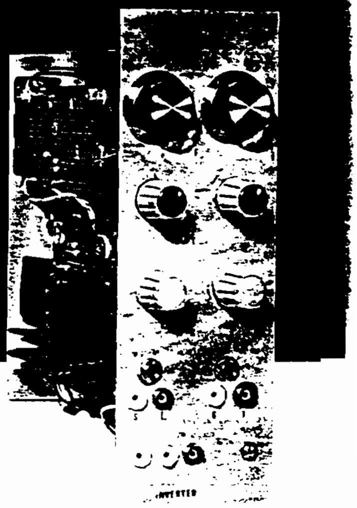
PE Sound Synthesiser 3
VOLTAGE CONTROLLED OSCILLATORS and INVERTER

By G.D.SHAW



THIS month the voltage controlled oscillator and voltage inverter will be described as well as details for assembling them.

THE VOLTAGE CONTROLLED OSCILLATOR

Perhaps the most important reason for the employment of a voltage controlled oscillator lies in the resultant ability of the oscillator to produce tone patterns by application of varying voltages to its control input. If these voltages are derived from what is essentially another oscillator, or series of oscillators, running at ultra low frequency, then the performance of the tone generating oscillator becomes quite automatic and dependent only on the continued operation of the programming devices.

The oscillators in the Synthesiser are based on the operational linear integrator and the circuit is shown in Fig. 3.1. In this arrangement IC1 acts as the integrator while IC2 is connected as a comparator and serves to switch the direction of integration.

The integrator programming signal is applied across the diode bridge D1–D4 and it is important that the polarities are maintained as shown.

CIRCUIT ACTION

To describe the circuit action assume that the comparator is sitting at its positive saturation level then diodes D1 and D3 in the integrator input bridge are reverse biased. There is a current flow into the integrator summing junction through R1, D2 and similarly a current flow away from the bridge through D4, R2, shown by solid arrows, so that the integrator begins to ramp negatively. The negative excursion of the integrator output voltage will continue until the current driven through R5 is equal to or greater than the current driven through R4 as a result of the output voltage of the comparator. At this time the voltage at point *P* will go negative and the comparator will switch rapidly to its negative saturation level.

Under these conditions diodes D2 and D4 in the integrator input bridge are reverse biased and current flows are established as shown by the dotted arrows. In the case of the current flow away from the integrator summing junction, this causes the integrator to ramp positively.

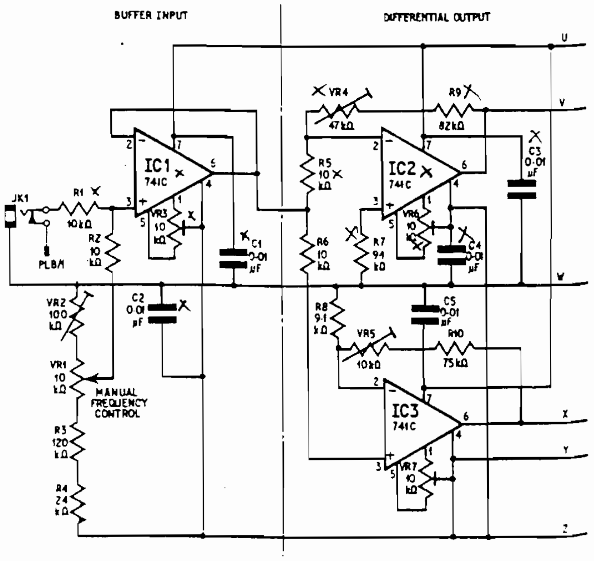
WAVESHAPES DEVELOPED

Providing that R2 is the same value as R1 and both polarities across the input bridge are at the same potential then the rate of change of integrator output voltage is the same as before and the result is a symmetrical triangular waveform appearing at point *Q*. The oscillogram of Fig. 3.1 shows the phase relationship between the triangular waveform generated by the integrator and the switching waveform generated by the comparator at point *R* in the circuit.

When the integrator output voltage is again equal to or greater than the level of positive feedback set by R4 the comparator switches back to its positive saturation level and the cycle repeats.

FREQUENCY CONTROL

Consideration of the foregoing reveals that R4 actually plays a part in the determination of fre-



quency by setting the point at which the integrator output causes the comparator to switch.

