Waveshapping Circuits and Data Converters

Lesson #19

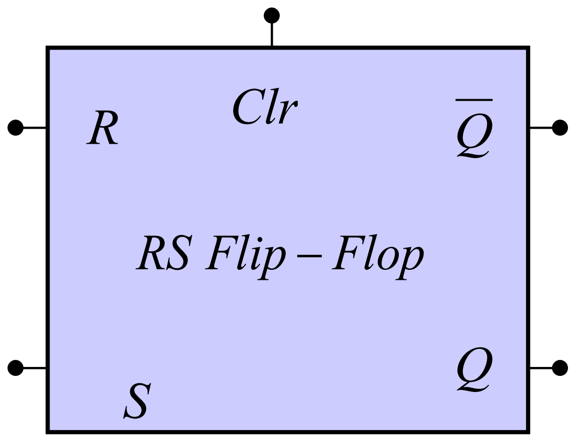
Timers

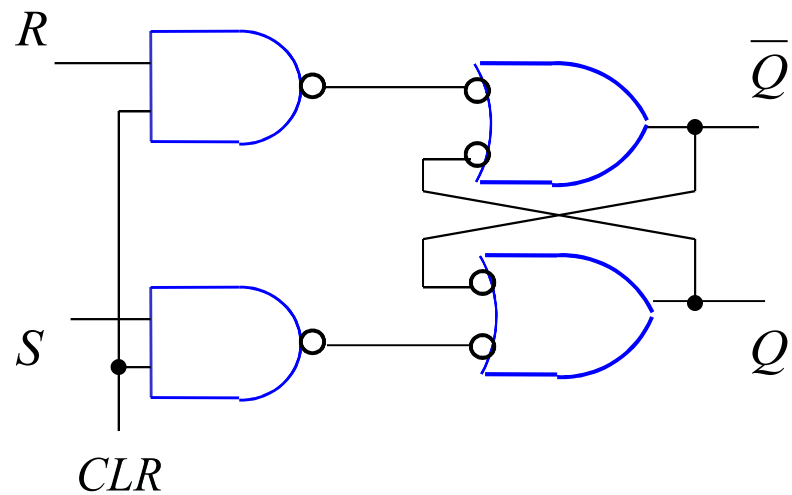
Section 12.3

555 Timer

- An device introduced by Signetics in 1972
- An economical and convenient way to design multivibrator circuits.
- Consists of voltage divider string, two comparators, a RS flip-flop and a switching transistor
- RS flip-flop is a device which can attain one of two states based on the states of its inputs RS.

RS Flip-Flop

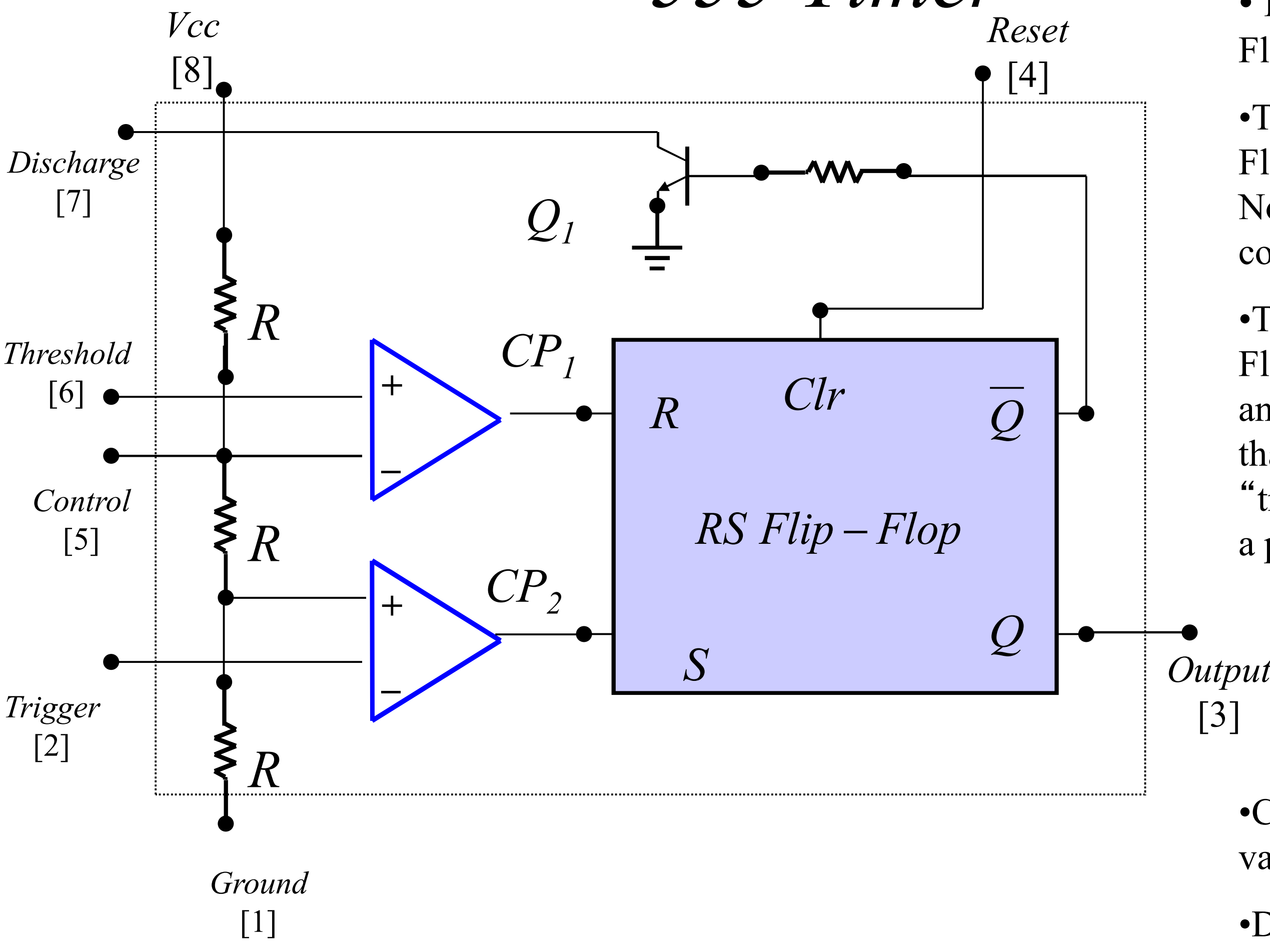




Clr	R	S	Q
0	x	x	0
1	0	0	NC
1	0	1	1
1	1	0	0
1	1	1	?

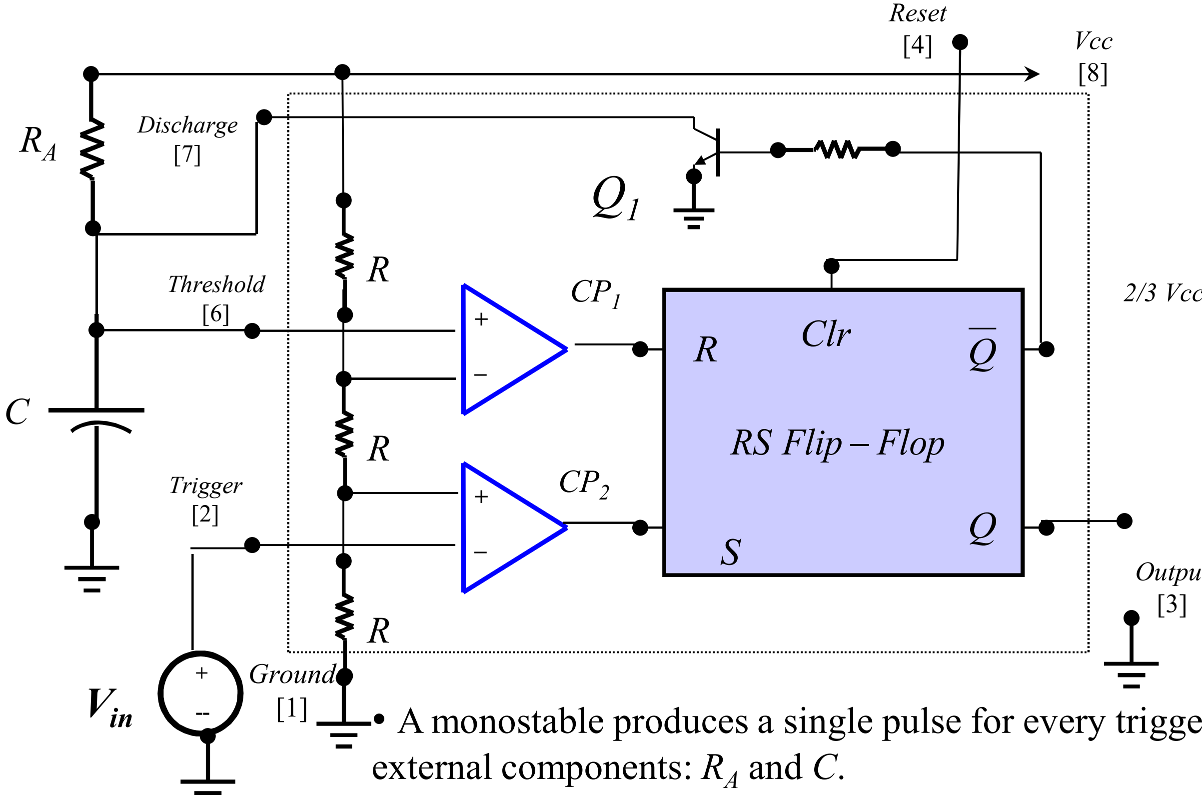
x - don't care
NC – No Change
? - indeterminate

