How to Design a Square-Wave Oscillator Using the LM 555/556 IC

This paper presents a design procedure for configuring the LM 555/556 IC as a square-wave oscillator (a.k.a. the astable multivibrator). The 555 is a multi-purpose chip that will operate at DC power supply potentials from $V_{CC} = +5$ Vdc to $+18$ Vdc. The schematic for the LM 555/556 square-wave generator is shown in figure 1. Our objective is to determine values for the capacitor C and the resistors R_A and R_B.

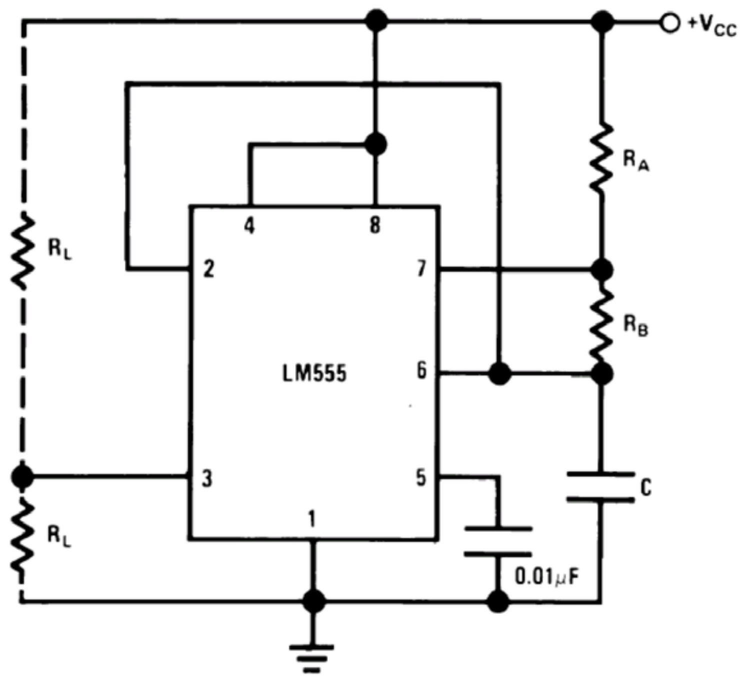

Figure 1 - Schematic for running the LM 555 as square-wave generator.

Note that this configuration requires that

$$t_1 > t_2 \qquad (1)$$

where:

$t_1 =$ the on-time for one period.

$t_2 =$ the off-time for one period.

i.e. the duty cycle must be chosen in the range of 55% - 95%. If a duty cycle in the range of 5% - 45% is required, then simply connect the output to an inverter (e.g. the LS7404 TTL IC). For a 50% duty cycle see the discussion at the end of this article.

Procedure:

Step 1). Choose a target frequency between 0.1 Hz and 100 kHz.

Step 2). Choose a duty cycle in the range of 55% - 95%. Do not choose a value near 50%. If you require a duty cycle of 50%, you will have to use a different circuit confiuration than the one shown in figure 1 (see the discussion at the end of this article). If we denote the the duty cycle by the variable d, then a duty cycle of say 65% corresponds to $d = 0.65$.

Step 3). Compute the period T (in seconds) of the square wave using the formula

$$T = \frac{1}{f} \tag{2}$$

Make sure the frequency f is entered in Hz.

Step 4). Compute the on-time t_1 for one period using the formula

$$t_1 = d \times T \tag{3}$$

Step 5). Compute the off-time t_2 for one period using the formula

$$t_2 = T - t_1 \tag{4}$$

Step 6). Choose a standard value for the capacitor C by referring to the graph of C *vs* f, in figure 2

