

# Designing Oscillators

One of the problems in electronics is stopping amplifiers from oscillating, another is getting oscillators to oscillate . . . Tim Orr explains.

AN OSCILLATOR IS BASICALLY an amplifier with positive feedback applied around it. The feedback must be AC coupled otherwise a DC latch up condition would occur. Having got some sort of oscillation, one of two things can happen. The oscillation can build up in amplitude until clipping occurs due to the power supply voltage levels. At this point a stable, but truncated waveform will be generated. Alternatively if the gain of the amplifier is too low the oscillation will die away. To produce a pure sinusoidal oscillation the level of the signal in the system must be accurately controlled. There must be some amplitude limiting or automatic gain control such that when the peak signal level tries to exceed a reference voltage, the amplifier's gain is reduced. This is in fact what limiting does. To maintain stable oscillation, the overall gain of the system must be exactly unity. Any less and the oscillations will never start. If the gain is more than unity, the oscillations will occur, but amplitude limiting will cause gross distortion.

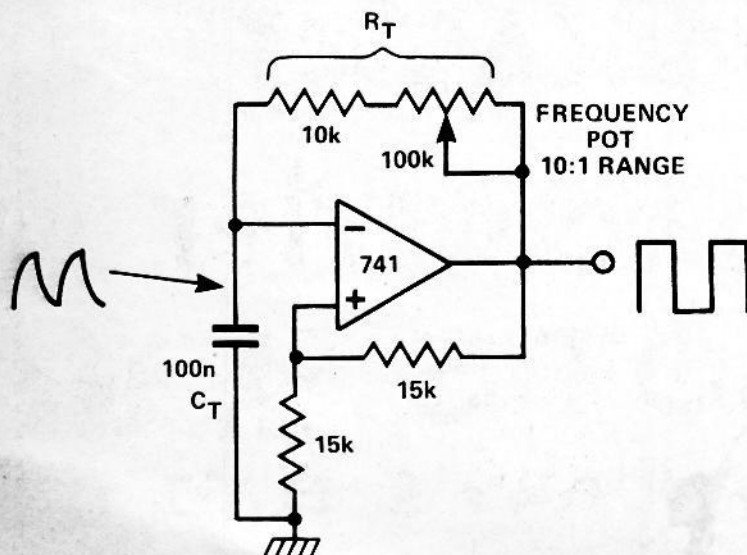
A very common method for stabilising the oscillations, which is often used in Wein bridge oscillators, is to employ a very sensitive thermistor as an AGC. However, the thermal time constant of this component often produces an annoying amplitude bounce which occurs

when changing to a new frequency.

Other methods are diode limiters (which tend to cause large amounts of distortion) and FET AGC circuits. The latter method can be used to generate super low distortion sinusoids by allowing the system gain to stabilise over tens of seconds.

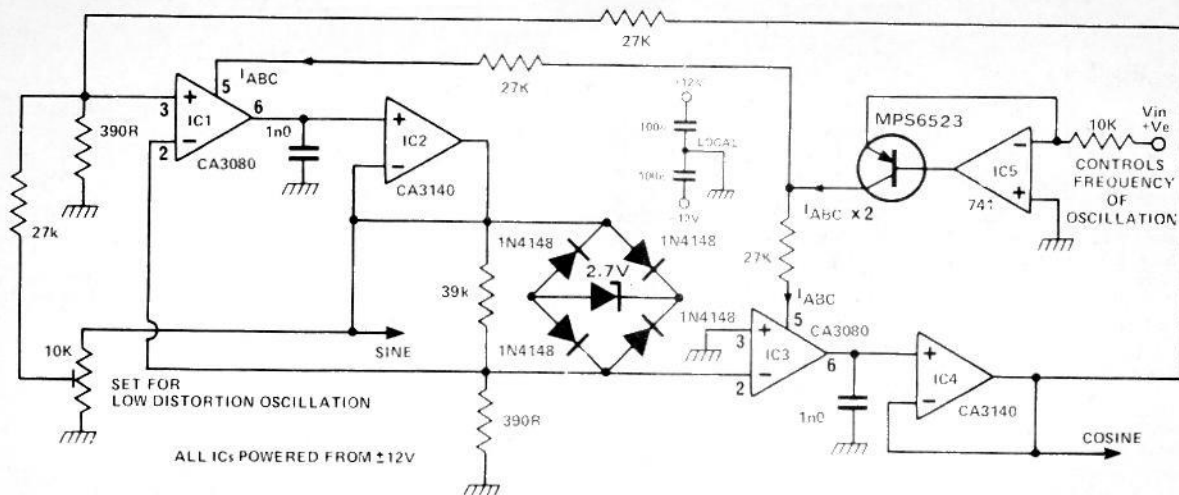
The oscillation frequency is mainly determined by the feedback around the amplifier. By making the feedback a reactive network, the phase of the feedback will vary as a function of frequency. Oscillations can only occur when the feedback is positive and thus the phase response of the feedback will determine the frequency of oscillation, assuming that the overall gain at this frequency is at least unity. By varying the phase response of the feedback, the oscillation frequency may be altered.