Lowering the value of this component has the effect of increasing the level of positive feedback to the comparator thereby requiring a higher integrator output voltage to switch the comparator and thus lowering the frequency of operation of the integrator..

Conversely, if the value of R4 is increased the overall frequency of operation is also increased.

PRACTICAL V.C.O.

The circuit shown in Fig. 3.2 is the three stage prototype v.c.o. arrangement. Starting from the output end, the third stage is a practical form of the oscillator shown schematically in Fig. 3.1. The second stage consists of two operational amplifiers arranged to provide a differential output across the oscillator input bridge. This particular stage is necessary since, in order to attain the full frequency range, the oscillator requires a drive potential greater than the individual power supply rails can provide.

The first stage of the circuit is a buffer follower which serves to reduce the current drive required from the control source and which also provides a test-bed on which to try out various forms of circuit response without the necessity of disturbing the settings of the oscillator and differential driver. The type of input stage used in the v.c.o. is of some importance since it has a bearing, not only on the performance of the oscillator as a whole, but also on the design and operation of other circuits in the synthesiser. The response of the input stage may therefore be either linear or logarithmic and there are advantages and disadvantages attached to both methods.

LOGARITHMIC OSCILLATORS

Most commercially available synthesisers use logarithmic v.c.o.s in which the slope of the response

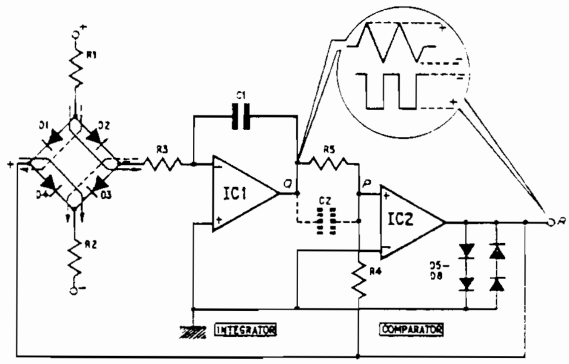


Fig. 3.1. Basic voltage controlled oscillator. Oscillogram snows phase relation between integrator and comparator outputs. The inclusion of the capacitor shown dotted linearises the input voltage/frequency relationship.

is adjusted so that equal increments of input voltage raise the frequency of oscillation by one semitone.

A typical response curve is shown in Fig. 3.3. This has the distinct advantage that if, say, three oscillators are programmed simultaneously by the same control voltage, two of the oscillators may be manually offset by fixed multiples of the semitonal voltage increment so that the effect of the mixed oscillator output is that of producing a chord by the depression of only one key.

The arrangement of having equal voltage increments per semitone also allows for a simplification in the construction of the keyboard divider network and some commercial instruments use a series chain of equal value resistors with a form of "tuning" control which varies the voltage across the chain.

