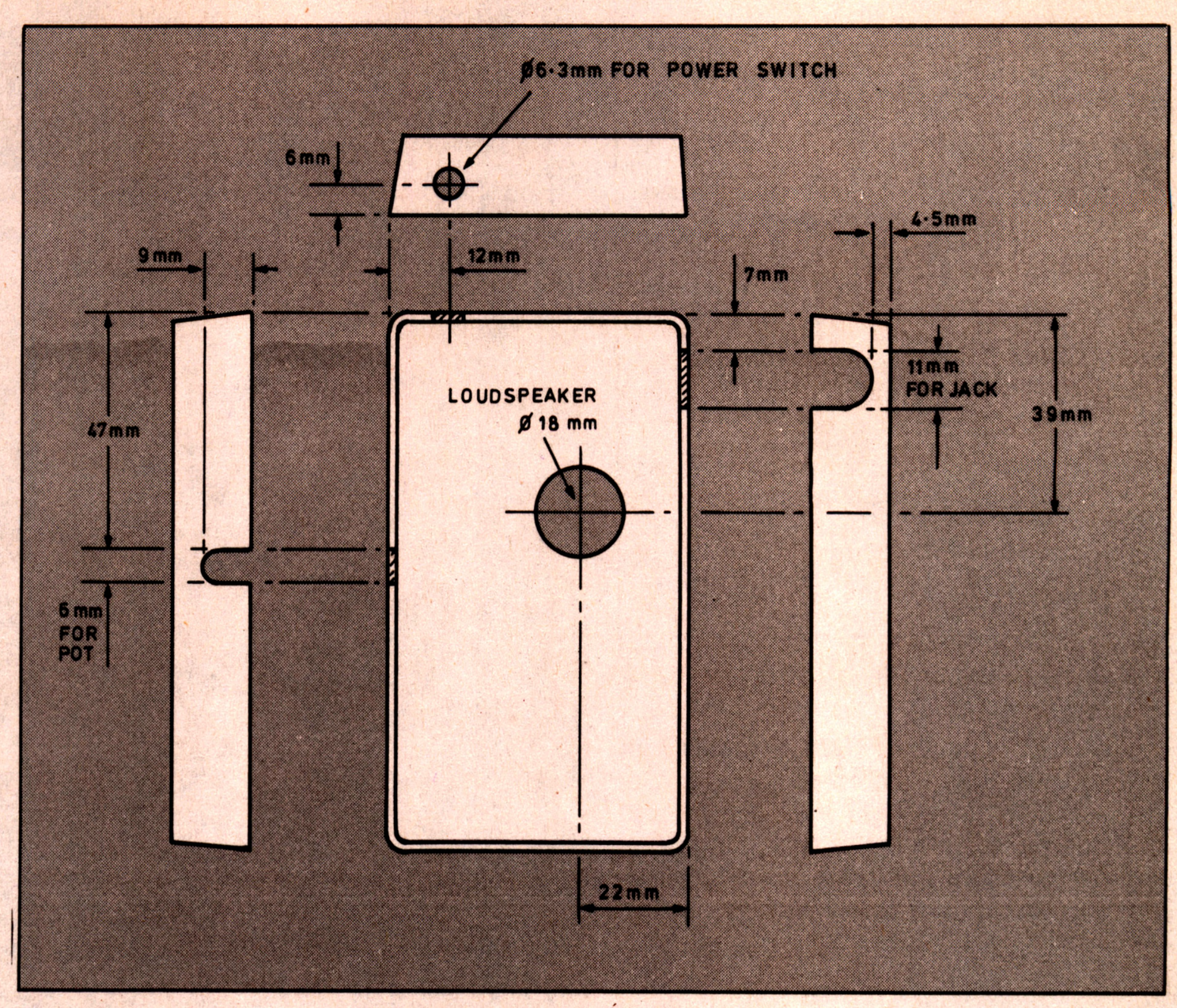
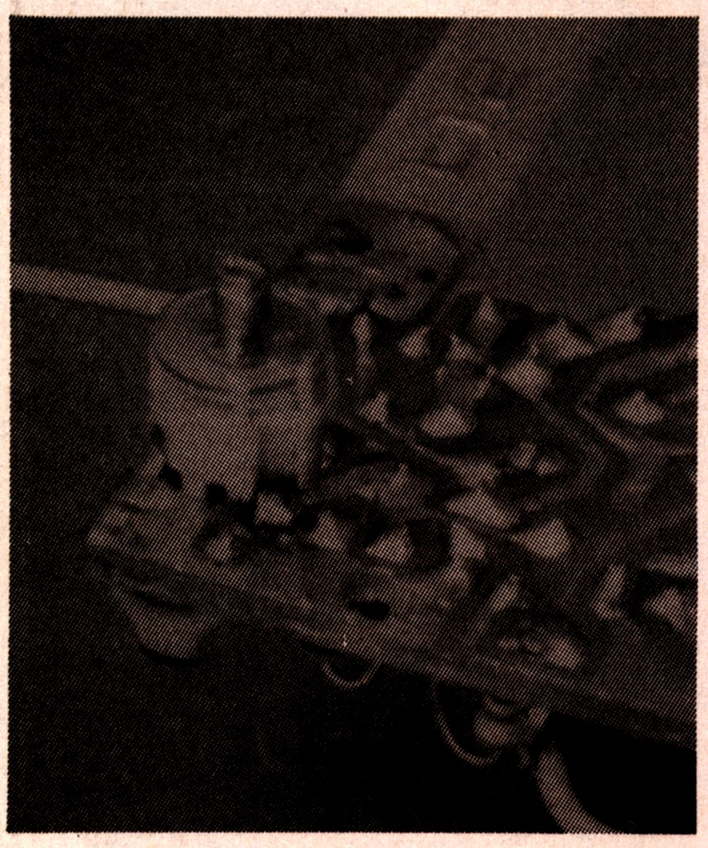


