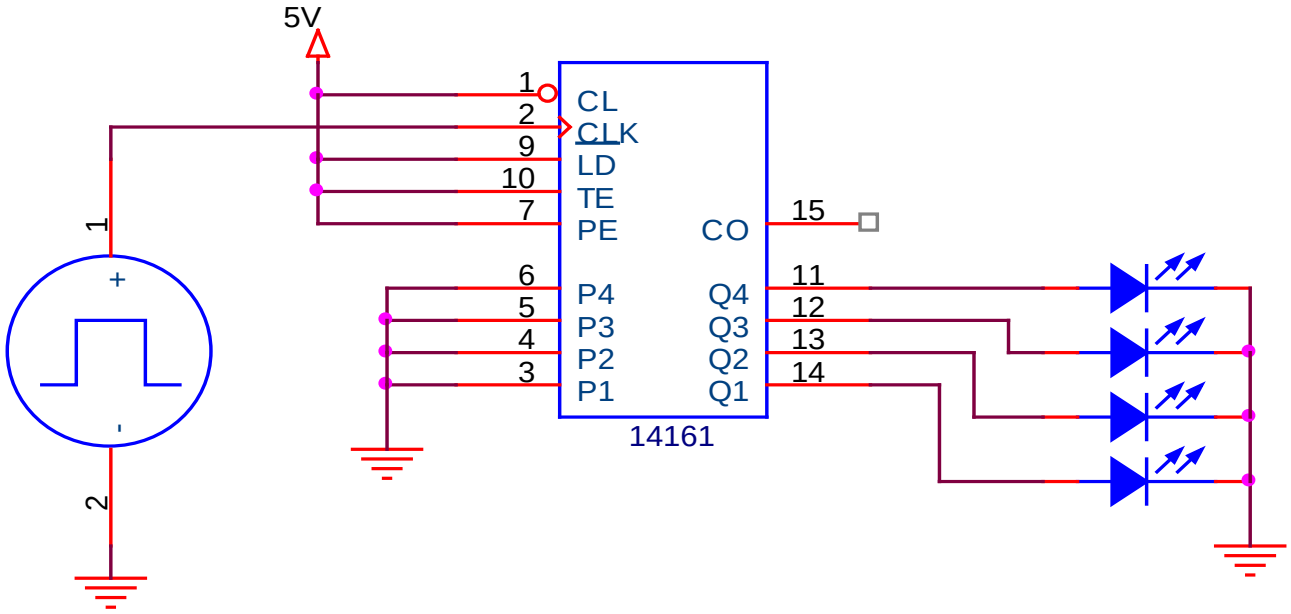


Electronic Instrumentation

Experiment 7

Digital Logic Devices and the 555 Timer

Part A: Basic Logic Gates

Part B: Flip Flops

Part C: Counters

Part D: 555 Timers

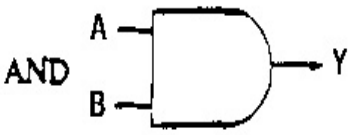
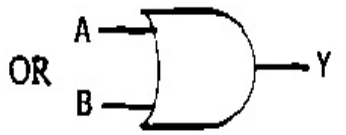
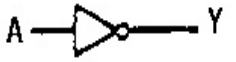
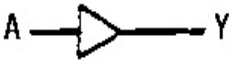
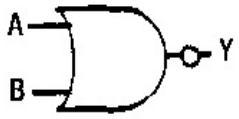
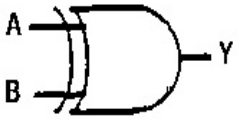
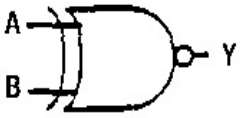
Part A Basic Logic Gates

- Combinational Logic Devices
- Boolean Algebra
- DeMorgan's Laws
- Timing Diagrams

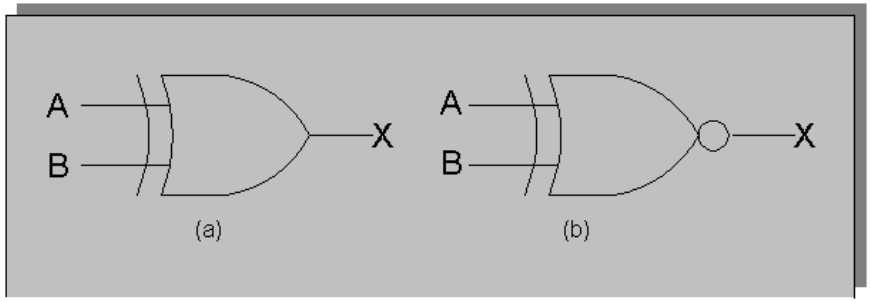
Combinational Logic Devices

- Logic Gates perform basic logic operations, such as AND, OR and NOT, on binary signals.
- We can model the behavior of these chips by enumerating the output they produce for all possible inputs.
- In order to show this behavior, we use truth tables, which show the output for all input combinations.
- The outputs of combinational logic gates depend only on the instantaneous values of the inputs.

Logic Gates

Name	Symbol	Algebraic function	Truth table
AND		Y=AB	A B | Y 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1
OR		Y=A+B	A B | Y 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 1
(NOT) Inverter		$Y=\overline{A}$	A | Y 0 | 1 1 | 0
Buffer		Y=A	A | Y 0 | 0 1 | 1
NAND		$Y=\overline{(AB)}$	A B | Y 0 0 | 1 0 1 | 1 1 0 | 1 1 1 | 0
NOR		$Y=\overline{(A+B)}$	A B | Y 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 0
Exclusive OR (XOR)		$Y=A\overline{B}+\overline{A}B$ $y=A\oplus B$	A B | Y 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 0
Exclusive NOR or equivalence		$Y=AB+\overline{AB}$ $Y=A\odot B$	A B | Y 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 1

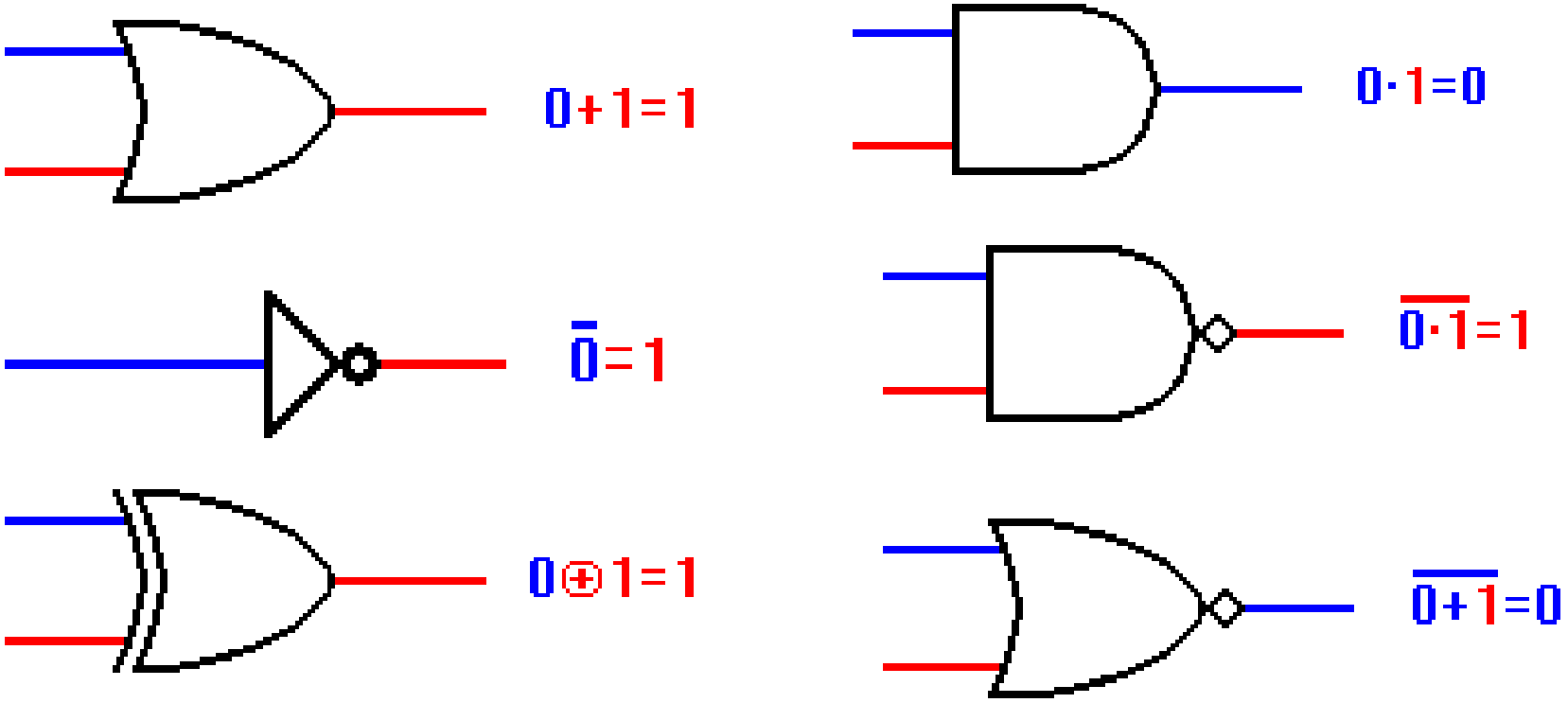
Logic Gate Example: XOR



Input	Input	Output
A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

Question: What common household switch configuration corresponds to an XOR?

Boolean Algebra



- The variables in a boolean, or logic, expression can take only one of two values, 0 (false) and 1 (true).
- We can also use logical mathematical expressions to analyze binary operations, as well.

- The basis of boolean algebra lies in the operations of logical addition, or the OR operation, and logical multiplication, or the AND operation.
- OR Gate
  - If either X or Y is true (1), then Z is true (1)

$$0 + 0 = 0$$
$$0 + 1 = 1$$
$$1 + 0 = 1$$
$$1 + 1 = 1$$

- AND Gate
  - If both X and Y are true (1), then Z is true (1)

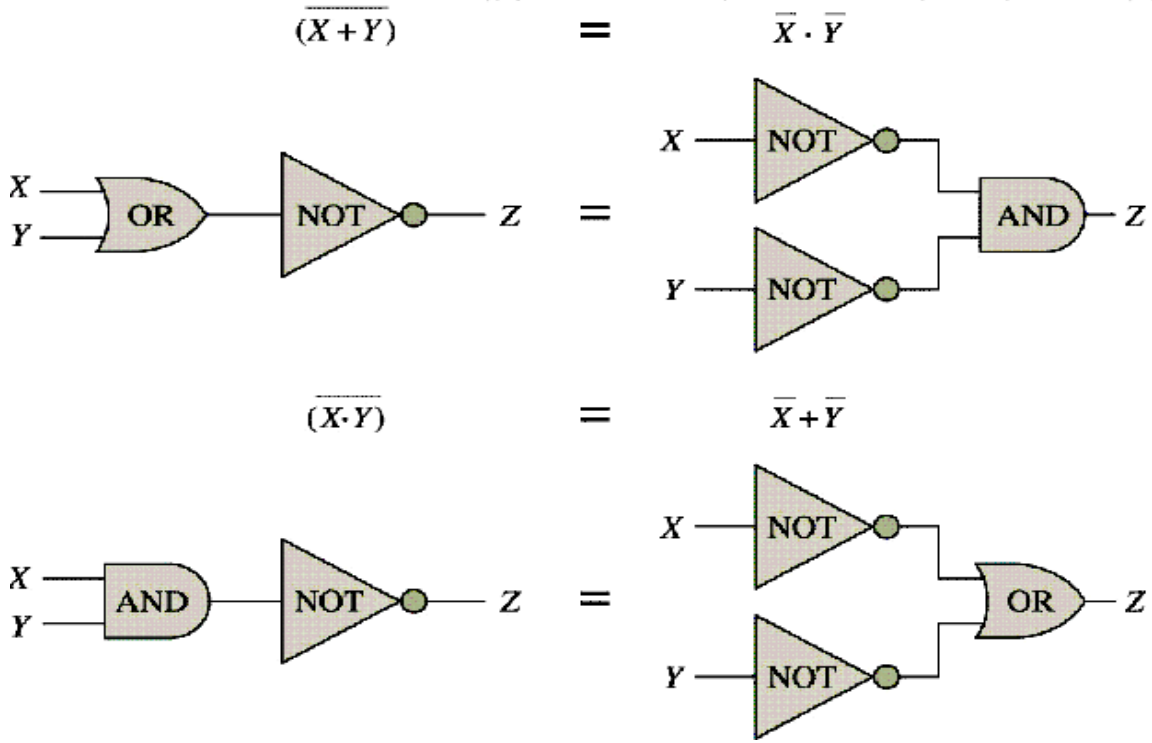
$$0 \cdot 0 = 0$$
$$0 \cdot 1 = 0$$
$$1 \cdot 0 = 0$$
$$1 \cdot 1 = 1$$

- Logic gates can have an arbitrary number of inputs.
- Note the similarities to the behavior of the mathematical operators plus and times.