An oscillator should be thought of as being a circuit which continuously generates a waveform, no matter what the shape of the waveform. There are very many circuit techniques for generating these signals which range from relaxation oscillators to piecewise approximations using square waves. Some of these methods will now be illustrated.



## Manually Controlled Oscillator

In this circuit there are two feedback paths around an op-amp. One is positive DC feedback which forms a Schmitt trigger, the other is a CR timing network. Imagine that the output voltage is +10V. The voltage at the non-inverting terminal is +15V. The voltage at the inverting terminal is a rising voltage with a time constant of  $C_T R_T$ . When this voltage exceeds +5V, the op amp's output will go low and the Schmitt trigger action will make it snap into its negative state. Now the output is -10V and the voltage at the inverting terminal falls with the same time constant as before. By changing this time constant with a variable resistor a variable frequency oscillation may be produced.



### Dual Integrator Quadrature VCO

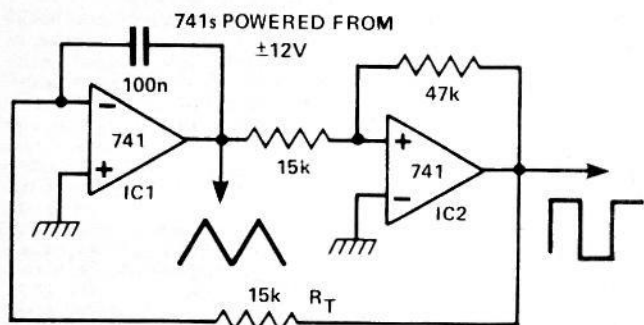
This is a sinusoidal oscillator which uses frequency dependent feedback and zener diode amplitude limiting. IC1,2,3&4 form a dual integrator circuit which is an analogue model of a second order differential equation! There is some positive feedback around IC1,2 which is analogous to having a zero damping factor in the equation. This means that the oscillations will build up. The positive feedback is controlled by the 10k preset. IC1,3 are integrators and IC2 and IC4 are voltage followers with high input impedance. The phase shift produced by an integrator is  $90^\circ$  so there is no overall feedback around the loop (IC1 is non-inverting, IC2 inverts). Thus we have all the conditions for oscillation, and in fact oscillations will occur when the preset is adjusted to give the correct phase shift around the IC1,2 stage. Amplitude limiting is produced by the 2.7V zener inside the diode bridge. By placing it inside the bridge the same diode is used for both positive and negative signals and the limiting is symmetrical. The integrators are two quadrant multipliers (CA3080s), so the gain of the loop can be controlled by the current  $I_{ABC}$ . In the solution of this second order differential equation, the gain

of the loop is proportional to the resonant frequency. Thus, by varying  $I_{ABC}$  or rather by varying  $V_{IN}$ , the frequency of oscillation may be altered.

As the integrators produce a  $90^\circ$  phase shift, the two sinusoid outputs are in phase quadrature, i.e. one is a sinewave, the other a cosine wave. The cosine output is lower in distortion than the sinewave, because the amplitude limiting (and hence the distortion) is produced at the IC1,2 stage.