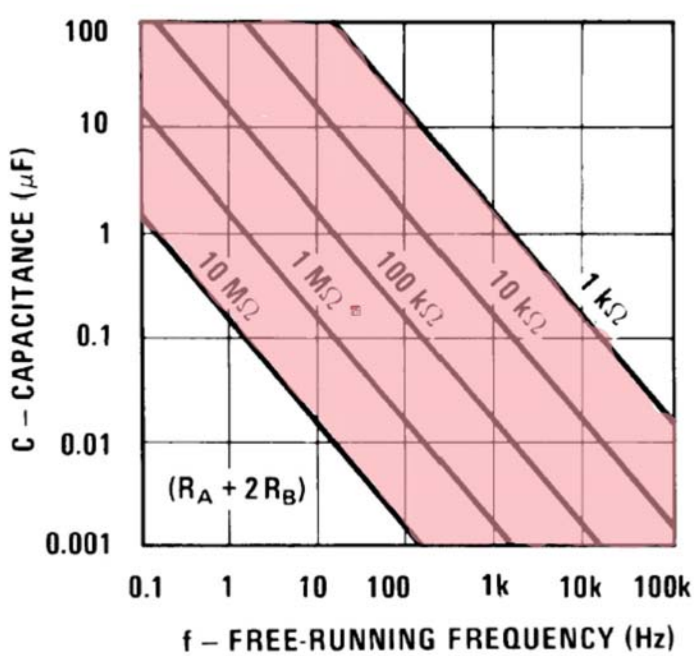

Figure 2 - Capacitance vs. frequency

Note that you must stay within the shaded area for a stable design. Alternatively, if this procedure will be programmed later, the value of C (in μF) can be determined using the following equation:

$$C = \frac{1}{a + bf} \tag{5}$$

where

$$a = -1.2905 \times 10^{-6} \quad , \quad b = 0.058900409 \tag{6}$$

The user should adjust the value of C to the nearest standard component value. A computer program written for Mathematica is given at the end of this document that automates the design.

Step 7). Compute the value of R_B using the following equation

$$t_2 = 0.693(R_B)C \tag{7}$$

Step 8). Use the result of step 7 and solve the following equation for R_A :

$$t_1 = 0.693(R_A + R_B)C \tag{8}$$

Step 9). Synthesize the necessary resistive networks to make R_A and R_B using the standard values for 5% tolerance resistors (i.e. 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2). Build and test the circuit to verify the correct operation. Record the percentage error between your target design and the actual design.

Design Example:

Design a square-wave oscillator with a frequency of 2 kHz and a duty cycle of 65%.

Step 1). Choose $f = 2000\ Hz$

Step 2). Choose $d = 0.65$

Step 3). Compute the period

$$T = \frac{1}{f}$$

$$T = \frac{1}{2000\ Hz}$$

$$T = 0.0005 \text{ sec}$$

Step 4). Compute the on-time t_1 for one period.

$$t_1 = d \times T$$
$$t_1 = (0.65)(0.0005)$$
$$t_1 = 3.25 \times 10^{-4} \text{ sec}$$

Step 5). Compute the off-time t_2 for one period

$$t_2 = T - t_1$$
$$t_2 = 0.0005 - 3.25 \times 10^{-4}$$
$$t_2 = 1.75 \times 10^{-4}$$

Step 6). Choose or compute the value for C in μF

$$C = 0.1 \ \mu F = 1 \times 10^{-7} \ Farads$$

Step 7). Compute the value of R_B

$$R_B = \frac{t_2}{(0.693)C}$$
$$R_B = \frac{1.75 \times 10^{-4}}{(0.693)(1 \times 10^{-7})}$$
$$R_B = 2525.3 \ \Omega$$

Step 8). Solve for R_A

$$R_A = \frac{t_1}{(0.693)C} - R_B$$
$$R_A = \frac{3.25 \times 10^{-4}}{(0.693)(1 \times 10^{-7})} - 2525.3$$
$$R_A = 2164.5 \ \Omega$$

Step 9). Synthesize the necessary resistive networks to make R_A and R_B using standard value 5% tolerance resistors. For $R_A = 2164.5\ \Omega$, simply use a $2.2\ k\Omega$ resistor since that results in only 1.6% error and is less than the 5% tolerance of our resistors (not to mention the probably higher tolerance on the capacitor value). For $R_B = 2525.3\ \Omega$, we can connect a $2.2\ k\Omega$ resistor in series with a $330\ \Omega$ resistor for a total resistance of $2.53\ k\Omega$ (a 0.2% difference).

