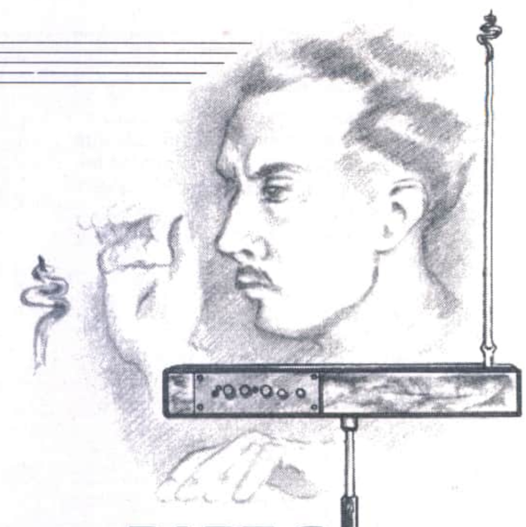
Constructional Project



EPE ELYSIAN THEREMIN WITH MIDI BOX

JAKE ROTHMAN

PART 2

A full specification professional-grade instrument for the serious musicmaker

A BRIEF "potted history" of the Theremin from the early valve designs to the development of our dual, solid-state, version was introduced last month. We conclude this month by undertaking the construction and final "tuning-in".

CIRCUIT BOARD DESIGN

The circuit layout of Theremins is especially critical; after all, a circuit that can detect the capacitance of a hand a couple of feet away is not going to be happy with wires flapping about inside the case and Paxolin stripboard!

The design of the p.c.b. (printed circuit board) for this circuit was beyond the realms of the author's manual tape-up methods and this task was taken up by Adam Fullerton at Rosedene Audio with his skilled use of his CAD system. The topside component overlay, is shown in Fig. 14. This board is available from the *EPE PCB Service*, code 121.

In keeping with modern high frequency practice, large area ground (0V) and power rail (+V) planes are used to maximise screening to avoid spurious r.f. emissions and pickup. Plated-through-holes (p.t.h.) are used to avoid links and enable small pad sizes to be used for compactness, while retaining strength to allow the reliable use of board mounting potentiometers, switches and sockets.

AERIALS

It is essential that the aerial track lengths to the oscillators are as short as possible to maximise the sensitivity. The ground plane was also removed around the oscillator area for the same reason. It is also essential to minimise interaction between the two

