MODULE 2: VCO

The VCO is based on the CEM 3340 IC produced by Curtis Electromusic Specialities and specifically designed for music applications. Figure 3 shows the block diagram of the device which is packaged in standard 16-pin DIL form. It provides the exponential law required for music, that is, a doubling of the frequency for a fixed increment of input control voltage, which for this project has been set at one volt per octave. The design provides excellent conformity to the exponential response from less than 10 Hz to over 16 kHz.

The CEM 3340 has triangle, sawtooth and pulse outputs. In the design presented a sine wave has been generated from the triangle output. The outputs are 0 to 10 V in amplitude which facilitates their use as control signals. Additionally, the triangle and sine waveforms are provided at ±5 V amplitude and are directly suitable for modulation applications. The duty cycle of the pulse output can be varied from 0 to 100%, either manually or by external voltage control. A linear frequency modulation input with a 10% change in frequency per volt is also included.

The IC allows three methods of synchronising the oscillator which provides an exceptional range of modulation and harmonic locking effects.

The circuit is shown in Figure 4.

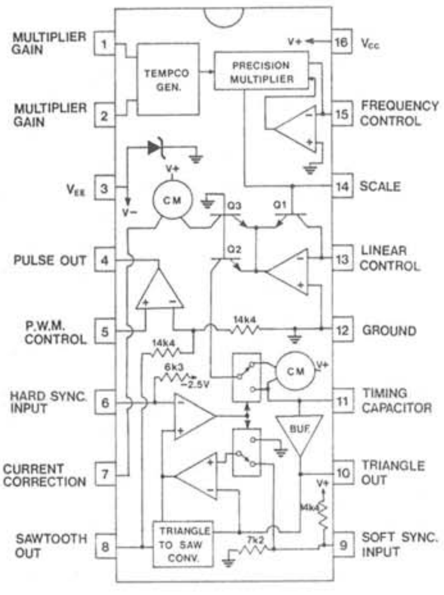


Fig. 3. Block diagram of CEM 3340 VCO chip.

Construction

Construction is straightforward and the component layout on the printed circuit board is shown in Figure 5. It is essential to use the components specified if the accuracy and stability of the design is to be realised. All jack sockets and potentiometers should be wired up except for the wiper of the fine control (RV2). Neat and short wiring reduces the likelihood of crosstalk and all inputs and outputs are provided at the front edge of the PCB to avoid excessive wire length. The PCB will fit the mounting lugs in a Teko Alba A23 case. It may also be mounted to the 228 x 76 mm panel with proprietary brackets or L-brackets. If the latter are used a 12.5 mm spacer between the panel and the bracket is recommended since this provides adequate space for the wires.

When all components have been installed carefully check their placement and orientation and also inspect the underside of the board to ensure that no solder bridges have been made. Before inserting the IC it is good practice to connect the board to the power supply and check that power is available at the correct points in the circuit and this is simplified by using IC sockets. If this step is satisfactory then disconnect power before inserting the IC.

A final check before calibration is to ensure that all outputs are functioning. Connect the 0 – 10 V triangle to an oscilloscope or amplifier (turn volume control nearly off) and then power up the circuit. If there is no response then switch off immediately and repeat the checking procedure. If functioning then check the other outputs although remember that the sine waveform has not been trimmed at this time.

Calibration

Set all trimmers to their mid positon.

The first step is to adjust the sinewave output. With an oscilloscope, or by ear via an amplifier, adjust TP 4 then TP 5 for purest sine output. These adjustments may have to be repeated a few times to obtain the best results. Next adjust TP 6 to get the 10 V output referenced to ground. The simplest method is using an oscilloscope, but it can be trimmed using another VCO. If the latter technique is used, set the other VCO to about 1 kHz and the frequency of the VCO being calibrated at a low frequency (coarse control switch on and RV1 fully anti-clockwise). The sinewave output is then plugged into the other VCO and TP 6 adjusted until there is no discernible jump in frequency.

The last and most important step is to calibrate the oscillator to the 1V/octave relationship. The easiest method requires a variable voltage source (from a potentiometer or a calibrated keyboard), an accurate voltmeter and a digital frequency meter.

