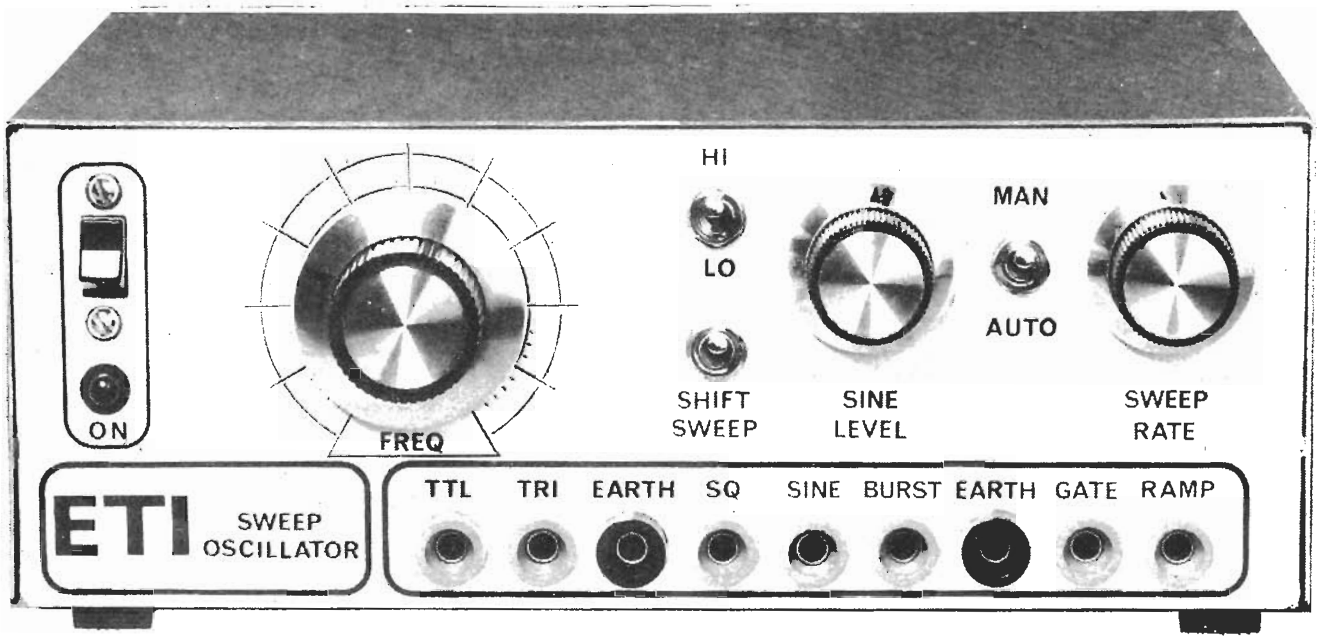
ETI PROJECT

SWEEP OSCILLATOR



Invaluable test unit at less than one fifth of the commercial cost!

By Tim Orr and P. Wielk

SWEEP OSCILLATORS are generally considered to be a rather fancy piece of test equipment and usually attract a fancy price. Units similar to the one to be described sell for around £200 to £300. It produces square and triangle waveforms from a voltage controllable oscillator, which can be internally swept by the machine's own ramp generator, (which is itself controllable), or it can be connected to an external control voltage source. Thus various frequency modulations can be performed, the most useful one being a wide range logarithmic sweep for resolving the frequency response of various networks and filters. To do this, a swept sinusoidal waveform must be synthesised. The triangle waveform is bent, by passing it through a diode function generator, until is closely resembles a sinewave.

Another waveform provided by the function generator is a tone burst output. This gates the sinewave signal on and off and thus generates a burst of sinewaves followed by a period of silence. Tone bursts are very useful for analysing the dynamic responses, (as opposed to the steady state responses), of networks such as filters, compressors, expanders, loudspeakers, etc. The last waveform provided is a square wave suitable for driving TTL circuits. This output uses a current sinking transistor, so that up to about 30 TTL unit loads can be driven by it.

Selecting IC's

The function generator needs fast op-amps to buffer the signals to the external world. These op-amps should also remain stable when connected to various reactive loads. Several devices were tried. The 741S, a fast version of the 741 made by Motorola; the 748, an uncompensated version of the 741; the CA3130 and the CA3140 made by RCA, both of which are fast CMOS devices. Also the LM318, a fast (50v/μS) slew rate op-amp made by National Semiconductors; and the NE531v, another fast device made by Signetics. Not all of these proved successful, particularly when driving reactive loads. Also some of them require external frequency compensation and so the PCB was designed to accept various capacitors. You can use any of the op-amps, but I feel that the best will be obtained by using the suggested devices. In fact you can use the ordinary 741, but this will result in degraded waveforms. Recommended ICs are show on page 12

Using The Machine

Generally try to keep the load impedances presented to the machine as high as possible. The current driving capabilities of all the outputs are limited, particularly at high frequencies and so you may find that outputs become degraded as the frequency increases.

If you want to investigate the frequency response of a filter design, to get a non flickering display, you may have to use a fast sweep rate, say 20 times a second. This could result in a 'time-smeared' display due to the ringing time of the filter. The display will be a cross between the filters dynamic and steady state ponse. To overcome this problem, there are two possible solutions. One, use a slow sweep speed, if you have a storage scope then this will be OK. Two, frequency scale the filter up in frequency, so that say, a 100Hz bandpass filter becomes a 1kHz filter. You can then increase the sweep speed by a factor of times 10. However this is generally only possible when you are designing a filter and when you know that there is a sufficient bandwidth margin still available.