The second stage (IC3,4), acts as a filter and hence produces a purer sinusoid. Using this circuit a 1000 to 1 continuous frequency sweep can be obtained. However, the inaccuracies in the CA3080's will cause some amplitude variations and it may be necessary to set the positive feedback a bit high (and hence attract more distortion), to maintain stable amplitude limiting over the sweep range. This circuit is an oscillating filter and if you turn down the positive feedback and inject a small signal through a 100k resistor into IC1 pin 3, a bandpass and low pass response is obtained from the sine and cosine outputs respectively.

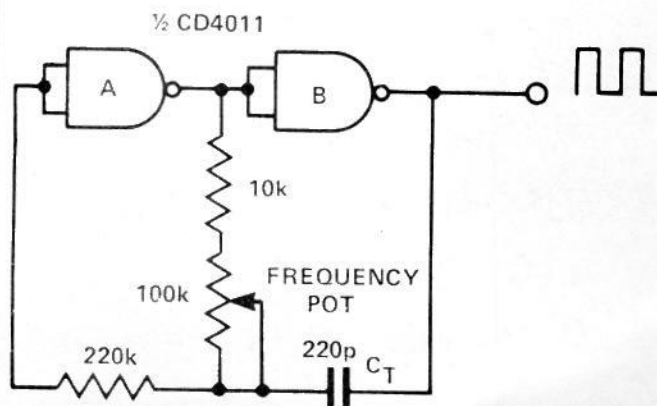
### Simple Triangle Square Wave Oscillator



This circuit generates simultaneously a triangle and a square waveform. The triangle could be 'bent' by a diode function generator to produce a sinewave. The circuit is always self starting and has no latch up problems. IC1 is an integrator with a slew rate determined by  $C_T$  and  $R_T$  and IC2 is a Schmitt trigger. The output of IC1 ramps up and down between the hysteresis levels of the Schmitt, the output of which drives the integrator. By making  $R_T$  variable it is possible to alter the operating frequency over a 100 to 1 range. Three resistors, one capacitor and a dual op amp is all that is needed to make a versatile triangle squarewave oscillator with a possible frequency range of 0.1Hz to 100kHz.