Alternatively, if a previously calibrated oscillator is available then the beat frequency technique may be employed. Another approach is to build two stable fixed frequency oscillators and use these in conjunction with an oscilloscope to calibrate the VCO by generating Lissajous figures. Whichever method is chosen the calibration proceeds as follows. With the coarse control switch, SW1 in the OFF position apply a positive voltage to Control Input 1 (R5) until the frequency is about 200 Hz. ▶

Increase voltage by one volt (as accurately as the measuring equipment allows) and adjust TP 1 until the frequency is doubled. This step is repeated until a doubling of frequency for a one volt change in input is achieved. Next increase the frequency to about 5 kHz, increase voltage by one volt and adjust TP 3 to obtain doubling of frequency. Finally, re-check the first step and if a DFM is available check the VCO over its full range.

Note that the oscillator has been (accurately) calibrated for Control Input 1. This input should be used for the keyboard, if fitted, since there may be a slight difference between Control Inputs 1 and 2 even though 1% resistors are used.

The oscillator may now be adjusted so that with no input voltages it will be tuned to the lowest frequency of a four octave C – C keyboard. Adjust TP 2 to 65.4 Hz, or if connected to a keyboard press note A and adjust to 440 Hz. This step is not essential until the VCO is connected to a keyboard. Also R4 and TP 2 may be changed to suit other keyboard requrements.

The wire to the wiper of the fine control potentiometer (RV2) may now be connected. ▶

HOW IT WORKS - VCO

Voltage Controlled Oscillator
The VCO utilises an integrated circuit which has been specifically designed for music applications. Understanding the IC and how it overcomes the many problems associated with building exponential converters from discrete components is best approached by considering the latter circuits. A transistor design makes use of the fact that in an ordinary transistor the collector current is an exponential function of the base-emitter voltage and the current can then be used for, say, charging a capacitor. The emitter saturation current, however, doubles for every 10°C change in temperature and so to employ a single transistor necessitates use of techniques such as 'ovening', that is, maintaining the transistor at an elevated temperature. A better approach is to use a well matched transistor pair, preferably on the same chip, and to arrange them so as to cancel out this particular temperature dependent term. A simplified oscillator input stage using two transistors is shown in Figure A below.

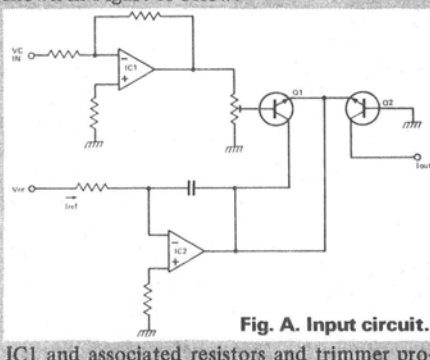


Fig. A. Input circuit.

IC1 and associated resistors and trimmer provide a means of scaling and ranging the input voltages and for the standard 1V/octave response the components are chosen to give approximately 18 mV increase at the base of Q 1 for an increase of 1 V at Vin. Next the control range is adjusted by applying a reference current to the collector of Q 1. Ideally this would be in the middle of the exponential range of the transistor, about 1uA, but considerations of bias current from IC2 usually dictate that Iref is 10uA, or more. IC2 also serves to sink the excess current from the emitters of Q 1 and Q 2. Thus the current from the output transistor Q 2 becomes:-

$$I_{out} = I_{ref} e^{V_b q/kT}$$

so that with Vin = 0, Iout = Iref. There remains, however, a temperature dependent term, 1/T, which changes the exponent by about 0.33% for every degree Centigrade change in temperature. To compensate for this the usual practice is to use a temperature compensating resistor, having a similar temperature coefficient, in the input stage so that Vin also changes by 0.33% per °C.

This project is based on the CEM 3340 Voltage Controlled Oscillator produced by Curtis Electromusic Specialities. Reference to the simplified block diagram (Figure 3) shows that the whole of the input stage described above has been incorporated within the IC. Pin 15 is the input summing stage while Pin 14 determines the scale. Since the current gain of the multiplier is set near unity a 100k input resistor (R5, R6) and a 1k8 scaling resistor (R3) provide the standard 1V/octave response and about 18mV/volt at the base of Q 1. Components R4 and TP2 set the initial frequency of the oscillator and have been chosen so that with no external voltage inputs the frequency can be adjusted to 65.406 Hz, i.e. the lowest note of a 4 octave C – C keyboard. R7 and RV1 allow manual adjustment of the oscillator by ±5 octaves. Switch S1 has been fitted between RV1 and R7 so that in normal use, i.e. keyboard; precise octave shift; and external voltage controls, slight variations in RV1 will not cause the oscillator to go out of tune. R8 and RV2 provide a fine adjustment of approximately ±0.5 octaves. The other components (R9, C5) on the summing input are for compensation and are always required. The sum of the input voltages should always remain positive for proper operation of the oscillator.