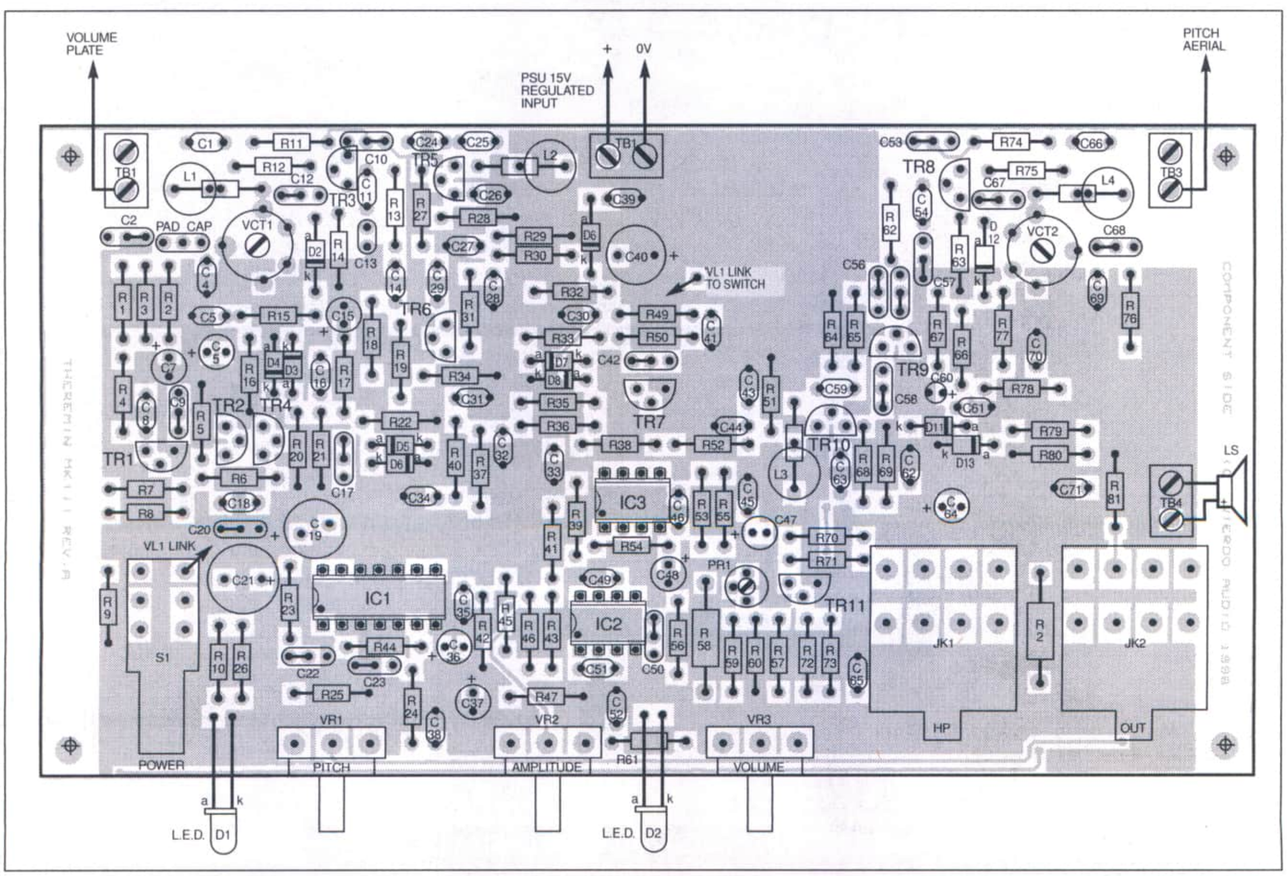


Fig.14. Printed circuit board component layout. This is a double-sided p.t.h. board.

"aerials" by keeping their entry points on the board as far apart as possible.

The way round all these conflicting requirements was to put the two aerial circuits at opposite ends of the board with the low frequency and d.c. circuitry in between. To stop r.f. bleeding into the audio, this section was placed right down at the front of the board to keep it away from the oscillators.

COILS

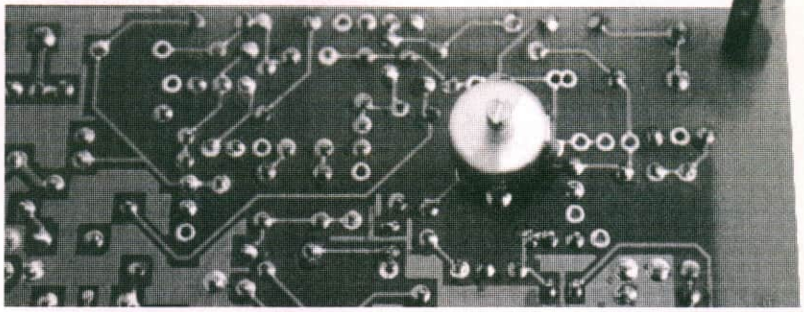
The Pitch oscillator coils are as far apart as practical and at right angles to each other to minimise coupling to put the lock frequency as low down as possible. The Volume oscillator coils, however, are on the same axis to give a degree of coupling. This ensures the oscillators lock at a reasonably high frequency to prevent the volume pulsing, which would occur at very low frequencies.

In common with good analogue design practice, no signals are routed through the front panel rotary pots. only d.c. control voltages. This means that the pots. can be positioned for maximum ergonomic advantage and long tracks used to connect them to their relevant circuit points if necessary. Using d.c. control also enables all the pots. to be the same value and linear, since it is simpler to implement any required law correction in the d.c. domain.

The p.c.b. is fed with a *regulated* d.c. power supply since any a.c., even the ripple on a basic smoothed d.c. supply, will cause modulation hum of the pitch. Another reason for leaving the regulator off the board was that its heat exacerbated problems with thermal drift.

