Background

The most popular timer or waveform-generator IC is the 555 (and its successors). It is also an easily misunderstood chip. A simple equivalent circuit of the 555 is shown in Figure 1. A resistor divider network produces reference voltages of $1/3V_{CC}$ and $2/3V_{CC}$ for the op amps — V_{CC} is the voltage used to power the chip, typically 5 volts or more. The two op amps function as comparators causing the output to change whenever the input voltage goes above or below their reference input. For example, whenever the TRIGGER* input is below $1/3V_{CC}$ the output of the 555 is high (near V_{CC}). The THRESHOLD works in exactly the opposite way; whenever the THRESHOLD input is above $2/3V_{CC}$ the output of the 555 will be low (approximately zero). There is also a separate transistor output called DISCHARGE which can be used as a separate switch to turn things on and off. By connecting these inputs and outputs in clever ways the 555 can be made to perform a very large number of electrical functions.

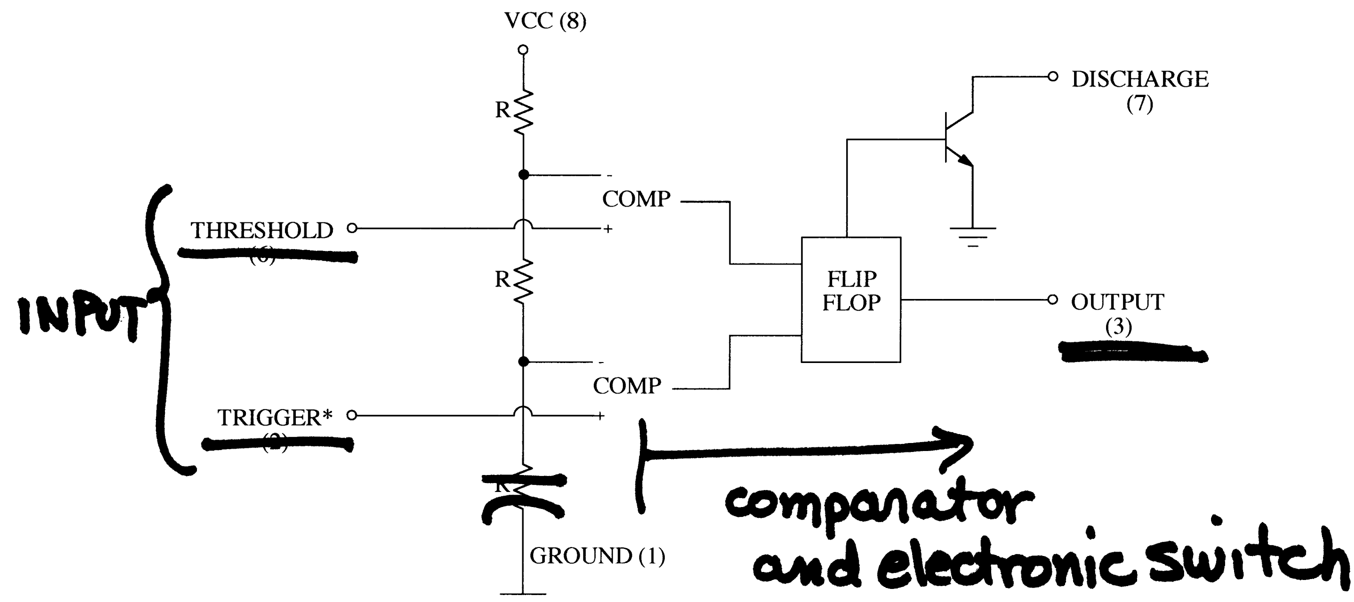


Figure 1. Simplified 555 schematic.

if input (trigger*) < $\frac{1}{3}V_{cc}$ output → Vcc

if input (threshold) > $\frac{2}{3}V_{cc}$ output → 0

NOTE: The * in the TRIGGER* is a common digital logic notation for indicating that this is a low true logical signal. When you see TRIGGER* you read it and say it as NOT TRIGGER. We will learn about digital logic later; however, a normal digital logic signal is “true” when it is high or near 5 volts, and “false” when it is low, or near zero volts. This is called a high true signal since the voltage is high when the signal is true. The * simply indicates that the logic signals are inverted, or low true — the signal is “true” when the voltage is near zero, and “false” when the voltage is near 5 volts.