### CMOS Oscillator

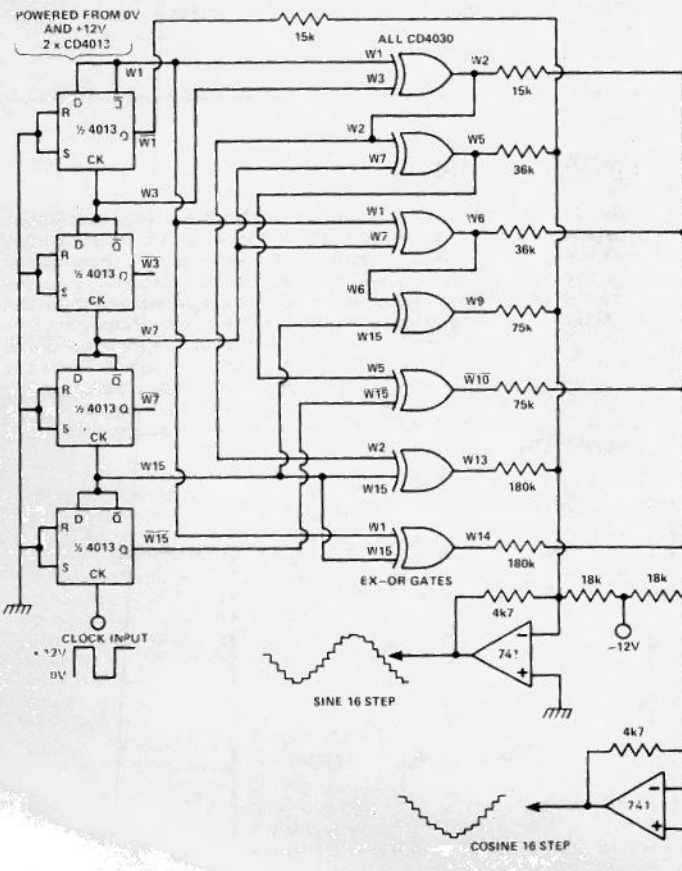
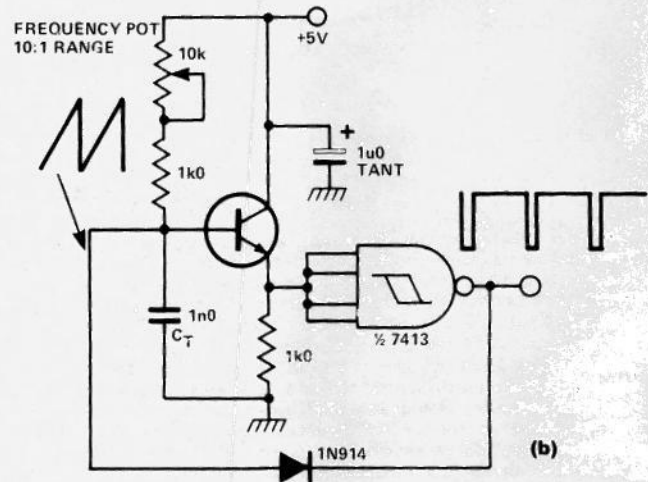
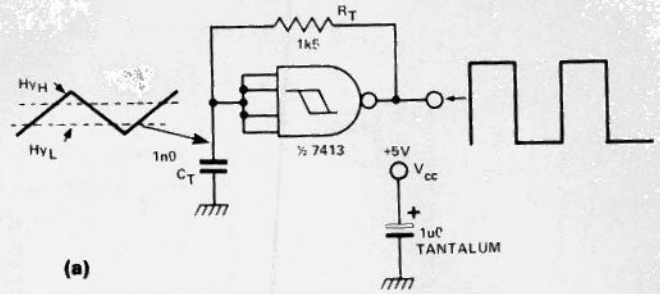
Two CMOS gates can be used to produce a simple oscillator. Imagine that output B is high. Then the input to A is also high due to it being coupled via the capacitor  $C_T$  to output B. Thus output A is low, input B is low and output B is high, which is as we would expect. However, capacitor  $C_T$  is being discharged via the 100k pot and 10k resistor to a logic 0. When this voltage reaches the crossover point for A, output A goes high, and thus output B goes low. Now the capacitor is charged up to a logic 1. Thus the process repeats itself. Varying the 100k pot changes the discharge rate of  $C_T$  and hence the frequency. A square wave output is generated. The maximum frequency using CMOS is limited to 2MHz.



## TTL Oscillator

A simple relaxation oscillator can be made using a TTL Schmitt trigger. The circuit 'a' is the most simple version that can be produced. Imagine that the output is high. Capacitor  $C_T$  is charged up via  $R_T$ . When the upper hysteresis level ( $H_{yh}$ ) is reached, the output goes low.  $C_T$  is now discharged until the low hysteresis level ( $H_{yl}$ ) is reached whereupon the output goes high. Thus the oscillator generates a square wave, with an uneven mark to space ratio, due to the input current requirements of the 7413. The frequency can be set at any value up to several megahertz by varying  $C_T$  and  $R_T$ .  $C_T$  can be an electrolytic but  $R_T$  must not be more than about 1k5 or it will not be able to pull down the Schmitt trigger inputs. (If you use a CMOS Schmitt this does not apply). The output is a nice fast squarewave capable of directly driving several TTL loads. One problem to be encountered is frequency jitter. When the input is very near to a hysteresis level, noise in the system may cause the oscillator to prematurely trigger, thus making that period slightly shorter and producing a noise induced frequency jitter. Also using two Schmitt triggers from the same IC is sure to cause interaction and thus jitter. To reduce power supply noise effects the IC should be decoupled with a 1uF tantalum capacitor actually at the  $V_{CC}$  and GND pins of the package.

Diagram 'b' shows the same oscillator, but with a 10 to 1 manual control of frequency. The timing capacitor is charged up by the 10k pot and the 1k resistor. This voltage is then buffered by the emitter follower and fed to the Schmitt trigger. When the upper hysteresis level is reached the output of the Schmitt goes low and the capacitor is rapidly discharged via the diode until the lower level is reached. The process then repeats itself. As the discharge period is so fast, it can be as short as a few hundred nano seconds, the period can be thought of as being determined by the charging time, which is controlled by the 10k pot.