CONSTRUCTION

Normal construction methods apply here, that is insert the components in height order. This means starting with the resistors. It is a good idea to solder the most common values in first (in this case, 14 1kΩ resistors) then move on to the next, since this minimises any errors in placing the more unusual values in place.



One of the trimmer capacitors soldered directly on the underside of the p.c.b.

The main points to watch are: first, it is much harder to remove components soldered in plated-through-holes, so watch out for those darned five-band resistors. A very common mistake with these resistors is to confuse brown and orange colour bands under tungsten or fluorescent light, halogen or daylight has much better colour rendering properties.

Second, l.e.d.s are about the only common components that can still be damaged by heat from soldering. Watch out for the diode pairs, some are pointing in opposite directions on the board, although the silk screened component identification should avoid any confusion here.

Note, all the transistors are BC182Ls which have the collector pin in the middle. BC182s without the **L** suffix will have to be bent round at a funny angle and their use is likely to cause errors.

It is sensible to put the i.c.s in sockets although a degree of heatsinking for the output chip can be obtained by soldering it directly onto the p.c.b. An unusual point to note is that the trimmer capacitors are mounted on the underside of the board since it looks better to have the adjustment holes in the bottom of the case rather than the top (see photograph).

There is one wire link, designated VL1, on the board carrying the power to the On/Off switch S1b. It is best to use a 125mm length of solid-core 1/0·6 red equipment wire. It can also be seen how to install the link from the photo below.

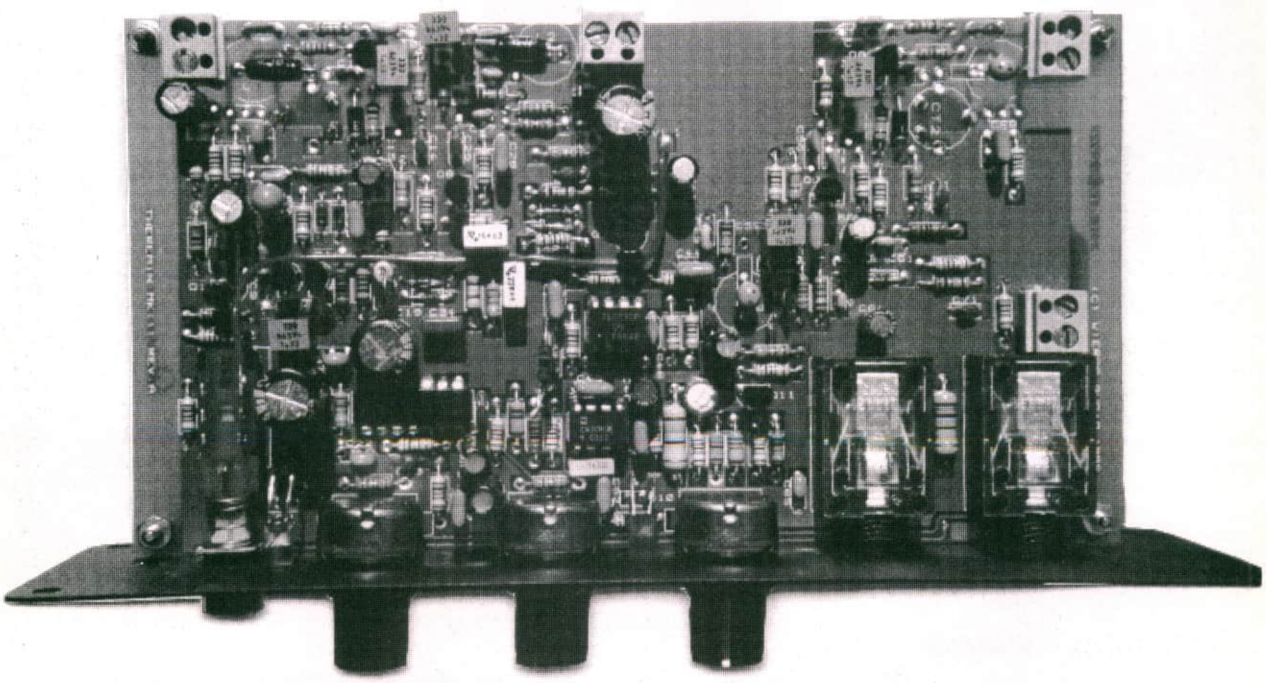
COMPONENTS

Standard wet aluminium electrolytics can be used throughout since they are all fully polarised. The only exception is C6 which should be *tantalum* or other dry type since it is only intermittently polarised.