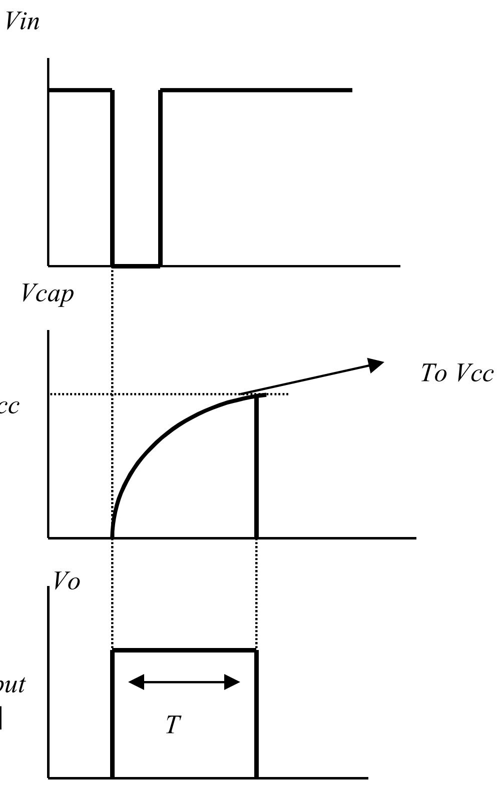
555 Timer



- Reset – will always reset the Flip-flop and usually set to Vcc
- Threshold – Value > 2/3 Vcc then Flip-flop is RESET, Q=0 and NotQ =1 and transistor Q_1 conducts
- Trigger – Value < 1/3 Vcc then Flip-flop is SET, Q=1 and NotQ=0 and transistor Q_1 is cutoff. Note that the Flip-flop will be "triggered" on the falling edge of a pulse applied to this input
- Control – probe to test threshold value
- Discharge – is the Q1 output and presents a short to ground when Q1 conducts

555 Monostable





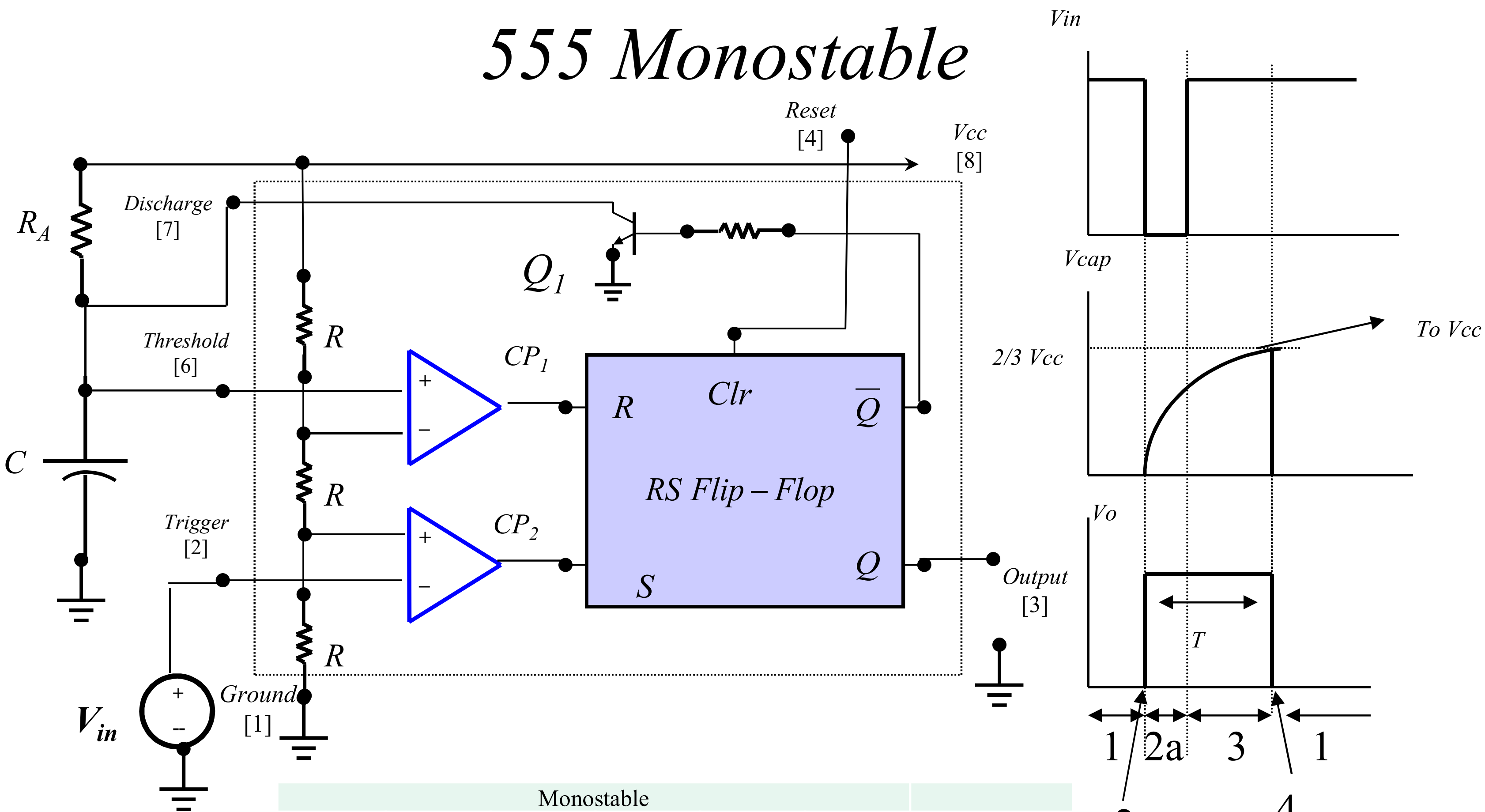
• A monostable produces a single pulse for every trigger signal applied. Only two external components: R_A and C.

• When the trigger drops below 1/3 Vcc, the comparator CP_2 causes the flip-flop to be SET and Q1 opens and C begins to charge through R_A. When the voltage of the capacitor reaches 2/3 Vcc, the comparator CP_1 causes the flip-flop to be RESET and Q1 saturates presents a "zero" resistance to ground for the capacitor to discharge through.

• As a result a single pulse of width T=R_AC ln(3) is produced.