Laws of Boolean Algebra

I. Properties of Operations	II. Rules of Combination
(I1) $A \cdot 0 = 0$	(II1) $A \cdot B = B \cdot A$
(I2) $A + 0 = A$	(II2) $A + B = B + A$
(I3) $A \cdot 1 = A$	(II3) $A \cdot (B+C) = (A \cdot B) + (A \cdot C)$
(I4) $A + 1 = 1$	(II4) $A \cdot (B \cdot C) = (A \cdot B) \cdot C$
(I5) $A \cdot A = A$	(II5) $A + (B+C) = (A+B) + C$
(I6) $A + A = A$	(II6) $A + (A \cdot B) = A$
(I7) $A \cdot \sim A = 0$	(II7) $A \cdot (A+B) = A$
(I8) $A + \sim A = 1$	(II8) $A \cdot (\sim A + B) = A \cdot B$
(I9) $\sim(\sim A) = A$	(II9) $A + (\sim A \cdot B) = A + B$
	(II10) $\sim A + (A \cdot B) = \sim A + B$
	(II11) $\sim A + (A \cdot \sim B) = \sim A + \sim B$

DeMorgan's Laws



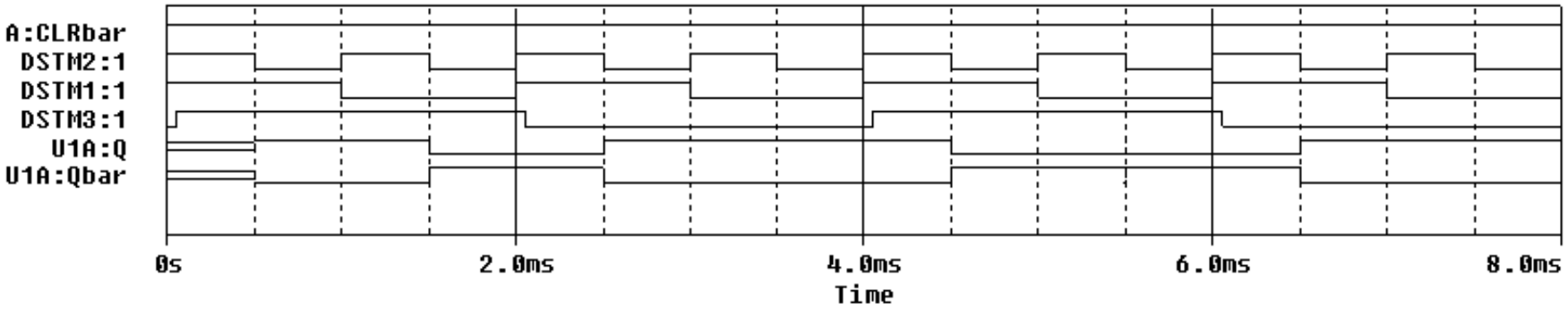
Truth table

X	Y	$Z = \overline{(X+Y)} = \overline{X} \cdot \overline{Y}$
0	0	1
0	1	0
1	0	0
1	1	0

Truth table

X	Y	$Z = \overline{(X+Y)} = \overline{X} + \overline{Y}$
0	0	1
0	1	1
1	0	1
1	1	0

Timing Diagrams – sequential logic



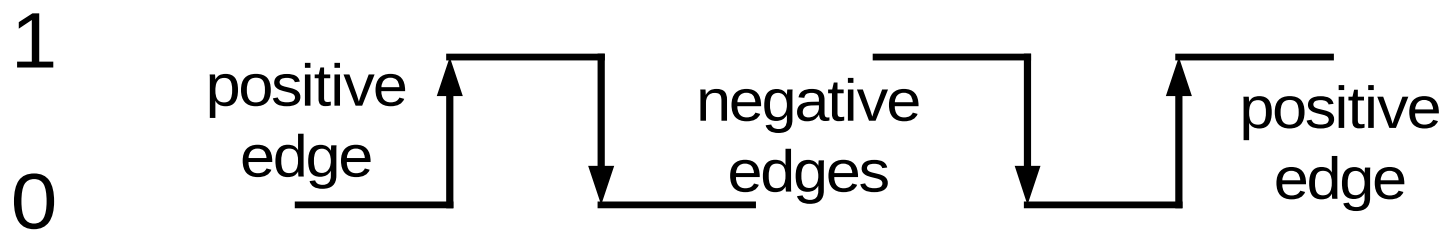
- When we deal with binary signals, we are not worried about exact voltages.
- We are only concerned with two things:
  - Is the signal high or low?
  - When does the signal switch states?
- Relative timing between the state changes of different binary signals is much easier to see using a diagram like this.

Part B – Flip Flops

- Sequential Logic Devices
- Flip Flops
- By-Pass Capacitors

Sequential Logic Devices

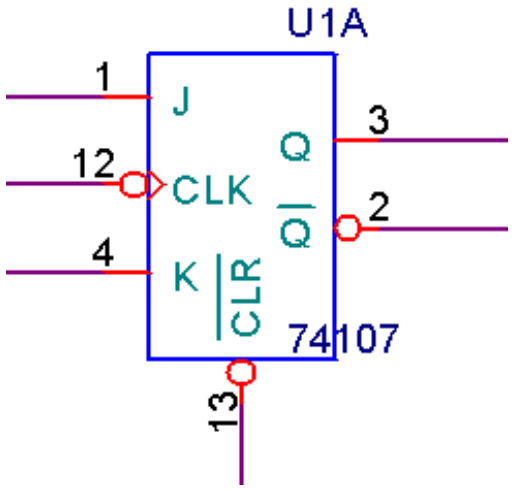
- In a sequential logic device, the timing or sequencing of the input signals is important. Devices in this class include flip-flops and counters.
- Positive edge-triggered devices respond to a low-to-high (0 to 1) transition, and negative edge-triggered devices respond to a high-to-low (1 to 0) transition.



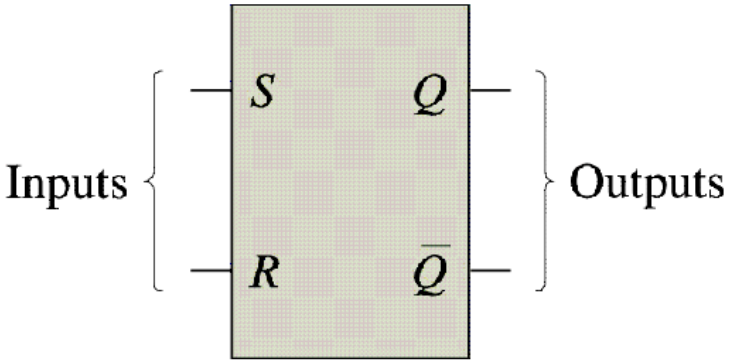
Flip-Flops

- A flip-flop is a sequential device that can store and switch between two binary states.
- It is called a bistable device since it has two and only two possible output states: 1 (high) and 0 (low).
- It has the capability of remaining in a particular state (i.e., storing a bit) until the clock signal and certain combinations of the input cause it to change state.

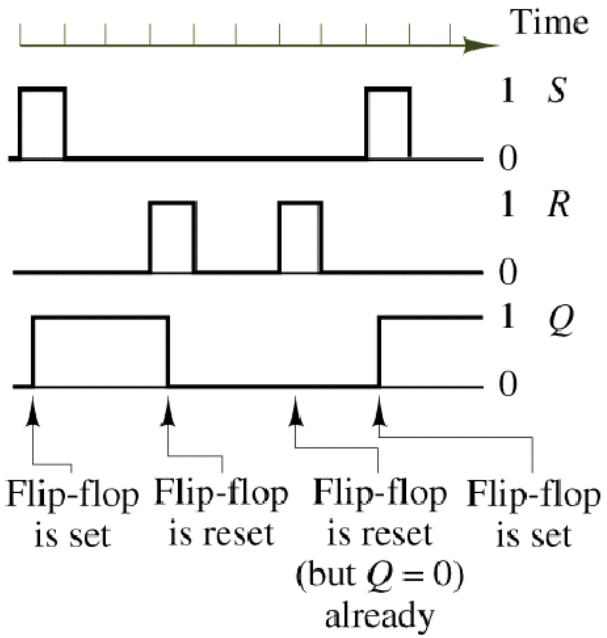
J	K	C	Q	$\overline{Q}$
0	0	p	no change	
0	1	p	0	1
1	0	p	1	0
1	1	p	toggle	



Simple Flip Flop Example: The RS Flip-Flop



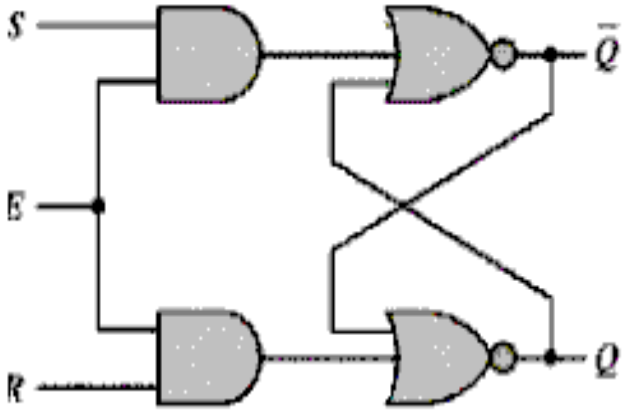
S	R	Q
1	0	1
0	0	1
0	0	1
0	1	0
0	0	0
0	0	0
0	1	0
0	0	0
1	0	1
0	0	1

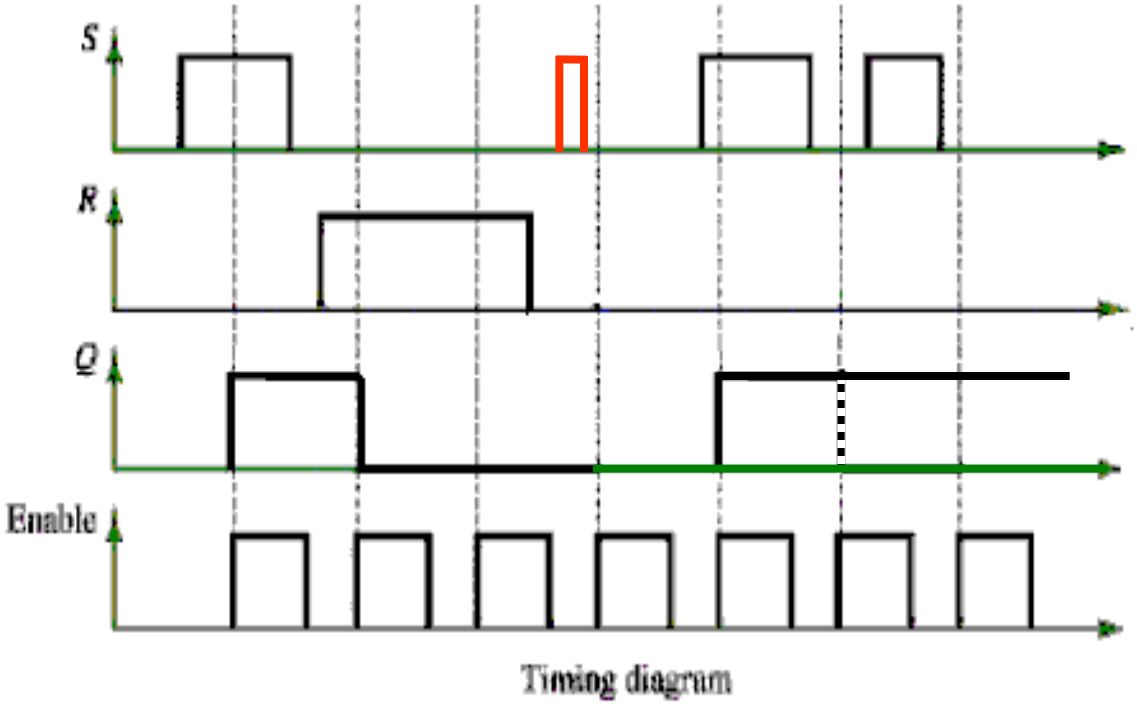


S	R	Q
0	0	Present state
0	1	Reset Q = 0
1	0	Set Q = 1
1	1	Disallowed

Note that the output depends on three things: the two inputs and the previous state of the output.