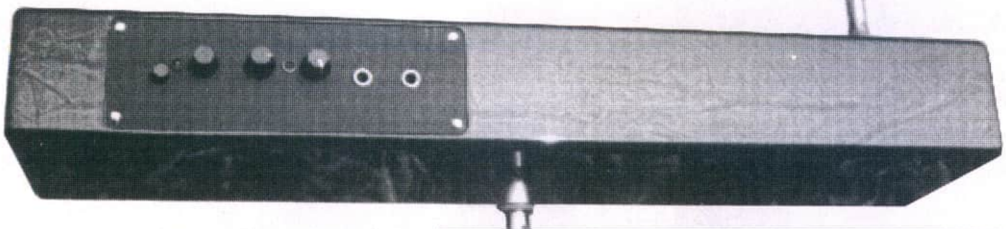
All the non-polarised capacitors are ceramic for their low inductance which makes them effective at bypassing r.f. The only exceptions are C31, C32 and C34 which are polyester and are used for timing of the volume control voltage, where the soakage effect of ceramics cause strange "handing-on" effects.

The p.c.b. is designed to accommodate both 0·1 inch and 0·2 inch non-polarised capacitors by the use of dual mounting holes. Take care that when using 2·5mm types that they are not inadvertently inserted into the two holes which are joined together. Since inductors come in all sorts of sizes, both axial and radial inductors can be used in the coil positions.

A "blue" l.e.d. is specified for D1 since it is in keeping with the mysterious nature of the Theremin. A normal l.e.d. can be substituted if resistor R10 is altered to 220



The completed double-sided, plated-through-hole, circuit board attached to the front panel. Note the power link wire from the push-switch to the board power pad VL1.



TAKE NOTE
Resistor R42 on circuit diagram should be 22k. Resistors R25 and R47 (Components List) should be 330k. VCT1, VCT2 5 to 55p trimmer capacitors and missing from Comp. List.

ohms or so to keep the bias voltage the same.

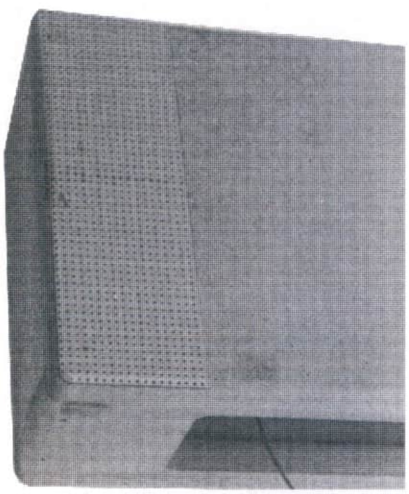
Schottky diodes are used for all the detector stages since their low forward voltage drop and soft turn-on characteristic give maximum output and lowest distortion. Any general purpose Schottky signal type can be used, with the BAT25 being the cheapest. Germanium types could be used but they tend to be less consistent.

Printed circuit board mounting rotary pots. should be used and the Alpha type are the most cost-effective and do not suffer from tag crimp failure like the more common Omeg variety.

The jack sockets are a special commercial type which have a proven contact reliability record in studio jack fields and can be supplied by the author (see *Shop Talk*).

CASE

It is essential that the case be made of some non-conducting material such as wood or plastic. The uses of a metal case would greatly impair the sensitivity of the instrument. If a metal front panel is used it must be "Earthed", better still use a plastic one.



A piece of stripboard glued to one end of the case forms the Volume Plate.