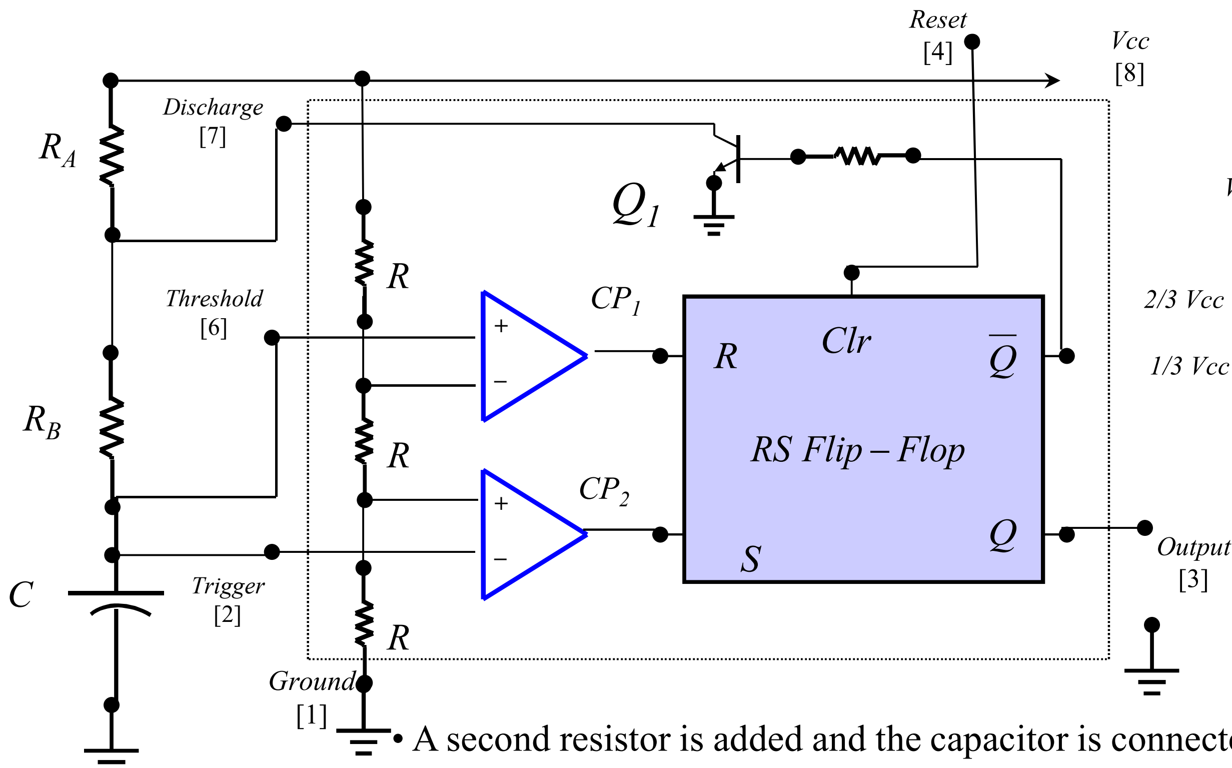
$$v_c(t) = K_1 + K_2 e^{-t/R_A C}$$
$$v_c(0) = 0 = K_1 + K_2$$
$$v_c(\infty) = +A = K_1$$
$$v_c(t) = A(1 - e^{-t/R_A C})$$
$$v_c(T) = \frac{2A}{3} = A(1 - e^{-T/R_A C})$$
$$\therefore T = R_A C \ln(3)$$

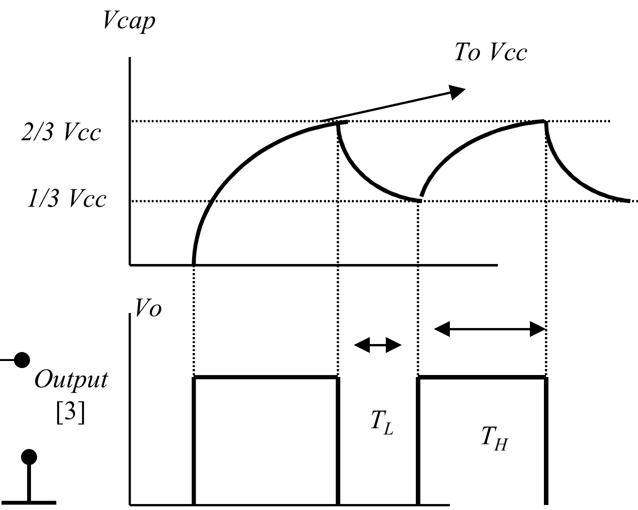
555 Monostable



Monostable						
State	1	2	2a	3	4	1
Vin	High	Low	Low	High	High	High
S	0	1	1	0	0	0
R	0	0	0	0	1	0
Q	0	1	1	1	0	0
Qnot	1	0	0	0	1	1
Transistor	ON	OFF	OFF	OFF	ON	ON
Vcap	0	0	<2/3 Vcc	<2/3 Vcc	=2/3Vcc	0

555 Astable

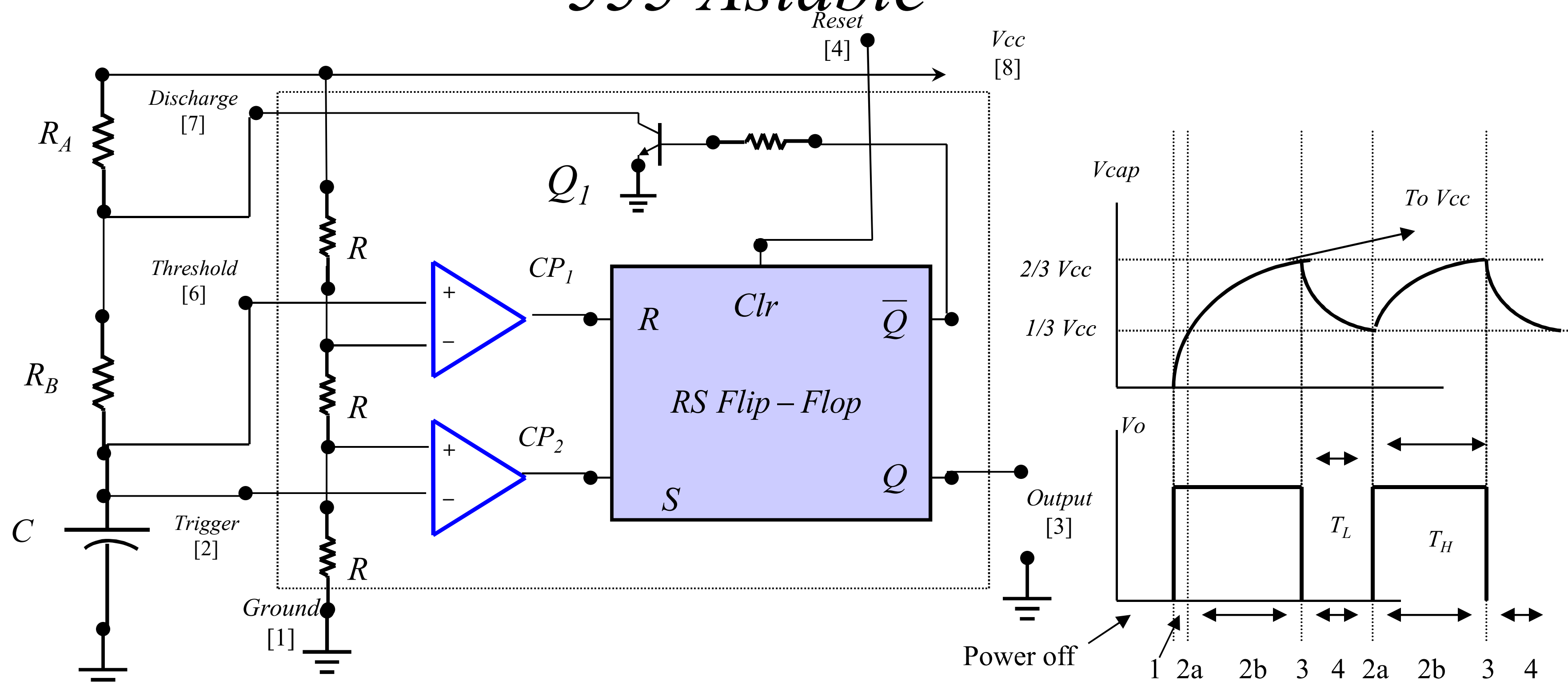




- A second resistor is added and the capacitor is connected to the trigger input.
- At startup the capacitor voltage is less than 1/3 Vcc, the flip-flop is SET (via the trigger comparator), Q1 opens and C begins to charge through R_A and R_B.
- As the capacitor voltage reaches 2/3 Vcc, the flip-flop is RESET (via the threshold comparator), Q1 saturates, and the capacitor starts to discharge through R_B.
- When the capacitor voltage drops below 1/3 Vcc, the flip-flop is SET again, Q1 reopens, and the process restarts again.