For greatest multiplier accuracy the current flowing out of Pin 2 ($22V_T/R2$, where V_T = 26 mV at 20°C) should be close to the current flowing out of Pin 1 (3.0/R1 + TP1). TP 1 is used to adjust the oscillator to a precise 1V/octave response.

The exponential generator is capable of delivering a current, I_{eg}, for charging and discharging the timing capacitor, from greater than 500 uA to less than the input bias current of the buffer which gives a typical frequency range of 500,000:1. For synthesiser applications one should use the most accurate portion of this range, which is from 50 nA to 100 uA. These current limits are used to determine the value of the timing capacitor, C_T (C7). The oscillation frequency is given by $f_o = 3I_{eg}/2V_{cc}C_T$ and therefore to keep within the above current limits and to maintain an accurate frequency range of 5 Hz to 10 kHz the capacitor will be 1000p with a Vcc of +15 V.

An Iref of 10 uA is produced by R11 connected to the +15 V supply. This input (Pin 13) is also used for linear frequency modulation of the oscillator. R12 adjusts the FM range to a 10% change in frequency per volt and an attenuating potentiometer (RV3) allows manual adjustment of this range. The FM input has been AC coupled so as to avoid errors from any DC drift although it may be DC coupled if required. A negative voltage at Pin 13 will gate the oscillator off.

Reference was made earlier of the need to provide temperature compensation. One of the many novel features of the CEM 3340 is the incorporation of temperature compensation within the device. This is achieved by multiplying the current sourced into the control pin (Pin 15) by a coefficient directly proportional to the absolute temperature. This coefficient is produced by the 'Tempco Generator' using the same mechanism as in the exponential generator and thus cancellation is nearly perfect.

A further problem that occurs with transistor exponential converters is their bulk emitter resistance which becomes a significant factor as current is increased and will cause the oscillator to go flat. With the CEM 3340 this situation applies when current from Q 2 is greater than 50 uA. Means of correcting for this effect have been included since Pin 7 outputs a current which is a quarter of the exponential generator current. The current is converted to a voltage across TP 3 and a proportion can be fed back into the control input via R10.

Waveform Outputs: All waveform outputs from the IC are short circuit protected and may be shorted continuously to any supply without damaging the device. A 0 – 10 V sawtooth waveform is available at Pin 8 which can sink at least 0.6 mA and source over several milliamps without any effect on oscillator performance and only a negligible effect on waveshape. The pulse output from Pin 4 is an open NPN emitter and therefore requires a pull down resistor to ground or a negative voltage. This output has been clamped with a 10 V zener diode (ZD 1) to give a 0 – 10 V pulse output. Pin 5 allows pulse width modulation and 0 to 5 V applied to this pin will vary the pulse width from 0 to 100%. Attenuating resistors R19, R20 increase the control range to our standard 0 to 10 V. P4 connected to +15 V provides manual control of pulse width and this control voltage is further attenuated by R18. RV4 input is connected via a jack socket so that it is disabled when an external voltage control source is used. Pin 10 outputs a 0 – 5 V triangle waveform. Although the sink and source capabilities approach those of the sawtooth this output has a finite impedance and also drives the comparator with the result that loading of this output into 100k impedance may lower frequency by 0.15%, in the worst case. This