If an earth is needed this can be connected to the spare earth pad on capacitor C28 if a 2·5mm component is installed. A piece of 22s.w.g. tinned copper wire can be used and looped around the bush of the Volume control VR2 to form a contact with the metal front panel.

The standard sort of case used in the model is shown in the photographs. The dimensions are shown in Fig.15. A Volume plate can be produced by using a piece of stripboard (38mm x 115mm).

INTERNAL WIRING

All external connections to the board are made through p.c.b.-mounting connectors (TBs) for ease of installation. It goes without saying that all wire runs must be kept short and glued down along the box corners to avoid shifts in output due to movement.

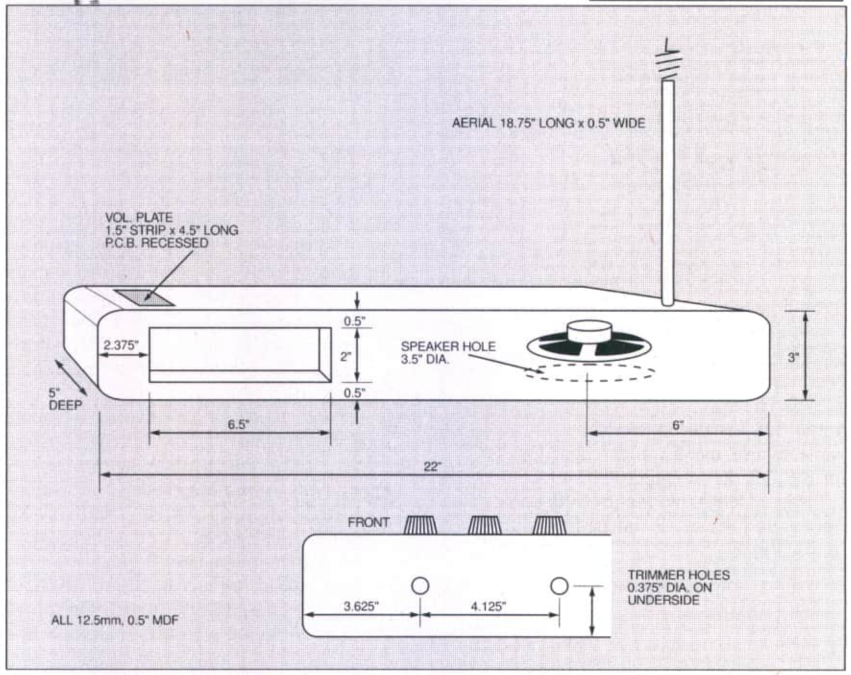


Fig.15. Dimensions and details for the Theremin case.

SPEAKER

Since the output of IC1 is only a couple of watts into 8 ohms there is no point in using a high power hi-fi drive unit. In fact, such units are very insensitive and will not be loud enough.

A 2W paper-cone unit of over 3·5 inch diameter will work fine, low-colouration plastic-cone speakers do not sound as rich as a distorting flimsy paper cone. This is a situation applicable to electric guitar amplifiers as well.

It was found that 8 ohm speakers give best results since the chip gets too hot with 4 ohm and the power output is halved with 15 ohm. To get a louder sound it is worthwhile experimenting with porting the box.

AERIALS

To minimise interaction, the aerials operate in different planes. The Volume Plate is sensitive to vertical motion while the Pitch Aerial is sensitive to horizontal.

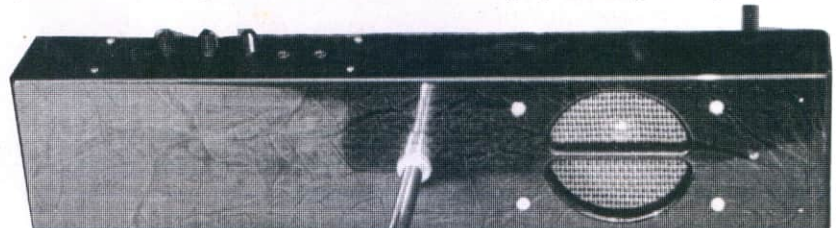
In fact, if the hand is moved up and down near the pitch aerial no change in pitch occurs. It is a common mistake for people new to the Theremin to move their hand vertically and wonder why nothing is happening. How the hands are normally placed while playing the Theremin is shown in last month's article.