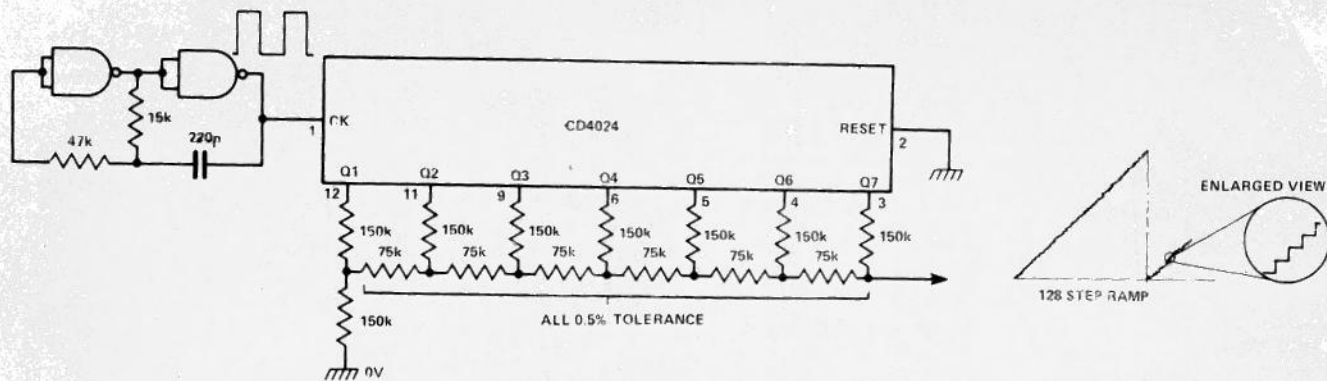


## Walsh Function Generator

The mathematician, Fourier, said that any repeating waveform could be made up out of harmonic components. These components are sinusoids which are integrally related to the fundamental period of the waveform in question. This is a convenient conceptual approach, but as a way of practically synthesising waveforms it is not on. You would have to generate a whole series of harmonically related sinewaves which might prove a little difficult. However, a man called Walsh said that you could do the same thing as Fourier, but with square waves. So, instead of using sinusoidal Fourier sets, we can use square wave Walsh functions to synthesise waveforms. There are various techniques for calculating the Walsh function co-efficients for generating particular waveforms but these are beyond the scope of an article such as this. The diagram shows the circuit for generating a sine and cosine waveforms using 16 steps. Walsh functions are orthogonal functions, just as sine and cosine are orthogonal, and so the generation of these two waveforms is relatively simple using this technique. The 4013 dividers and the exclusive OR gates generate the Walsh functions, which in turn are converted into analogue waveforms by use of the correctly weighted resistor networks. Note that you only need 4 resistors to generate a 16 step sinewave approximation.

The resultant outputs can be easily filtered by fixed or tracking filters to produce pure sinusoids. The output frequency is 1/16th of the input clock frequency. The clock can be stopped and the outputs will remain fixed, try that with analogue techniques!