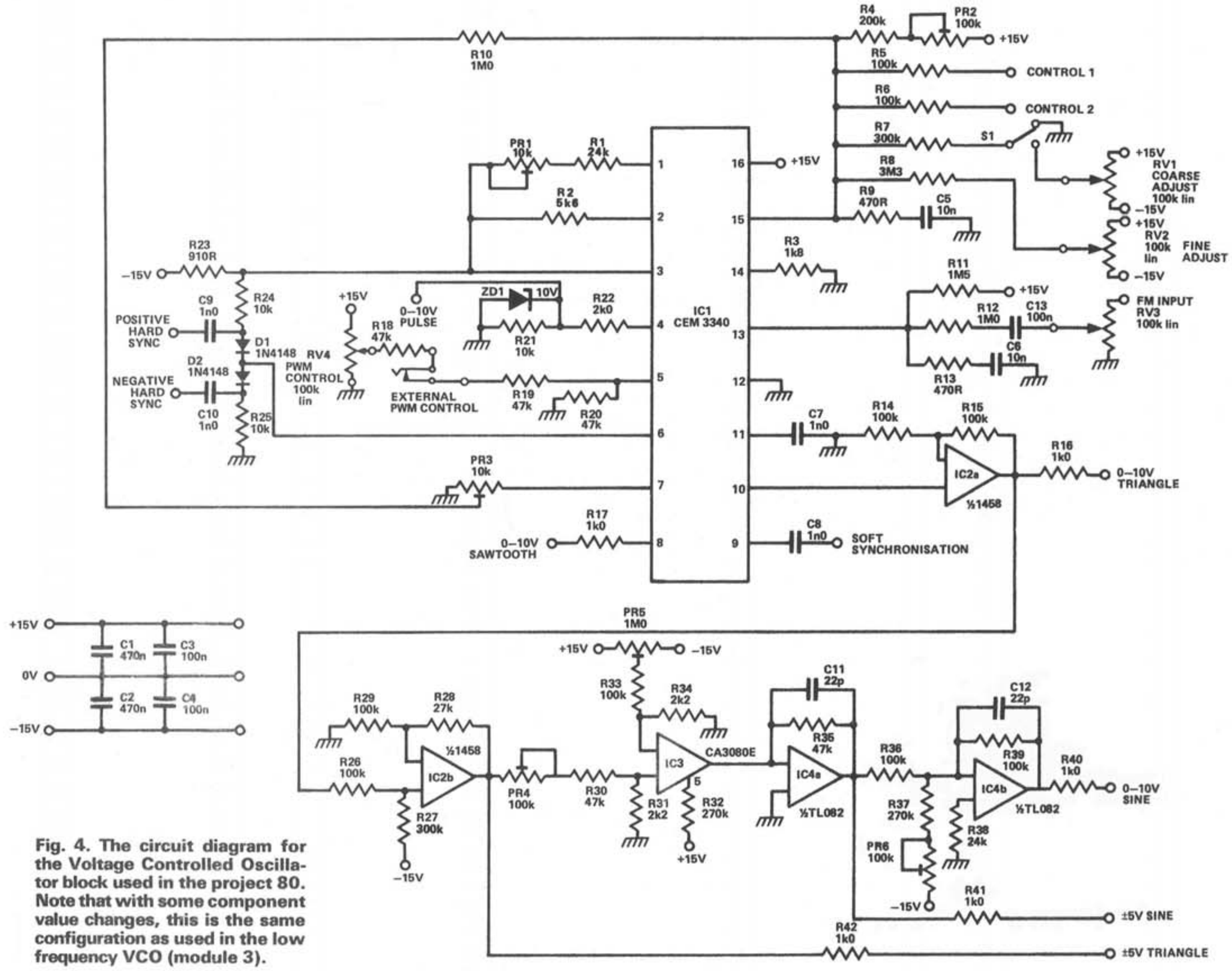


Fig. 4. The circuit diagram for the Voltage Controlled Oscillator block used in the project 80. Note that with some component value changes, this is the same configuration as used in the low frequency VCO (module 3).

output has therefore been buffered by IC2a and addition of R14, R15 increases gain by two to give a 0 – 10 V triangle output.

The triangle output is converted to ±5 V at IC2b (this output is made available from the VCO) and attenuated to about ±100 mV by TP 4, R30 and R31 prior to IC3 which is a CA 3080E. Use is made of the non linear characteristics of the OTA at high input levels to convert the triangle into a sine wave. TP 4 adjusts the 3rd harmonic content and TP 5 and associated components at the inverting input of IC3 trim the 2nd harmonic. IC4a converts the current from IC3 to a voltage and provides a ±5 V sinewave. This output is 180° out of phase compared to all other outputs but this is not detrimental in most applications of this output. Finally the sine wave is shifted to a 0 – 10 V input by IC4b with R37 and TP 6 as the level shifter.