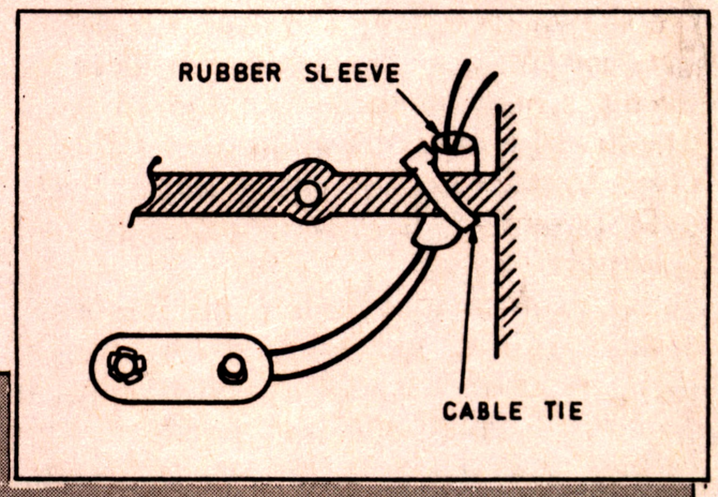
Fig. 5. Case measurements and drilling details.

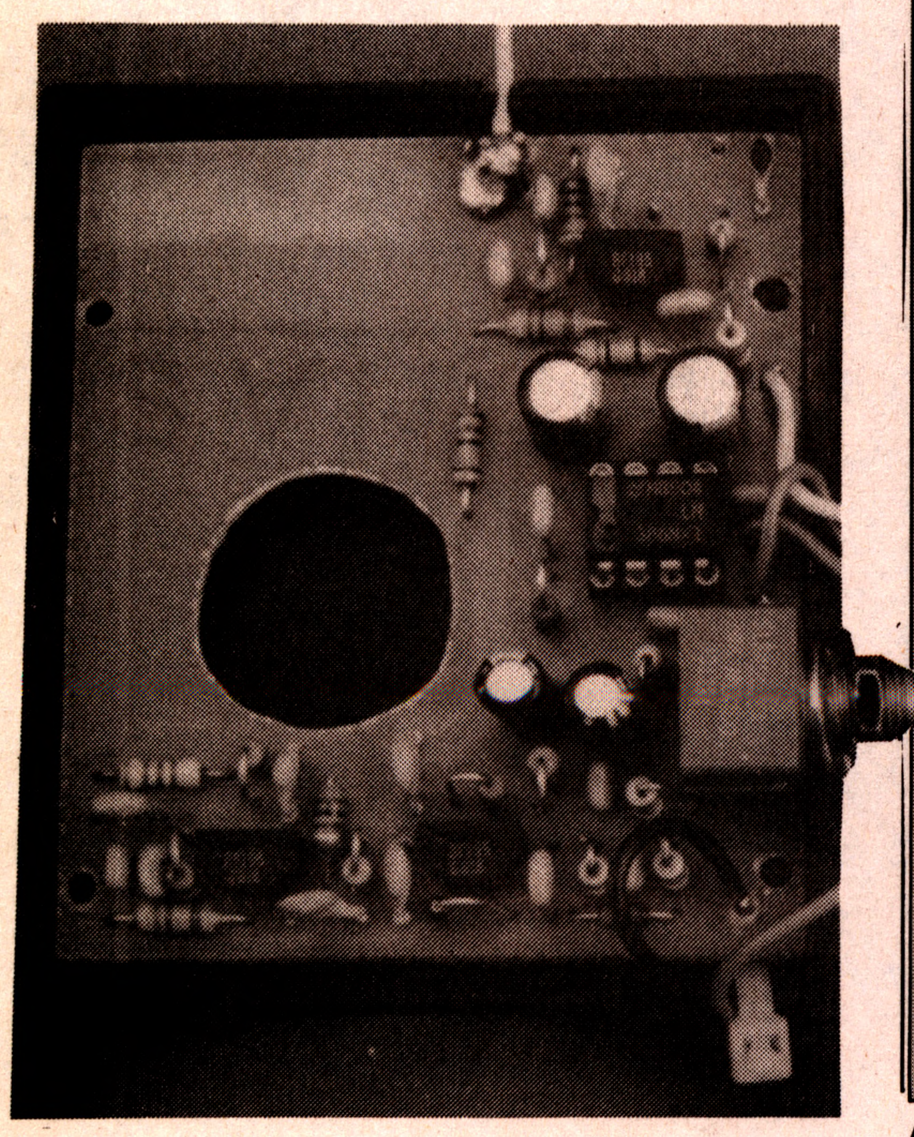


The trimmer capacitor mounted on the track side of the p.c.b.

INTERWIRING

There is very little wiring in the unit, it only being necessary for the battery clip, switch, output jack socket and loudspeaker. The full interwiring details are shown in Fig. 6. Note that the connecting tags for the jack socket SK1 must be bent over to give a maximum clearance to be able to close the box.





The completed p.c.b. is a tight fit in the case.