Construction

Even though this is electronically a complex project, construction is reasonably straightforward! Main points to note are as follows — first insert and solder all the wire links, followed by the presets. The link near RV1 is insulated. It's a good idea to use terminal pins for all the off board leads, saves trouble if you have to move a wire. Next the resistors, capacitors and diodes can be fitted. C3 only needs to be fitted if you can't get C2 on the board. Q7 needs its base lead bending underneath to fit the board. The only IC that really needs a socket is IC15, but sockets can save hours if used for all ICs — if a fault develops.

All off board connections should be soldered before inserting IC15 anyway. Screened wire should be used to the controls — but only the socket end should be earthed, otherwise nasty hum loops can develop. The external voltage control socket was mounted on the rear panel. The transformer specified has twin windings which are used in parallel. IC1 does not need any heat sink, as very little of its capacity is used. Last and by no means least, R16 and R34 are both mounted off the main board — good luck!

Setting Up And Alignment

Having built and tested the generator it now only remains for you to align the six presets. **RV1, frequency bias.** Set switch SW2 to manual and switch SW4 to the high frequency range. By turning the frequency control knob, the output of the machine should range from approximately 20Hz to 20kHz. However the transistors in the transistor array IC3 are only matched to within + or — 5mV

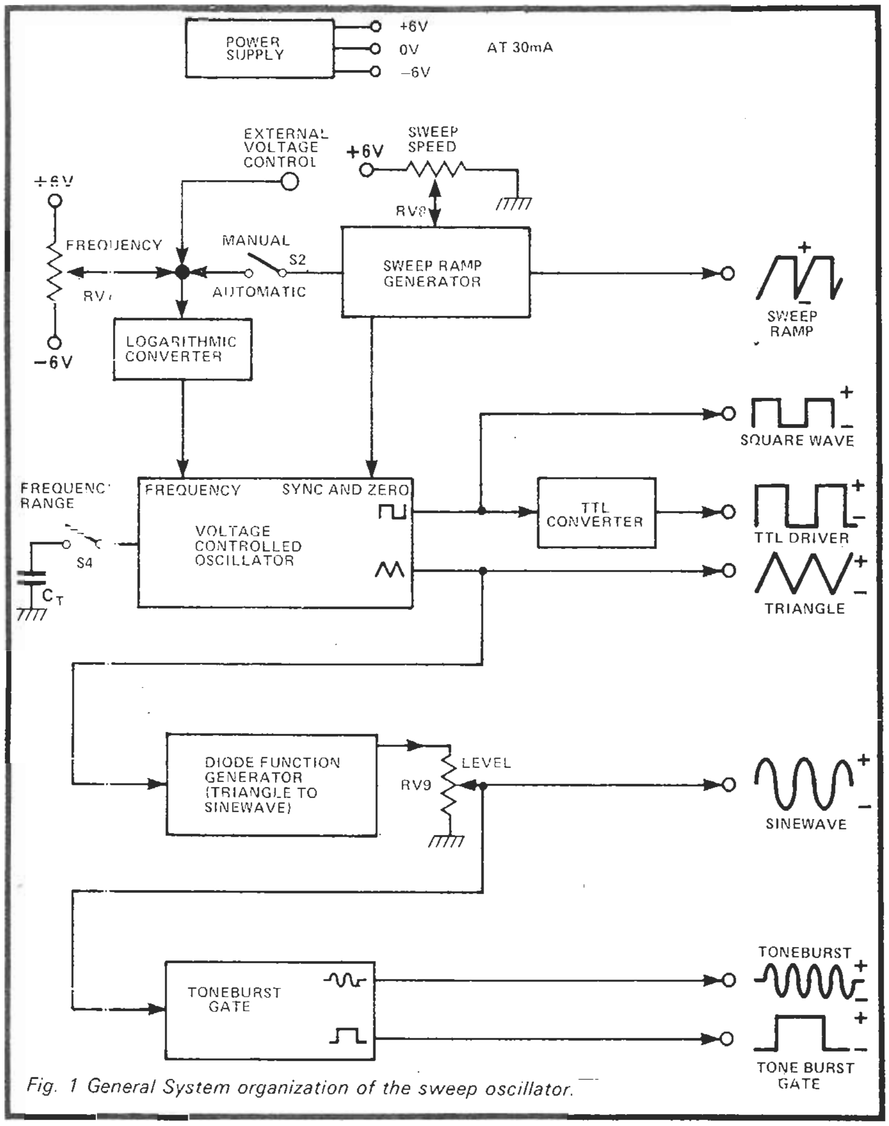


Fig. 1 General System organization of the sweep oscillator.