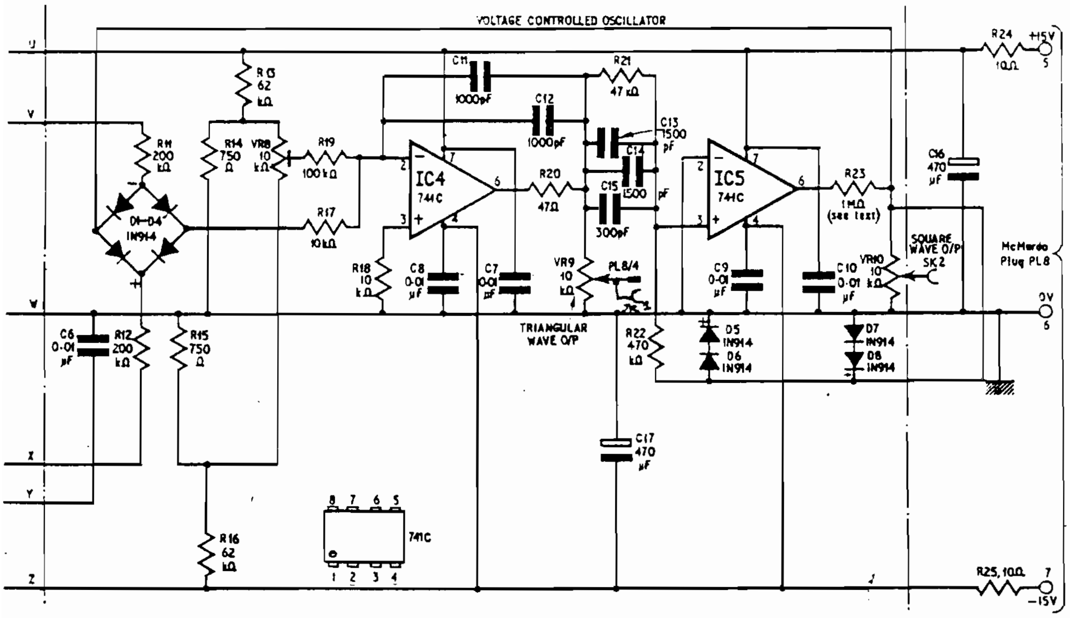


Fig. 3.2. Circuit diagram of the three stage voltage controlled oscillator

LINEAR V.C.O.'s COMPARED

The oscillators in this Synthesiser are arranged with an input stage having a linear performance such that the overall response is as shown in Fig. 3.4.

The resulting loss of the ability to play "chords" was not considered a disadvantage when weighed against the advantages of simplification in building and setting up. Furthermore, the use of linear characteristics in the oscillators provides greater justification for the use of a parallel divider network in the keyboard which, although rather more complex than the series arrangement, means that the accuracy of each semitone is dependent only on the accuracy and stability of its own resistors and not upon the remainder of the chain.

The overall performance of the oscillator, however, is solely dependent upon the response characteristic of the buffer/follower stage and it will be noted that space has been left on circuit board B (Fig. 3.6) for the benefit of constructors who may wish to try out their own ideas of logarithmic response.

The SN76502 manufactured by Texas Instruments is a logarithmic amplifier in integrated circuit form.

MAJOR COMPONENTS

The estimated total cost of this project is around £200. Obviously this figure can be reduced if bulk purchase of components which will appear in quantity is made. To make this possible, components in excess of 12 are listed below.

Resistors	**Quantity**
10kΩ	52
33kΩ	12
All 5% ½ watt carbon	
5·1kΩ	13
7·5kΩ	36
10kΩ	15
All 2% ½ watt metal oxide	
Potentiometers	**Quantity**
10kΩ carbon linear	19
All 25mm dia. midget moulded carbon types	
10kΩ carbon linear horizontal presets	12
100Ω linear horizontal Cermet presets	53
10kΩ linear horizontal Cermet presets	21
Integrated Circuits	**Quantity**
741C 8 pin D.I.L.	56
Diodes	**Quantity**
1N914	39
1SJ50	14
Capacitors	**Quantity**
470µF elect. 25V	12
0·01µF polyester	46
Sockets	**Quantity**
3·5mm miniature jack sockets	15
2mm miniature sockets	48

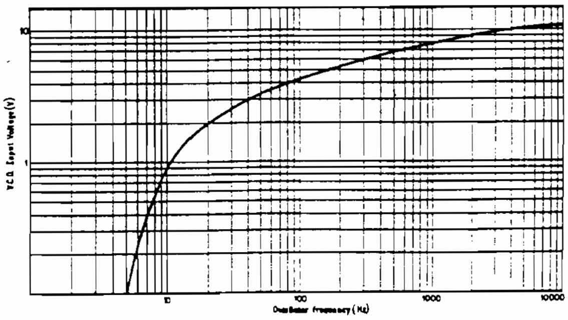


Fig. 3.3. Logarithmic response curve showing the positive exponential relationship obtained when control voltage required is IV/octave

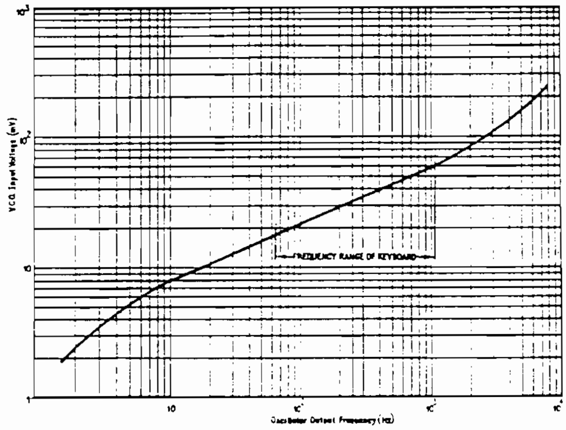


Fig. 3.4. Linear response curve of v.c.o. showing frequency range of keyboard

The advantage of this device is that its response slope may be varied by adjustment of one external component so that performance matching becomes a relatively simple matter.