The easiest way to understand the workings of the 555 is to look at an example. Figure 2 shows the 555 connected to operate as an oscillator. When the power is first turned on, the capacitor is initially discharged; so the 555 TRIGGER* input is low (near zero) which makes the OUTPUT HIGH, the DISCHARGE transistor is open, and the capacitor charges toward 10 volts (the power supply voltage) through $R_A + R_B$. When the capacitor voltage reaches about $2/3*V_{CC}$, the op amp connected to the THRESHOLD input causes the OUTPUT to go to zero. The DISCHARGE switch also turns on and shorts C to ground through R_B. This causes the capacitor voltage to decrease to zero. However, as soon as C's voltage drops below $1/3*V_{CC}$ the op amp connected to the TRIGGER* input senses this. The op amp output changes which causes the 555's OUTPUT to go high and opens the DISCHARGE pin causing C to charge up again. The basic operation of this circuit is cyclic, with C's voltage going back and forth between $1/3*V_{CC}$ and $2/3*V_{CC}$, with a period given by $T = 0.693(R_A+2R_B)C$. This formula is an approximate one supplied by the manufacturer on data sheets for the 555.

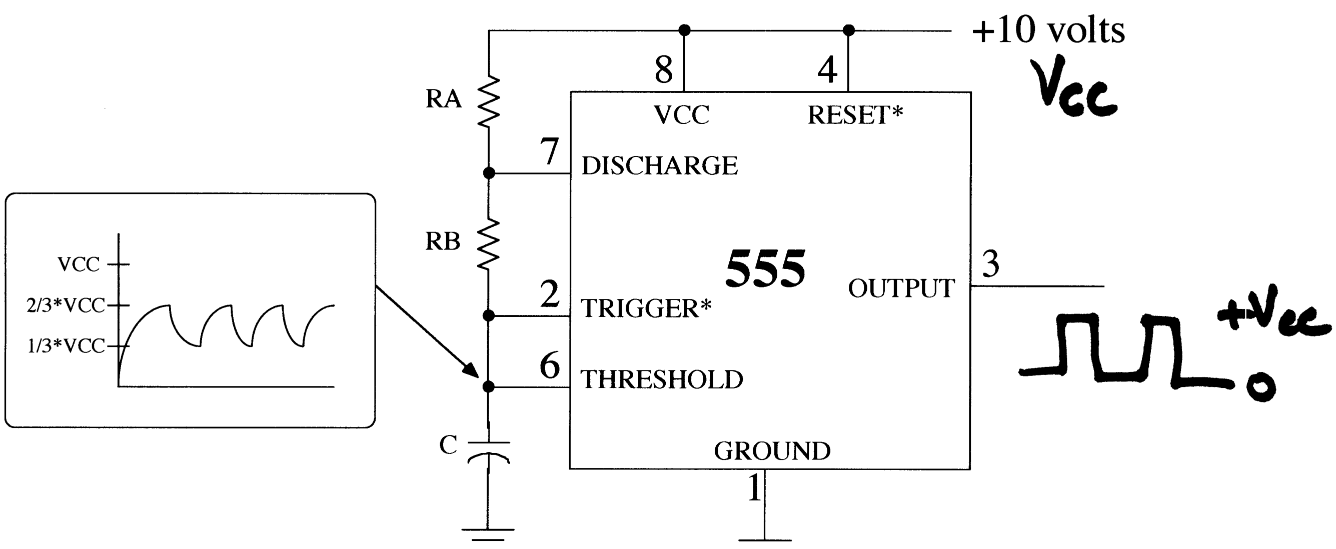
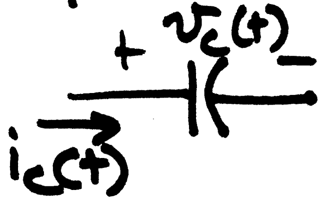


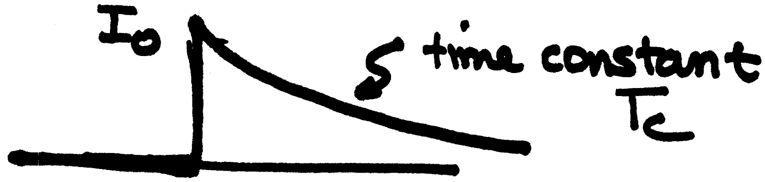
Figure 2. The 555 connected as an oscillator.