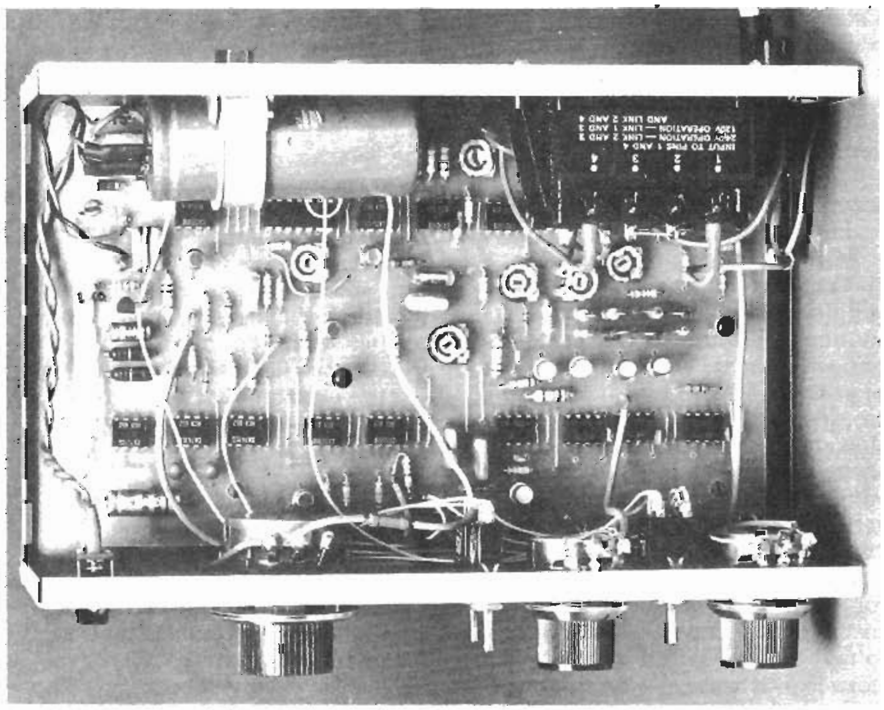


Fig. 2 Internal view of the completed unit.

and this can shift the generator's operating range. So to counteract this mismatch adjust RV1 until the manual operating range is as near to 20Hz to 20kHz as possible.

RV2, triangle time symmetry. The time symmetry of the triangle wave form may not be exactly 1 to 1, and if it is not then the sinewave will have a large THD. The root cause of any time symmetry is IC5, which is a CA3080. If the time symmetry varies significantly when the frequency is changed then IC5 will have to be changed until a suitable output is obtained. To align RV2, set the operating frequency to 1kHz, look at the triangle waveform and rotate RV2 until the best symmetry is obtained. This preset should be readjusted later on when the THD alignment is being performed. Move the frequency throughout its range and check that the symmetry is well maintained.

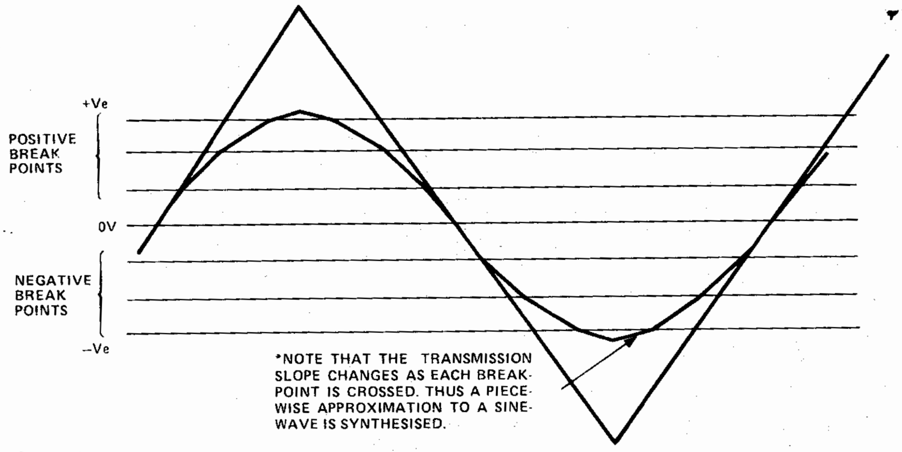


Fig. 3 Technique used to synthesise sine wave for triangle wave form.

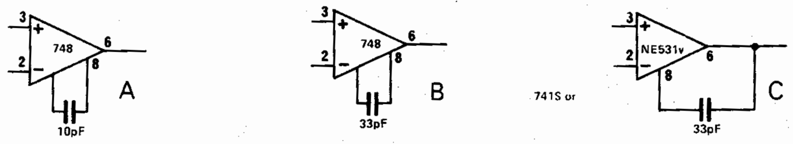


Fig. 4 Suggested ICs for IC11, 12, 13, 16 with correct equalization capacitors. IC11 is C, IC12 is A. IC13, 16 are B.

Ears and Things

THD minimisation RV3, 4, 5, 6. As it was not practical to use high tolerance components and matched diodes in this design, it is necessary to perform several alignments to produce the best possible sinewave. The way in which you align this generator depends on the equipment at your disposal. Here are four methods.

First, by ear. Your hearing apparatus is surprisingly accute to matters of frequency and harmonic structure. For instance if you listen to the square wave output on a good pair of headphones (high impedance preferably), then you can adjust the time symmetry (RV2) by ear with far more accuracy than you can with a direct visual display on an oscilloscope.

As RV2 is adjusted and the symmetry changes there comes a null point where all the even harmonics disappear, which can be distinctly heard. You can also try to align RV3, 4, 5, 6 by listening to the sinewave output at a frequency of say 400Hz. As you adjust each preset you should be able to minimise the harmonics and generally converge upon settings that give the purest tone.

Second, using an oscilloscope. Look at the sinewave (set to 1kHz) on the oscilloscope and adjust RV6 so that the waveform, whatever it looks like, is vertically symmetrical. RV6 merely compensates for any loss of DC offset that has occurred in the production of the triangle. Presets RV3, 4,5, can now be used to adjust the breakpoint slopes. By careful adjustment of them it is possible to converge upon a waveform that looks very nearly sinusoidal.

