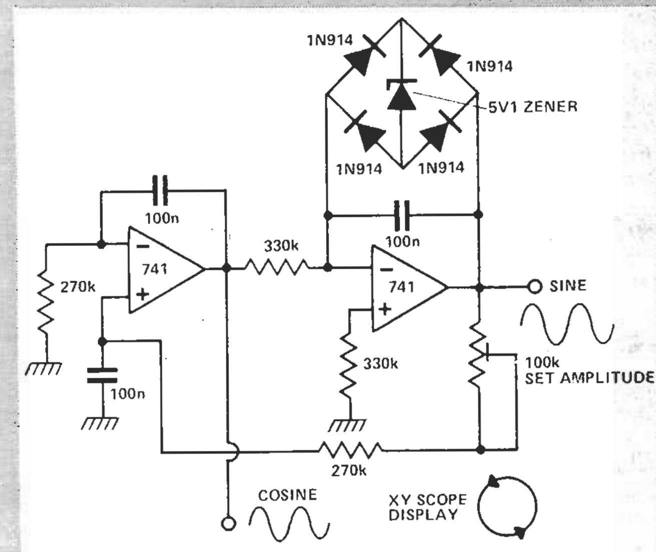
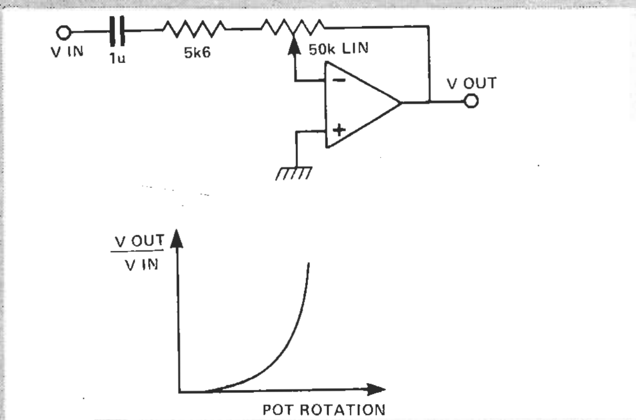
OP~AMPS PART 4

Tim Orr concludes his series by offering up circuits for some unusual applications.

Drawing circles on a scope

The circuit is that of a quadrature sine and cosine oscillator. Two integrators are employed and there is overall positive feedback. Thus the system oscillates producing sinusoids. Amplitude stabilisation is obtained with a diode bridge and a zener diode. The process of integration produces a 90° phase shift. Therefore if there is a sine wave being put into an integrator, a cosine will appear at its output. Quadrature oscillators can be used to generate circular displays on oscilloscopes by connecting the two outputs to the X and Y inputs. Other uses include quadrature panning in voltage controlled audio systems and they are also used in audio frequency shifters.



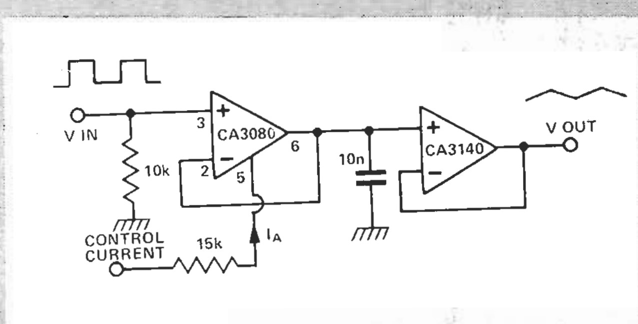


Turning a Linear Pot into a Log Pot

By using the virtual earth characteristic of an op amp, a linear pot can be made to have the characteristics of a log pot. It seems to be fair to say that low cost linear pots are far more linear than log pots are logarithmic. Thus the linear pot can be turned into a better log pot than the actual log pot itself. By varying the resistor ratio 5k6 to 50k, other laws can be produced, such as something in between log and linear or maybe a law that is even more extreme than a log law.