Inside the R-S Flip Flop

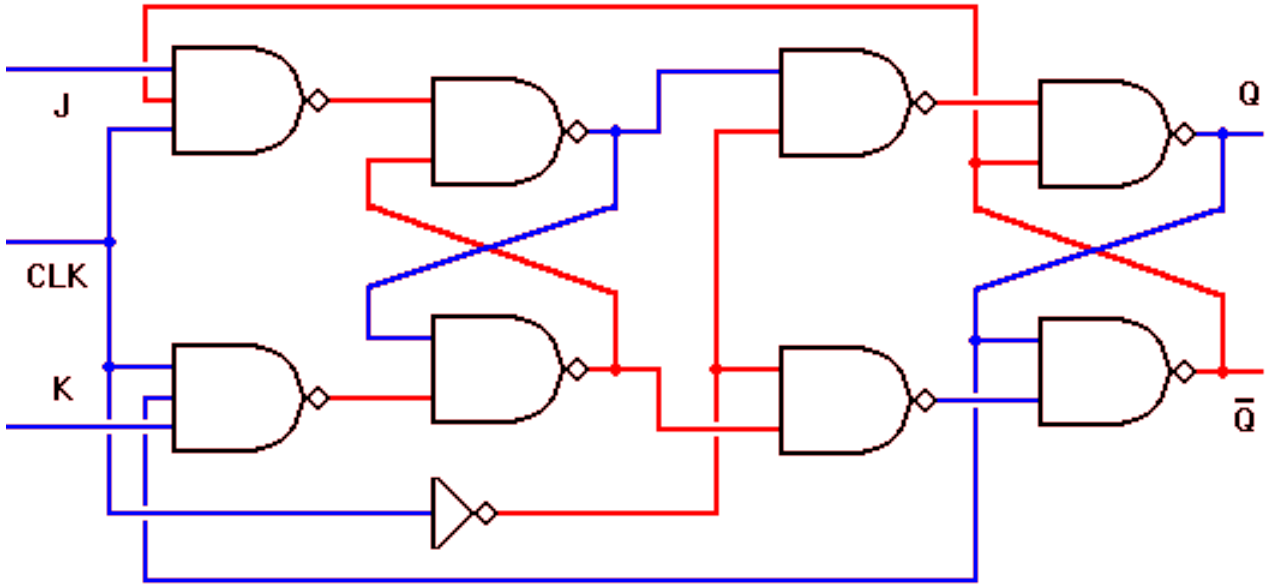




Timing diagram

Note that the enable signal is the clock, which regularly pulses. This flip flop changes on the rising edge of the clock. It looks at the two inputs when the clock goes up and sets the outputs according to the truth table for the device.

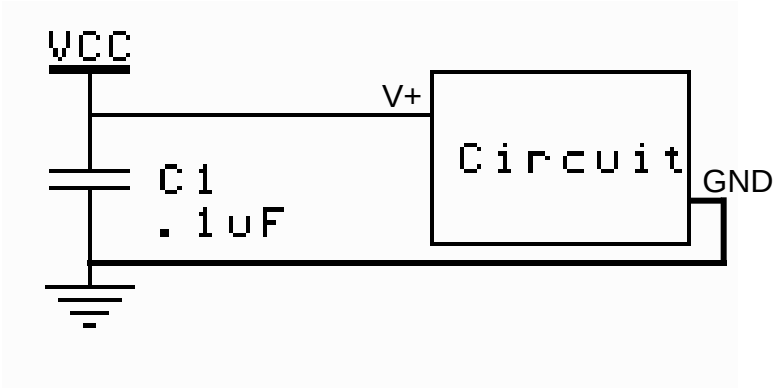
Inside the J-K Flip Flop



J	K	C	Q	$\overline{Q}$
0	0	p	no change	
0	1	p	0	1
1	0	p	1	0
1	1	p	toggle	

Note this flip flop, although structurally more complicated, behaves almost identically to the R-S flip flop, where J(ump) is like S(et) and K(ill) is like R(eset). The major difference is that the J-K flip flop allows both inputs to be high. In this case, the output switches state or “toggles”.

By-Pass Capacitors

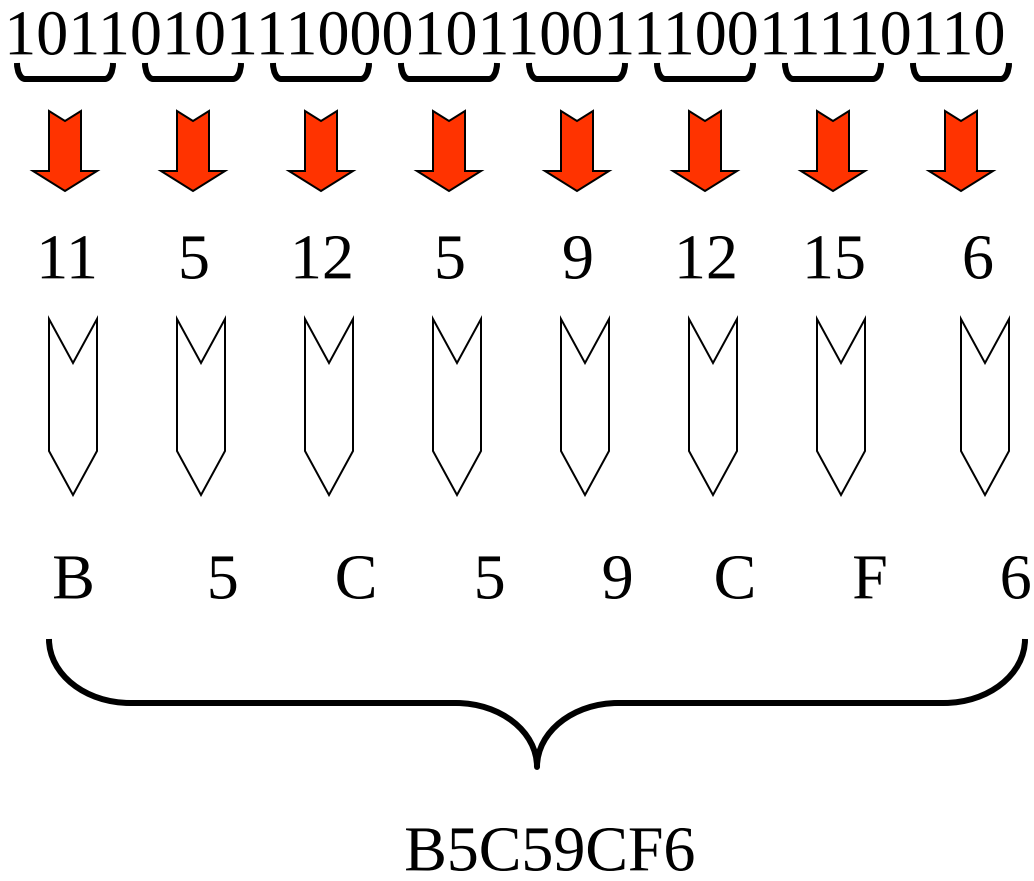


- In a sequential logic device, a noisy signal can generate erroneous results.
- By-pass capacitors are placed between 5V and 0V to filter out high frequency noise.
- A by-pass capacitor should be used in any circuit involving a sequential logic device to avoid accidental triggering.

Part C: Counters

- Binary Numbers
- Binary Counters

Binary – Decimal -- Hexadecimal Conversion



binary number

equivalent base 10 value for each group of 4 consecutive binary digits (bits)

corresponding hexadecimal (base 16) digit

equivalent hexadecimal number

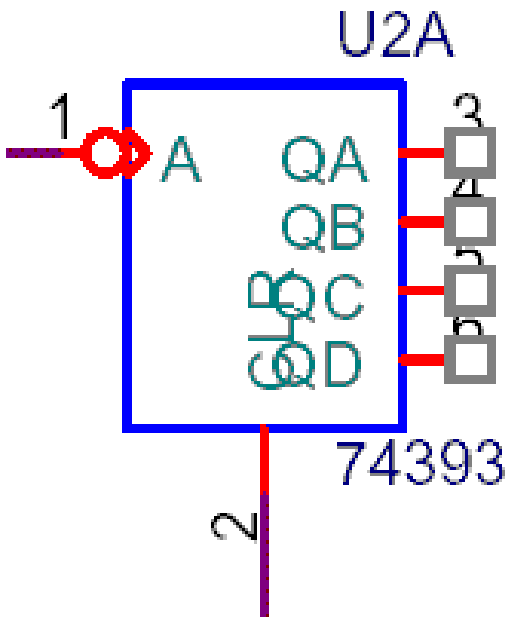
Decimal 8 = $1x2^3 + 0x2^2 + 0x2^1 + 0x2^0$ = 01000 in Binary

Calculator Applet

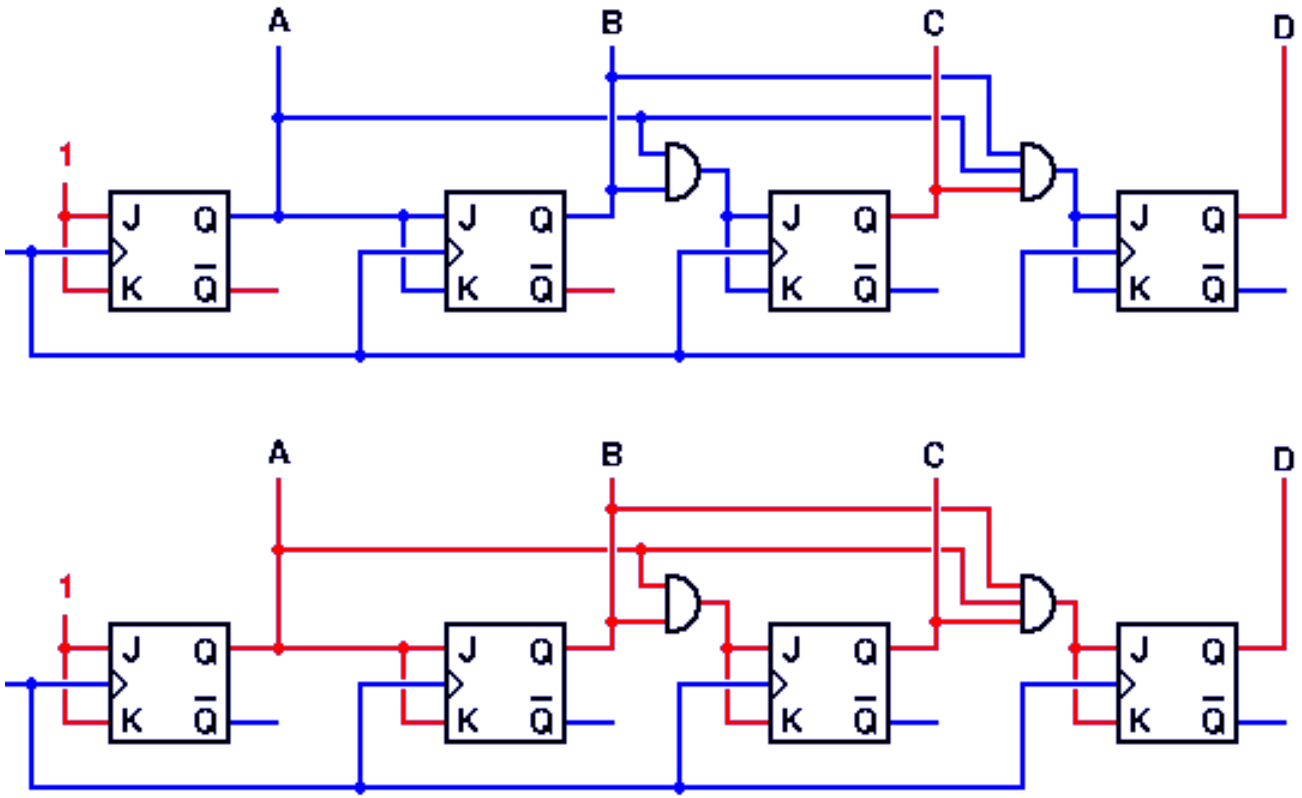
Binary Counters

- Binary Counters do exactly what it sounds like they should. They count in binary.
- Binary numbers are comprised of only 0's and 1's.

