ELECTRONOTES

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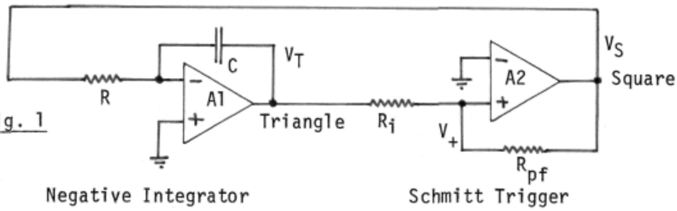
SIMPLE TRIANGLE-SQUARE OSCILLATOR

The simple op-amp multivibrator discussed in AN-28 uses only one op-amp and is relatively easy to use if only a square-wave output is needed. The curved triangle-like waveform that also appears in the circuit is completely unbuffered, and is therefore difficult to use in many applications. The present circuit produces a well-defined triangle waveform. It uses two op-amps and is essentially a negative integrator and a Schmitt trigger in a closed loop. The basic circuit is well known. Here we will review it, set up the basic equations, and show how some refinements in the calculations can be used to allow for the use of real op-amps.

The basic Triangle-Square oscillator is shown in Fig. 1.

Fig. 1



The analysis of Fig. 1 starts with two assumptions. First we assume that since there is no negative feedback on A2 that the output of A2 is either at +15 or -15 (assuming a ±15 volt supply), and secondly that since there is negative feedback on A1, that the (-) input is at ground potential along with the (+) input. These two assumptions tell us that there is a current through R of magnitude 15/R, which may be either toward or away from the capacitor C. Since the (-) input of A1 is a very high impedance (ideally, it draws no current at all), the current through R must be flowing through the capacitor C (where else would it go?). Thus, the capacitor C is being charged and correspondingly the voltage across it is changing. Since negative feedback is being employed, the (-) input of A1 remains at ground potential and therefore the output voltage of A1 must be changing. We can consider the manner in which a capacitor charges. The voltage on a capacitor is related to the charge (Q) on it by Q = CV. Since C is a constant, the voltage and the charge are proportional, and hence the change of charge and the change of voltage are proportional as well. Now, the change of charge is the current into or out of the capacitor. We can represent small changes by the symbol Δ. Thus ΔQ is a small change in charge and ΔV is a small change in voltage. We can assume all these changes to take place over a small interval of time Δt. The rates of change of charge and voltage are thus ΔQ/Δt and ΔV/Δt respectively. Since Q = CV, it is also true that:

$$\text{Current Through R} = \frac{\Delta Q}{\Delta t} = C\,\frac{\Delta V}{\Delta t} = C\cdot[\text{Slewing Rate of Triangle}]$$

Thus, for a constant magnitude of current, the output voltage of A1 changes at a constant rate.

We have assumed that A2 is either at +15 or at -15 volts. In either case, we are interested in the conditions under which the output of A2 will change. The circuitry around A2 is that of a Schmitt Trigger as discussed in AN-31. We can think of A2 as operating as a comparator, and since the (-) input is grounded, the output will change whenever, the voltage on the (+) input crosses zero. We can consider R_i and R_{pf} to form a voltage divider. We assume no current is drawn by the (+) input of A2. Thus the voltage on the (+) input is:

$$V_+ = \frac{V_T R_{pf} + V_S R_i}{R_{pf} + R_i}$$

which is equal to zero when $V_T R_{pf} = -V_S R_i = -15R_i$. This value of V_T is such that the (+) input of A2 is zero, and corresponds to the peak value of the triangle since beyond this point the output of A2 will switch, and the direction of change of V_T will reverse. Thus, we can get an expression for the amplitude of the triangle as:

$$V_{TM} = 15\frac{R_i}{R_{pf}} \qquad \text{[Maximum value (amplitude) of } V_T\text{]}$$

For one full cycle of the triangle, the voltage at the output of A1 must change through a full range of $4V_{TM}$ (up, back to zero, down, back up to zero). We are now in a position to calculate the time for one cycle, and thus the corresponding frequency. We previously found the slewing rate of the triangle to be:

$$\Delta V/\Delta t = (\text{Current Through R})/C = (15/R)/C = 15/RC$$

To use the old terminology for "Hertz" as "cycles-per-second", we can write:

$$\frac{\text{Cycles}}{\text{Second}} = \frac{\text{Volts}}{\text{Second}} \cdot \left[\frac{\text{Volts}}{\text{Cycle}}\right]^{-1}$$

Volts/Second is just $\Delta V/\Delta t$ and Volts/Cycle is just $4V_{TM} = 60R_i/R_{pf}$, so we can arrive at the equation for the frequency of the oscillator of Fig. 1 as:

$$f = (15/RC)\cdot(60R_i/R_{pf})^{-1} = \frac{1}{4RC}\frac{R_{pf}}{R_i} \qquad \text{[Frequency of Oscillation]}$$

Note that for oscillation to occur, R_{pf} must be greater than R_i, so the ratio R_{pf}/R_i must always be greater than 1. For normal safe ampiltude levels, the ratio will be at least 2 or more. A 5 volt amplitude of the triangle gives $R_{pf}/R_i = 3$. Thus, the frequency of oscillation in most cases will be of general magnitude 1/RC. Note that if R_{pf}/R_i is set exactly to 4, the frequency is 1/RC and the amplitude is 3.75 volts.

Fortunately, for a moderate range of frequencies, 1 Hz to 2 kHz say, the above analysis works quite well. About the only change we need make is an adjustment for the fact that real op-amps may not reach the full supply voltage, and thus the output of A2 will not be at a 15 volt level, but often more like 14 volts. This changes the amplitude formula to $V_{MT} = 14R_i/R_{pf}$, but the output voltage of A2 cancels out of the frequency formula so that stays the same. For normal op-amps, R should not be more than 1 megohm, and R_i and R_{pf} should be chosen in the range of 10k to 100k.

When it comes to very low frequencies (below 1 Hz), it is sometimes necessary to use an op-amp for A1 that has very low bias current, and perhaps to correct for input offsets of A1 and A2 according to the data with the op-amps. Note that in general you can not just make C larger to get lower frequencies because eventually you will need to use electrolytic capacitors which will have polarity and leakage problems. There are plenty of good and inexpensive op-amps available for A1 however (the CA3140 for example). R can be 100 megohms or more with such op-amps.

At high frequencies (greater than 2 kHz) the speed of A2 is likely to become a problem. Here, an uncompensated LM301 or type 748 is suggested for frequencies to 10 kHz. Above that, a high speed comparator should be used according to the setup data specified by the manufacturer. The 301 and 748 type op-amps may be used up to 30 kHz if waveform inaccuracies and inaccuracy in the frequency formula can be tolerated.