A circuit that produces a repetitive output like that shown in Figure 2 is called an oscillator. The 555 makes a pretty good oscillator. The 555 can also be used to generate single pulses of arbitrary width. This type of circuit is called a monostable or one shot and is extremely useful to “clean up” noisy pulses. Because the 555 integrated circuit contains comparators, gates, and flip-flops people have found many non-timer uses for the 555 and it has become a game in the

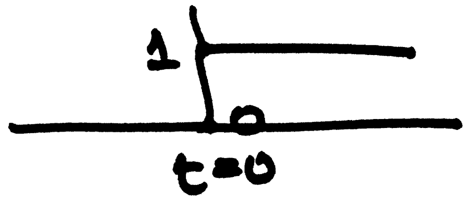
Example 6-4 exponential waveform



$$i_c(t) = I_0 e^{-\frac{t}{T_c}} u(t)$$



$u(t) =$



$$i_c = C \frac{dv_c}{dt}$$

$$\int_0^t \frac{1}{C} i_c \, dt = \int_0^t dv_c$$

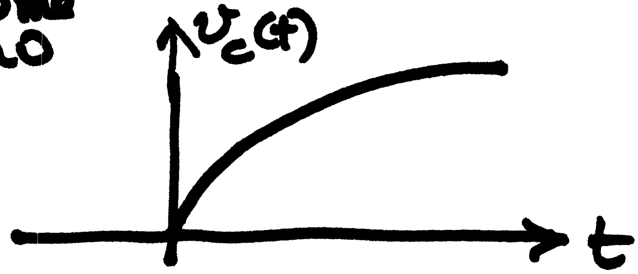
$$\frac{1}{C}\int_0^t I_0 e^{-\frac{t}{T_c}} u(t) \, dt = v_c(t) - v_c(0)$$

($u(t) \to 1$; $v_c(0)$: initial condition often zero)

$$\frac{I_0}{C} \left. \frac{e^{-\frac{t}{T_c}}}{-\frac{1}{T_c}} \right|_0^t = -\frac{I_0 T_c}{C}\left[e^{-\frac{t}{T_c}} - e^0\right] = \frac{I_0 T_c}{C}\left[1 - e^{-\frac{t}{T_c}}\right]$$

($e^0 \to 1$)

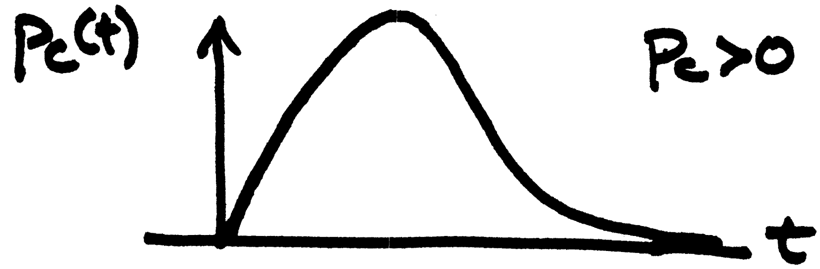
$$v_c(t) = \underbrace{v_c(0)}_{\text{assume zero}} + \frac{I_0 T_c}{C}\left[1 - e^{-\frac{t}{T_c}}\right]$$



$$p_c(t) = v_c(t)\, i_c(t)$$

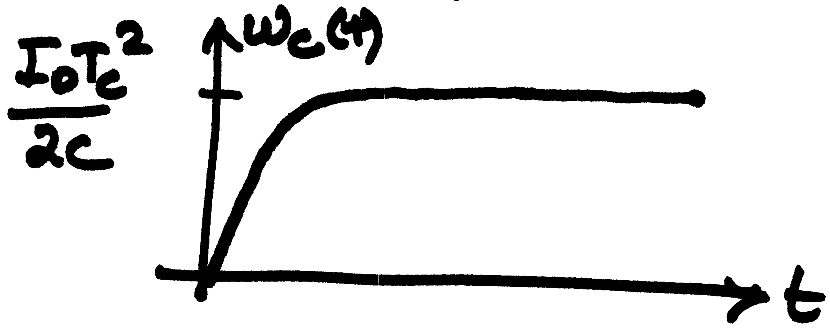
$$= \frac{I_0 \tau_c}{C}\left[1 - e^{-\frac{t}{\tau_c}}\right] I_0 e^{-\frac{t}{\tau_c}}$$