Decimal	QD	QC	QB	QA
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1

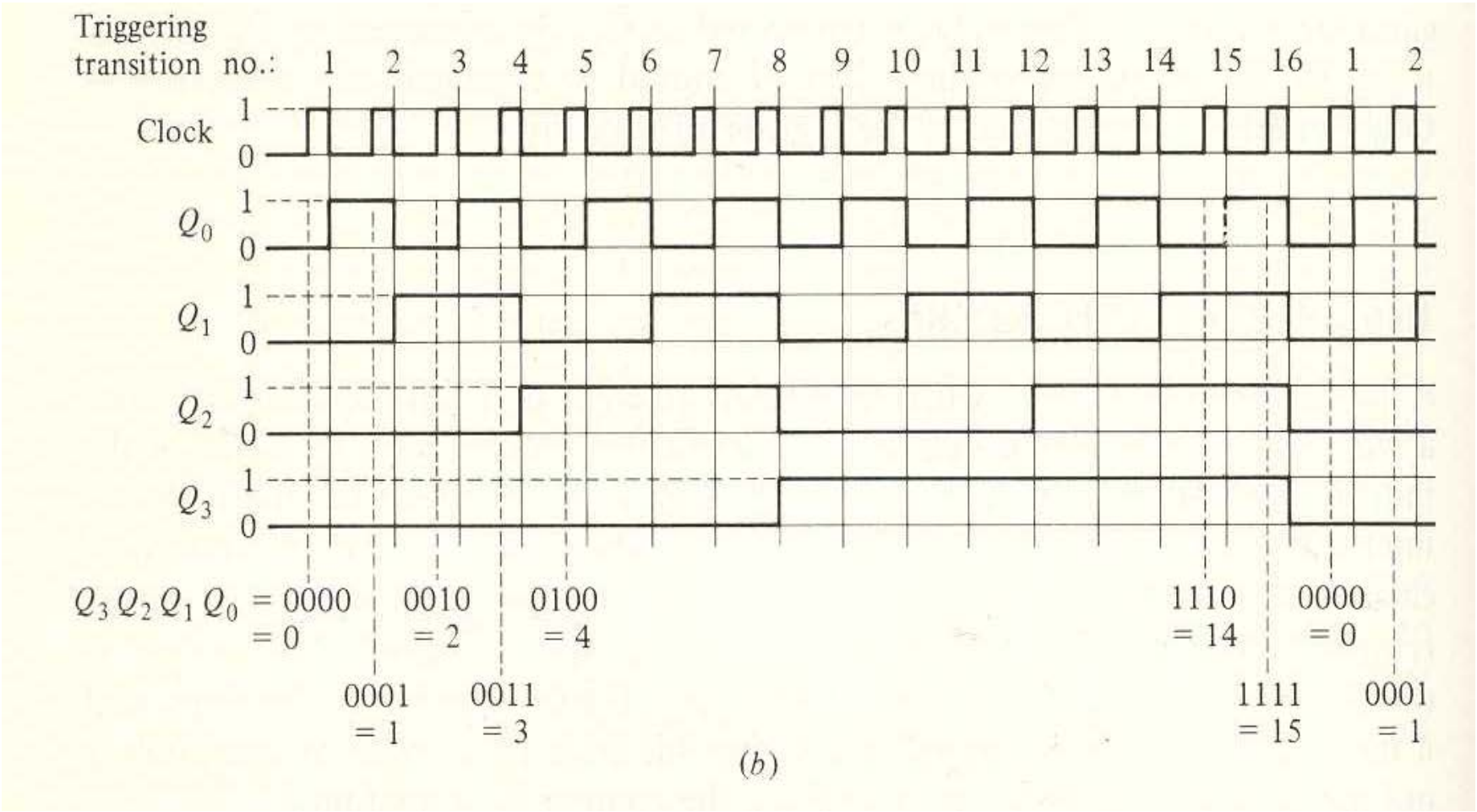


Binary Counters are made with Flip Flops



Each flip flop corresponds to one bit in the counter.
Hence, this is a four-bit counter.

Typical Output for Binary Counter

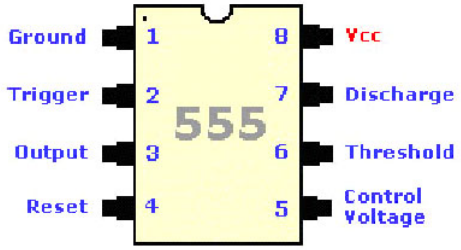


- Note how the Q outputs form 4 bit numbers

Part D: 555-Timers

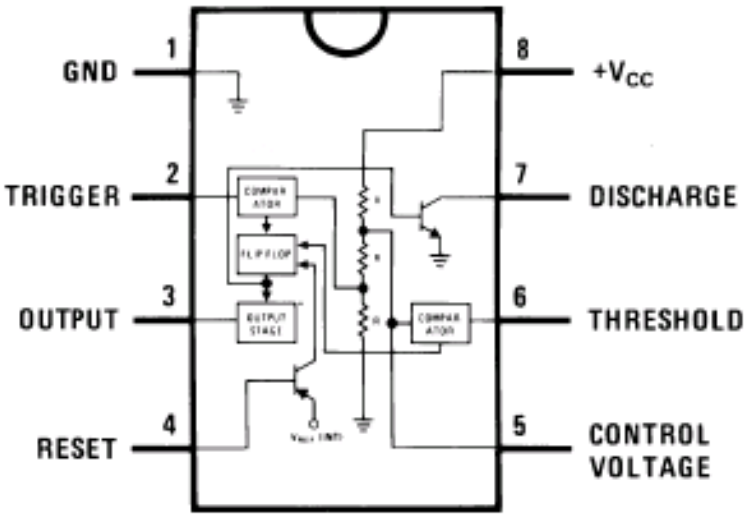
- The 555 Timer
- Inside the 555-Timer
- Types of 555-Timer Circuits
- Understanding the Astable Mode Circuit
- Modulation
- Pulse Width Modulation

The 555 Timer

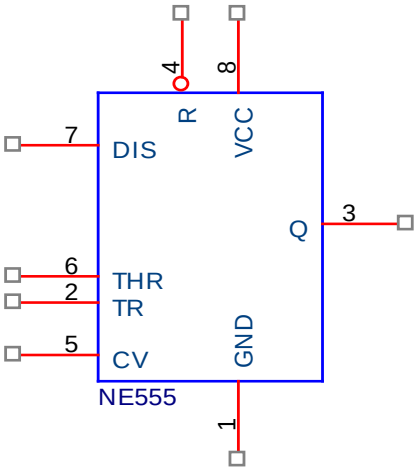


- The 555 Timer is one of the most popular and versatile integrated circuits ever produced!
- It is 30 years old and still being used!
- It is a combination of digital and analog circuits.
- It is known as the "time machine" as it performs a wide variety of timing tasks.
- Applications for the 555 Timer include:
  - Bounce-free switches and Cascaded timers
  - Frequency dividers
  - Voltage-controlled oscillators
  - Pulse generators and LED flashers

555 Timer

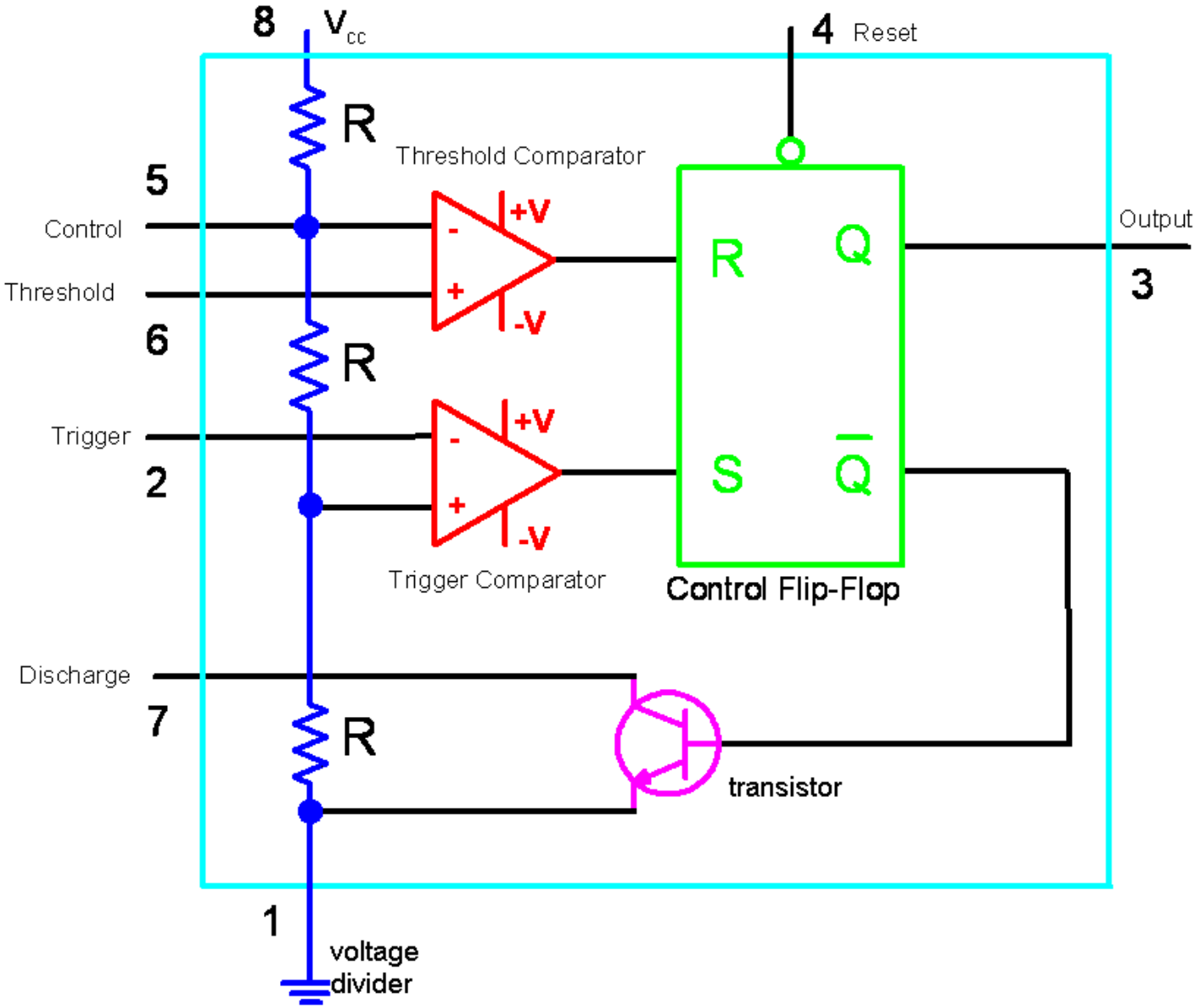


Top View



- Each pin has a function
- Note some familiar components inside

Inside the 555 Timer

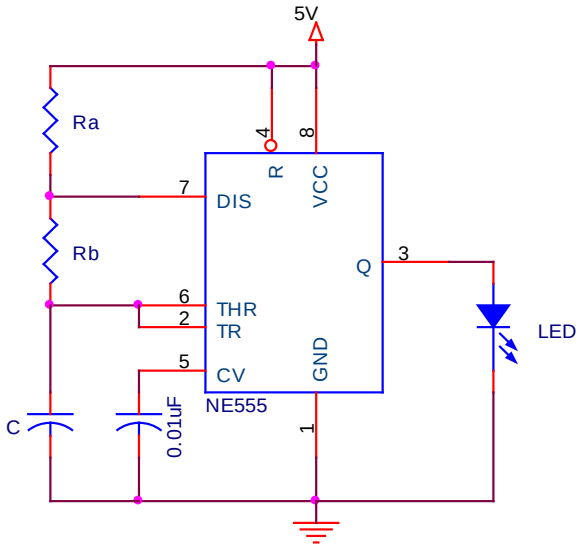


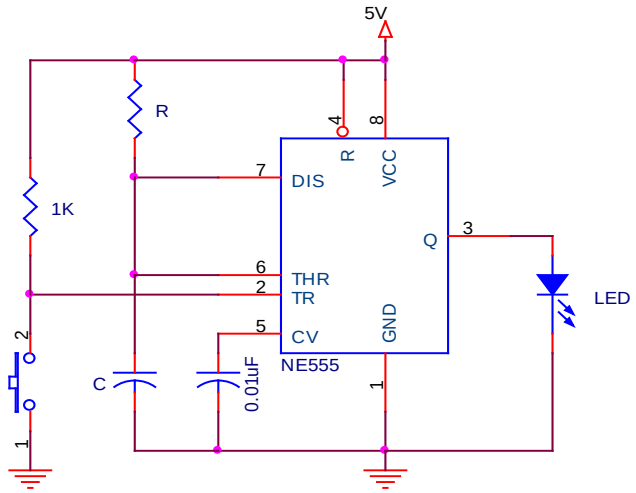
Inside the 555 Timer

- The voltage divider (blue) has three equal 5K resistors. It divides the input voltage (Vcc) into three equal parts.
- The two comparators (red) are op-amps that compare the voltages at their inputs and saturate depending upon which is greater.
  - The Threshold Comparator saturates when the voltage at the Threshold pin (pin 6) is greater than (2/3)Vcc.
  - The Trigger Comparator saturates when the voltage at the Trigger pin (pin 2) is less than (1/3)Vcc

- The flip-flop (green) is a bi-stable device. It generates two values, a “high” value equal to Vcc and a “low” value equal to 0V.
  - When the Threshold comparator saturates, the flip flop is Reset (R) and it outputs a low signal at pin 3.
  - When the Trigger comparator saturates, the flip flop is Set (S) and it outputs a high signal at pin 3.
- The transistor (purple) is being used as a switch, it connects pin 7 (discharge) to ground when it is closed.
  - When Q is low, Qbar is high. This closes the transistor switch and attaches pin 7 to ground.
  - When Q is high, Qbar is low. This open the switch and pin 7 is no longer grounded