Schematic for a 50% Duty Cycle

If a duty cycle of 50% is desired (for say a standard clock signal) then the following circuit schematic may be used:

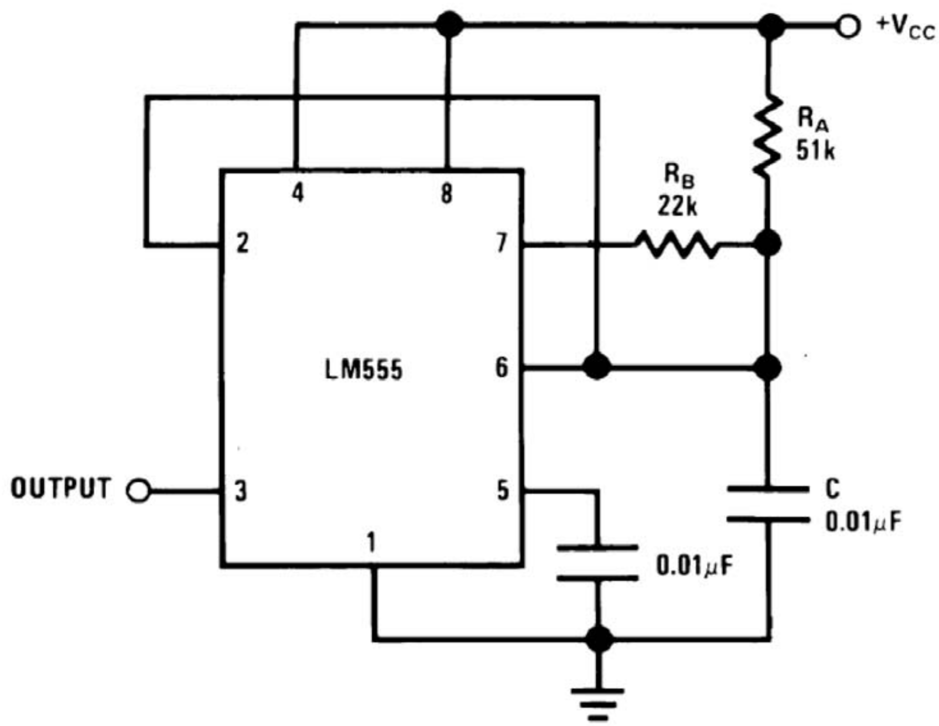

Figure 3 - LM555 Schematic for a 50% Duty Cycle

The value for the on-time (or output high) t_1 is the same as before

$$t_1 = (0.693)R_A$$

Mathematica Program to Design the Square Wave Generator

```
f = 2000;                          (* Frequency in Hz *)
d = 0.65;                          (* Duty Cycle in %/100 *)
a0 = -1.290523 × 10^-3;
b0 = 0.058900409;
a1 = 0.16660773;
b1 = 0.96966209;
c1 = 5.5762949;
a2 = 0.83636364;
b2 = 0.14859694;
c2 = 0.0099436092;
d2 = 0.005455575;
e2 = -0.00061617321;
f2 = 3.0165919 × 10^-5;
c = 1 / (a0 + b0 * f);
mag = 10^(Floor[Log[10, c]]);
cint = c / mag;
index = c1 * Log[(cint - a1) / b1];
index =
  Round[index];
stdvalue = a2 + b2 * index + c2 * index^2 + d2 * index^3 +
   e2 * index^4 + f2 * index^5;
stdvalue = Round[stdvalue * 10] / 10;
stdcap = stdvalue * mag;
```

```
period = 1 / f;
t1 = d * period;
t2 = period - t1;
RB = t2 / (0.693 * stdcap * 1 × 10 ^ -6);
RA = t1 / (0.693 * stdcap * 1 × 10 ^ -6) - RB;
Print["LM555 Square Wave Oscillator Design"];
Print["-----------------------------------"];
Print["Frequency = ", f, " Hz"];
Print["Period = ", N[period], " seconds"];
Print["Duty Cycle = ", d];
Print["C = ", N[stdcap], " microfarads"]
Print["RA = ", RA];
Print["RB = ", RB]
```

Program Output

```
LM555 Square Wave Oscillator Design

-----------------------------------

Frequency = 2000 Hz

Period = 0.0005 seconds

t1 = 0.000325 seconds

t2 = 0.000175 seconds

Duty Cycle = 0.65

C = 0.0082 microfarads

RA = 26396.4

RB = 30795.8
```