$$= \frac{I_0^2 \tau_c}{C}\left[e^{-\frac{t}{\tau_c}} - e^{-\frac{2t}{\tau_c}}\right]$$

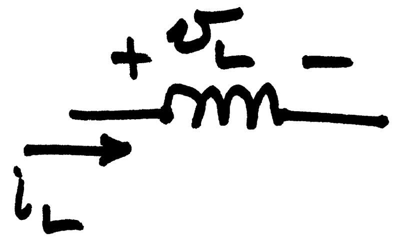


$p_c > 0$ charging

$$w_c = \frac{1}{2} C V^2 = \frac{1}{2} C v_c^2(t)$$



Inductor



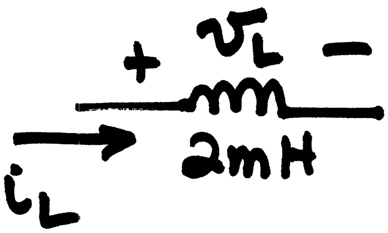
$$v_L = L\frac{di_L}{dt}$$

observations

① if i_L = constant $v_L = 0$
i.e. looks like a short

② if i_L is discontinuous
$u(t)$
↓
$\delta(t)$

Example 6-6

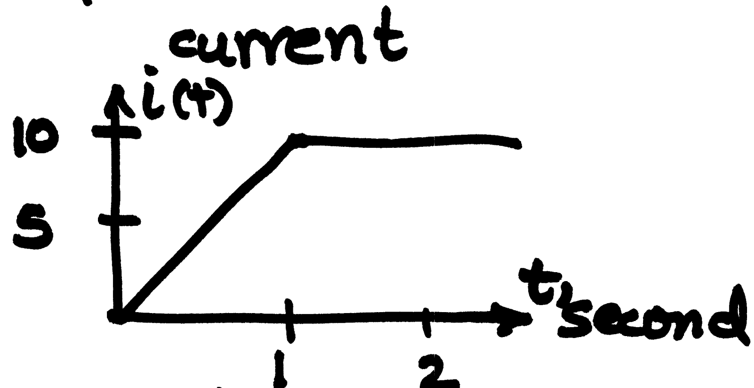


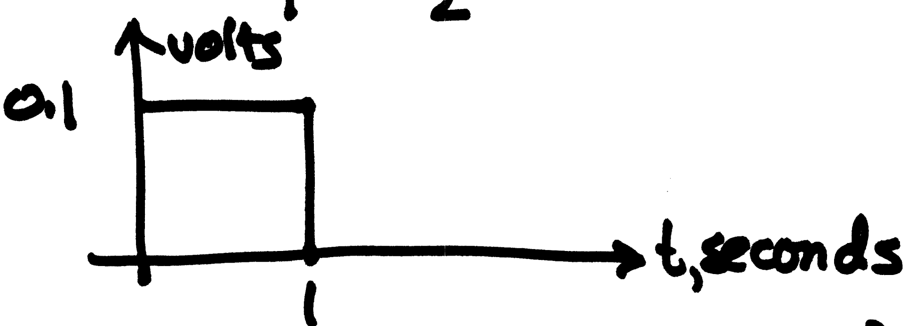
given $i_L = 4\sin 1000t + \sin 3000t$ Amps

$$v_L = L\frac{di}{dt} = (.002)\left[4(1000)\cos(1000t) + 1(3000)\cos(3000t)\right]$$