Types of 555-Timer Circuits

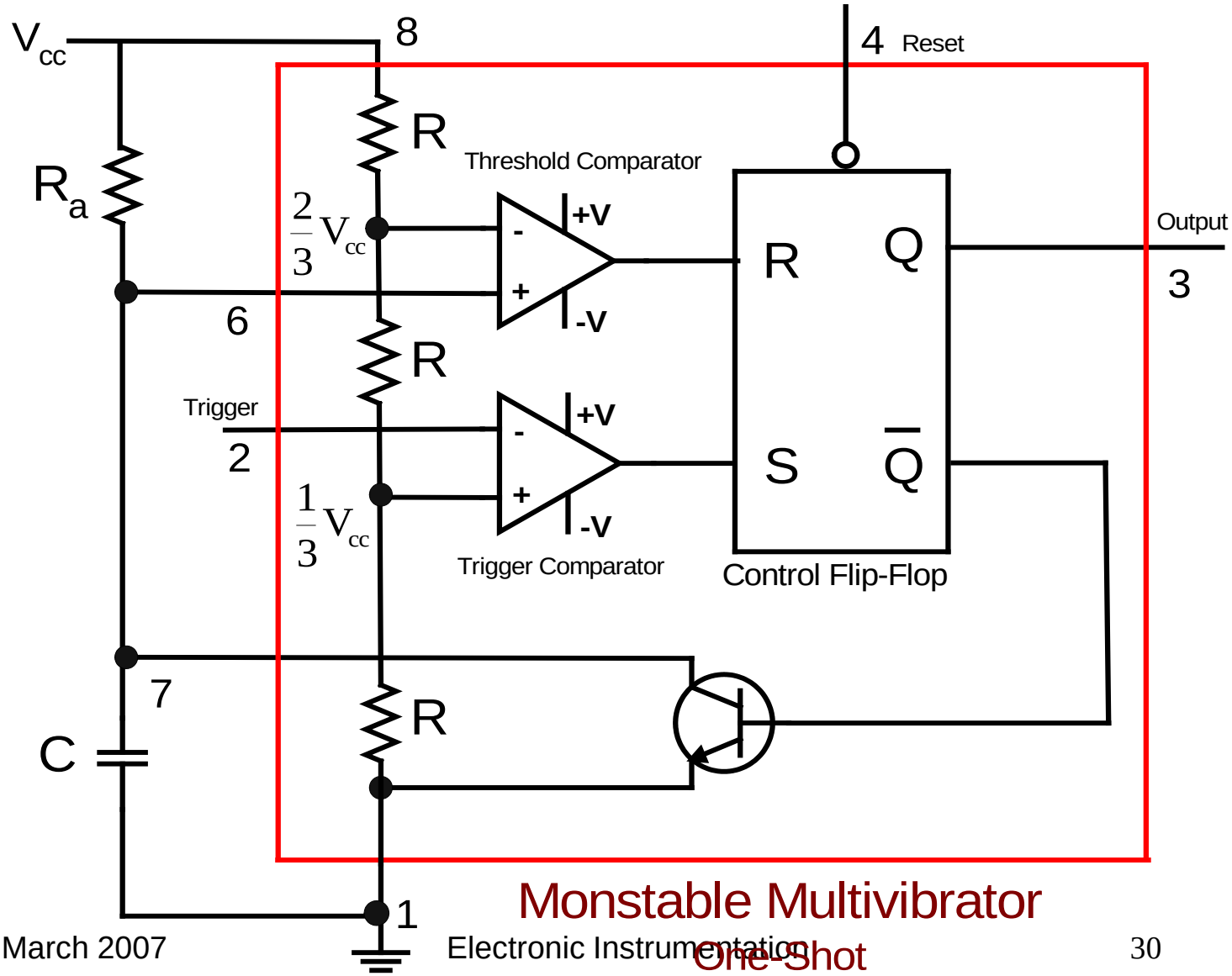




- Astable Multivibrator puts out a continuous sequence of pulses

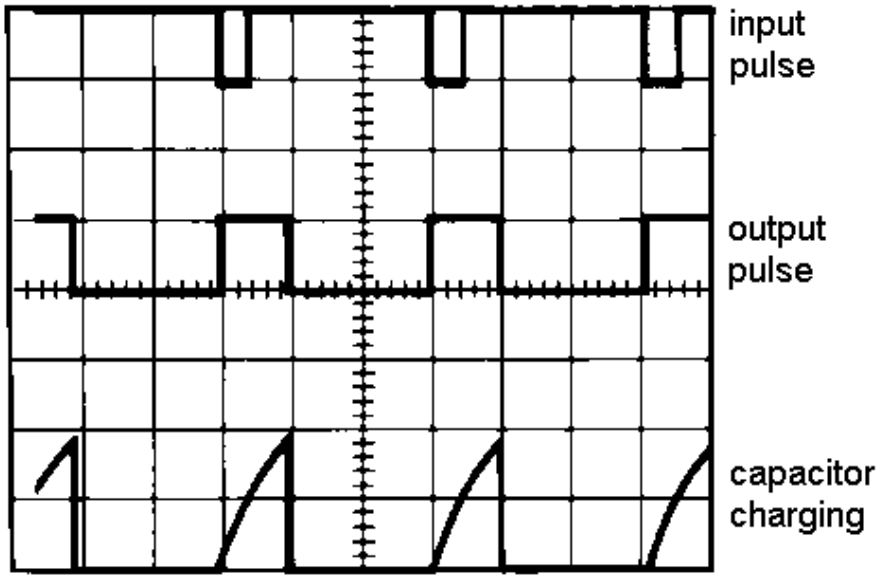
- Monostable Multivibrator (or one-shot) puts out one pulse each time the switch is connected

Monostable Multivibrator (One Shot)



Behavior of the Monostable Multivibrator

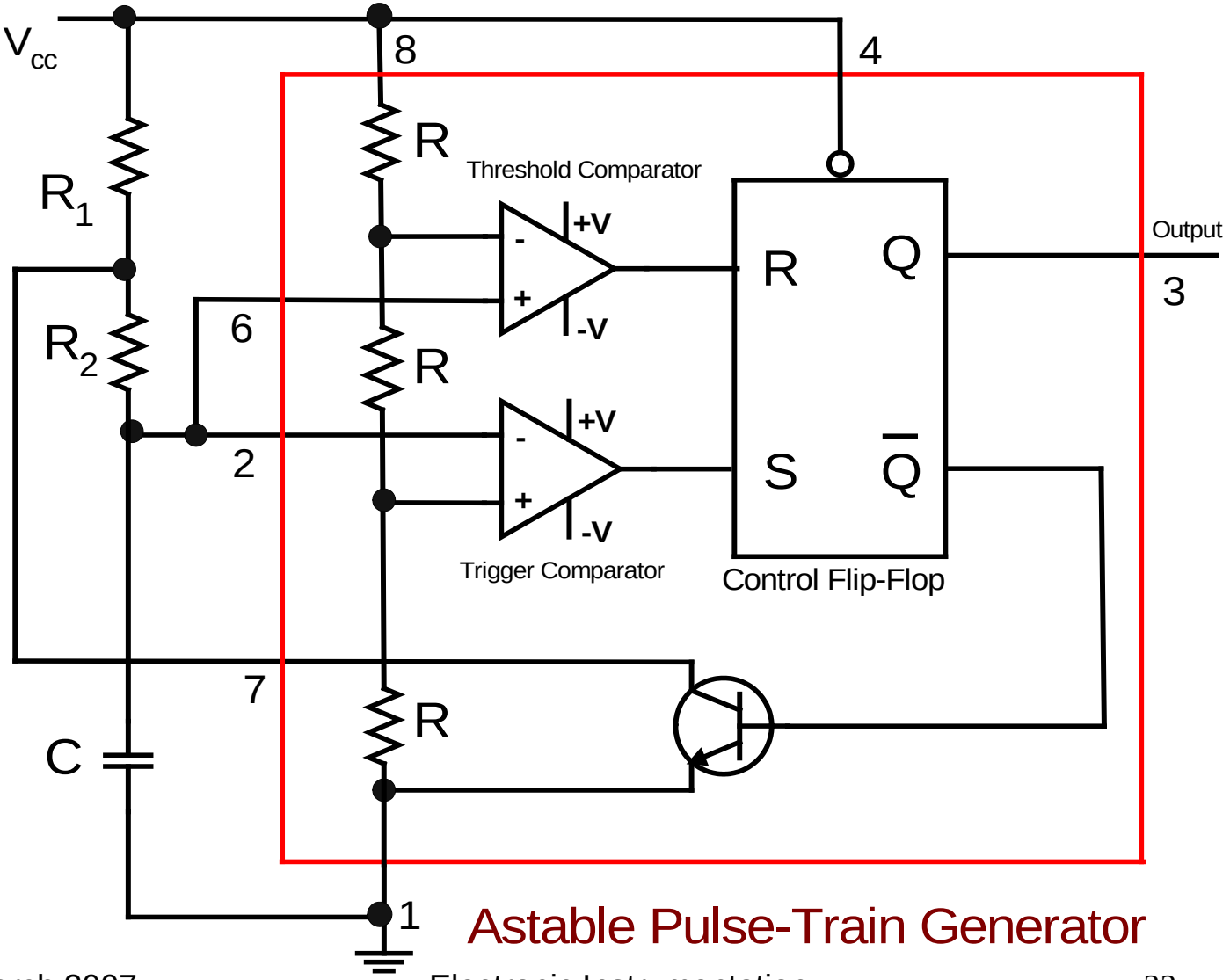
- The monostable multivibrator is constructed by adding an external capacitor and resistor to a 555 timer.
- The circuit generates a single pulse of desired duration when it receives a trigger signal, hence it is also called a one-shot.
- The time constant of the resistor-capacitor combination determines the length of the pulse.



Uses of the Monostable Multivibrator

- Used to generate a clean pulse of the correct height and duration for a digital system
- Used to turn circuits or external components on or off for a specific length of time.
- Used to generate delays.
- Can be cascaded to create a variety of sequential timing pulses. These pulses can allow you to time and sequence a number of related operations.

Astable Pulse-Train Generator (Multivibrator)

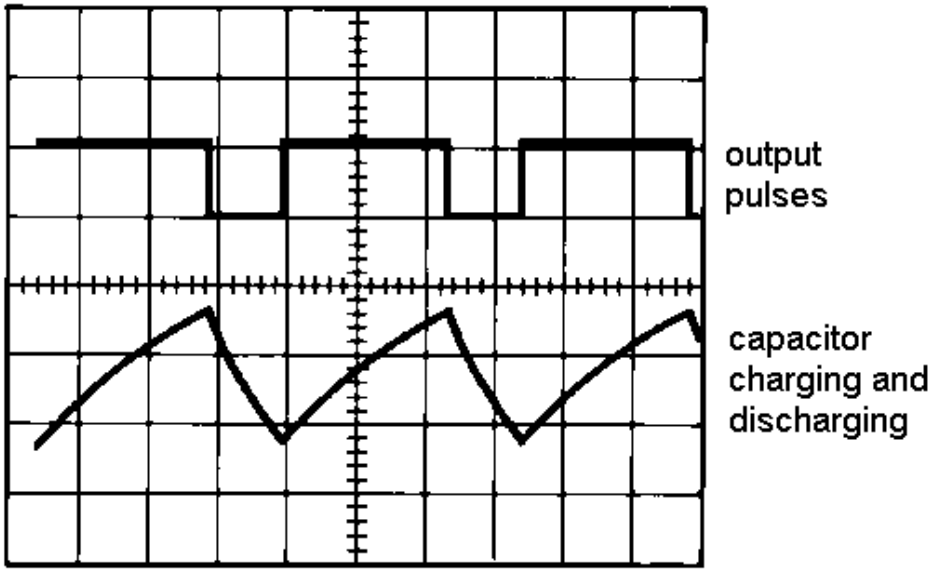


Astable Pulse-Train Generator

Behavior of the Astable Multivibrator

- The astable multivibrator is simply an oscillator. The astable multivibrator generates a continuous stream of rectangular off-on pulses that switch between two voltage levels.
- The frequency of the pulses and their duty cycle are dependent upon the RC network values.
- The capacitor C charges through the series resistors R_1 and R_2 with a time constant