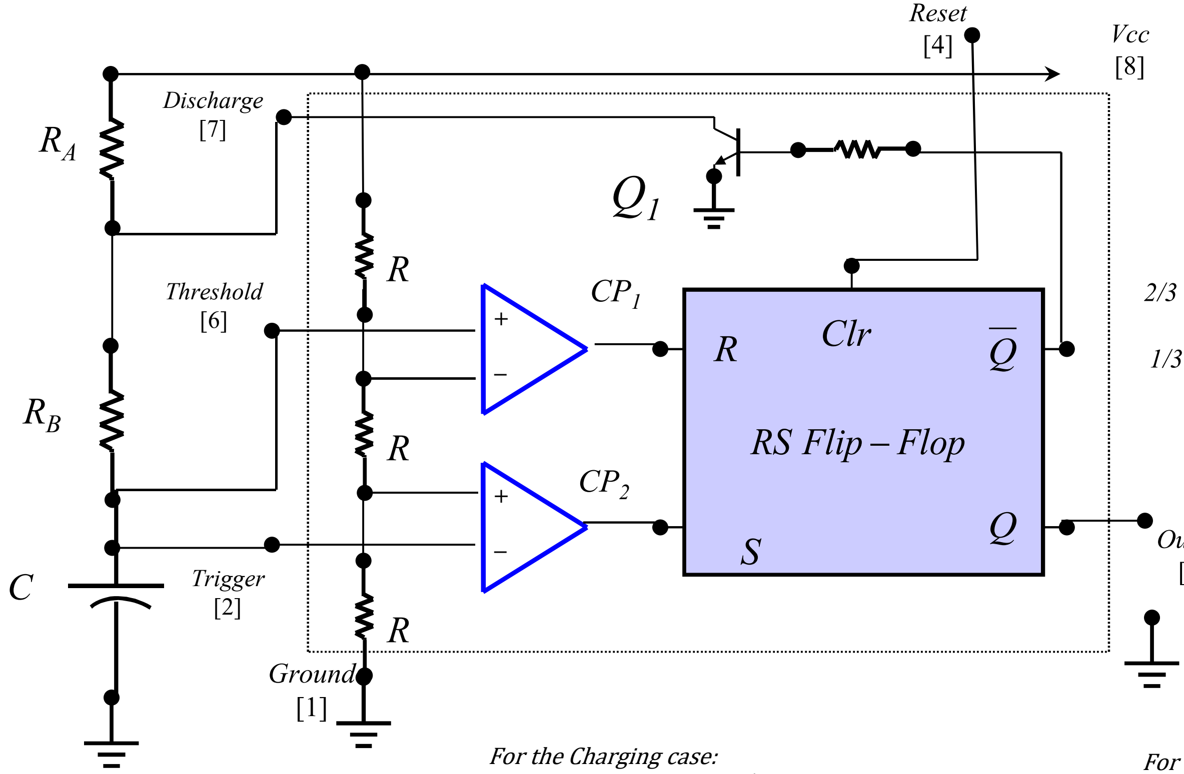
$$T_H = (R_A + R_B)C\ln(2)$$
$$T_L = R_B C\ln(2)$$
$$T = T_H + T_L$$
$$= (R_A + 2R_B)C\ln(2)$$

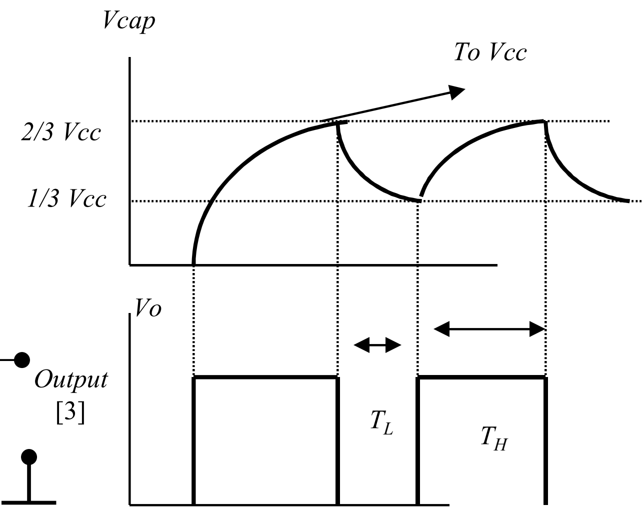
555 Astable



Astable									
State	1	2a	2b	3	4	2a	2b	3	4
Vcap	<1/3Vcc	=1/3Vcc	<2/3Vcc	=2/3Vcc	<2/3Vcc	=1/3Vcc	<2/3Vcc	=2/3Vcc	<2/3Vcc
S	1	0	0	0	0	1	0	0	0
R	0	0	0	1	0	0	0	1	0
Q	1	1	1	0	0	1	1	0	0
Qnot	0	0	0	1	1	0	0	1	1
Transistor	OFF	OFF	OFF	ON	ON	OFF	OFF	ON	ON
RC	(Ra+Rb)C	(Ra+Rb)C	(Ra+Rb)C		RbC		(Ra+Rb)C		RbC

555 Astable Timing





$$T_H = (R_A + R_B)C\ln(2)$$
$$T_L = R_B C\ln(2)$$
$$T = T_H + T_L$$
$$= (R_A + 2R_B)C\ln(2)$$

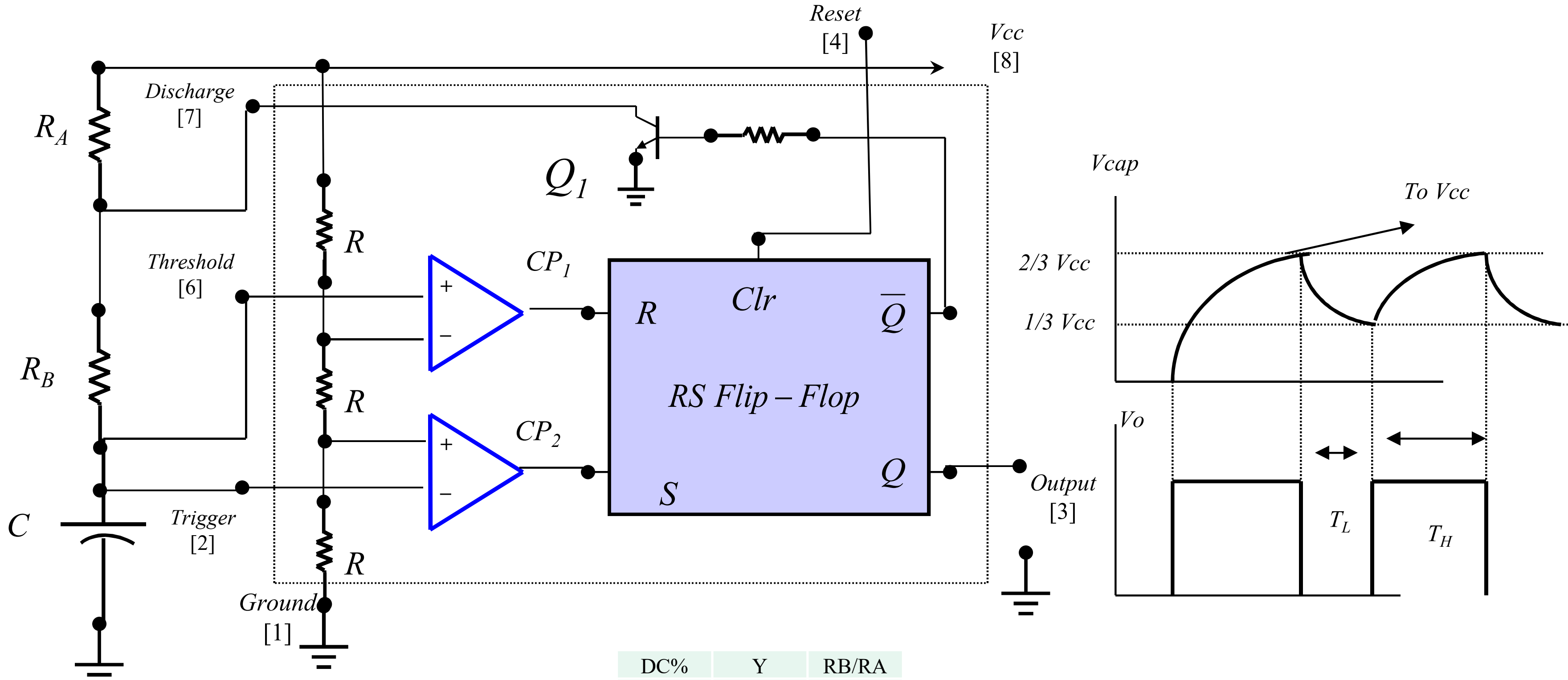
For the Charging case:

$$V_c(t) = K_1 + K_2 e^{-\frac{t}{(R_A+R_B)C}}$$
$$V_c(0) = \frac{1}{3}V_{CC} = K_1 + K_2$$
$$V_c(\infty) = V_{CC} = K_1$$
$$K_2 = \frac{1}{3}V_{CC} - K_1 = -\frac{2}{3}V_{CC}$$
$$V_c(t) = V_{CC} - \frac{2}{3}V_{CC}e^{-\frac{t}{(R_A+R_B)C}}$$
$$V_c(T_H) = \frac{2}{3}V_{CC} = V_{CC} - \frac{2}{3}V_{CC}e^{-\frac{T_H}{(R_A+R_B)C}}$$
$$\frac{1}{2} = e^{-\frac{T_H}{(R_A+R_B)C}}$$