BUILDING THE OSCILLATOR

Due to the restricted space in the finished module construction should start by assembly and wiring of all the components on to the front panel before the panel is mounted to the circuit board support plate. Figs. 3.5 and 3.6 give the front panel drilling details and component layout. The leads from the controls should be formed into a harness which passes down the centre of the panel between the potentiometers as shown, those for routing to the circuit boards being about ten inches long.

Next mount the McMurdo plug to the rear of the circuit board support plate complete with its wire leads already soldered into position. Fit the eight stand-off supports to the plate—transipillars are recommended but six B.A. screws with metallic spacers may be used providing that these are isolated from the conducting strips on the circuit boards.

The front panel should now be fixed to the circuit board support plate using a 4B.A. countersunk screw and nut in the upper hole, and the locking rod and bush in the lower one. If the assembly seems to be

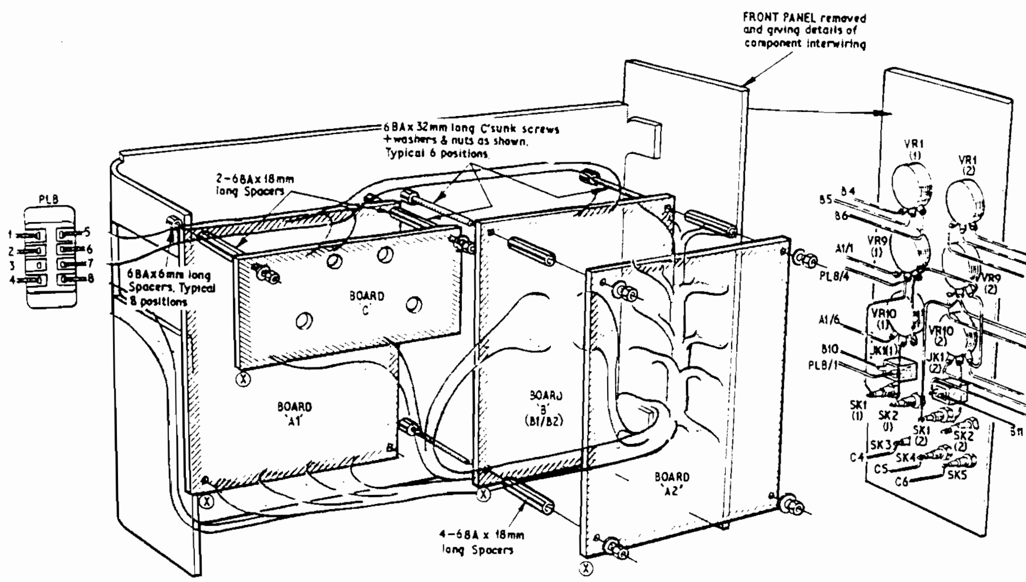


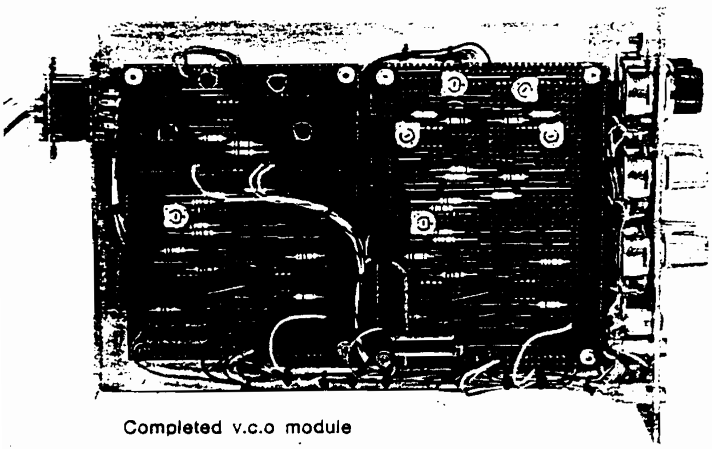
Fig. 3.5. Front panel component assembly and wiring with details of mounting and disposition of boards on the module support plate. The small ringed X at the board edges indicates orientation. (See board details)

on the slack side this may be corrected by fitting a thin steel washer between the bush and lug on the circuit board support plate.