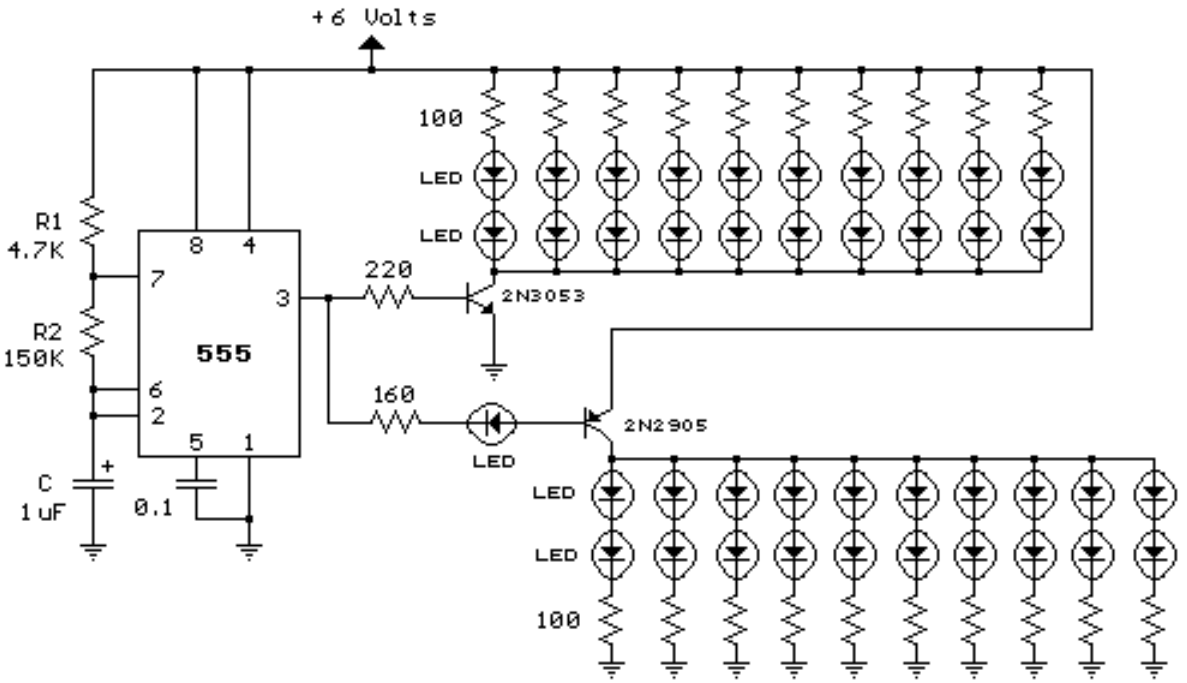
  $(R_1 + R_2)C$.
- The capacitor discharges through R_2 with a time constant of R_2C



Uses of the Astable Multivibrator

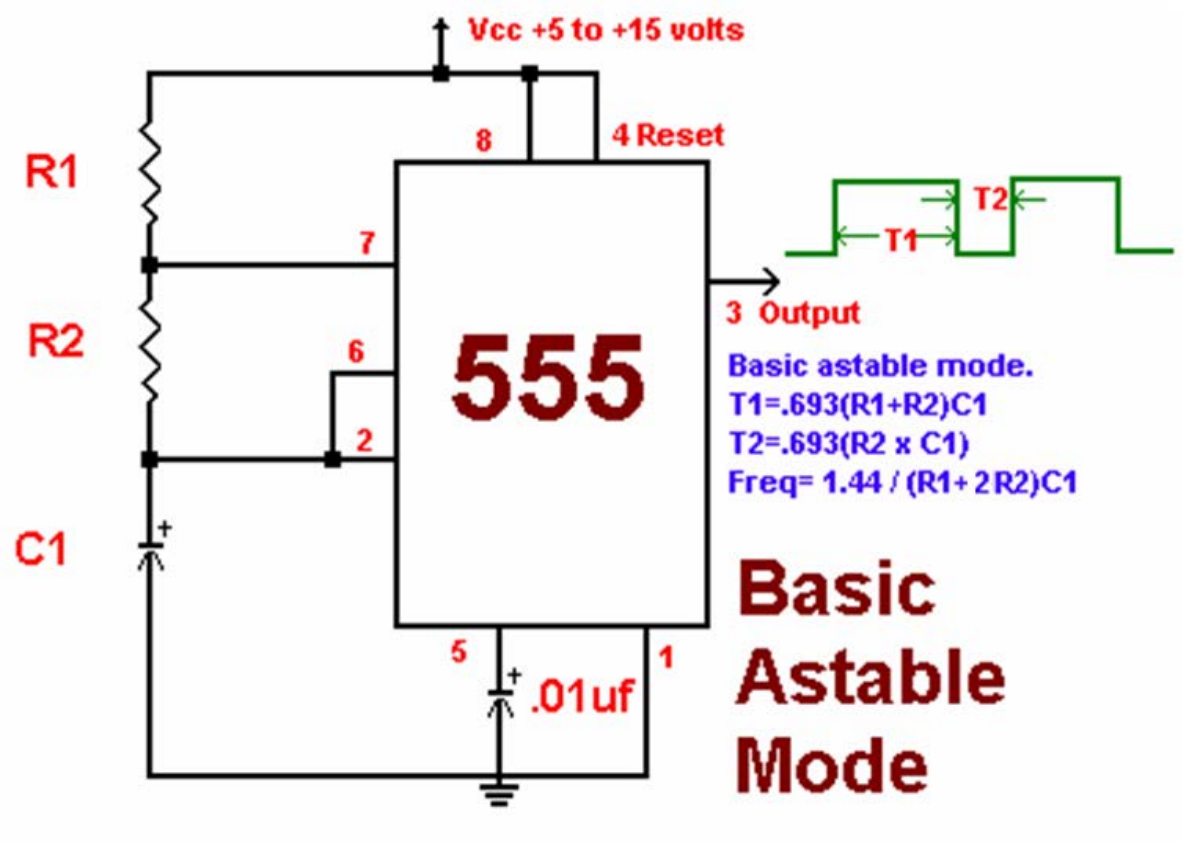
- Flashing LED's
- Pulse Width Modulation
- Pulse Position Modulation
- Periodic Timers

Flashing LED's



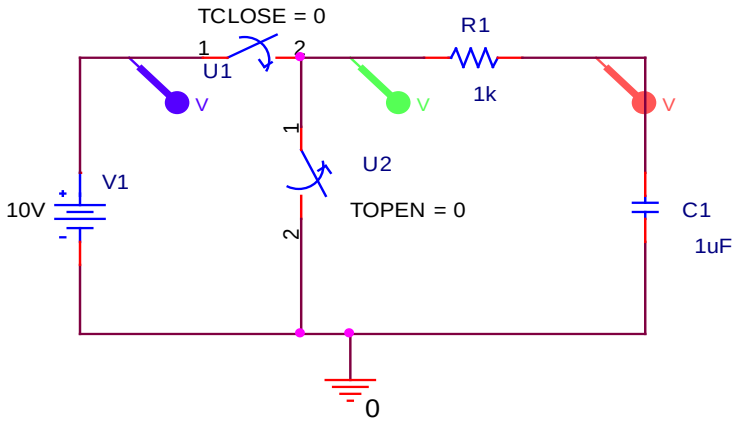
- 40 LED bicycle light with 20 LEDs flashing alternately at 4.7Hz

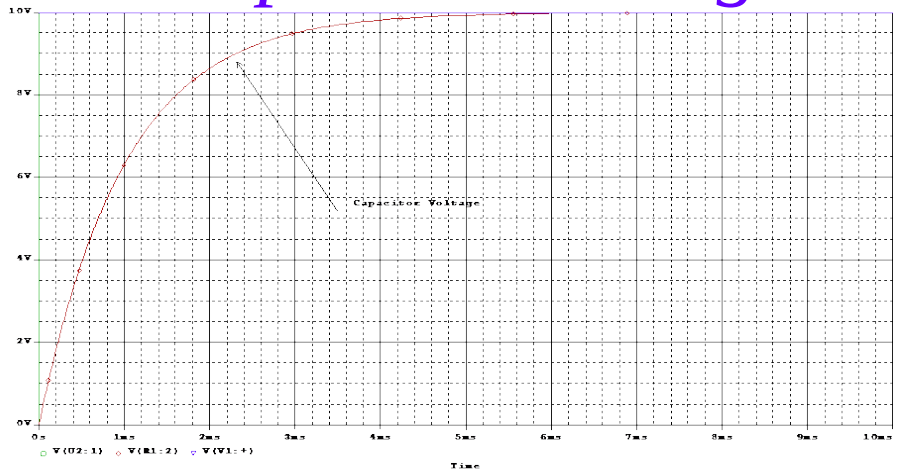
Understanding the Astable Mode Circuit



- 555-Timers, like op-amps can be configured in different ways to create different circuits. We will now look into how this one creates a train of equal pulses, as shown at the output.

First we must examine how capacitors charge



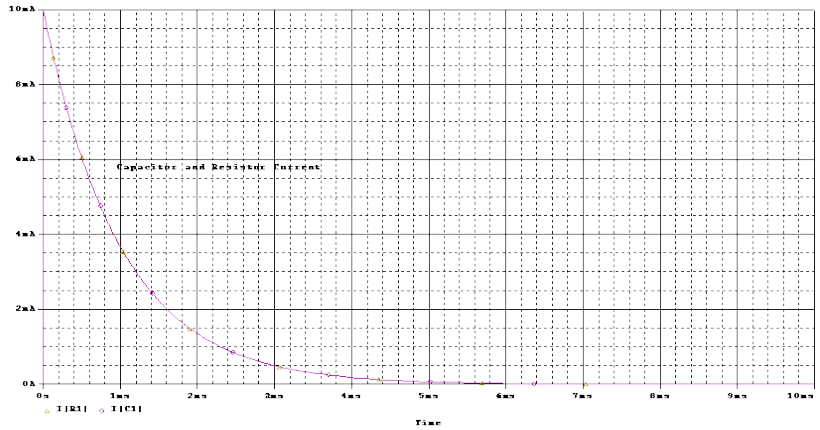


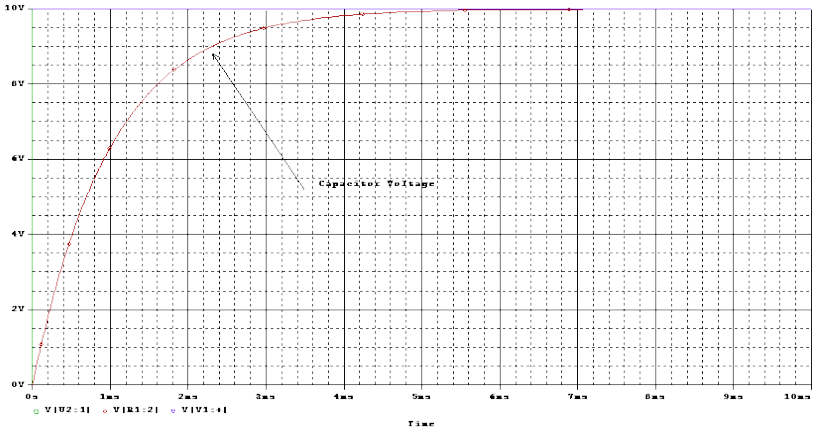
- Capacitor C1 is charged up by current flowing through R1

$$I = \frac{V1 - V_{CAPACITOR}}{R1} = \frac{10 - V_{CAPACITOR}}{1k}$$

- As the capacitor charges up, its voltage increases and the current charging it decreases, resulting in the charging rate shown