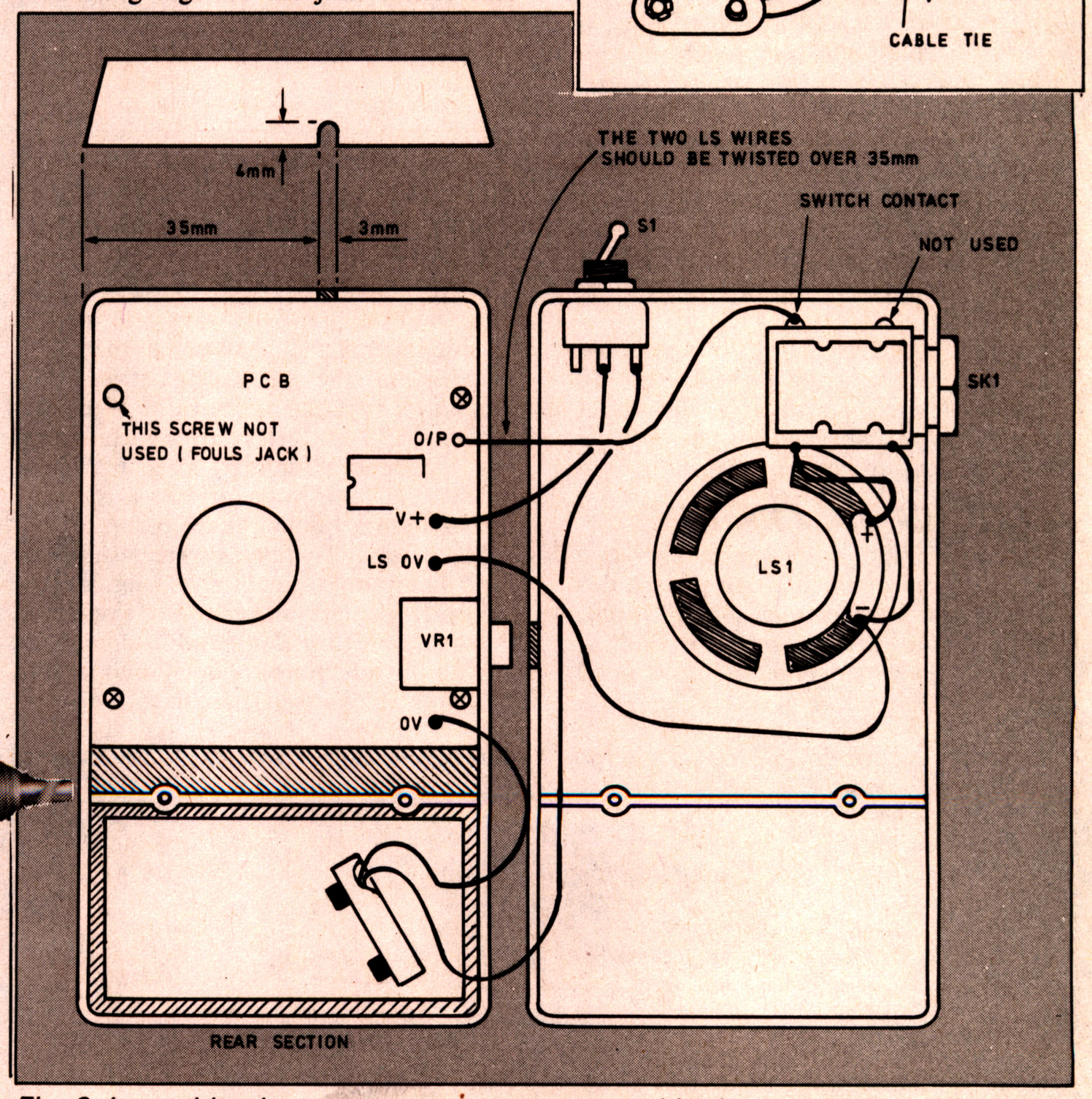


Fig. 6. Interwiring between components mounted in the two sections of the small case. The battery lead is secured to the battery compartment mounting/dividing strut as shown inset.

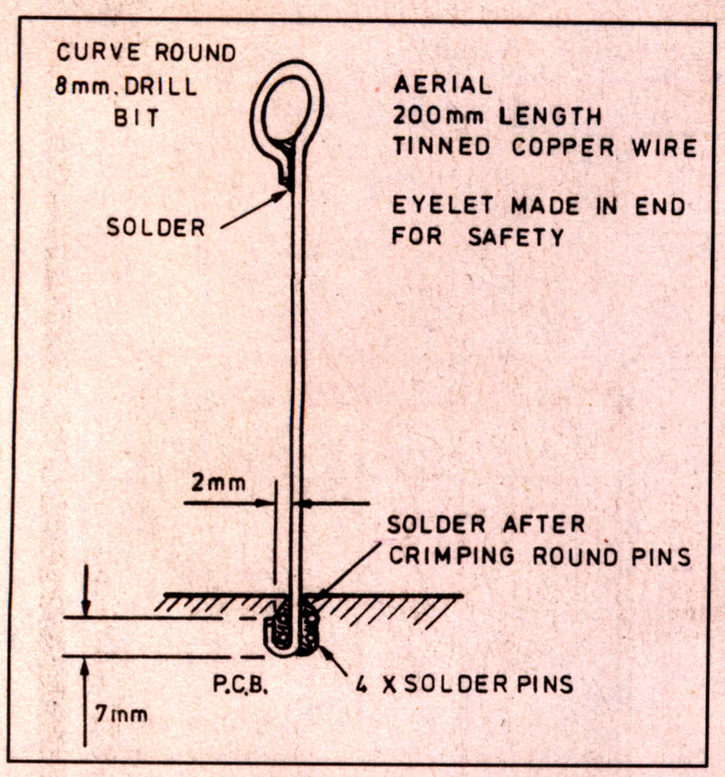


Fig. 7. Construction and mounting of the Pitch aerial.

The aerial is made of 16s.w.g. tinned copper wire and is soldered between four solder pins as illustrated in Fig. 7 and photographs. For maximum strength it is best to insert the pins using a large soldering iron by heating the pin up for a few seconds before firmly pushing it into the board with the bit. Using the standard pin insertion tool does not seem to work with glass fibre boards so the soldering iron technique was found to be the most effective approach.