Controllable Slew Limiter

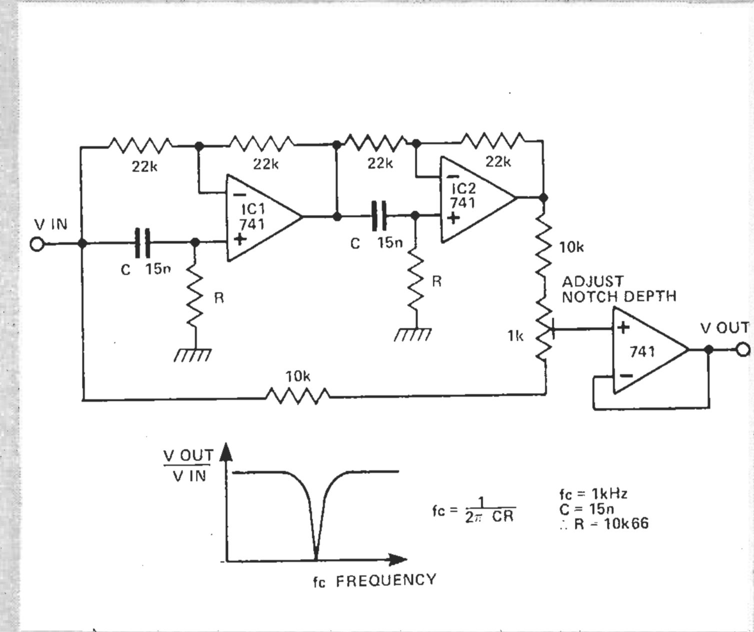
The current output of a CA3080 can be used to produce a controllable slew limiter. The 3080 is used as a voltage follower, but with a capacitive load. Thus it is possible for this stage to correctly follow small signal variations, but to slew limit when the input signal is larger. The speed of the slew limiting is determined by the current I_A. A high input impedance voltage follower (CA3140) is used to buffer the signal. This circuit is sometimes used as a non-linear filter to limit fast signals; also, it can be used as a portamento circuit for a music synthesiser.

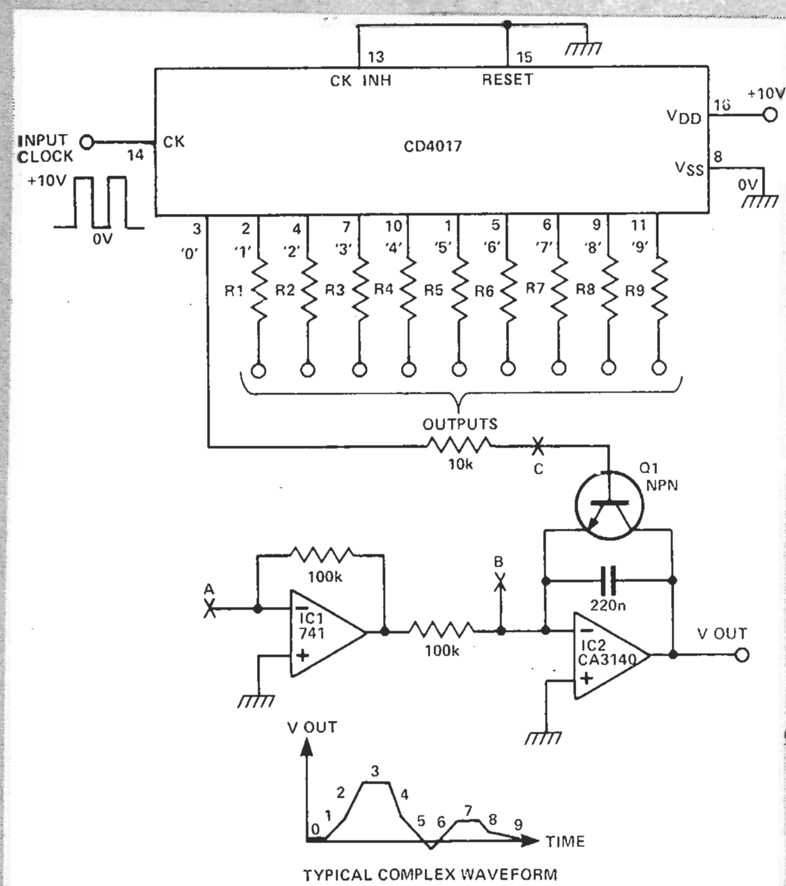


All Pass Notch Filter

Sometimes when processing analogue signals there is a constant tone which is causing a nuisance and so an active filter is called upon to 'notch' it out. The filter can be tuned so that its notch is at exactly the same frequency as this signal so that it can be selectively attenuated. This method is sometimes used to remove unwanted mains hum from poor quality recordings. The circuit works as follows: IC1 and 2 are a pair of all pass filters. These filters have a flat frequency response, but their phase changes with frequency. Their overall maximum phase shift is 360°, a phase shift of 180° occurring at a frequency of 1/2CR Hz. At this frequency the signals are inverted. Thus, by mixing the phase delayed signal with the original, cancellation can be produced which forms a notch in the frequency response. The preset is used to get the deepest notch available. The operating frequency can be changed by varying the two resistors R. For instance for 50 Hz operation, R should be —

$$10.66k \times \frac{1000}{50} = 213.2k$$ Nearest E12 fit is 220k.