$$= 8\cos 1000t + 6\cos 3000t \text{ volts}$$

Example





capacitor

$$i = C\frac{dv}{dt}$$

inductor

$$v = L\frac{di}{dt}$$

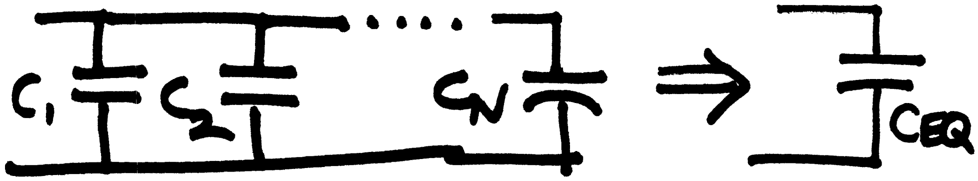
$$0.1 = L\frac{10}{1}$$

$$L = 0.01 \text{ Henrys}$$

equivalent capacitors & inductors

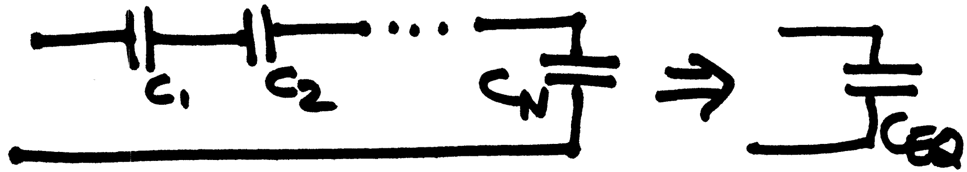
capacitors

parallel



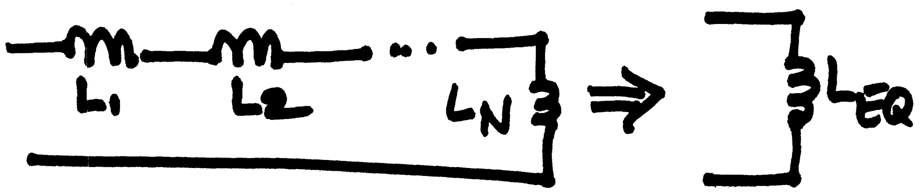
$$C_{EQ} = C_1 + C_2 + \dots + C_N$$

series

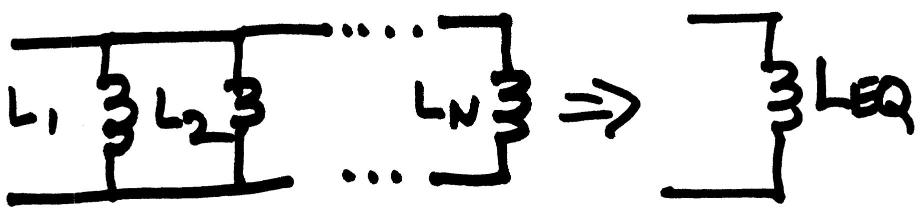


$$\frac{1}{C_{EQ}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots \frac{1}{C_N}$$

