Mechatronics (ROB-GY 5103 Section A)

- **Today's lecture:**
  - Multivibrator (555 timer)
- (See Topics #4 from Main Text for details)

Review of RC Circuit

- What is the time constant?
- Why does 63.2% mean?

Two-state devices

- Button/switch provides digital (two-state) inputs
- Comparator produces digital output
- Deceptively simple:
  - Pull-up/pull-down and active-high/active/low
  - Use hysteresis to remove chattering in a comparator

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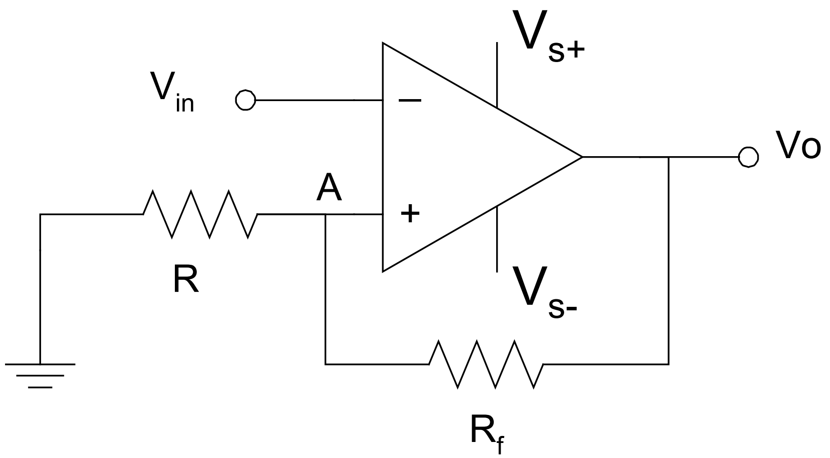
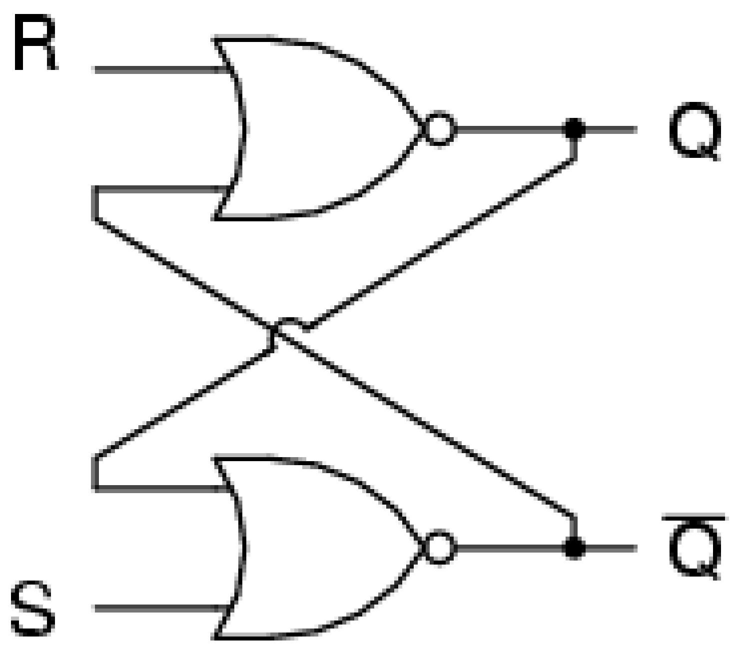


SR Latch (Set-Reset Latch)