The aerial mounting methods are also shown. Note that the wrought iron aerial gives better range than the "Do-It-All" aluminium tube.

ALIGNMENT AND TESTING

Do not expect the Thermin to work first time since there are so many variables and some tests and trimming are always required first.

As usual, the very first tests are the d.c. conditions, power rail, half-rail bias and output amplifier quiescent voltage. The next step is to verify the power amplifier is working by touching the input pin 6 of



Underside of Theremin showing speaker grille.

The speaker is mounted on a piece of board and inserted through the front panel aperture.

IC1 with a screwdriver and listening for hum.

It is essential the aerials be connected for testing or the oscillators will be too far apart in frequency, since the circuit takes into account the aerial capacitance.

The basic method of trimming Theremin circuits is to put the trim control in the middle of its rotational range and tweak the trimmer capacitor for the zero beat point. An insulated trimmer tool, such as the popular yellow Spectrol model, has to be used here. Using a *screwdriver* will cause a large frequency shift.

OSCILLATION

The most common cause of non-functioning Theremins is the oscillators being insufficiently close in frequency to produce an audible tone, making a frequency too high to be heard. In this situation an oscilloscope is essential to verify that the oscillators are working (note the probe must be set to ×10 to isolate the lead capacitance).

To find out which way the oscillators must be pushed in frequency, it is possible to use the trimmer capacitors VCT1 or VCT2 as a guide. If a faint high whistle is detectable (vanes fully enmeshed) more capacitance is needed on the fixed oscillator.

If this is not the case, it will be necessary to apply padder capacitors in turn to each oscillator. It is not effective holding the capacitors by hand or piers, it is essential to apply them by insulated means. The author has a collection of small two per cent ceramic plate capacitors from 4·7pF to 47pF glued into old Biro tubes for this purpose. If extra padder capacitors are needed they are fitted in positions C68 and C3.

It is sensible to get the Pitch oscillators (Fig. 10, last month) set up first before worrying about the volume side. While doing this the Theremin can be listened to by monitoring the continuous pitch output. Headphones can be used if desired.

VOLUME PLATE

Once the pitch side is working, attention can be focused on the Volume Plate. This is adjusted like the Pitch aerial in that the trim control is placed in the middle, and the trimmer capacitor is tuned to the zero beat point. It's a good idea to check the square wave at the collector of TR4 at this point.

The preset VR4 is used to trim out any variations in the turning-on point of the 3080 (IC2). To set it up, turn VR4 fully anti-clockwise and put the volume control VR3 at minimum.

While placing a hand near the Volume Plate, ensure the Orange l.e.d. D10 is on. There will be a point where the volume will just begin to come on as preset VR4 is turned clockwise. This sets the minimum volume for the Theremin and minimises any dead-band on the volume control.

CIRCUIT TWEAKS

Theremin circuits are generally very interactive and sensitive to component values and this circuit is no exception. Some much more complex designs can avoid this by buffering between every stage, but this will double the component count.

However, interactive circuits can be extensively "tweaked" (if time is available) to give synergistic effects that can make them very cost effective.