Analogue Linear Segment Drawer

If you want to draw, repeatedly, a complex analogue waveform with up to 9 discrete sections then the circuit shown will enable you to do it. The CD4017 is a decade counter/decoder. A clock is applied to its input and a sequence of decoded outputs is generated. That is, output 0 goes high, then output 1, then output 2, etc. Only one output is high at any point in time. This is the sequence generator. There is also an inverter (IC_1) which drives an integrator (IC_2) which can be reset to zero by a switch. Thus, if we connect output 1 to A, the integrator's output will ramp upwards, if we connect it to B it will ramp downwards and if we connect it to C the switch will clamp the output to 0V. Also, by varying the values of R1 to 9, the integrator's ramp rate can be controlled. Thus by selectively routing the outputs to either A, B, or C and by selecting the resistor values, a complex 9 segment waveform can be drawn out.

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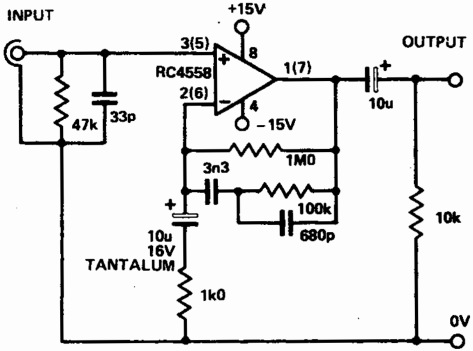
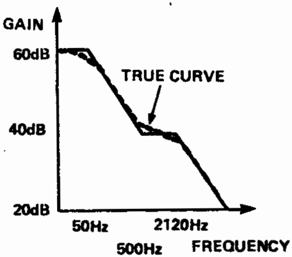
RIAA Preamp

Suitable for use with magnetic cartridge
Use RC4558 for low noise





RIAA playback curve

VOLTAGE TO CURRENT CONVERTER

The virtual earth of an op-amp and the current source characteristic of a transistor can be combined to produce a precision linear voltage to current converter. Consider the 'SOURCE' circuit. A positive voltage is applied and the op-amp adjusts itself to that a 'virtual earth' condition is maintained. This means that a current i flows through the input resistor R, where i = Vin/R. Now this current has got to go somewhere, and so it flows through the PNP transistor and comes out of the collector and into its load. Thus, the input voltage generates a current which is lineally proportional to it. There are, however, three sources of error that will affect this linearity. First the input offset voltage of the op-amp may become significant at low levels of Vin. Second, the input bias current may well rob a lot of the current when Vin is low. Third, the base current of the transistor must be subtracted from the final output current. Note that the current gain of the transistor will change with collector current variations, and so the base current loss is not a fixed percentage. However, a precise voltage to current converter can be made using an op-amp with a FET input so that the bias current is low. Also, an input balance can be used to zero out the input offset voltage, and if a FET is used to replace the bipolar transistor, then the base current problem can be removed.

The 'SINK' circuit merely swaps the transistor for an NPN type. Note that the input voltage now must be negative.

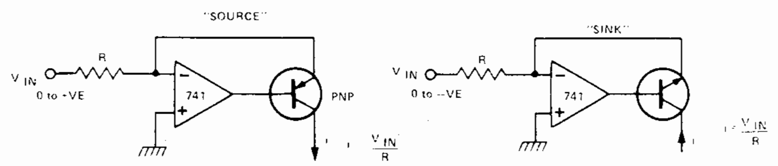


Fig. 14. Precision linear voltage to current converters.