Third, using a distortion meter. This device is merely a tuneable notch filter. The sinewave is connected to this device and the fundamental is notched out leaving only the harmonics, which you can see and measure. The procedure is to set the frequency to 1kHz and adjust the distortion meter so that the 'sinewave' fundamental has been removed. Look at the residue with an oscilloscope and/or millivoltmeter and adjust RV3, 4, 5 until this residue is at a minimum.

If you don't happen to own a distortion meter you can construct a notch filter at about 1kHz, (see ETI, 'Active filters' and notch out the fundamental by altering the function generator's frequency.

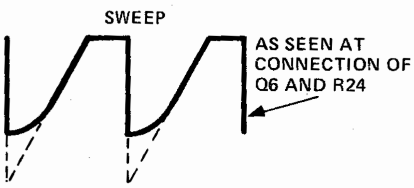
Lastly, using a real time spectrum analyser. These devices are quite cheap, usually about £7000 each. The analyser will display all the harmonics, and so the effect of adjusting RV2, 3, 4, 5, 6 will be instantaneously displayed.

Problems likely to be Encountered

The power supply can be a problem source. The 12V regulator can be responsible for many deviations from the predicted performance, due to the ±5% spread in output voltage. This could cause the sweep range to be larger or smaller, or it can effect the distortion of the sinewave. Here is a list of some common problems and their solutions.

Reduced frequency range. If the manual or swept frequency range is less than expected then increase R12 from 1k to 1k1. This will provide approximately an increase of one octave. If the range is too large then reduce R12 to 910 ohms

Clipped Triangle. This could be caused by a low power supply rail or a large Vp in Q3. Either change Q3 for a low Vp FET or reduce R17 to 470 ohms. Similarly, if the sweep output waveform (output 19) is bent on its negative end, change Q6 for a low Vp device or reduce R24 to 4k7.



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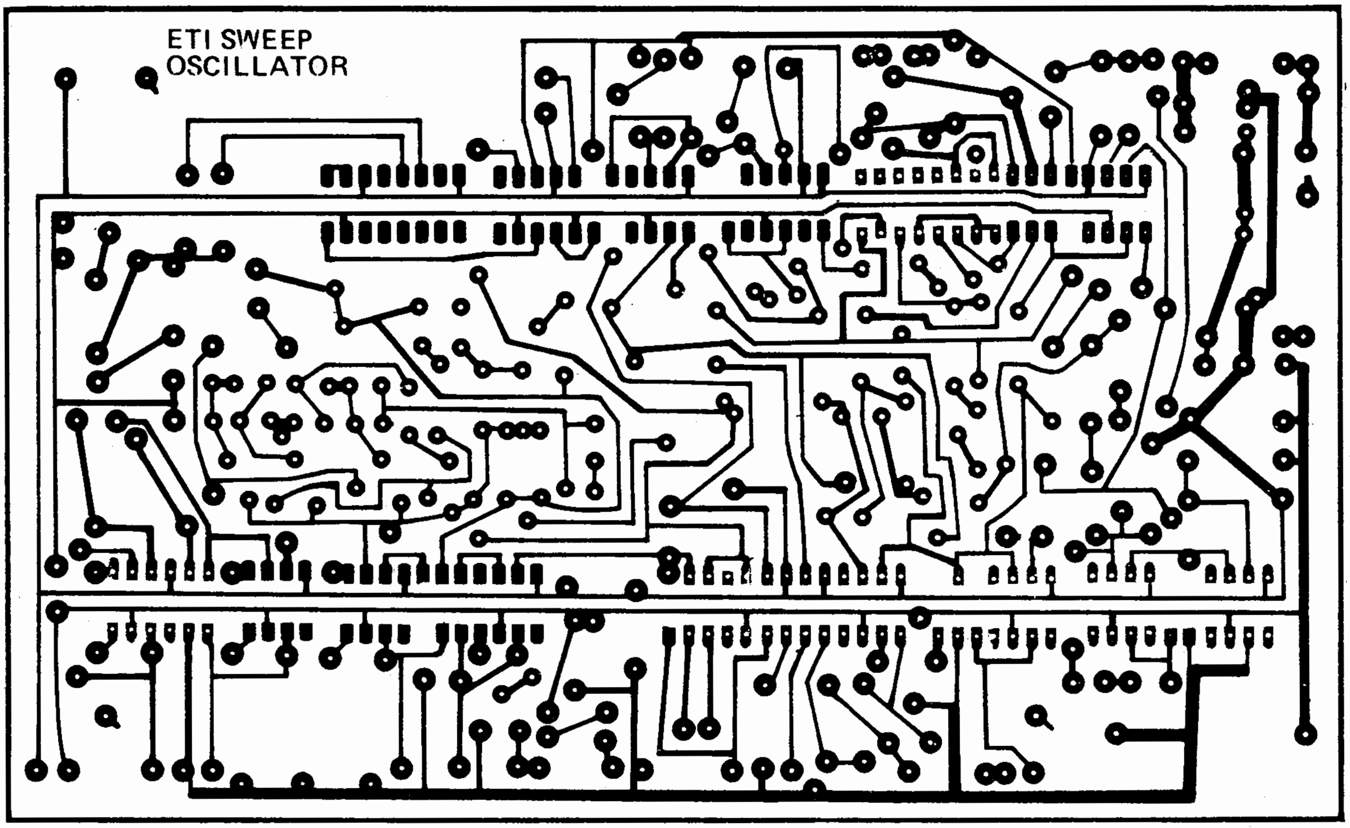


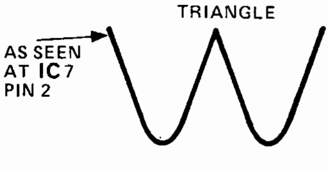
Fig. 5 Full size pattern for the PCB.