TESTING

When testing the unit, the most common cause of no output is the oscillators being too far apart in frequency due to component tolerances. It should be possible to adjust VC1 so that the null point or "zero beat" should occur when its plates are half enmeshed.

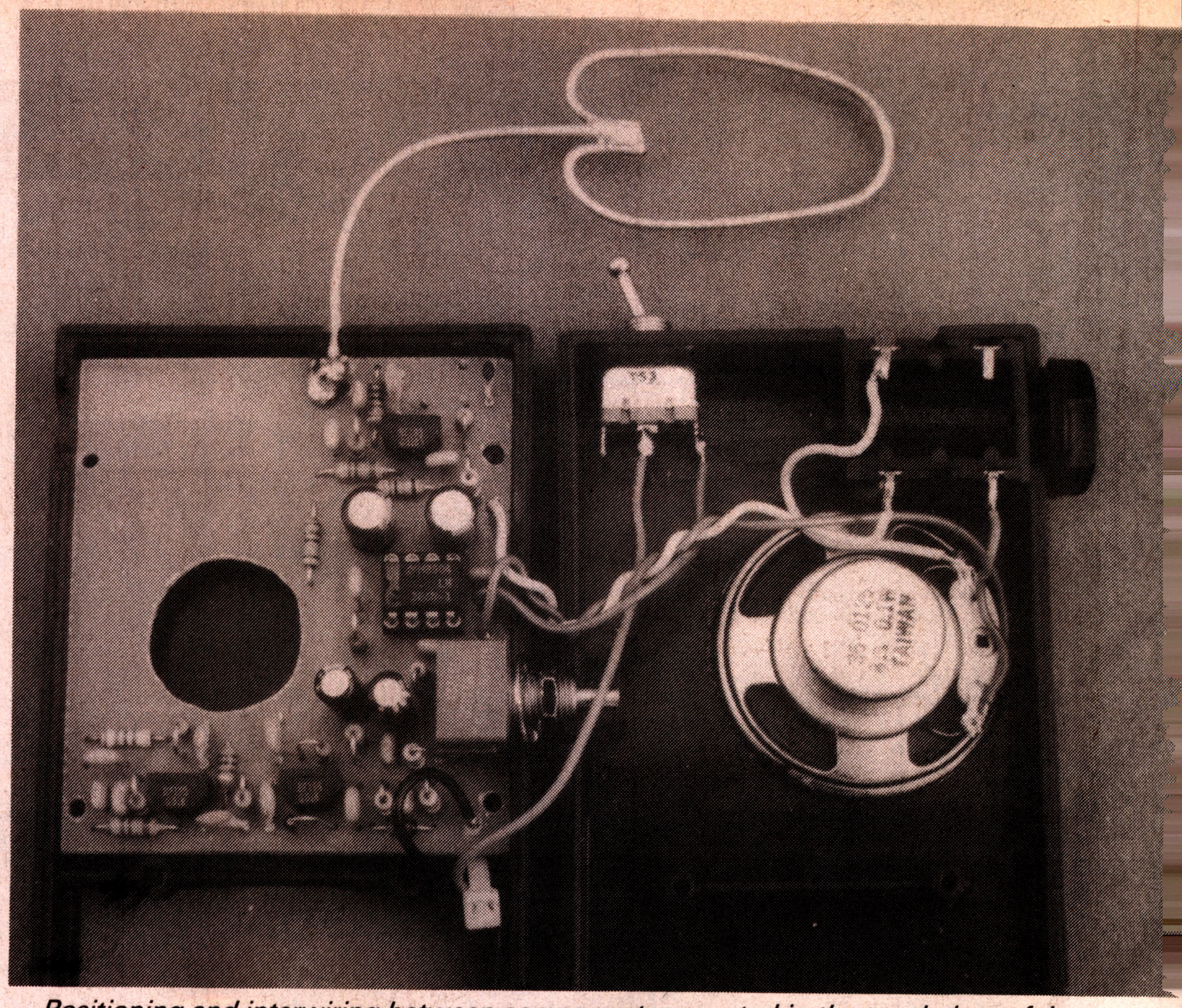
Above the null point the frequency should increase as the hand is brought nearer the "Pitch aerial". Interestingly, at the other side of the null point the frequency goes down. If the oscillator frequencies cannot be brought close enough with VC1 it will be necessary to pad-up either capacitor C10 or C3.