inductors

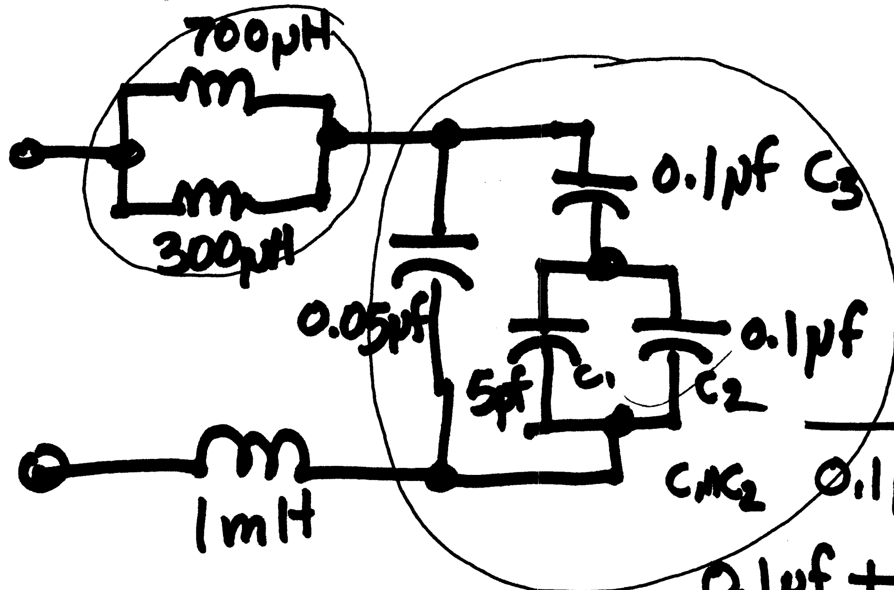


$$L_{EQ} = L_1 + L_2 + \dots + L_N$$



$$\frac{1}{L_{EQ}} = \frac{1}{L_1} + \frac{1}{L_2} + \dots + \frac{1}{L_N}$$

Example 6-14 (c)



$C_1 \| C_2$ 0.1µf ∥ 5pf

0.1µf + 0.000005µf

≈ 0.1µf

$$\frac{1}{L_{EQ}} = \frac{1}{700} + \frac{1}{300}$$

$L_{EQ} = 210\mu H$

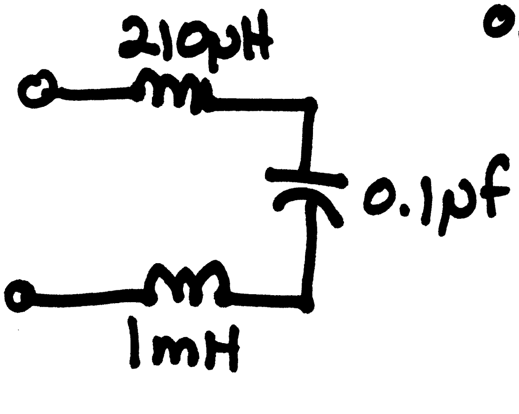
$C_1 \| C_2$ series with C_3

$$\frac{1}{C_{EQ}} = \frac{1}{C_1 \| C_2} + \frac{1}{C_3}$$

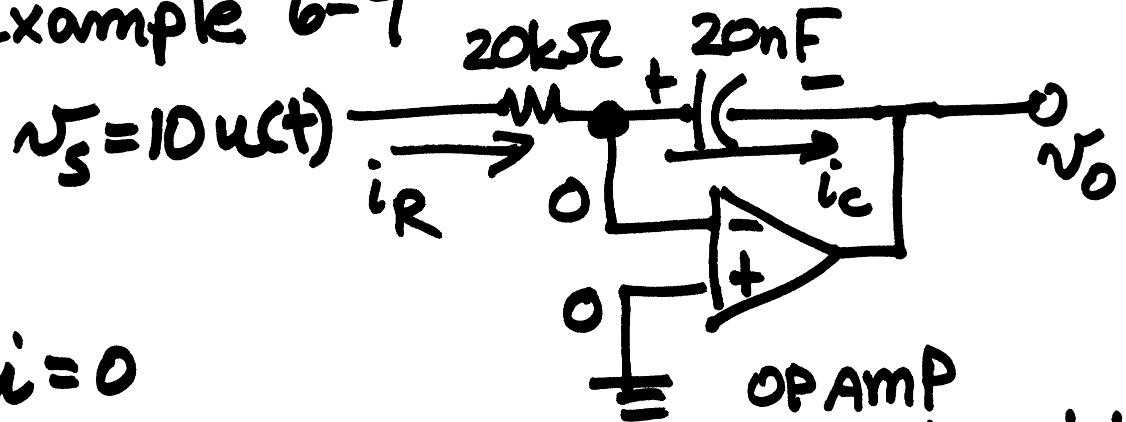
≈0.1µf   0.1µf

$$C_{EQ} = \frac{0.1\mu f}{2} = \underline{0.05\mu f}$$

0.05 ∥ 0.05µf ⇒ 0.1µf



Example 6-9



OP AMP saturates at ±15V

$$\sum_{+in} i = 0$$

$$i_R - i_C = 0$$

$$\frac{v_s - 0}{20000} - (20\times10^{-9})\frac{d}{dt}(0 - v_o) = 0$$

$$v_s + (4\times10^{-3})\frac{dv_o}{dt} = 0$$

$$\int_0^t -\frac{1}{4\times10^{-3}} v_s \, dt = \int_0^t dv_o$$