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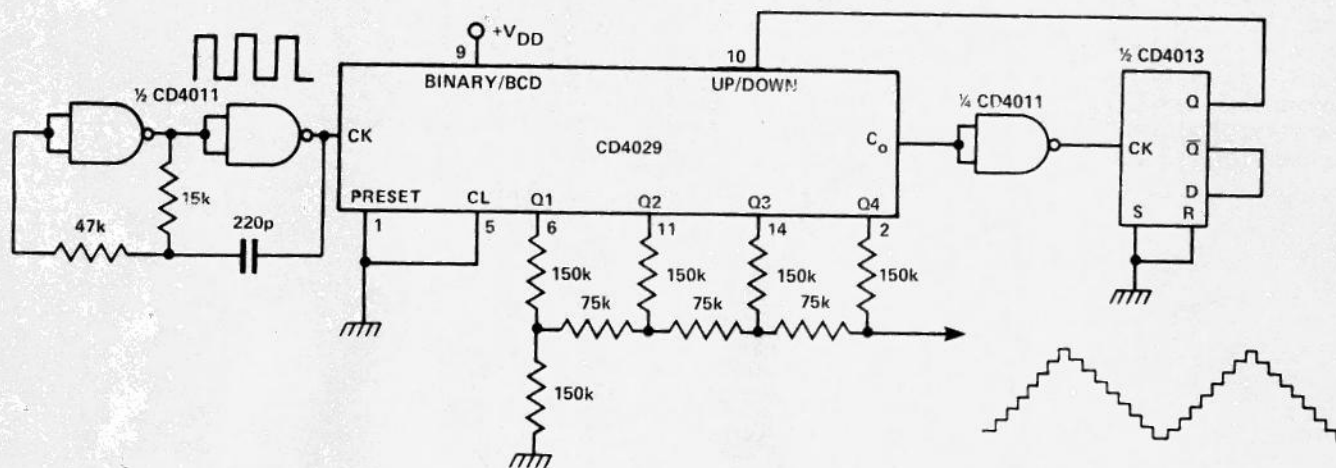


## R-2R Staircase Generator

Waveforms can be constructed by building them up out of separate elements. In this case a linear ramp waveform is generated out of 128 steps. The CD4024 is a seven stage binary counter. It is being driven from a CMOS clock oscillator similar to that already described.

The Q1 to 7 outputs divide this clock frequency by

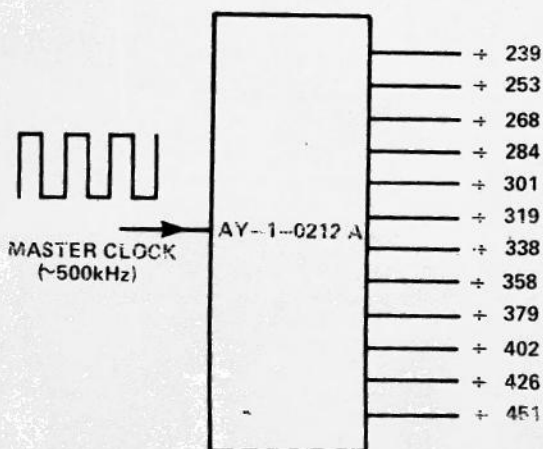
2,4,8,16,32,64 and 128 respectively and the divided outputs are then fed into an R,2R ladder network. This is in fact a Digital to Analogue Converter (DAC) and as the counter is merely counting up, then the converter will generate a linearly rising waveform made out of 128 steps. When the counter overflows, the ramp waveform resets and the process repeats itself.



## R-2R Triangle Generator

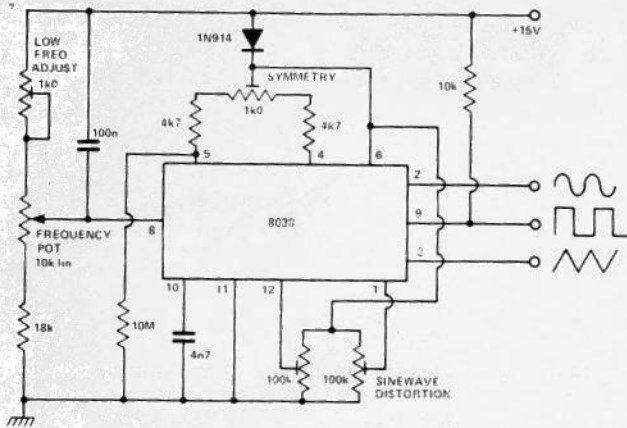
This circuit is similar to the previous except an up down counter is included. A clock signal is applied to the 4029 counter. When it has counted 16 clocks a Carry signal is generated. This clocks a D type flip-flop (4013), which changes state and reverses the up

down mode of the 4029. Thus the circuit counts up, down, up, etc. The counting is converted via an R,2R ladder into an analogue output, a triangle waveform made up out of several steps.