For the Discharging case:

$$V_c(t) = K_1 + K_2 e^{-\frac{t}{R_B C}}$$
$$V_c(0) = \frac{2}{3}V_{CC} = K_1 + K_2$$
$$V_c(\infty) = 0 = K_1$$
$$K_2 = \frac{2}{3}V_{CC}$$
$$V_c(t) = \frac{2}{3}V_{CC}e^{-\frac{t}{R_B C}}$$
$$V_c(T_L) = \frac{1}{3}V_{CC} = \frac{2}{3}V_{CC}e^{-\frac{T_L}{R_B C}}$$
$$\frac{1}{2} = e^{-\frac{T_L}{R_B C}}$$

555 Astable Duty Cycle



The Duty Cycle:

$$\text{DC\%}=\frac{R_A+R_B}{R_A+2R_B}=\frac{R_A+R_B}{R_A+R_B+R_B}=\frac{1}{1+\frac{R_B}{R_A+R_B}}$$

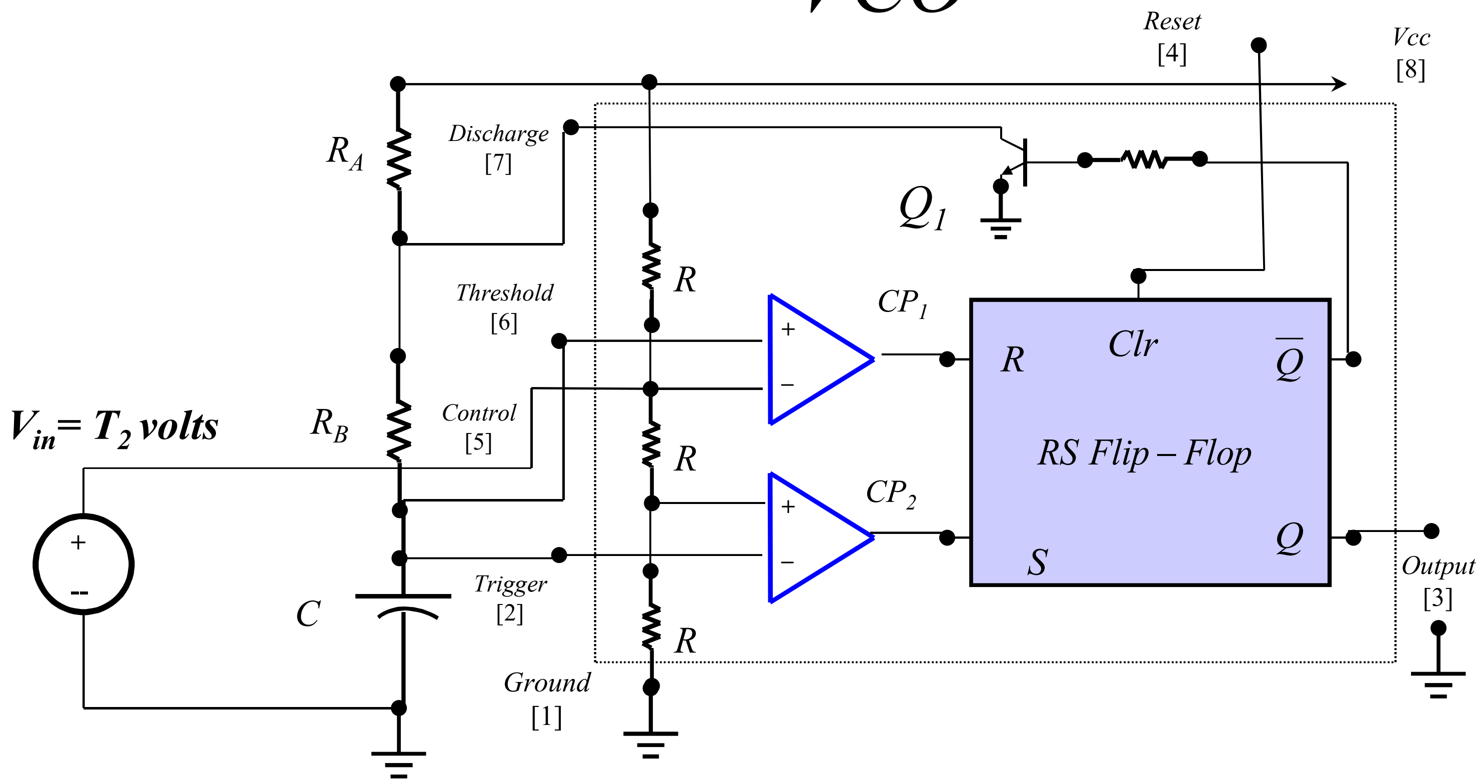
$$\frac{R_B}{R_A+R_B}=1-\frac{1}{\text{DC\%}}=Y$$

$$\frac{R_B}{R_A}=\frac{Y}{1-Y}$$

DC%	Y	RB/RA
0.1	9.0	-1.13
0.2	4.0	-1.33
0.3	2.3	-1.75
0.4	1.5	-3.00
0.5	1.0	#DIV/0!
0.6	0.7	2.00
0.7	0.4	0.75
0.8	0.3	0.33
0.9	0.1	0.13
1	0.0	0.00

Note that for Duty Cycle<=0.5 there is no solution.
Also note that for Duty Cycle=0.51, RB/RA=24.5.

VCO



Reset
[4]
Vcc
[8]
Discharge
[7]
R_A
Q_1
R
Threshold
[6]
CP_1
R
Clr
Q̅
Control
[5]
V_in = T_2 volts
R_B
R
RS Flip – Flop
CP_2
Q
S
Trigger
[2]
Output
[3]
C
R
Ground
[1]