SCHMITT TRIGGER

When DC positive feedback is applied around an op-amp, its output will come to rest in one of two states, that is in its most positive or most negative position. This type of circuit is known as a Schmitt Trigger and it is said to exhibit the property of hysterysis. Consider the circuit shown in Figure 15. Let us assume that RB is 2k and RA is 1k and the output voltage is +10V. Therefore the voltage at the non-inverting terminal is +3V3. When the input voltage becomes more positive than +3V3, the output of the op-amp will start to swing negative and in doing so will increase the voltage difference between the inputs. This will in turn make the output swing even more negative. Thus the process becomes regenerative, the output finally 'snapping' into its negative state (−10V say). The only thing that will now change the op-amp's output is if the inverting input goes more negative than the non-inverting input. When this occurs it will revert back to its original state. The two input voltages at which these transitions happen are known as the upper and lower hysterysis levels. The graph in Fig 15 shows the circuit's transfer function. Figure 16 is another Schmitt trigger circuit, but the mode of operation is inverted.

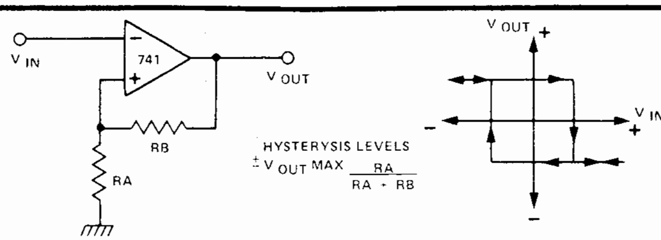


Fig. 15. Schmitt trigger configuration.

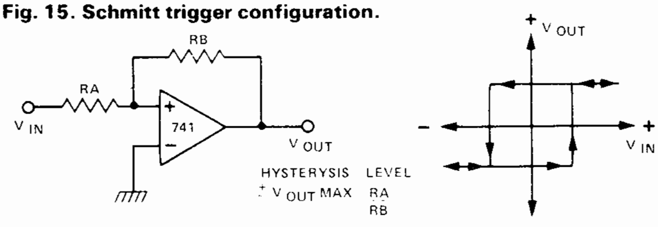


Fig. 16. Schmitt trigger with mode of operation inverted with respect to that shown in Fig. 15.

TRIANGLE SQUARE OSCILLATOR

A Schmitt trigger and an integrator can be used to construct a very reliable oscillator which generates triangle and square wave forms. The operation of the circuit is very simple and always self starting. The Schmitt trigger is formed from IC1, the integrator from IC2. Suppose the output of the Schmitt is positive. This will cause the integrator to generate a negative going ramp. This ramp is then fed back to the input of the Schmitt. When the lower hysterysis level has been reached the output of the Schmitt snaps into its negative state, current is taken out of the integrator which then generates a positive going ramp. The integrator's output ramps up and down between the upper and lower hysterysis levels. The speed at which the integrator moves is determined by the magnitude of the voltage applied to it. In this circuit, the magniture of the voltage and hence the oscillation frequency, are controlled by a potentiometer, giving a 100 to 1 control range. This circuit is the basis of most function generators. By bending the triangle it is possible to synthesis an approximation to a sinewave. With a bit more electronics it is also possible to make the oscillator voltage controlled.

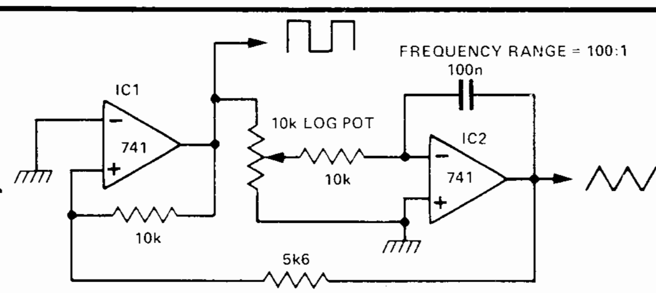


Fig. 17. A Schmitt trigger and integrator combined to produce a triangle and square wave generator.

This series continues next month with many more Op-Amp circuit configurations including envelope shapers, sample and hold circuits and various oscillators.

No Noise Is Good Noise

The last op-amp characteristic to be discussed is 'Noise'. The noise figures given in the specifications are very confusing. This is due to the fact that noise is specified in so many different ways that it is often difficult to compare devices. One may be specified in terms of Equivalent Input Noise and another device in terms of $nV/\sqrt{Hz}$ (nano volts per root Hertz)! As a generalisation it is true to say that most op-amps are relatively noisy. Some op-amps are labelled low noise, and these are quieter than the average op-amp but more noisy than a well designed descrete component amplifier. For audio work you can use ordinary op-amps for processing high level signals (100 mV to 3 V), but for amplifying low level signals (1 mV to 100 mV) you would be advised to use a low noise device. The larger the voltage gain you obtain from an op-amp stage, the worse will be the noise, therefore keep the closed loop gain to a bare minimum.