## Master Tone Generator

If you have ever made an electric organ, piano or string machine you would have had to produce the top twelve notes for the top octave by some means or other. More expensive organs might use 12 master oscillators which would be tuned to the top twelve semitones on the keyboard. This gives a nice free phase quality to the sound. The notes in the octaves below are made by using binary dividers and filtering. Very expensive organs would use an oscillator per note. This allows every note to be individually tuned and produces a very good sound quality. However, there is an easy way of producing the semitones and this is with a master tone generator chip. This is a pre-programmed divider having one input and twelve or thirteen outputs. A high frequency master clock is put into the chip which is divided by numbers ranging from 239 to 451. These divisions produce the semitone outputs. Thus, by using one master oscillator and one master tone generator a lot of the work of making an organ is removed. It is possible to produce more accurate intervals using 12 oscillators, but the speed and efficiency of the chip usually wins in the lower price end of the market.

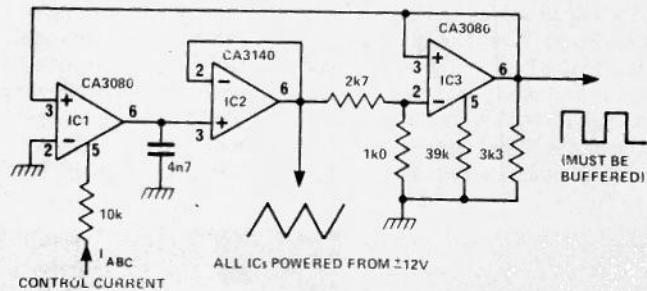


## 8038 Function Generator

There are several ICs available which perform some sort of oscillator function. One such is the Intersil 8038 which is a VCO with sine, triangle and squarewave outputs. The basic oscillator is a triangle squarewave device with a function generator to produce the sinewave. The frequency is voltage controllable but is not a linear function. The triangle symmetry and hence sinewave distortion are adjustable with a preset but change when the frequency is altered. Operation up to 1MHz is possible.

## Triangle Squarewave ICO Using CA3080's

This circuit is very similar to that of the simple triangle/square oscillator, except that the operating frequency is controlled by a current IABC. (ICO stands for current controlled oscillator, as opposed to VCO, voltage controlled oscillator). Using this circuit, a sweep range of 10,000 to 1 is possible (for IABC 500 $\mu$ A to 50nA). The CA3080 is a two quadrant multiplier and the CA3140 is a MOS FET op-amp. IC1 is used as an integrator. IC2 is a high input impedance voltage follower and IC3 is a Schmitt trigger. The CA3080 has a current output which in the case of IC1 is used to charge up a capacitor. The voltage on this capacitor is buffered by the CA3140 and fed into the Schmitt IC3. The CA3080 (IC3) forms a very fast Schmitt trigger but as it has a current output, it cannot be loaded in any way without effecting the operating frequency. The output of the Schmitt is used to make the integrator inverting or non-inverting. Thus the operation is as follows. The integrator ramps upward until the positive hysteresis level is reached. The Schmitt flips over, the integrator then ramps downwards until the negative hysteresis level is reached. The Schmitt flips back and the process is



repeated. The ramp rate is determined by the size of the current IABC is linearly proportional to the oscillation frequency. At very low currents the triangle waveform may become very asymmetrical. This is due to current mirror mismatches inside IC1 and this device may have to be specially selected for continuous symmetry.

## Precision Voltage Controlled Oscillator

The RC 4151 is a precision voltage to frequency converter. It generates a pulse train output which is linearly proportional to the input voltage. The linearity for the circuit shown is 0.05%. The IC compares the input voltage with an internally generated one. It dumps controlled pulses of charge into a Parallel RC network and compares this generated voltage with the input. If the input is greater it puts more pulses of charge into the RC network until the two are balanced. To get a larger sustained voltage in the RC network the frequency of the pulses must be increased. Thus the frequency of the pulses generated is made to be proportional to the input voltage.

The output is a pulse waveform and is intended to drive some sort of counting system, the chip being used as simple analogue to digital converter. It can also be used as a frequency to voltage converter. A maximum frequency of 10kHz has to be observed.