VCO

$$v_c(t) = K_1 + K_2 e^{-\frac{t}{(R_A+R_B)C}}$$

Low To High

$$v_c(0) = K_1 + K_2 = T_1$$

$$v_c(\infty) = K_1 = V_{CC}; K_2 = T_1 - V_{CC}$$

$$v_c(T_H) = V_{CC} + (T_1 - V_{CC})e^{-\frac{T_H}{(R_A+R_B)C}} = T_2$$

$$(T_1 - V_{CC})e^{-\frac{T_H}{(R_A+R_B)C}} = T_2 - V_{CC};$$

$$e^{-\frac{T_H}{(R_A+R_B)C}} = \frac{T_2 - V_{CC}}{T_1 - V_{CC}}$$

$$-\frac{T_H}{(R_A+R_B)C} = \ln\left(\frac{T_2 - V_{CC}}{T_1 - V_{CC}}\right)$$

$$T_H = (R_A + R_B)C\ \ln\left(\frac{V_{CC} - T_1}{V_{CC} - T_2}\right)$$

$$T_2 = xV_{CC}; T_2 = 2T_1$$

$$T_H = (R_A + R_B)C\ \ln\left(\frac{1 - 0.5x}{1 - x}\right)$$

$$v_c(t) = K_1 + K_2 e^{-\frac{t}{R_B C}}$$

High To Low

$$v_c(0) = K_1 + K_2 = T_2$$

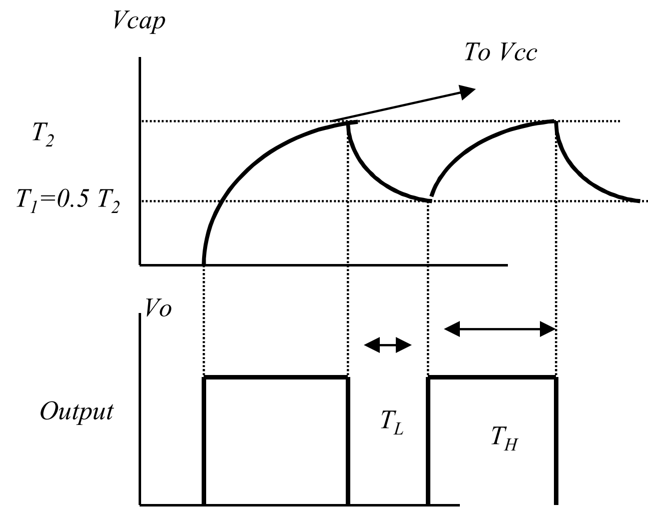
$$v_c(\infty) = K_1 = 0; K_2 = T_1$$

$$v_c(T_L) = T_1 e^{-\frac{T_L}{R_B C}} = T_2$$

$$T_1 e^{-\frac{T_H}{R_B C}} = T_2;$$

$$e^{-\frac{T_H}{R_B C}} = \frac{T_2}{T_1} = 2$$

$$T_L = R_B C\ \ln(2)$$



VCO

$$T = T_L + T_H$$

$$T_H = (R_A + R_B)C \ln(\frac{1-0.5x}{1-x})$$

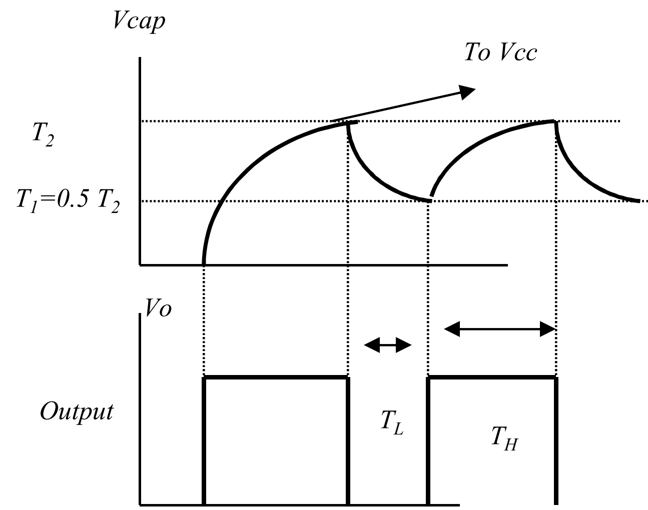
$$T_L = R_B C \ln(2)$$

$$T = R_B C \ln(2) + (R_A + R_B)C \ln(\frac{1-0.5x}{1-x})$$

$$= R_B C \ln(2) + (R_A + R_B)C \frac{\ln(\frac{1-0.5x}{1-x})}{\ln(2)} \ln(2)$$

$$= [R_B + (R_A + R_B)\lambda(x)]C \ln(2)$$

$$\lambda(x) = \frac{\ln(\frac{1-0.5x}{1-x})}{\ln(2)}$$



VCO

Standard Astable

$$T_{\text{stand}} = R_B C\ln(2) + (R_A + R_B)C\ln(2);\ f_{\text{stand}} = \frac{1}{[2R_B + R_A]C\ln(2)}$$

VCO

$$T_{VCO} = R_B C\ln(2) + (R_A + R_B)C\ln\left(\frac{1-0.5x}{1-x}\right);\ f_{VCO} = \frac{1}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)}$$

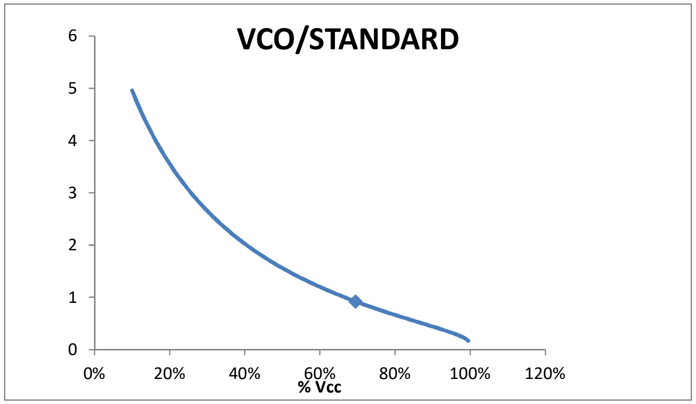
$$\frac{f_{VCO}}{f_{\text{stand}}} = \frac{\dfrac{1}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)}}{\dfrac{1}{[2R_B + R_A]C\ln(2)}}$$

$$= \frac{[2R_B + R_A]C\ln(2)}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)} = \frac{[2R_B + R_A]C\ln(2)}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)}$$

$$\lambda(x) = \frac{\ln\left(\frac{1-0.5x}{1-x}\right)}{\ln(2)}$$

When $\lambda = 1$, then $f_{VCO} = f_{\text{stand}}$

$$\lambda(x) = 1 = \frac{\ln\left(\frac{1-0.5x}{1-x}\right)}{\ln(2)} \Rightarrow \frac{1-0.5x}{1-x} = 2 \Rightarrow x = \frac{2}{3}$$



VCO

Standard Astable

$$T_{\text{stand}} = R_B C\ln(2) + (R_A + R_B)C\ln(2);\ f_{\text{stand}} = \frac{1}{[2R_B + R_A]C\ln(2)}$$

VCO

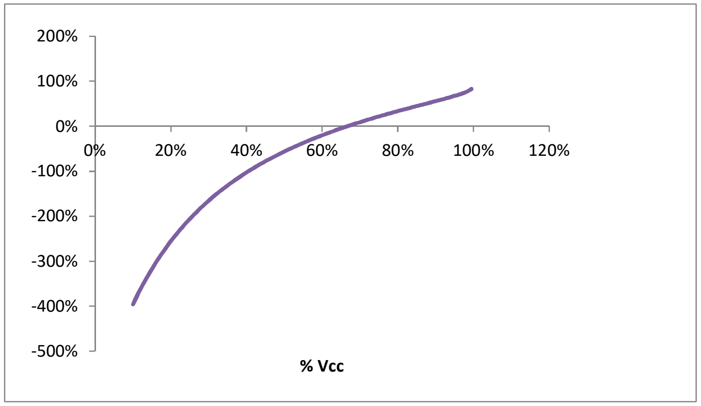
$$T_{VCO} = R_B C\ln(2) + (R_A + R_B)C\ln(\frac{1-0.5x}{1-x});\ f_{VCO} = \frac{1}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)}$$

$$\%\ \text{Change} = \frac{f_{\text{stand}} - f_{VCO}}{f_{\text{stand}}} = \frac{\frac{1}{[2R_B + R_A]C\ln(2)} - \frac{1}{[R_B + (R_A + R_B)\lambda(x)]C\ln(2)}}{\frac{1}{[2R_B + R_A]C\ln(2)}}$$