SINE WAVE (Variable 0-4V)	**THD<1.5%**
TONE BURST (Variable 0-4V)	**16Hz on 48Hz off**
TRIANGLE (3V5 Fixed)	**Summetry ±2% (better than)**
SQUAREWAVE (3V5 Fixed)	**Markspace 1:1 ±2% (better than)**
TTL (5V, pulldown to zero)	**Markspace 1:1 ±2% (better than)**

TONEBURST GATE	**12V Fixed**
X SWEEP RAMP	**1V9 Fixed**
CONTROL INPUT	**+1V/Octave +3V3/Decade**
SWEEP RANGE (Logarithmic)	**1000:1**
RAMP RANGE	**500:1 (30Hz to 0.06Hz)**
HIGH RANGE	**20Hz to 20kHz**
LOW RANGE	**0.2Hz to 200Hz**
(Manual or Automatic Sweep)	

Tone burst does not shut off. This is because Q12 will not switch off. Change Q12 for a low Vp device.

Sine wave has a high THD. If the THD cannot be trimmed to about 1% then it is likely that the diode function generator has the wrong gain. If the sinewave looks more like a triangle(a), then increase R42 to 20k. If it has flattened ends(b), then decrease R42 to 16k. Note, very small changes in R42 have a large effect on the THD figure.



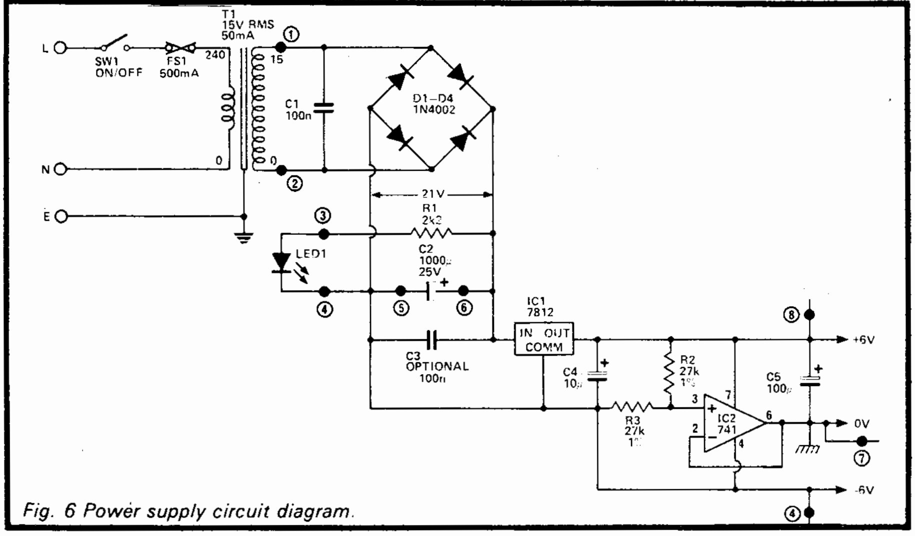


Fig. 6 Power supply circuit diagram.