It is useful, at this stage, to make up a jumper lead carrying power supplies from the main busbars so that modules may be tested and set up outside the main frame assembly. The lead should be about 24in (61 cms) in length terminated at one end by a McMurdo plug and at the other by a McMurdo socket wired to match the power supply outputs.

Figs. 3.7 and 3.8 show the circuit board layouts for the oscillator. Board A carries the differential output stage together with the oscillator itself and two of these boards are required.

Board B carries the buffer input stages and power supply decoupling stages for both the other boards.



Completed v.c.o module

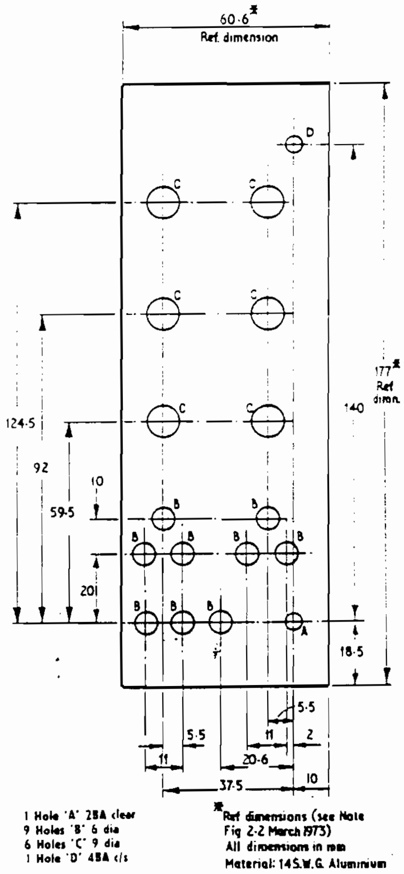


Fig. 3.6. Drilling details for v.c.o. module front panel

BOARD B

The next stage of construction covers assembly of the buffer input stage and power supply decoupling Board B./ Fig. 3.7 shows the recommended layout. Wiring of the completed board into the support frame is simplified if single ended Veropins are inserted into the boards at the indicated positions of the lead out wires.

Mount Board B to the support plate adjacent to the front panel and couple up the leads to the power supply, VR1 (manual frequency control) and external input sockets. The leads to Boards A may be omitted at this stage.

COMPONENTS . . .

VOLTAGE CONTROLLED OSCILLATOR (2 REQUIRED)

Resistors

R1	10kΩ	R13	62kΩ
R2	10kΩ	R14	750Ω
R3	120kΩ	R15	750Ω
R4	24kΩ	R16	62kΩ
R5	10kΩ	R17	10kΩ
R6	10kΩ	R18	10kΩ
R7	9·1kΩ	R19	100kΩ
R8	9·1kΩ	R20	47Ω
R9	82kΩ	R21	47kΩ
R10	75kΩ	R22	470kΩ
R11	200kΩ	R23	1MΩ (see text)
R12	200kΩ	R24–R25	10Ω (2 off)

All 2% ½ watt metal oxide

Capacitors

C1–C10 0·01μF Polyester (10 off)
C11–C12 1,000pF Silver Mica (2 off)
C13–C14 1,500pF Silver Mica (2 off)
C15 300pF Silver Mica
C16–C17 470μF elect. 25V (2 off)

Diodes

D1–D8 1N914 (8 off)

Potentiometers

VR1 10kΩ carbon log
VR2 100Ω horizontal preset
VR3 10kΩ horizontal preset
VR4 47kΩ horizontal preset
VR5 10kΩ horizontal preset
VR6 10kΩ horizontal preset
VR7 10kΩ horizontal preset
VR8 10kΩ horizontal preset
(VR2–VR8: miniature cermet types)
VR9 10kΩ midget moulded carbon linear
VR10 10kΩ midget moulded carbon linear

Integrated Circuits

IC1–IC5 741C 8 pin dual-in-line (5 off)

Miscellaneous

SK1—3·5mm jack socket, SK2–SK3 2mm miniature socket (2 off) 0·1in matrix Veroboards as required.

CHECK-OUT

Set VR3 to mid position and VR2 to the minimum position and attach the jumper lead. With the power supply switched on and VR1 at minimum position measure the voltage at VR1 wiper. Adjust VR2 on both drivers so that voltages are exactly the same.