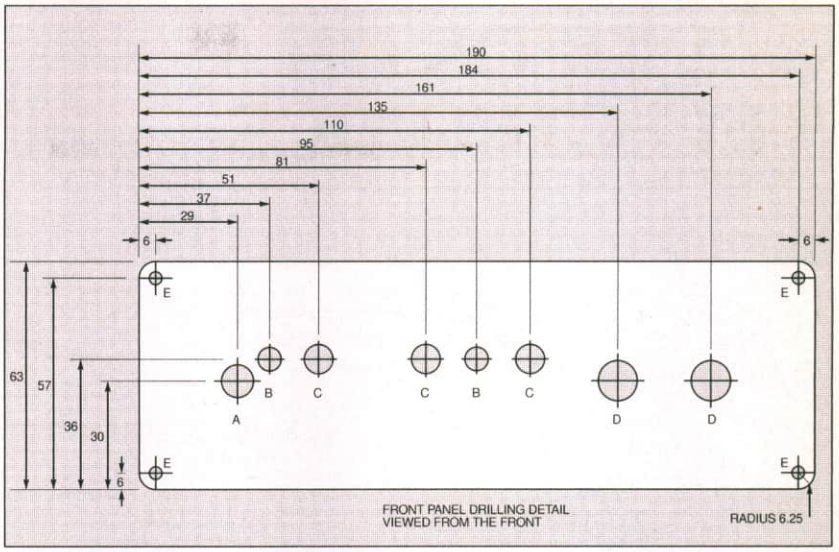


Fig.16. Control mounting front panel drilling details and measurements.

FREQUENCY RESPONSE

The audio frequency response of the Theremin rolls-off at approximately 6dB/oct from about 100Hz. This is to compensate for the small loudspeaker used in the box, the increased sensitivity of the ear at mid-range frequencies and as a consequence of the r.f. filtering.

It is possible to engineer a flatter response by lacing a top-boost filter network consisting of a 15nF capacitor and a 13k resistor, in series, placed in parallel with resistor R41. Note that R41 must be increased to 39k to compensate for the network if fitted.

The Theremin MIDI unit (starting Jan'97 issue) works better with a flat frequency response, this can be done by adding a network consisting of a 6n8 capacitor and a 3k3 resistor in parallel with the lower arm feedback resistor (R54) of the op.amp IC3.

AERIAL RANGE

It is possible to extend the range of the aerials by inserting loading coils in series. Around 4·3mH seems to give optimum improvement of the pitch range. Unfortunately, such coils need to be of very low self-capacitance and standard types do not work.

Wave-wound multi-sectioned types similar to the radio frequency chokes (r.f.c.s) used by radio constructors, which were available in the past, work. It may be possible to try old Repanco CH2 5mH types, *if they can still be found.* Old long-wave radio ferrite rod aerial coils may also work.

TEMPERATURE COMPENSATION

The circuit as it stands is sensitive to temperature variations and needs to be left on for some time to warm up and achieve stability. Obvious considerations have been taken into account such as keeping the oscillators away from components emitting heat. Also, the capacitors used in the oscillators have been specified to have a *negative* temperature coefficient to partly cancel the positive temperature coefficient of the coils.

However, there are thermal drifts due to the board material, resistors and the internal capacitances of the transistors themselves. By using special r.f. transistors, where the capacitances are predictable and specified, in place of the ubiquitous BC182s, stability could be improved. It is possible to obtain ceramic plate capacitors with quite high negative temperature coefficients of 750 ppm (denoted by a purple band across the top on the Philips types) and these could be used to provide compensation.

CRYSTAL CONTROL

By replacing the fixed oscillators with crystal controlled types, stability could be greatly enhanced at increased cost. However, there is the problem of obtaining pure sine waves using crystals, most crystal oscillators produce squarewaves.

DIGITAL THEREMINS

Some attempts have been made to apply digital techniques to the Theremin. One idea of the author's is to run the basic Theremin circuit at a much higher frequency then divide it down digitally to get a greater range.

Microprocessor control could also be used to provide feedback control to enforce stability in all situations. The question is, once one is far removed from the two r.f. sinewave oscillators beating together, is it a Theremin anymore?

SOUND CHANGES

Since volume and pitch are voltage controlled it is a simple matter to add Tremolo and Vibrato if required by driving the "varicap diodes" with low frequency oscillators (l.f.o.s). Reverb greatly improves the sound, and the old Springline Units work very well in this application, since high bandwidth and good transient capability are not required. Extra harmonics can be added by diode clipper fuzz boxes and the like followed by a parametric equaliser.

Of course, to get the widest range of sounds the Theremin signals have to be converted to MIDI/CV so that any synthesizer can be driven. This can be accomplished by using Adam Fullerton's MIDI/CV Box starting next month. □