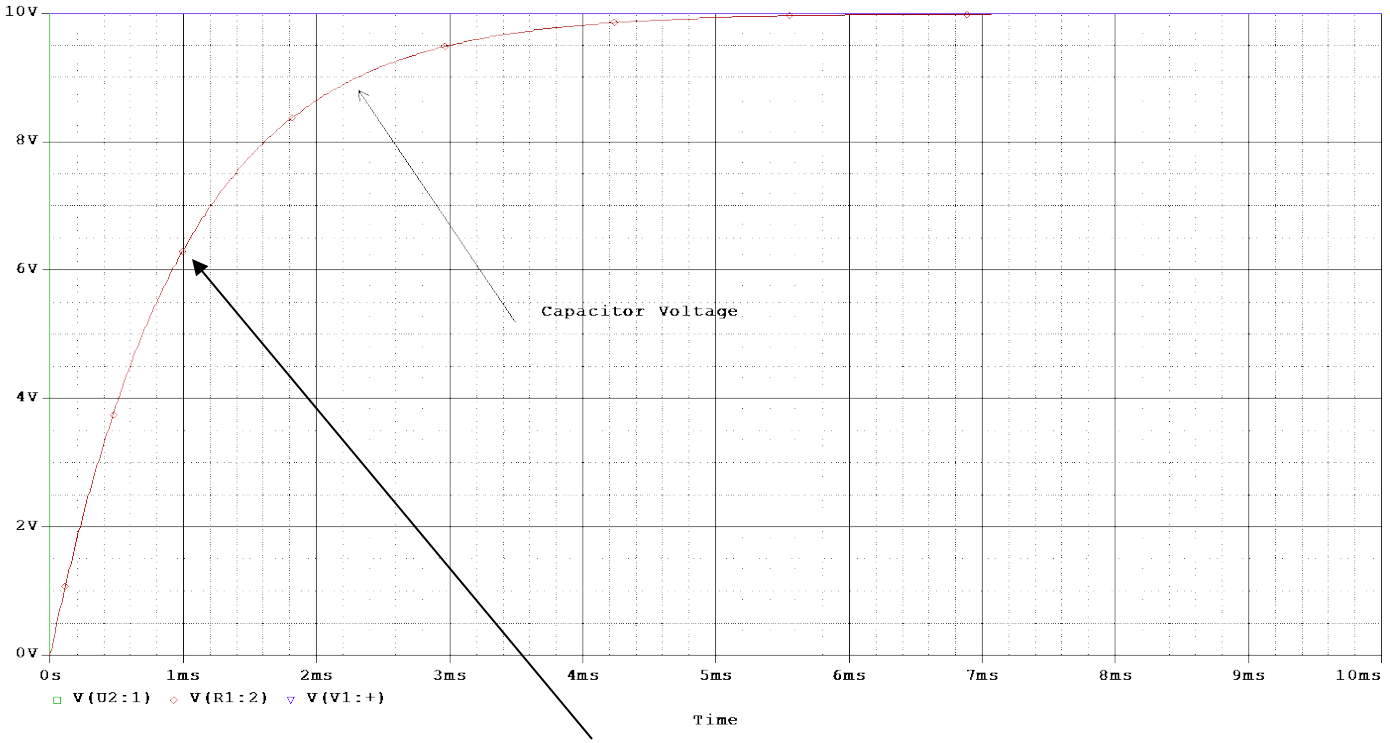
Capacitor Charging Equations





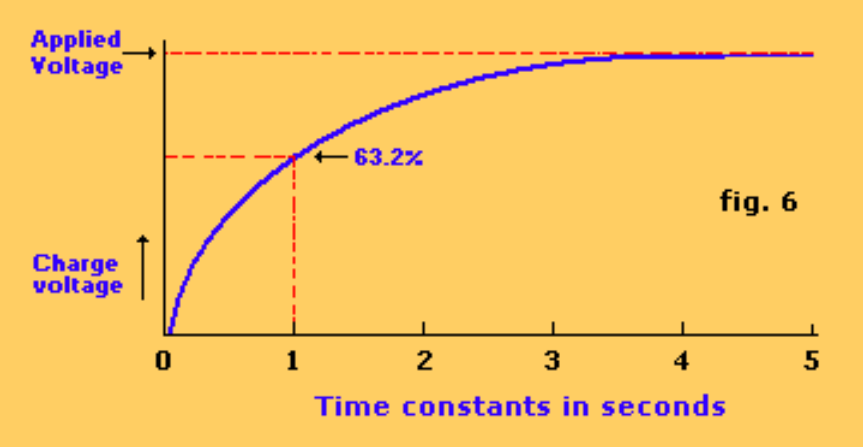
- Capacitor Current $I = I_o e^{-t/\tau}$
- Capacitor Voltage $V = V_o\left(1 - e^{-t/\tau}\right)$
- Where the time constant $\tau = RC = R1 \cdot C1 = 1ms$

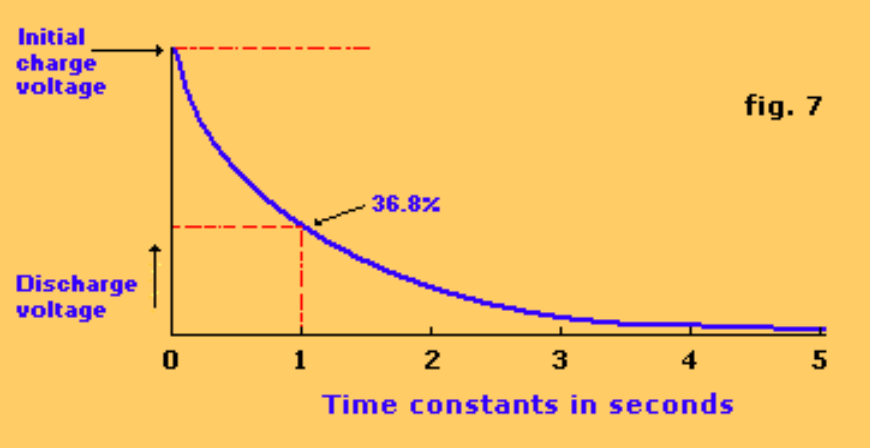
Understanding the equations



- Note that the voltage rises to a little above 6V in 1ms. $(1 - e^{-1}) = .632$

Capacitor Charging and Discharging





- There is a good description of capacitor charging and its use in 555 timer circuits at http://www.uoguelph.ca/~antoon/gadgets/555/555.html

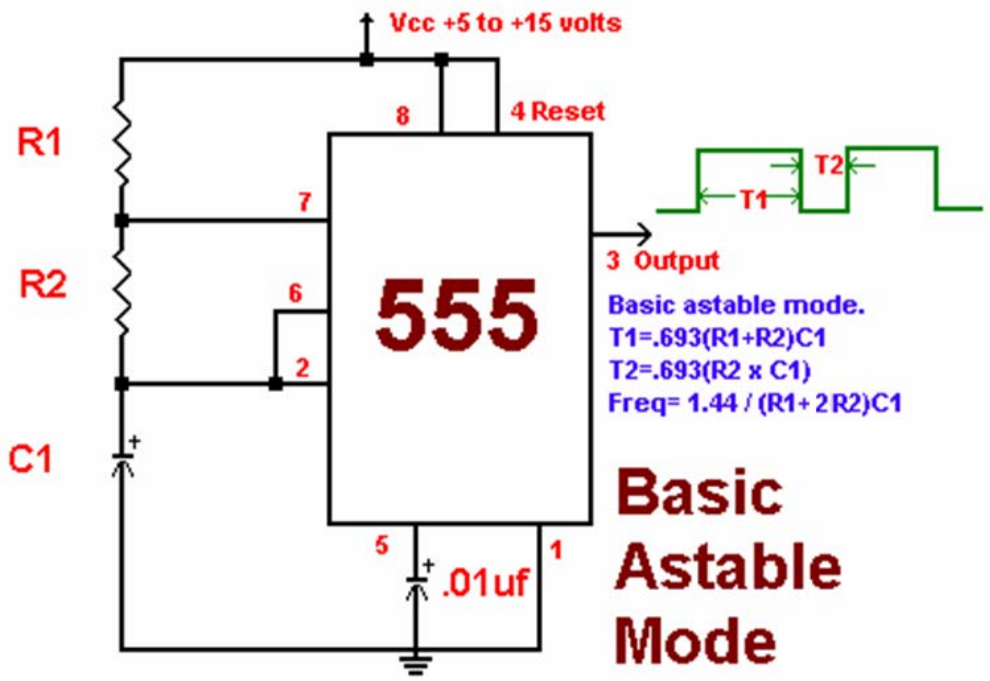
555 Timer

- At the beginning of the cycle, C1 is charged through resistors R1 and R2. The charging time constant is

$$\tau_{charge} = (R1 + R2)C1$$

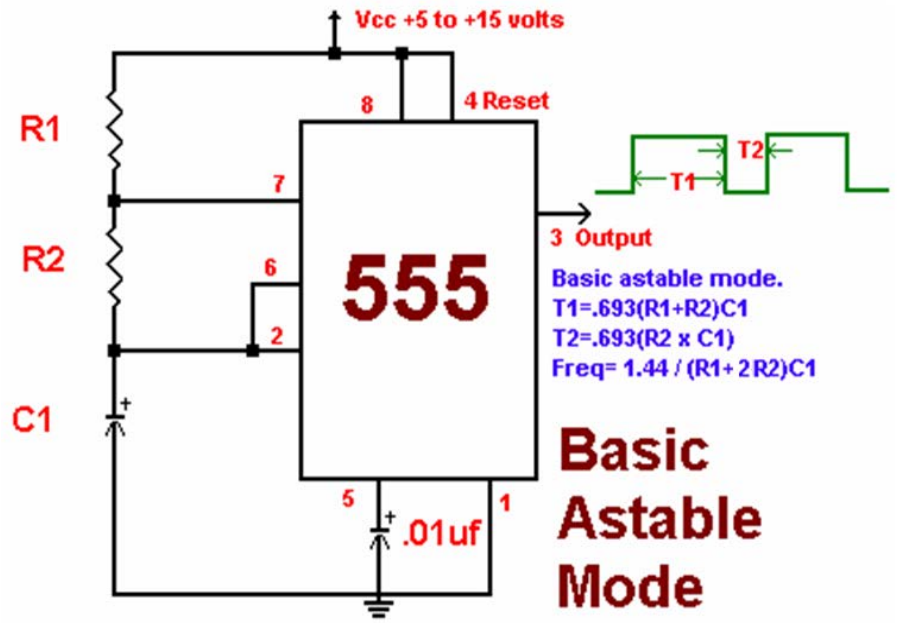
- The voltage reaches (2/3)Vcc in a time

$$t_{charge} = T1 = 0.693(R1 + R2)C1$$



555 Timer

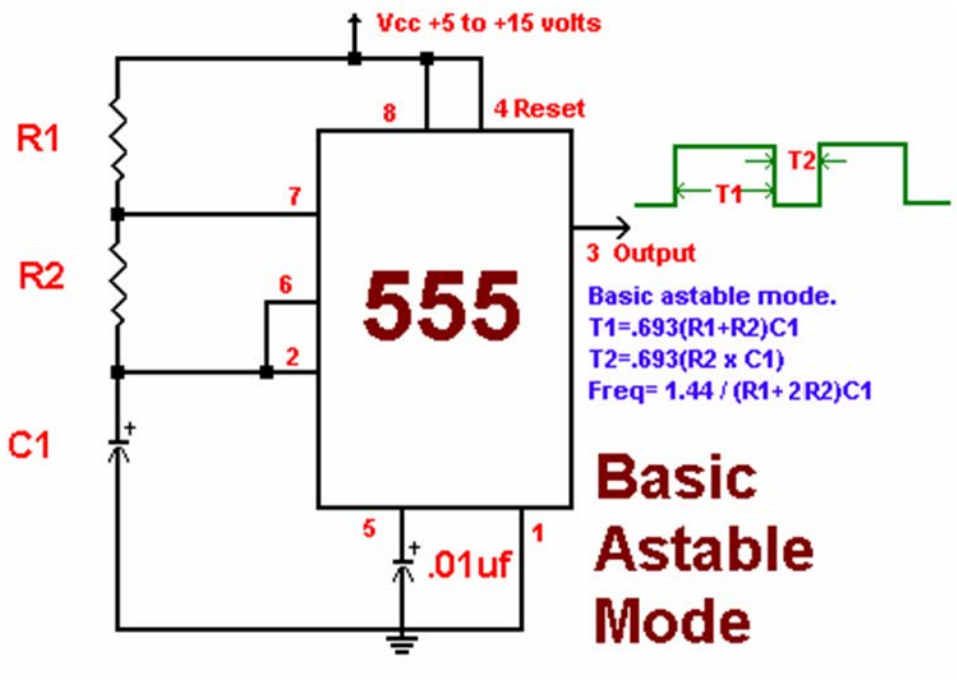
- When the voltage on the capacitor reaches (2/3)Vcc, a switch (the transistor) is closed (grounded) at pin 7.
- The capacitor is discharged to (1/3)Vcc through R2 to ground, at which time the switch is opened and the cycle starts over.