The value is not critical at this stage but is preferably in the range −5mV to −10mV. Measure the output voltage of both drivers and adjust VR3 until it is equal to whatever voltage has been set on the wipers of VR1.

Connect a temporary link between the external input and ground on both drivers. The purpose of these links is to simulate a zero-voltage prewired programming connection and they will be removed on completion of the setting up of the oscillators. Finally, set VR1 to its maximum position and measure the voltage at the sliders. This should be about −750mV, depending on the actual potential of the power supply rails, any discrepancy between the two readings being corrected by adjustment of the values of R3 and/or R4.

BOARD A: ASSEMBLY AND CHECK-OUT

Assembly of Board A should commence with the differential output stage which should be constructed up to and including R11 and R12. This stage should now be set up before proceeding with the construction of the oscillator.

Make temporary power supply connections from Board B, attach an input lead to the differential output stage and connect this directly to ground. With VR4 and VR5 at their maximum settings and VR6 and VR7 at their mid positions switch on.

Monitor the output voltages of both halves of the stage and adjust VR6 so that the output of IC2 reads +5mV and VR7 so that the output of IC3 reads −5mV. Now reconnect the input of the differential stage to the output of the driver from which the power supply is being taken and set the output voltage of the driver to −25mV by means of VR1.

Monitor the outputs of IC2 and IC3 and adjust VR4 and VR5 until these read +255mV and −255mV respectively. Repeat the measurements at various settings of VR1 to ensure that the gain of each half of the stage is linear at × 10 throughout the working range. Remember that the actual readings should be, in the case of IC2, + [5mV + (10 × driver output voltage)] and in the case of IC3, − [5mV + (10 × driver output voltage)].

Having set the gain and offset of the differential output stage the assembly of the oscillator section may now be completed (Fig. 3.8).

CHOICE OF CAPACITOR

The type of capacitor used in the integrator is of some importance as far as frequency stability is concerned and it is best to use a type having low leakage and as low a value of inductance as possible. Silver mica is thus the best choice and the value shown may be made up of two or more parallel wired capacitors.

R23 serves to limit the current output of the comparator. With this omitted the comparator has only the forward resistance of D5–8 between its output and ground and, although IC5 is capable of handling the current involved, this means that a substantial ripple will be present on the oscillator power supply rails and could possibly be transmitted through to

