Variable Duty-Cycle Oscillator

by Kenneth A. Kuhn
March 31, 2013

This is a demonstration circuit for students intended to be useful for some student applications and to be educational on some of the finer points of circuit design. The circuit in Figure 1 can tune over a ten to one frequency range and create an output waveform with a duty cycle variable between 0 and 1. The circuit has the feature that frequency and duty cycle are independent although a certain interaction may occur as discussed later. The circuit will operate to over 100 kHz. The low frequency limit is determined by whatever the practical maximum capacitance that can be obtained for C_2.

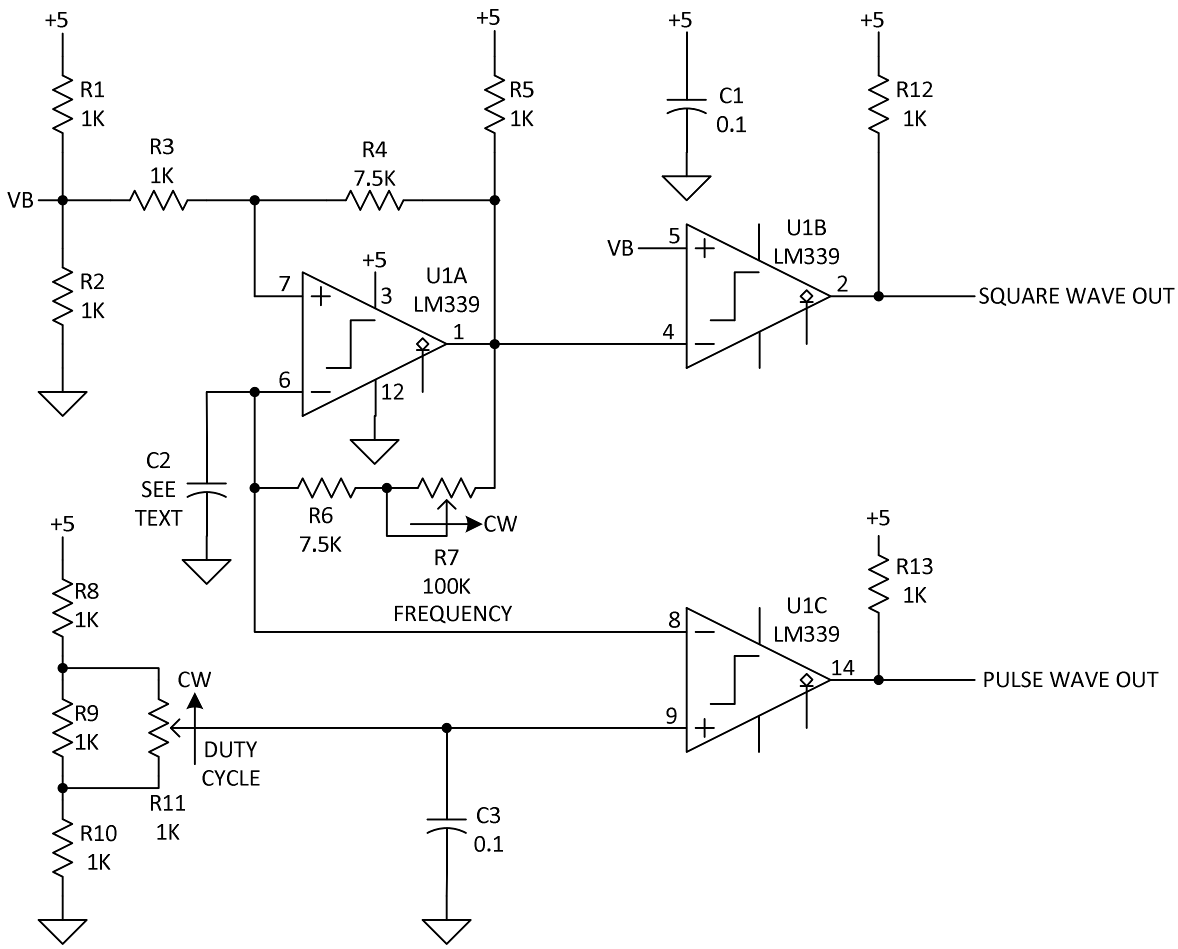

Figure 1: Variable duty-cycle oscillator schematic

The frequency in Hz is approximately

$$\boldsymbol{F = \frac{1.23}{(R_6 + R_7)C_2}} \quad \textbf{(1)}$$

Variable Duty-Cycle Oscillator

R_7 is used in rheostat mode so its resistance is a function of the wiper position. Equation 1 tends to overestimate the frequency particularly at high frequencies because it does not take into account the switching time of U_1 and effects of R_5 and other resistors. The student should derive this equation based on class notes for Schmitt triggers and state machine oscillators.