Power supply to IC: The CEM 3340 will operate directly from positive supplies of between 10 and 18 V (although the amplitude of the waveforms as given above will decrease and increase respectively) and negative supplies from –4V5 to –6V0. Nevertheless the IC has a 6V5 zener diode within the chip which allows it to operate from virtually any negative supply voltage if R23 is selected according to (VEE – 7.2)/0.008. In this design R23 allows use of the ±15 V supplies described earlier.

Synchronisation of waveforms: Synchronisation of oscillators is often used to prevent unpleasant beating effects when two oscillators are set to ratios to produce a complex waveform. Synchronisation can, however, also be used to produce some pleasing timbral effects. The CEM 3340 has a wider range of synchronising effects than found on conventionally synchronised oscillators. Soft synchronisation by negative pulses to Pin 9 causes the triangle upper peak to reverse direction prematurely with the result that the oscillation period is an integral multiple of the pulse period. If this input will not be used it should be by-passed to ground with a 100n capacitor (provision for this has been made on the PCB). Alternatively, the 100n capacitor (C8A) may be connected to ground via a jack socket input. By-passing is to prevent unwanted synchronisation or waveform instability from noise pulses on the Vee supply line. Pin 6 is used for hard synchronisation and R24, D1 and C9 allow synchronisation from rising edges while R25, D2 and C10 allow synchronisation from falling edges. A positive sync. pulse will cause the triangle wave to reverse direction only during the rising portion of the triangle, whereas a negative sync. pulse will cause direction reversal only during the falling portion. Figure B illustrates the hard synchronisation capabilities of the CEM 3340.

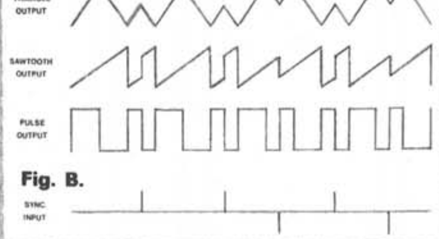


Fig. B.

PARTS LIST - VCO

RESISTORS All ¼W, 5%.

R8	3M3
R9,13	470R
R12	1M0
R14,15,26, 29,33,36,39	100k
R16,17,40, 41,42	1k0
R18,19,20, 30,35	47k
R21,24,25	10k
R22	2k0
R23	910R
R27	300k
R28	27k
R31,34	2k2
R32,37	270k
R38	24k

RESISTORS All ¼W, 1%, 100ppm T.C.

R1	24k
R2	5k6
R3	1k8
R4	200k
R5,6	100k
R7	300k
R10	1M0
R11	1M5

CAPACITORS

C1,2	470n polyester
C3,4,13	100n polyester
C5,6	10n polyester
C7	1n0 polystyrene
C8,9,10	1n0 polyester
C8A (see text)	100n polyester
C11,12	22p polystyrene

TRIMMERS

TP 1	10k cermet multiturn
TP 2	100k cermet
TP 3	10k cermet multiturn
TP 4,6	100k carbon
TP 5	1M carbon

POTENTIOMETERS

RV1,2,3,4	100k lin.

SEMICONDUCTORS

IC1	CEM 3340
IC2	LM 1458
IC3	CA 3080E
IC4	TL 082
D1,2	1N4148
ZD1	BZY 8810V

MISCELLANEOUS

S1	SPDT miniature switch; 3.5mm jack sockets (13)