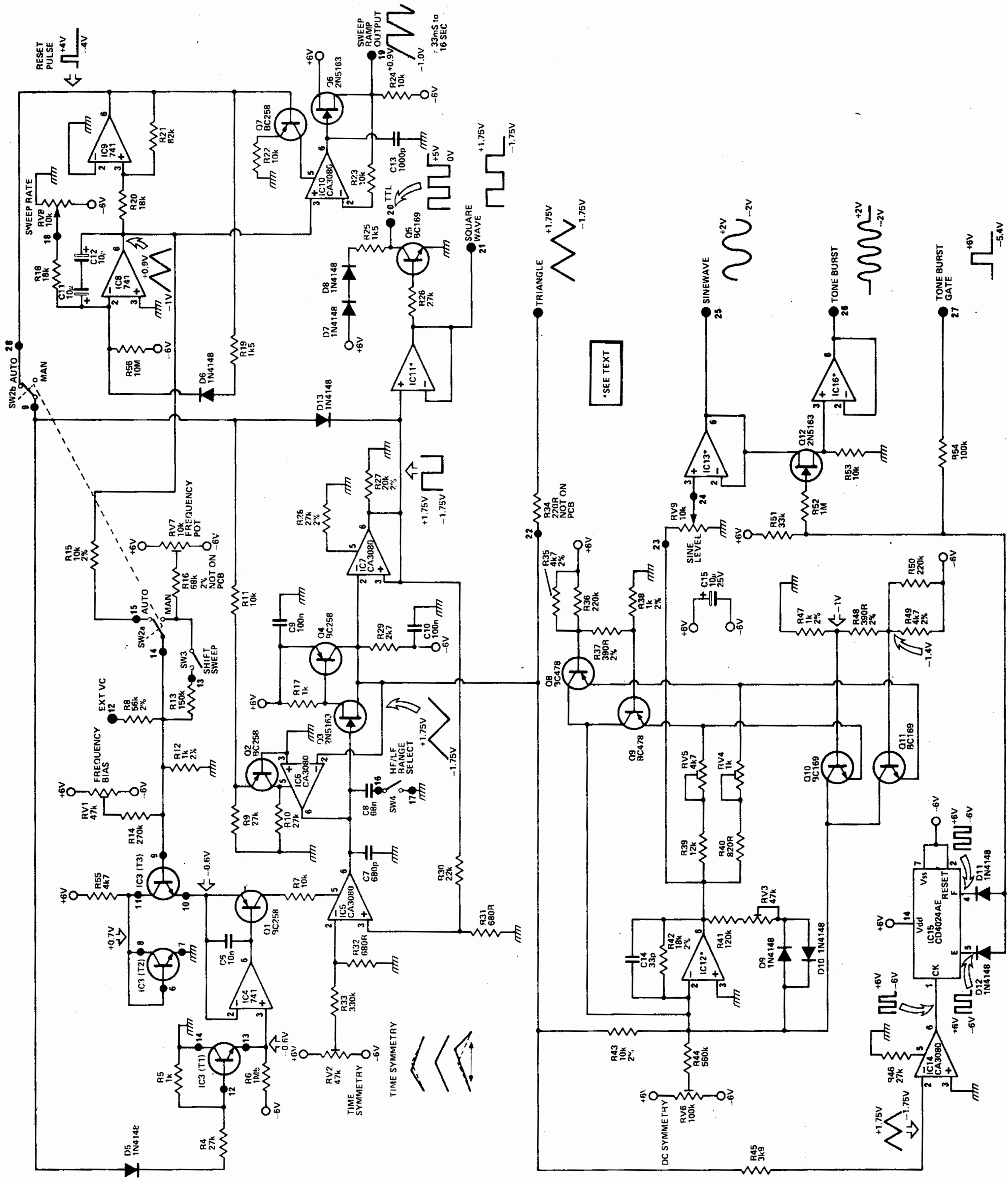


Fig. 7 Main circuit diagram, see page 12 for details of IC11, 12, 13, 16 and compensation capacitors.

HOW IT WORKS

The general system diagram is shown in Fig 1. The heart of the generator is the voltage controlled oscillator shown in more detail in Fig 3 and in the circuit diagram, fig 7. This is the well known triangle square wave oscillator made from an integrator and a schmitt trigger. A control current, (this determines the oscillating frequency), is fed into a current steering device IC5. When a positive voltage is applied to the non-inverting terminal, this control current comes out of IC5 and charges up the timing capacitors C7 and C8. When C8 is switched so that it is in parallel with C7, this selects the low frequency range of operation, (0.2Hz-200Hz). If the applied voltage is negative, then a current equal to the control current is 'sunk' into IC5 and the timing capacitors are discharged. Thus IC5 can either charge or discharge the capacitors, this being determined by the steering voltage.

The speed at which the capacitors charge or discharge is determined by the magnitude of the control current. If this current is constant then the capacitor voltage will increase or decrease linearly. The voltage on the timing capacitor is buffered by a high impedance buffer, Q3,Q4. The FETQ3, has such a high impedance that it hardly takes any current from the timing capacitor, so that it does not affect the charging or discharging operation. Q4 is arranged to drive Q3 at constant current, and the pair, (Q3, Q4), form a high input impedance voltage follower, with a DC shift caused by the FET characteristics. In fact it would be advisable to use low pinch off voltage FET's throughout so as to minimise the effects of these offset voltages.

The way in which oscillation occurs is as follows. Control current is injected into IC5 and the voltage on the timing capacitor rises. This voltage is buffered and presented to the schmitt trigger IC7. When this voltage reaches the upper hysterysis level, the schmitt flips over to its low state and thus the steering voltage becomes reversed. The timing capacitor voltage then ramps down until the lower hysterysis level is reached and then the schmitt flips back to its original state. Thus the timing capacitor voltage ramps up and down between these two hysterysis levels, the speed at which this occurs being determined by the control current. Switching in another capacitor C8, will reduce the ramp rate and hence the frequency of operation. This circuit produces triangles and square waves with a 1 to 1 time symmetry and symmetry about OV.

IC6 and Q2 are used to 'zero' the triangle output for the start of sweep. IC6 adjusts the voltage on the timing capacitor so that the triangle output is at OV. It does this only when Q2 supplies it with current.

The triangle output has a 220ohm resistor connected in series to prevent any damage caused by possible short circuits. The square wave output is buffered by A11 which has a fast slew rate. Q5 is the TTL driver stage. When switched on, it will pull down almost any load to a voltage near to OV. If a faster pull up is required the 1K5 resistor can be reduced.

Next the logarithmic converter. This device converts the sum of all the control voltages into a current, (the control current), to which it is logarithmically related. That means that for every IV increase of external control voltage the control current and hence the operating frequency will double. This logarithmic relationship is very useful for audio work, because when using a swept output, (displayed on an oscilloscope), the X axis is in octaves and decades rather than being linear. The circuit that does the conversion is known as an exponentiator and works in the following manner (see IC3, (T1,2,3.) IC4 and Q1).

IC3 is a CA3046 which is a transistor array providing us with a set of well matched devices at a low cost. Transistor IC3, (T1), has a current of 3.5μA passing through it and this produces a reference voltage of about −600mV at its emitter. IC4 and Q1 adjust themselves so that the emitter of IC3 (T3), is also held at this reference voltage. There are three control voltages, from the frequency pot wiper, the external control voltage terminal and the internal sweep ramp. These are resistively summed together and presented to the base of IC3, (T3). This transistor converts the control voltage into a current which flows out through the emitter, completely through Q1 and then to IC5. This is the control current. The voltage at the base of IC3, (T3) is logarithmically related to its emitter current. A voltage increase of about 18mV will double this current. However, this process is very sensitive to temperature changes which would result in drift in the function generators operating frequency, and so the arrangement of IC3 (T1) and IC3 (T3) has been used to provide temperature compensation. Also to keep self-heating effects to a minimum, IC3 (T2) is used to clamp the collector voltage of IC3 (T3) to +0.7v and thus reduce the power dissipated in the transistor array.