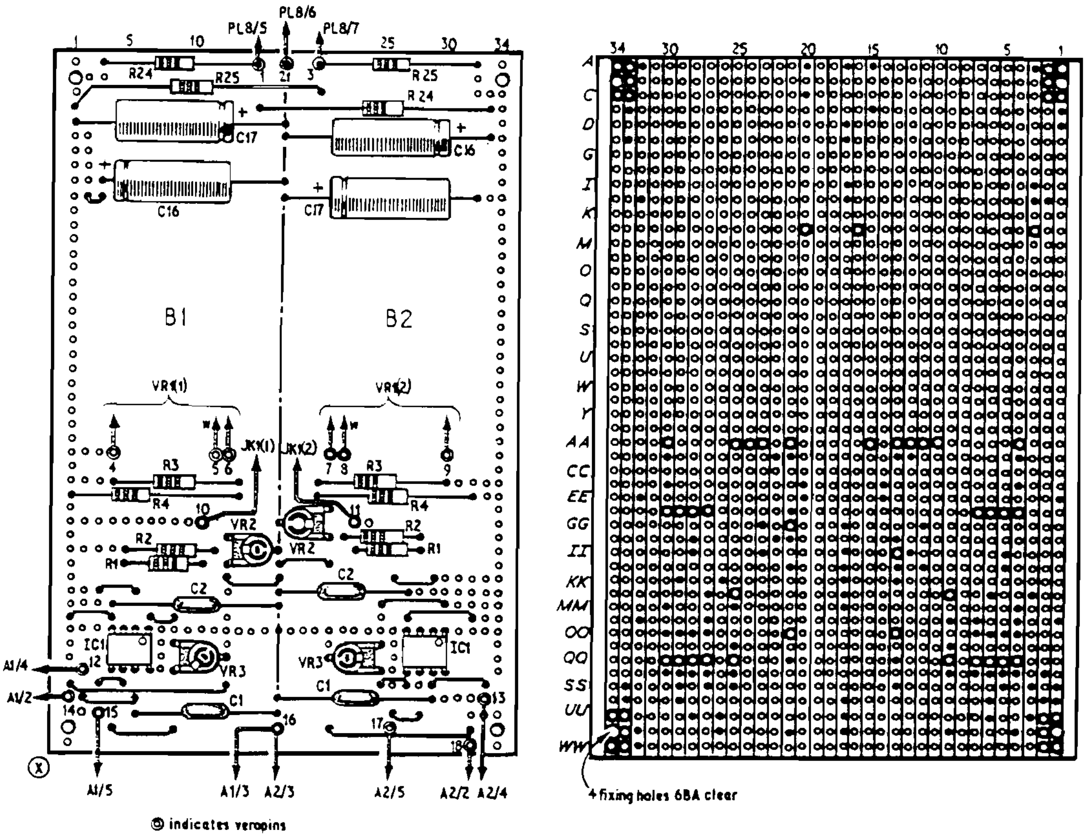


Fig. 3.7. Component layout and wiring for Board B. Since two v.c.o.'s are required, components for each are arranged in board areas B1 and B2

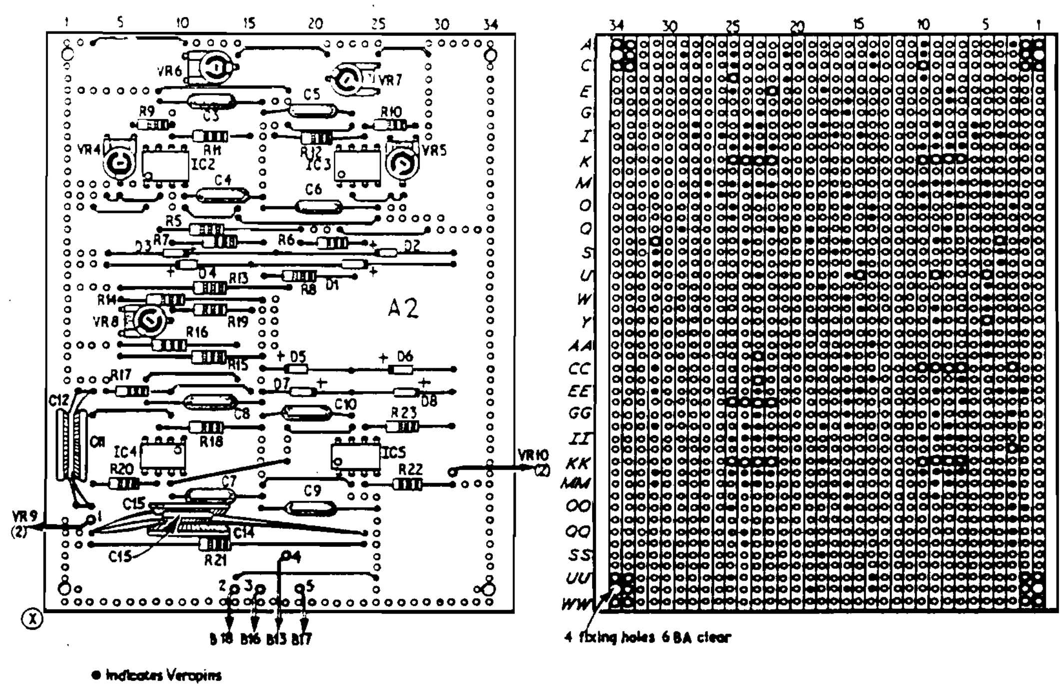


Fig. 3.8. Component layout and wiring for Board A. Two of these are required as shown in Fig. 3.5

the main bus-bars. Thus, where it is intended to use the comparator square wave output as a signal source the value of R23 should be 2·2 kilohms, that is, sufficient to reduce the ripple to an acceptable level. When the square wave output is not to be used, such as in the keyboard oscillators, the value may be increased to 1 Megohm to reduce ripple to negligible proportions. The inclusion of this resistor will however reduce the triangular wave voltage swing to 200mV p-p and limit the maximum frequency of the oscillator to about 8·3kHz.

R13 to R16 and VR8 form a divider network which provides a value of bias current to the summing junction of the integrator.