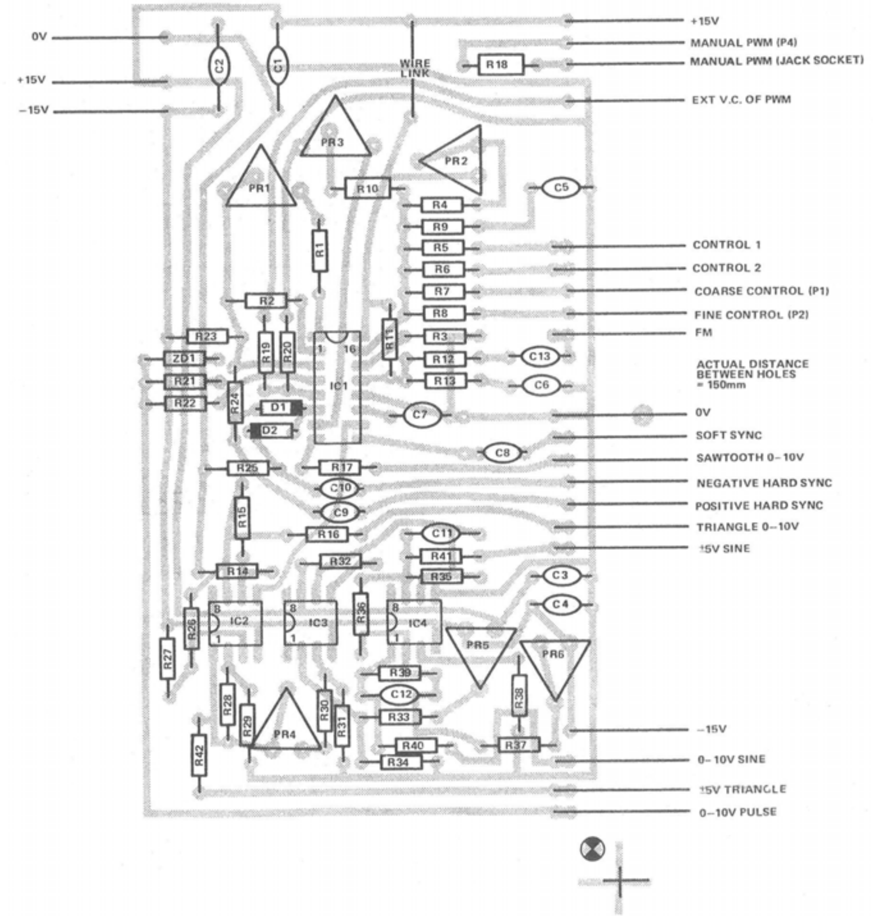
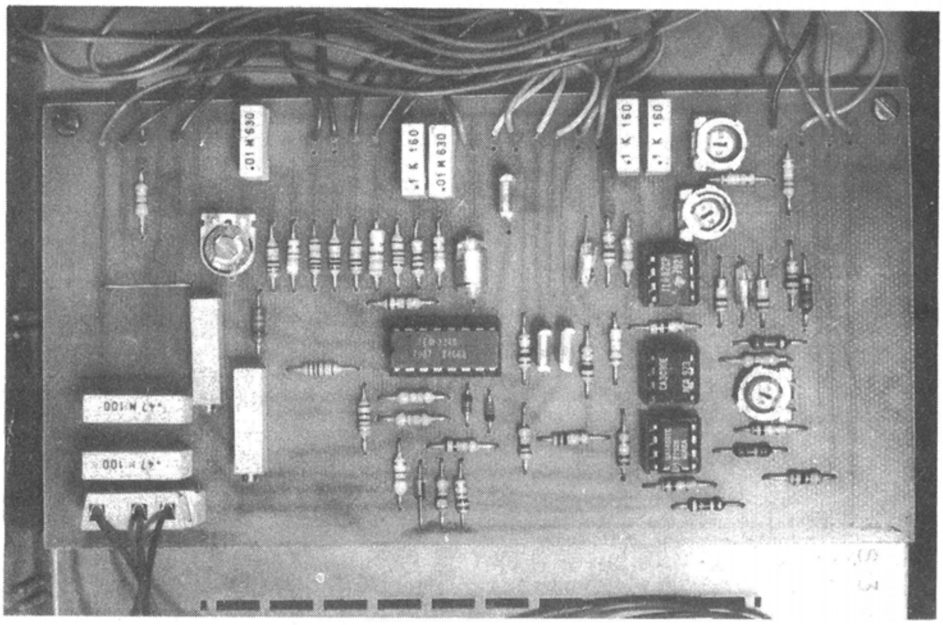


Fig. 5 (above). Component overlay for the VCO/VCLFO modules. The parts list to the left is for a standard VCO circuit. Use the changes given to the far right of page facing to convert to a low frequency oscillator.
Below: A made up PCB sat sitting in its box.



MODULE 3: VCLFO

The VCLFO is identical in design to the VCO described above. It is designed to operate in the range of 0.2 to 205 Hz with a 10 V control input. It is, however, capable of about 5 kHz. Alternatively a lower minimum frequency may be obtained by using a higher value timing capacitor, C7, provided that the capacitor is a very low leakage type.