$$\tau_{discharge} = (R2)C1$$

$$t_{discharge} = T2 = 0.693(R2)C1$$

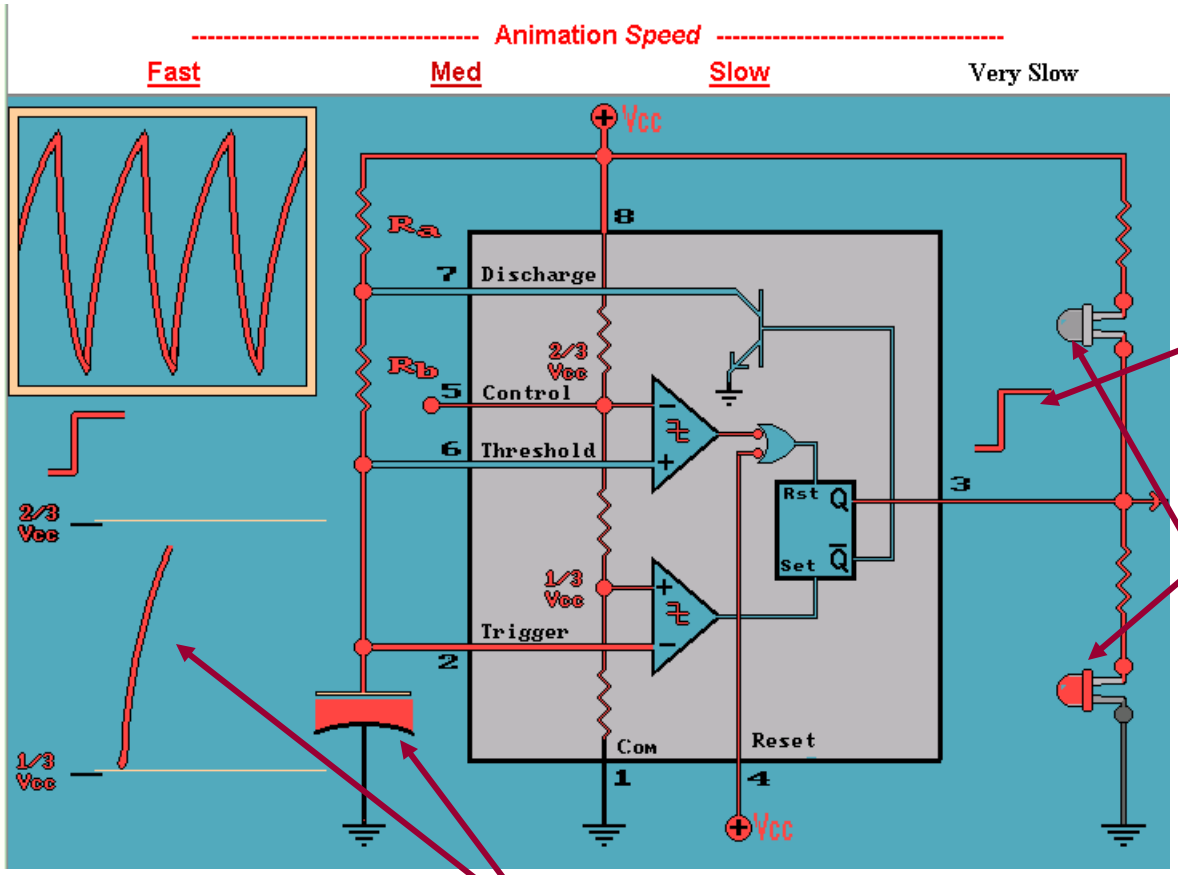
555 Timer



- The frequency is then given by

$$f = \frac{1}{0.693(R1 + 2 \cdot R2)C1} = \frac{1.44}{(R1 + 2 \cdot R2)C1}$$

555 Animation



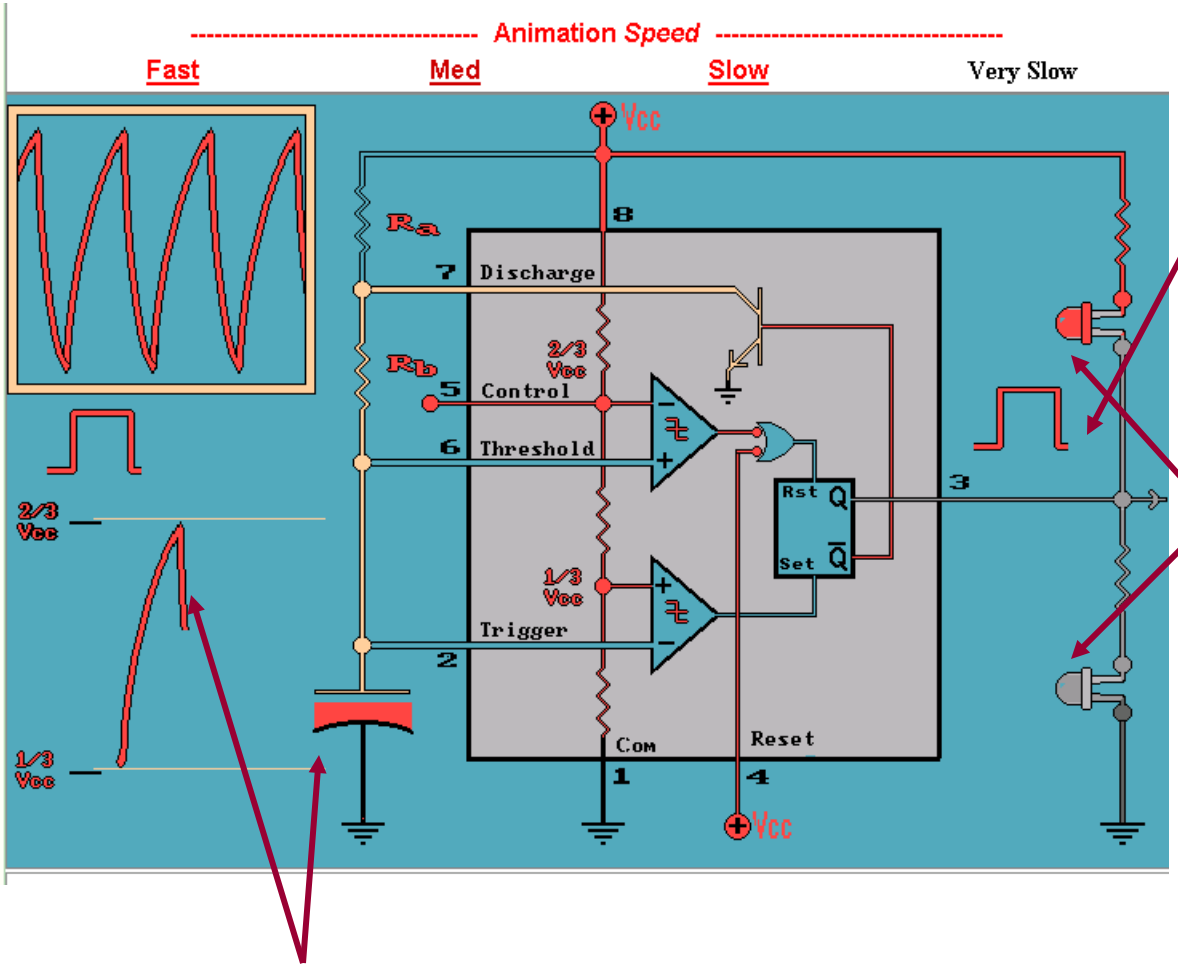
Output is high for $0.693(R_a+R_b)C$

Output voltage high turns off upper LED and turns on lower LED

Capacitor is charging through R_a and R_b

- http://www.williamson-labs.com/pu-aa-555-timer_slow.htm

555 Animation

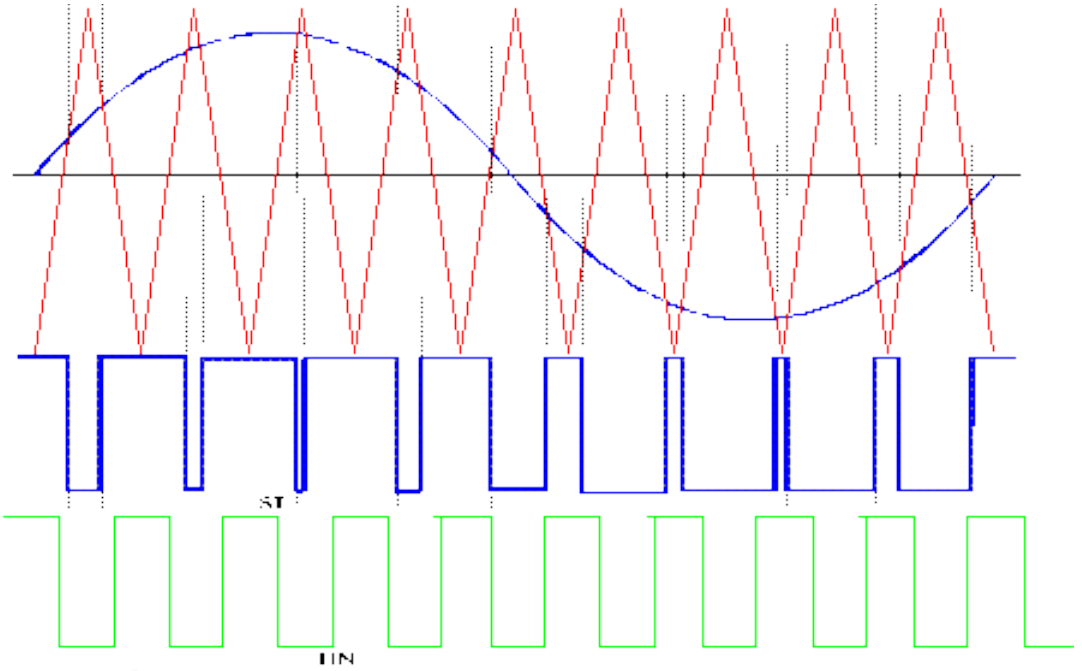


Output is low for $0.693(R_b)C$

Output is low so the upper LED is on and the lower LED is off

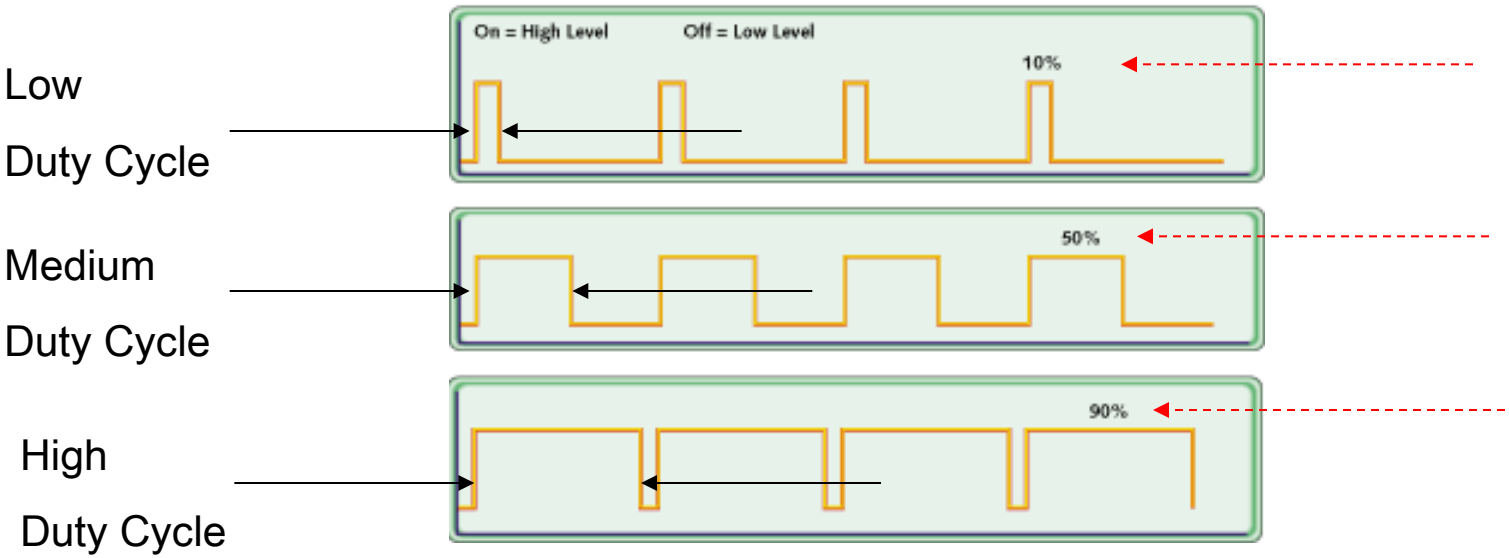
Capacitor is discharging through R_b

PWM: Pulse Width Modulation



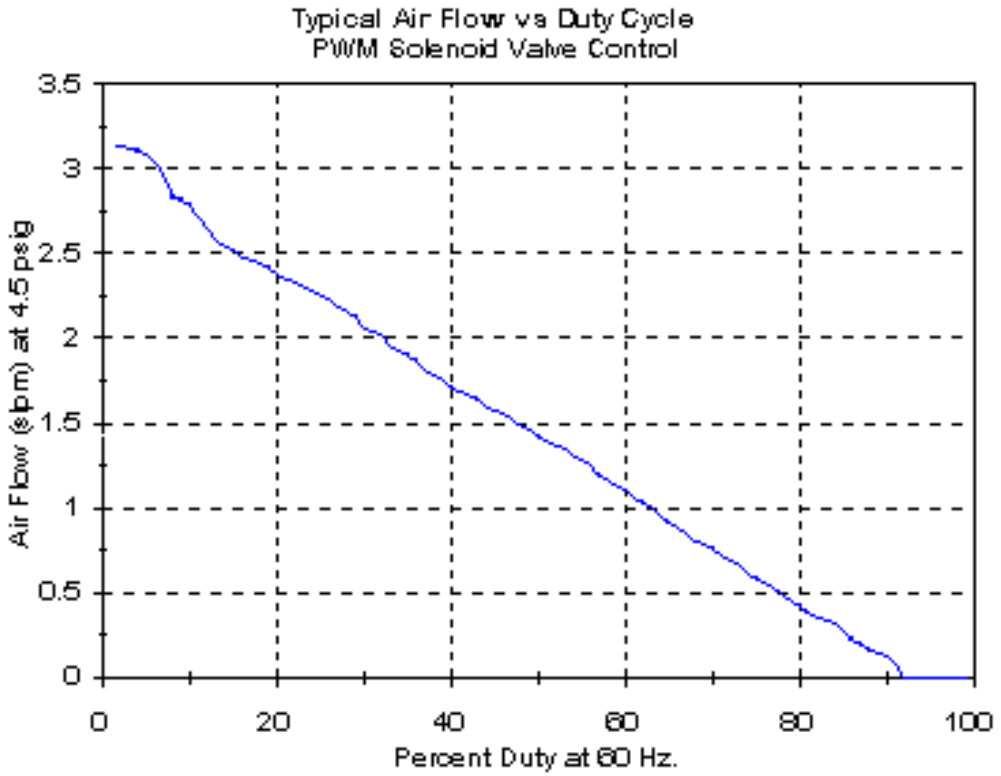
- Signal is compared to a sawtooth wave producing a pulse width proportional to amplitude

What Can Be Done With PWM?



- Question: What happens if voltages like the ones above are connected to a light bulb? Answer: The longer the duty cycle, the longer the light bulb is on and the brighter the light.

What Can Be Done With PWM?



- Average power can be controlled
- Average flows can also be controlled by fully opening and closing a valve with some duty cycle