The next section to be discussed is the internal sweep ramp generator, (IC8,9,10,Q6,Q7). IC8, 9 form another triangle/square wave oscillator, having a controllable rise time and a fast reset time. IC8 is the integrator, IC9 the schmitt trigger. The output of IC8 ramps up at a rate largely determined by the sweep rate pot setting. When the upper hysterysis level is reached, IC9 output goes high, D6 becomes forward biased and the integrator ramps down very rapidly, reaches the lower hysterysis level, the schmitt trigger flips over and the process repeats itself. The ramp output is then used to drive the base of IC3 (T3), eventually sweeping the oscillator over a frequency range of 1000:1. This is approximately 10 octaves which requires a change in Vbe IC3 (T3) of about 180mV.

The ramp waveform can be used to drive the X axis on an oscilloscope but it needs some slight modifications to make it suitable. It needs to have a very fast reset of the order of a few microseconds to make the fly back invisible. This is achieved with the track and hold circuit Q6, 7, IC10. During the sweep the output of this circuit follows the input. However, during the reset period, IC10 is 'held' by virtue of the fact that no current is supplied to it. When the reset period is over, current returns to IC10 but its input has the 'start' ramp waveform presented to it, but its output has the stored value of the 'finish' ramp waveform. The output jumps as fast as it can, (within a few microseconds) to the input voltage and proceeds to track it. The process repeats itself. The reset voltage is used (in the sweep mode only), to perform three other tasks. **One,** it sets the schmitt trigger IC7 into a high state so that it always starts a new sweep with the same phase, (via the D13 route). This stops jitter on the display. **Two,** the reset is used to activate the zeroing switch mechanisms Q2 and IC6. **Three,** the control current is reduced during reset, due to the connection of D5. This helps the zeroing process. When switch SW2 (this is a double pole switch) is in the automatic position, both the sweep wave form and the reset pulse are routed to their respective sections of the circuit, and a logarithmically swept output is generated. The manual frequency control knob has no effect on the process, except when switch SW3 (the shift sweep), is closed.

This enables the sweep to be manually displaced up or down the frequency axis by a factor of about 5 times. That is if the sweep were between 20Hz to 20kHz it could be shifted up to 100Hz to 100kHz or down to 4Hz to 4kHz, thus enabling the useful range of the generator to be greatly extended. When switch SW2 is in the manual position, the sweep and reset signals are disconnected and so the generators output frequency is entirely determined by the manual control knob, plus any external control voltages and of course the position of the range switch SW4.

Next the diode function generator IC12, Q8, 9, 10, 11 and D9, 10. This circuit converts the triangle waveform into one that approximates a sinewave, see fig. 3. It is called a diode function generator, although four of these supposed diodes are transistors, Q8,9,10,11). The triangle is applied to an op-amp with several feedback routes, the purpose of which are to change the gain of the section, depending upon the instantaneous signal level. As the triangle waveform (which is symetrical about OV) goes positive, the output of IC12 goes negative. When it exceeds −0.6V, diode D9 begins to turn on and in doing so, the overall feedback resistance is reduced and so therefore the transmission slope is also reduced. This is known as the first break point. Transistors Q10,11 have their bases biased to voltages of −1.0v and −1.4v respectively. These transistors will provide further feed back routes when the output of IC12 exceeds −1.6v and 2.0v, and this extra feedback will decrease even more the transmission slope. Thus, the triangle waveform is gradually bent to resemble a sinewave in the negative excursion of IC12.

However there is also a complementary set of feedback routes for positive excursions via D10,Q9 and Q8 and so a complete sinewave is synthesised. This process is far from perfect and the best THD figure that can be obtained by careful adjustment of RV3, 4, 5, 6 is about 1.0% at 1kHz. This compares with a figure of about 0.2 to 0.5% THD for moderately expensive commercial function generators. These lower figures can only be obtained by having a precision regulated power supply, good tolerance resistors (0.5%) and a more elaborate set of MATCHED diodes. Also, some high quality equipment will be needed to make the final adjustments to the sinewave.

The sinewave from IC12 is passed through a manual level control and is buffered by the voltage follower IC13 to the output terminal. The sinewave also goes to the **toneburst section.** IC14, 15, 16 and Q12 FET Q12 is used as an analogue switch between the sinewave and the voltage follower/buffer IC16. This switch is turned on for 16 cycles of the sine wave and off for 48 cycles. The switching occurs synchronously as the waveform passes through OV. The control for the FET switch is generated by IC14 and 15. IC14 is used as a voltage comparator which determines whether the triangle waveform is positive or negative. It generates a square wave of + and −6V state as the triangle waveform passes through OV. This square wave is used to clock a seven stage CMOS counter, IC15. The divide by 32 and 64 outputs are AND'd together to generate the voltage control for the FET switch. This voltage is high (FET switch on) for 16 cycles and low (FET switch off) for 48 cycles and is used as an output (toneburst gate) to trigger, say, an oscilloscope.

The last piece of circuitry to be described is the power supply, IC1, 2. This delivers + and −6V at about 30mA. The transformer delivers 15V RMS which produces about 21V of unregulated supply. A 12VRMS transformer would be rather low and you might experience problems of the supply dropping out.