Note the component changes listed. Construction and initial setting up follows the same procedure as the VCO except that the fine control potentiometer can be wired up prior to calibration.

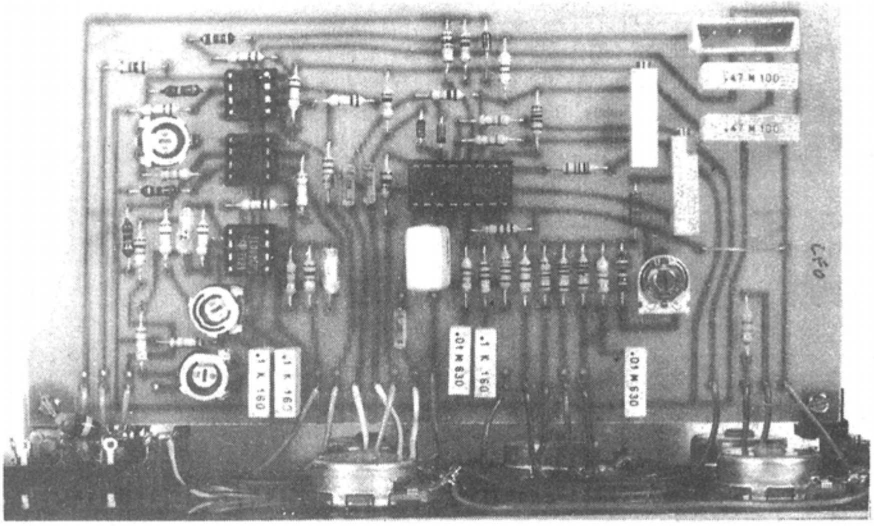
Calibration

Set all trimmers to their mid position.
Adjust sinewave output as described for VCO.
Turn both coarse and fine controls fully anti-clockwise (zero input) and apply a voltage to Control Input 1 to obtain doubling 100 Hz. Increase voltage by one volt and adjust TP 1 to obtain doubling of initial frequency. Repeat step until the one volt per octave response is achieved. Next increase frequency to about 1500 Hz, increase voltage by one volt and adjust TP 3 to obtain doubling of frequency. After adjusting TP 3 re-check setting of TP 1. Finally with 10 V applied to Control Input 1 adjust TP 2 to give a frequency of 205 Hz which will result in a frequency of 0.2 Hz with no external input voltages applied. ETI

BUYLINES

The power supply PCB and components, including the heatsink and illuminated rocker switch but not the connectors, are available from Digisound for £19.55 incl. postage and VAT.
The PCB and components (including pots) for each voltage controlled oscillator are available from Digisound for £18.86 incl. postage and VAT.
Digisound Ltd
13 The Brooklands
Wrea Green
Preston
Lancashire PR4 2NQ
The modules are cased in Teko Alba A23G cases, available from
West Hyde Developments Ltd
Unit 9
Park Street Industrial Estate
Aylesbury
Bucks HP20 1ET
They cost £4.43 each incl. postage and VAT. Please use order code TEK A23G.

Above and below: the inside and outsides of a low frequency VCO. The PCB is panel mounted just to show we did both ways! This method of construction is best suited to professional (or *very* serious amateur) use.



HOW IT WORKS - VCLFO

Voltage Controlled Low Frequency Oscillator
The LFO is identical in design to the VCO described above. A larger timing capacitor (C7) is used to give a frequency range of between 0.2 and 200 Hz with a 0 to 10 V control voltage. R4 and TP 4 are used to set the lower limit; RV2 provides an adjustment of one octave; and RV1 a range of 10 octaves. A switch is not required between RV1 and R7 in this instance. One reason is that both RV1 and RV2 are connected between +15 V and ground and so when the controls are fully anti-clockwise the oscillator is at the pre-set frequency (0.2 Hz). Secondly minor variations in frequency arising from RV1 and RV2 are of little importance for low frequency applications.

PARTS LIST - VCLFO

Component changes from VCO parts list.

R7	150k, 1%
R4	470k, 1%
C7	10n polycarbonate
R8	1M5, 5%
TP2	1M0 cermet