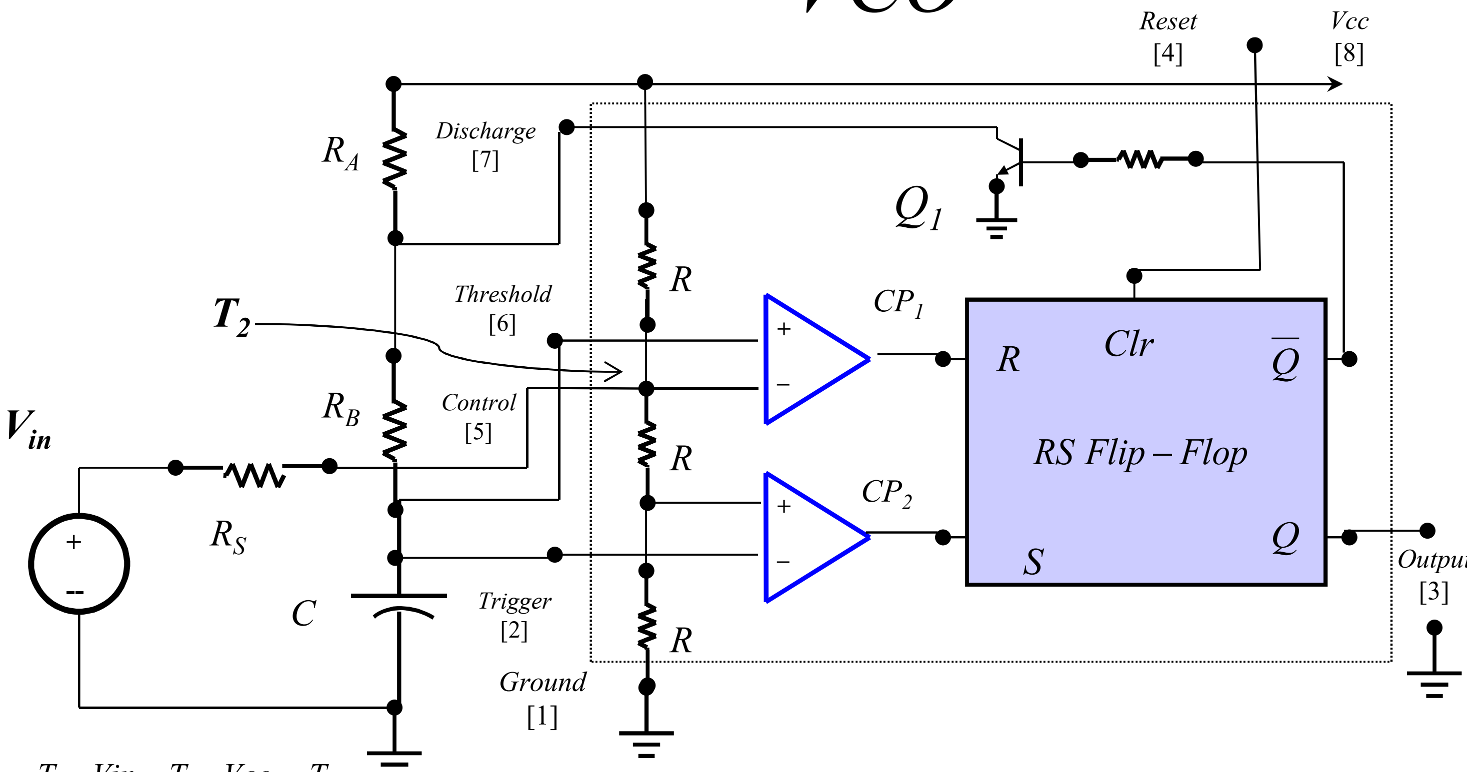
$$= \frac{\frac{1}{[2R_B + R_A]} - \frac{1}{[R_B + (R_A + R_B)\lambda(x)]}}{\frac{1}{[2R_B + R_A]}}$$

$$= 1 - \frac{[2R_B + R_A]}{[R_B + (R_A + R_B)\lambda(x)]}$$

$$\lambda(x) = \frac{\ln(\frac{1-0.5x}{1-x})}{\ln(2)}$$



VCO



$$\frac{T_2 - Vin}{R_s} + \frac{T_2 - Vcc}{R} + \frac{T_2}{2R} = 0$$

$$T_2\left(\frac{1}{R_s} + \frac{1}{R} + \frac{1}{2R}\right) = \frac{Vin}{R_s} + \frac{Vcc}{R}$$

$$T_2 = \frac{RVin + R_s Vcc}{R + \frac{3}{2}R_s}; Vin = xVcc$$

$$T_2 = \left(\frac{Rx + R_s}{R + \frac{3}{2}R_s}\right)Vcc$$

VCO

$$v_c(t) = K_1 + K_2 e^{-\frac{t}{(R_A+R_B)C}}$$

Low To High

$$v_c(0) = K_1 + K_2 = T_1$$

$$v_c(\infty) = K_1 = V_{CC}; K_2 = T_1 - V_{CC}$$

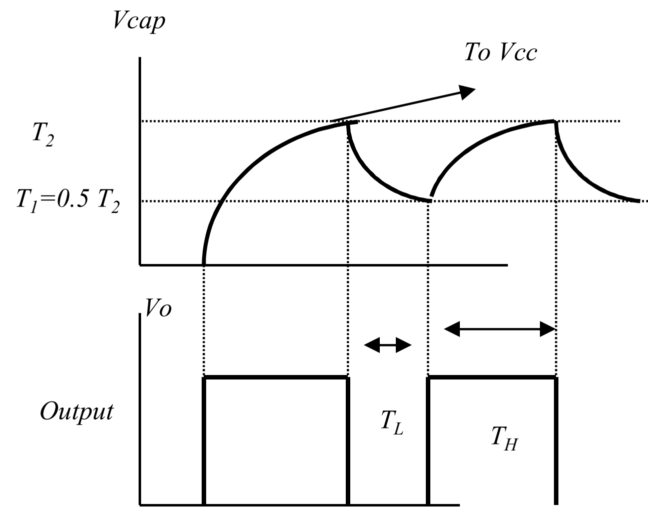
$$v_c(T_H) = V_{CC} + (T_1 - V_{CC})e^{-\frac{T_H}{(R_A+R_B)C}} = T_2$$

$$(T_1 - V_{CC})e^{-\frac{T_H}{(R_A+R_B)C}} = T_2 - V_{CC};$$

$$e^{-\frac{T_H}{(R_A+R_B)C}} = \frac{T_2 - V_{CC}}{T_1 - V_{CC}}$$

$$-\frac{T_H}{(R_A+R_B)C} = \ln(\frac{T_2 - V_{CC}}{T_1 - V_{CC}})$$

$$T_H = (R_A + R_B)C\ \ln(\frac{V_{CC} - T_1}{V_{CC} - T_2})$$



$$T_2 = (\frac{Rx + R_s}{R + \frac{3}{2}R_s})Vcc; T_2 = 2T_1; T_1 = (\frac{Rx + R_s}{2R + 3R_s})Vcc$$

$$T_H = (R_A + R_B)C\ \ln(\frac{1 - (\frac{Rx + R_s}{2R + 3R_s})}{1 - (\frac{Rx + R_s}{R + \frac{3}{2}R_s})}) = (R_A + R_B)C\ \ln(\frac{2R + 3R_s - (Rx + R_s)}{2[R + \frac{3}{2}R_s - (Rx + R_s)]})$$

$$= (R_A + R_B)C\ \ln(\frac{(2 - x)R + 2R_s}{2(1 - x)R + R_s})$$

where $R_s = yR$

$$= (R_A + R_B)C\ \ln(\frac{2 - x + 2y}{2 - 2x + y})$$

VCO

$$v_c(t) = K_1 + K_2 e^{-\frac{t}{R_B C}}$$

High To Low

$$v_c(0) = K_1 + K_2 = T_2$$

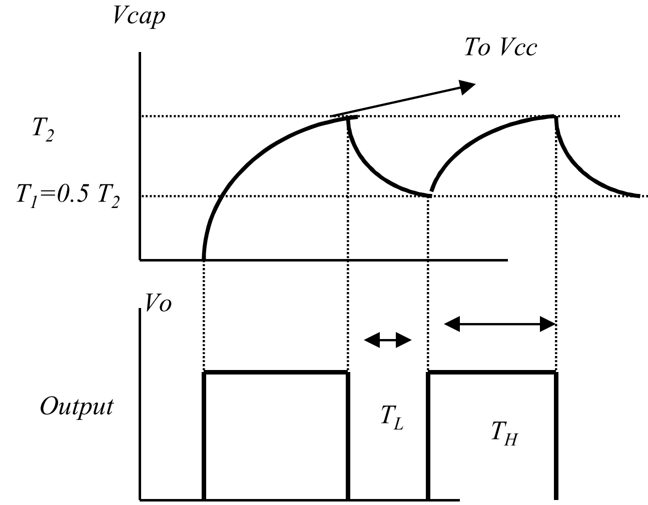
$$v_c(\infty) = K_1 = 0; K_2 = T_1$$

$$v_c(T_L) = T_1 e^{-\frac{T_L}{R_B C}} = T_2$$

$$T_1 e^{-\frac{T_H}{R_B C}} = T_2;$$

$$e^{-\frac{T_H}{R_B C}} = \frac{T_2}{T_1} = 2$$

$$T_L = R_B C \ln(2)$$



$$T = T_L + T_H$$

$$T_H = (R_A + R_B)C \ln(\frac{2 - x + 2y}{2 - 2x + y})$$

$$T_L = R_B C \ln(2)$$

$$T = R_B C \ln(2) + (R_A + R_B)C \ln(\frac{2 - x + 2y}{2 - 2x + y})$$

$$\lambda(x, y) = \frac{\ln(\frac{2 - x + 2y}{2 - 2x + y})}{\ln(2)}$$

$$T = [R_B + (R_A + R_B)\lambda(x, y)]C \ln(2)$$

VCO

Standard Astable

$$T_{\text{stand}} = R_B C\ln(2) + (R_A + R_B)C\ln(2);\ f_{\text{stand}} = \frac{1}{[2R_B + R_A]C\ln(2)}$$