That is the end of the theory, now for some practical examples of op-amps in use. ETI

SIMPLE DIFFERENTIATOR:

Mathematically, differentiation is the reverse process to integration. Thus, in the differentiator circuit the C and the R are reversed with respect to the integrator circuit.

The input waveform is a triangle with a constant rise and fall slope. This constant slope, when presented to a capacitor will generate a constant current. When the slope direction reverses, then so will the current flow. This current when passed through a resistor (R1), will then generate a square wave.

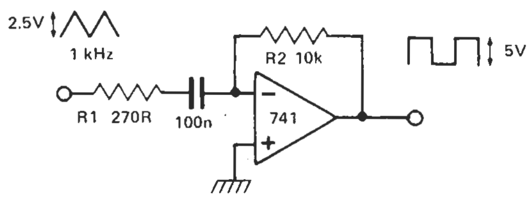


Fig. 11. Simple differentiator.

12 V REGULATED POWER SUPPLY:

The large open loop voltage gain of an op-amp is very useful in providing a regulated low output impedance power supply. A 5V1 voltage reference is generated by a zener diode ZD1 (this voltage reference could be made more stable by running it at constant current). A PNP transistor is used as a series regulator. However, this transistor inverts the signal from the op-amp output, and so, in order to get negative feedback, the feedback is taken to the non-inverting input! The operations is as follows. The inverting input is held at 5V1. If the 'PSU OUTPUT' tries to fall, the voltage at the non-inverting input falls. Therefore the op-amp's output will also fall, thus turning on the PNP transistor which then pulls up the 'PSU OUTPUT.' Thus the output voltage is stabilised. Also, the output impedance is very low, due to this negative feedback. The output impedance at high frequencies (where the op-amp gain is low) is further reduced by the 10u capacitor. To squeeze the last drop of voltage out of the system, before a collapsing unregulated supply rail causes the regulated supply to drop out, a 5V1 zener diode (ZD2) has been included. This allows the op-amp output to work at about 7 volts below the unregulated supply rail. Thus, a regulated output is maintained until the PNP transistor saturates. This means that the unregulated rail can fall to within about 200 mV of the regulated rail!

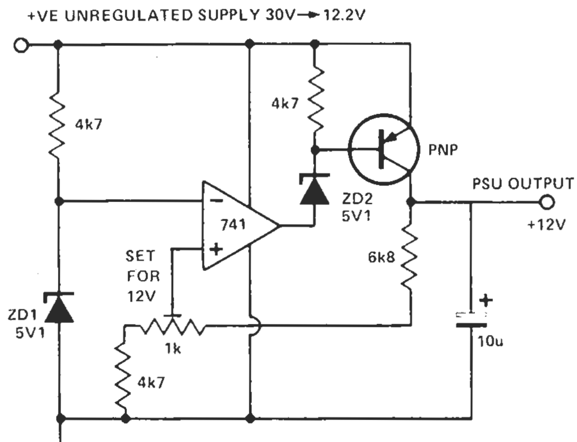


Fig. 12. 12 V regulated power supply.

LEVEL CLAMPING:

It is sometimes required to limit the excursion of the output voltage of a linear amplifier. This can be achieved by using non-linear feedback, in this case with zener diodes. Once the voltage at the op-amp's output exceeds the zener breakdown voltage plus a forward diode drop (0V7) from the forward biased Zener), the effective impedence of the feedback becomes very low. Thus the voltage gain, above this zener voltage, also becomes very low. The output voltage appears to be clamped at a fixed potential. By changing the zener value, this potential can be varied at will. Also, by making the two zeners have different values, correspondingly different negative and positive levels can be obtained. This circuit is, however, far from ideal. The zener diodes don't have very sharp 'Knees' in their transfer characteristics and the clamping can sometimes be very sloppy, particularly when low voltage zeners are used. Also, the zener diodes tend to have a large amount of charge storage, which impairs the high frequency performance.

Sometimes, however, sloppy clamping is considered useful. For instance, if the zeners are replaced by two ordinary diodes in parallel and pointing in different directions. Then any signal applied to the input will receive some non-linear distortion. This distortion is rich in odd harmonics, and is the basis of many FUZZ box designs for musical effects units.

Fig. 13. Level clamping.