PARTS LIST

RESISTORS	(all ¼ W 5% unless otherwise stated)
R1	2 k 2
R2,3	27 k 1%
R4,9,10,26,46	27 k
R5,17	1 k
R6	1 M 5
R7,11,22,23,24,53	10 k
R8	56 k 2%
R12,38,47	1 k 2%
R13	150 k
R14	270 k
R15,43	10 k 2%
R16	68 k 2%
R18,20	18 k
R19,25	1 k 5
R21	82 k
R27	20 k 2%
R28	27 k 2%
R29	2 k 7
R30	22 k
R31,32	680 R
R33	330 k
R34	220 R
R35,49	4 k 7 2%
R36,50	220 k
R37,48	390 R 2%
R39	12 k
R40	820 R
R41	120 k
R42	18 k 2%
R44	560 k
R45	3 k 9
R51	33 k
R52	1 M
R54	100 k
R55	4 k 7
R56	10 M

CAPACITORS	
C1,3,9,10	100 n polyester
C2	1000 u 25 V tant.
C4,11,12,15	10 u 25 V tant.
C5	100 u 25 V tant.
C6	10 n polyester
C7	680 p polystyrene
C8	68 n polyester
C13	1 n polystyrene
C14	33 p ceramic

TRANSFORMER	
T1	240 V, 0-15 + 0-15 V (3 VA per winding) (Doram 207-217)

CASE	
Samos S7	(Doram 984-497)

MISCELLANEOUS
500 mA fuse, holder, single screened wire, stranded flex, pcb as per pattern, 3-core mains wire, 8 off 4 mm. red sockets, 2 off 4 mm. black sockets, pcb mountings, etc, instrument knobs.

POTENTIOMETERS	
RV1,2,3	47 k Hor. min. trim
RV4	1 k " " "
RV5	4 k 7 " " "
RV6	100 k " " "
RV7	10 k lin. moulded track pot.
RV8,9	10 k log. carbon pot.

SWITCHES	
SW1	off-on rocker etc. 3 A 250 V
SW2	D.P.D.T. toggle
SW3,4	S.P.S.T. Toggle

SEMICONDUCTORS	
Q1,2,4,7,8,9	BC 258 or similar (BC 477,8,9)
Q3,6,12	2N 5163 or 2N 3819 (N type FET)
Q5,10,11	BC 169
D1-4	1N 4002
D5-13	1N 4148
LED1	.2" type
IC1	7812
IC2,4,8,9	741
IC3	CA 3046 or CA 3146
IC5,6,7,10,14	CA 3080
IC11,12,13,16	see text
IC15	CD4024AE

BUYLINES

Most of the components are easily available, if they are in stock! **Marshalls** are preparing various packs for this project to make construction easier. All resistors for **£1.50**, capacitors for **£1.60**, switches **£2.70** and a complete semiconductor pack (preferred ICs for IC11, 12, 13, 16) for **£16.75**. All prices include VAT but add **30p** per order for postage etc.

Total cost for the whole project should be under **£35.00.**

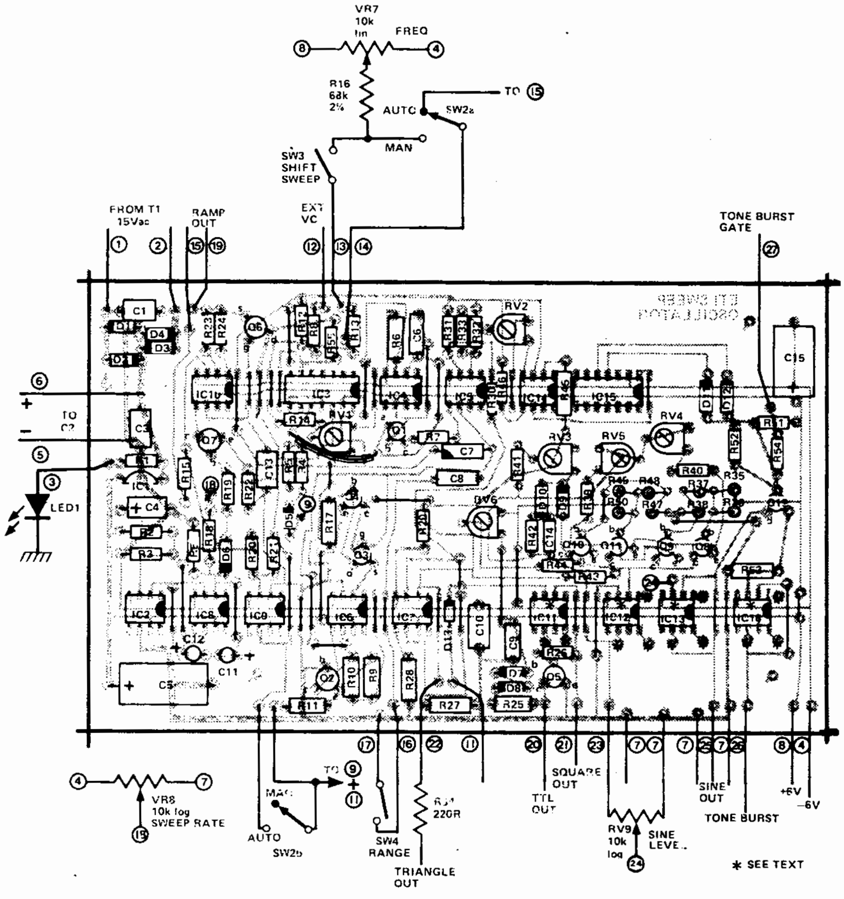


Fig. 8 Overlay and interconnection pattern.