VCO

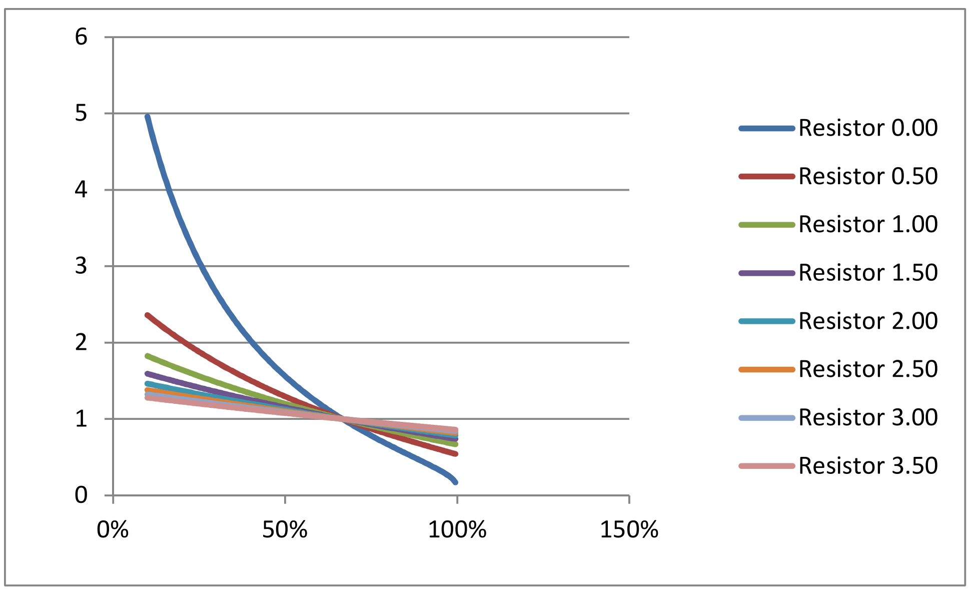
$$T_{VCO} = [R_B + (R_A + R_B)\lambda(x,y)]C\ln(2);\ f_{VCO} = \frac{1}{[R_B + (R_A + R_B)\lambda(x,y)]C\ln(2)}$$

$$\lambda(x,y) = \frac{\ln\left(\frac{2 - x + 2y}{2 - 2x + y}\right)}{\ln(2)}$$

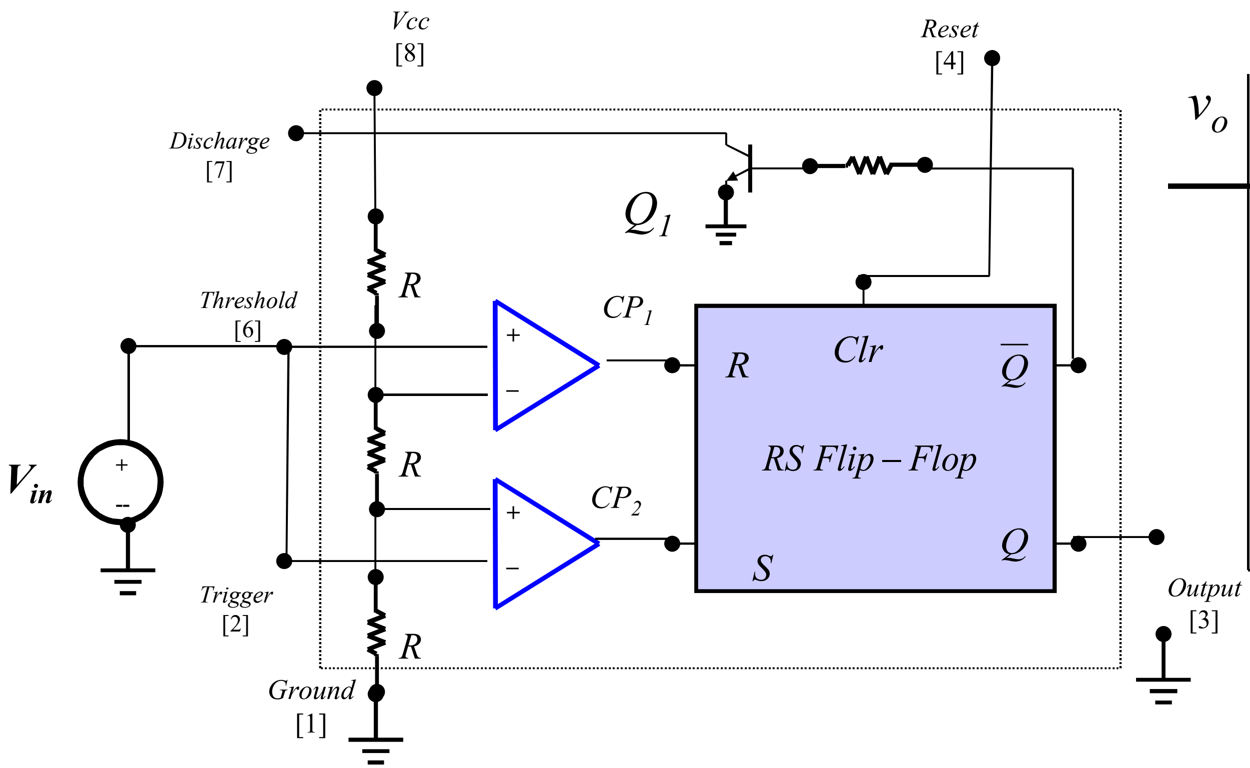
$$\%\ \text{Change} = \frac{f_{\text{stand}} - f_{VCO}}{f_{\text{stand}}} = \frac{\frac{1}{[2R_B + R_A]C\ln(2)} - \frac{1}{[R_B + (R_A + R_B)\lambda(x,y)]C\ln(2)}}{\frac{1}{[2R_B + R_A]C\ln(2)}}$$

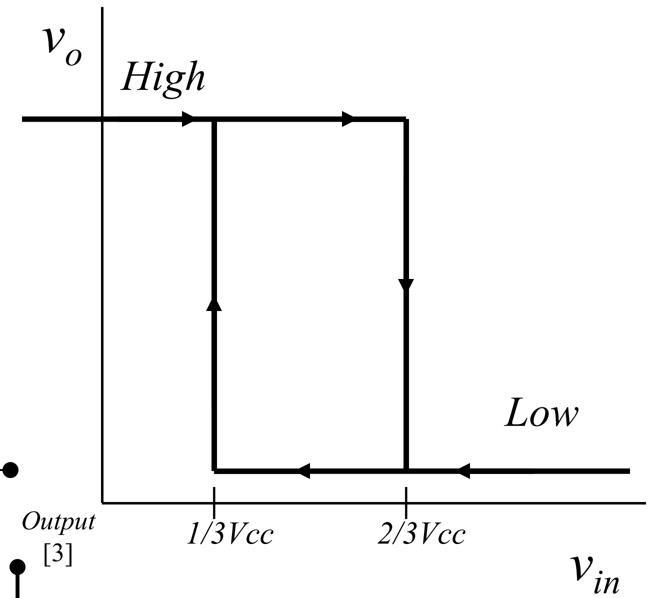
$$= \frac{\frac{1}{[2R_B + R_A]} - \frac{1}{[R_B + (R_A + R_B)\lambda(x,y)]}}{\frac{1}{[2R_B + R_A]}}$$

$$= 1 - \frac{[2R_B + R_A]}{[R_B + (R_A + R_B)\lambda(x,y)]}$$



555 Schmitt Trigger





Schmitt Trigger				
State	Vin going from 0 to Vcc			
Vin	<1/3Vcc	=1/3Vcc+	=2/3Vcc+	>2/3Vcc
CP2	High	Low	Low	Low
Set	1	0	0	0
CP1	Low	Low	High	High
Reset	0	0	1	1
Q	High	NC	Low	Low
Qnot	Low	NC	High	High

Schmitt Trigger				
State	Vin going from Vcc to 0			
Vin	>2/3Vcc	<2/3Vcc	=1/3Vcc-	<1/3Vcc
CP2	Low	Low	High	High
Set	0	0	1	1
CP1	High	Low	Low	Low
Reset	1	0	0	0
Q	Low	NC	High	High
Qnot	High	NC	Low	Low

Homework

- 555 Timer
  - Problems: 12.18-20