As shown the frequency is adjustable over a ten to one range. R_7 could have less resistance for a smaller tuning range if a wide range is not needed. The tuning is inversely related to resistance and is thus a very non-linear function of pot rotation. R_6 could have higher resistance if desired, particularly at low frequencies so that the required capacitance of C_2 is not so large.

The waveform across the capacitor is an exponential charge/discharge waveform in the fraction of a time constant region and approaches a triangle wave. The amplitude is nominally 1 volt peak-peak centered about 2.5 volts. The duty cycle adjustment varies a voltage to the non-inverting input of U_3 from 2 volts for a 0 duty cycle (output of U_3 is always low) to 3 volts for a unity duty cycle (output of U_3 is always high). The output of U_3 is high when the voltage from the duty cycle potentiometer exceeds the waveform voltage. Depending on the actual resistance of the resistors the duty cycle adjustment may not go all the way to zero or to unity. R_9 could be tweaked upwards or downwards to compensate so that full duty cycle adjustment is possible.

Equation 2 provides a rough guide (assuming R_6 is 7.5K – the equation can be rescaled for other values) for choosing C_2 based on the highest frequency of oscillation ($R_7 = 0$). It is best to round this value down and use a capacitor one or more standard values below this computation. R_7 can be adjusted upwards to reduce the frequency to that desired.

$$\boldsymbol{C_{2\_rough} = \frac{1.64 \times 10^{-4}}{F_{HIGH}}}$$

(2)

Design discussion

The circuit was designed to utilize readily available components. Rather than a variety of different resistor values, most of the resistors are 1K as it is desirable to minimize the number of different values in a system – although that should not compromise the function – functionality is more important that component minimization. So all the pull-up resistors (R_5, R_{12}, and R_{13}) were chosen to be 1K as it was desired to make those as small as possible consistent with the current sinking capability of the LM339 – 1K is not much above the practical minimum resistance. The 2.5 volt (V_B) reference voltage divider (R_1 and R_2) was also constructed using 1K resistors although other values could have been used but 1K works well and is in keeping with the minimum different value concept. The Schmitt trigger consists of an R_P of 1.5K ($R_1||R_2 + R_3$) and an R_F (R_4) of 7.5K. That produces a low threshold voltage of 2 volts and a high threshold voltage of 3 volts. U_{1B} buffers and also inverts the square wave generated by U_{1A}. The switching threshold is derived from the R_1, R_2 voltage divider which fluctuates about 2.5 volts but the input signal from U_{1A} is practically 5 volts peak-peak so that small fluctuation is of no consequence. The inversion tends to keep the power supply current to U_1 constant over the oscillation cycle – in one half of the cycle U_{1A} is sinking current and in the other half cycle U_{1B}

is sinking current. That concept helps to reduce some odd interactions that can occur in such circuits.

It is critical that C_1 be located as close as possible across the power pins of U_1 to reduce the effects of multiple switching in the same device. It is not possible for the math to bear it out but there are inevitable edge couplings in a device where logic switching is taking place at similar times. The effect in this circuit is that when any edge of the rectangular output is close in time to an edge of the square wave that there will be a tendency for the edges to cause convergence or divergence depending on the phase of the coupling. The frequency of oscillation will be perturbed and certain duty cycles will be unattainable. It is an effect that is best observed in an actual circuit. At low frequencies the effect may be so minimal as to be ignored. The effect becomes worse as frequency is increased. The only practical solution is to separate the oscillator function from the duty-cycle function by using separate devices and high isolation in the power supply and ground. Be aware that this problem can occur in any circuit unless precautions are taken to prevent it. Experience with the issue is a much better teacher than this text ever can be. This is a classic case where the physical layout of all aspects of the circuit determines whether the performance is acceptable or useless.

At frequencies above several tens of kHz it will be observed that the amplitude of the charge/discharge waveform across C_2 increases with frequency. This is a result of the finite switching time of U_1.

The purpose of C_3 is to hold the voltage at the non-inverting input of U_{1C} steady when the duty cycle potentiometer (R_{11}) is adjusted so that possible momentary erratic wiper contact does not cause jumpiness in the duty cycle. The 0.1 uF shown is probably adequate for most cases but larger capacitance may be required when using lower quality potentiometers.