Another cause of zero output is one of the oscillators not oscillating. This is most commonly due to an "open circuit" inductor, incorrect insertion of the transistor or solder bridges.

If available, the oscillator output should be checked with a 'scope probe set to × 10 to provide a degree of isolation. The output should be a good sine wave in the order of a few volts peak-to-peak, see Fig. 8.

AUDIO OUTPUT

The audio output of the simple Theremin should also be a clean sine wave, since this is the standard "Theremin sound". Some circuits have a buzzy sound as a result of harmonics. This can sometimes give good results if sound processing is used.



Positioning and interwiring between components mounted in the two halves of the case. Note the jack socket connecting tags have been bent down.

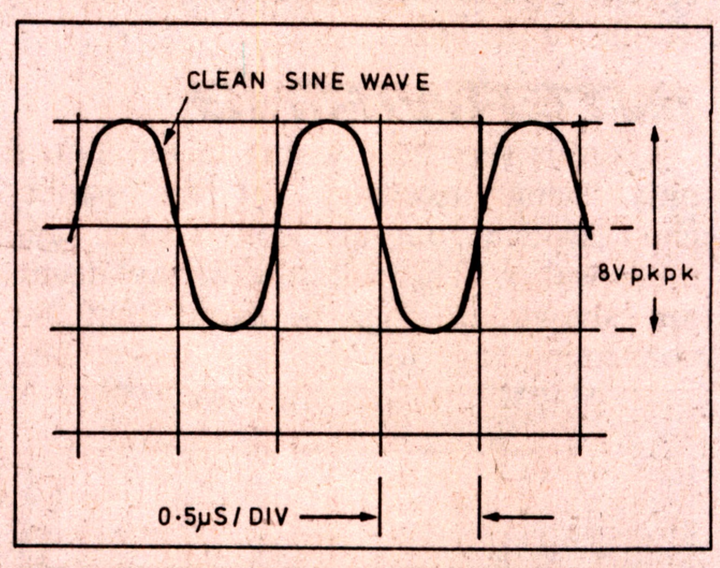


Fig. 8. Oscillator output waveform taken with x10 probe. Voltage may be higher than battery voltage due to resonance.

A harmonically rich sound can be achieved by clipping the waveform by over driving the mixer stage. Another method is to increase the coupling between the oscillators by reducing the value of the mix resistors, R9 and R10, or by encouraging magnetic coupling. This technique produces a ramp waveform as a result of the oscillators "pulling" each other.

The original Theremins were designed to have a harmonic structure very similar to a violin. It is interesting that Leon achieved this by careful tweaking and listening, not having the advantage of oscilloscopes and spectrum analysers in those days.

USING THE THEREMIN

Do not expect to be able to play a tune on the Theremin immediately; they are very hard to play, even making the violin seem easy! One of the reasons for this, is the unusual control law which results in the rate of pitch change rapidly increasing as the hand gets nearer the "aerial".

Secondly, the effective range of the pitch control is only a few inches and thirdly there is no tactile feedback. However, the unit is great for special effects and a tuneful rendition can be obtained if the instrument is sampled.

For loudness control a guitar style volume pedal can be used.

The Theremin will cause slight interference to a.m. radios and will transmit its whistle at the low end of the MW band, where it should cause few problems since there are hardly any stations and the range of the interference is only a few feet.

Traditionally, Theremins are played by moving a hand near the Pitch aerial. However, with the Simple Theremin the unit can be handheld and moved against a fixed conducting object, such as a desk lamp.

Interesting effects can be made when two Theremins are played against each other since they beat together and may also lock when the aerials touch. Having suffered the effects of children having a "Theremin war" it is suggested this is tried in a sound-proofed room! Generally, children love Theremins and they may be of some therapeutic value to the handicapped.

MIDI

Pitch to MIDI converters are now available which greatly extend the possibilities for using Theremins. One advantage is that special software can be employed to make the instrument's control characteristic easier to play, such as by increasing the spacing between notes for example. Theremin manufacturers Longwave Instruments are currently developing a pitch to MIDI converter. □

Playing or "conducting" the Theremin is accomplished by "waving" the hand(s) near the Pitch aerial.