MOUNTING THE A AND B BOARDS

The completed A boards should be mounted on the support plate such that one is immediately

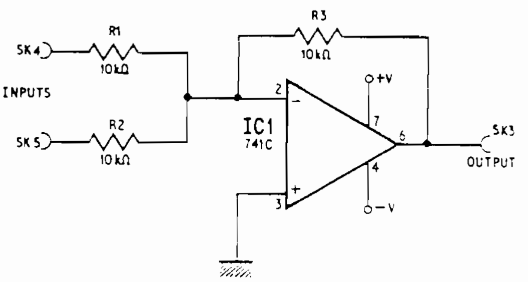


Fig. 3.9. Circuit diagram of voltage inverter

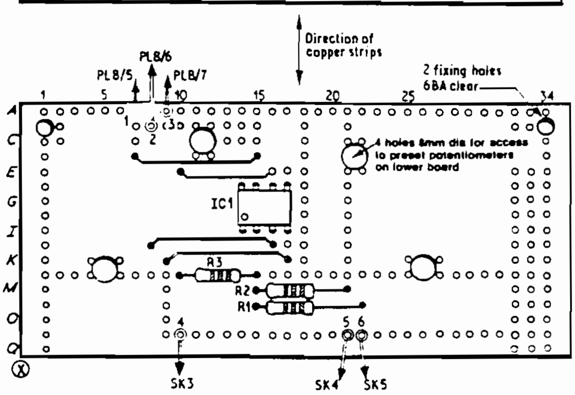
COMPONENTS . . .

INVERTER

Resistors
R1–R3 10kΩ (3 off)

Integrated Circuit
IC1—741C 8 pin D.I.L.

Miscellaneous
SK1–SK3 2mm miniature sockets (3 off) 0·1in matrix Veroboard as required



Copper strips broken at holes G14, 15, 16, 17

Fig. 3.10. Inverter component Board C layout and wiring

adjacent to the McMurdo plug and the other directly above Board B. It is best to mount and set-up the oscillator boards one at a time. When a board has been fully connected, set VR8 and VR1 to their mid positions and switch on the power supply. Observe the triangular waveform on the oscilloscope—the frequency of oscillation should be about 7kHz.

Gradually reduce the setting of VR1 until the waveform begins to exhibit marked signs of assymmetry. At this point adjust the setting of VR8 *with great care* to restore the symmetry, this latter operation also being seen to cause an increase in the frequency.

Continue reducing the setting of VR1, adjusting VR8 as necessary, until VR1 is at its minimum setting and the output waveform is symmetrical.

At very low frequencies the setting of VR8 is extremely critical, too large a shift in either direction causing IC4 to saturate. If this happens, VR1 should be set to its mid position again and the various steps repeated.

With VR1 in its minimum position final setting of the very low frequency end of the range is accomplished by adjustment of VR2 in conjunction with VR8 as before. If IC4 saturates at or before minimum setting of VR1 the setting of VR2 will have to be increased.

Very low frequency instability can be a problem with this type of oscillator and although it can be made to operate at less than 1Hz with the component values given it is best to set the minimum operating frequency to about 5Hz.

MATCHING THE OSCILLATORS

If the component values and tolerances specified have been adhered to, comparison of performance between both oscillators will show that the input voltage/frequency relationship is substantially similar, any differences in performance characteristic being due to tolerance variations in the components.

Extreme accuracy in the matching of oscillators is not necessary since linear response is involved.

INVERTER

Little need be said concerning the assembly of the voltage inverter which is essentially an inverting unity gain amplifier of the simplest kind. The circuit is shown in Fig. 3.9 while the recommended circuit board layout is shown in Fig. 3.10.

The completed board should be mounted directly over the A board furthest from the front panel.

USING THE MODULE

On completion of the whole module use the voltage inverter to investigate the effects of mixing triangular and square waves at varying frequencies.

The output may be fed to the high level input of most power amplifiers, but bear in mind that the output will be equal to the sum of the voltage swings at the inputs.

Additionally it is possible to carry out some simple experiments in frequency modulation by setting one of the oscillators to modulate the other. A low amplitude modulation at about 7Hz produces a true vibrato to the tone of the modulated oscillator whilst varying the amplitude and frequency of modulation can produce some strange, even bizarre effects.

Next month: the ramp generators and input amplifiers are described.