- Simple **active** two-state device with two NOR gates



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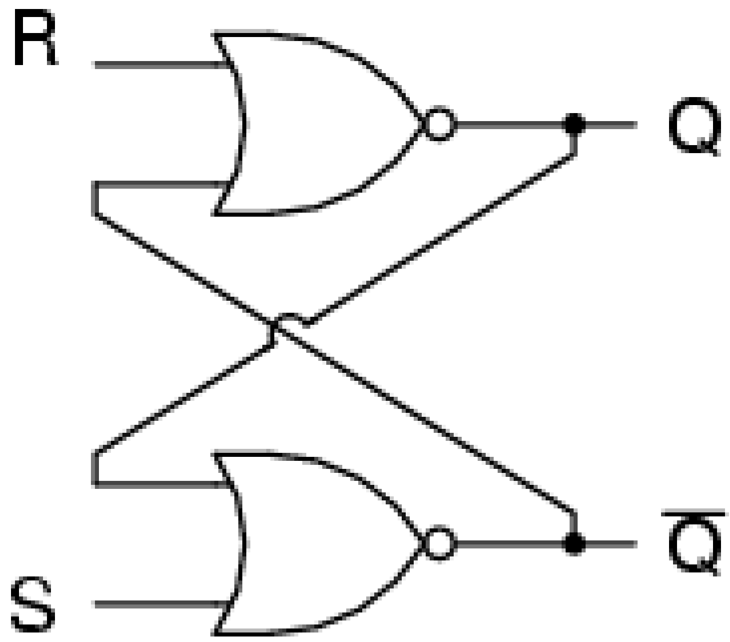
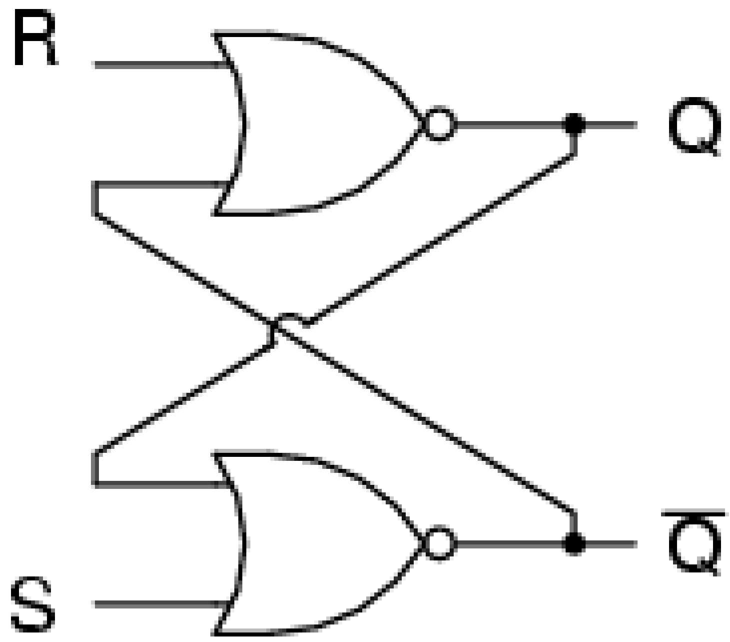


S	R	Q	$\overline{Q}$
0	0	latch	latch
0	1	0	1
1	0	1	0
1	1	0	0

SR Latch (Set-Reset Latch)

- Simple **active** two-state device with two NOR gates
- System has memory!



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0	0	latch	latch
0	1	0	1
1	0	1	0
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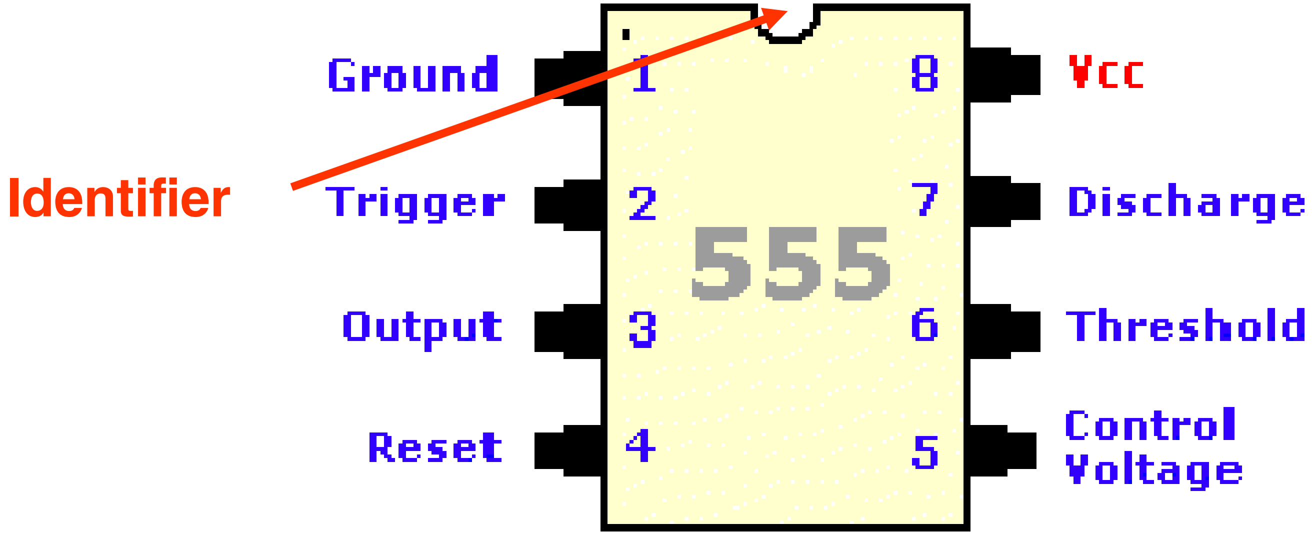
Multivibrator

- **Astable** multivibrator circuit
    - Oscillates between two states
        - No trigger input
- **Monostable** multivibrator circuit (**one-shot** circuit)
    - Stable in one state (transient in the other state)
        - One trigger input
- **Bistable** multivibrator circuit
    - Stable in either state
        - Two trigger inputs (on/off) or toggle
        - Building block for memory

555 timer

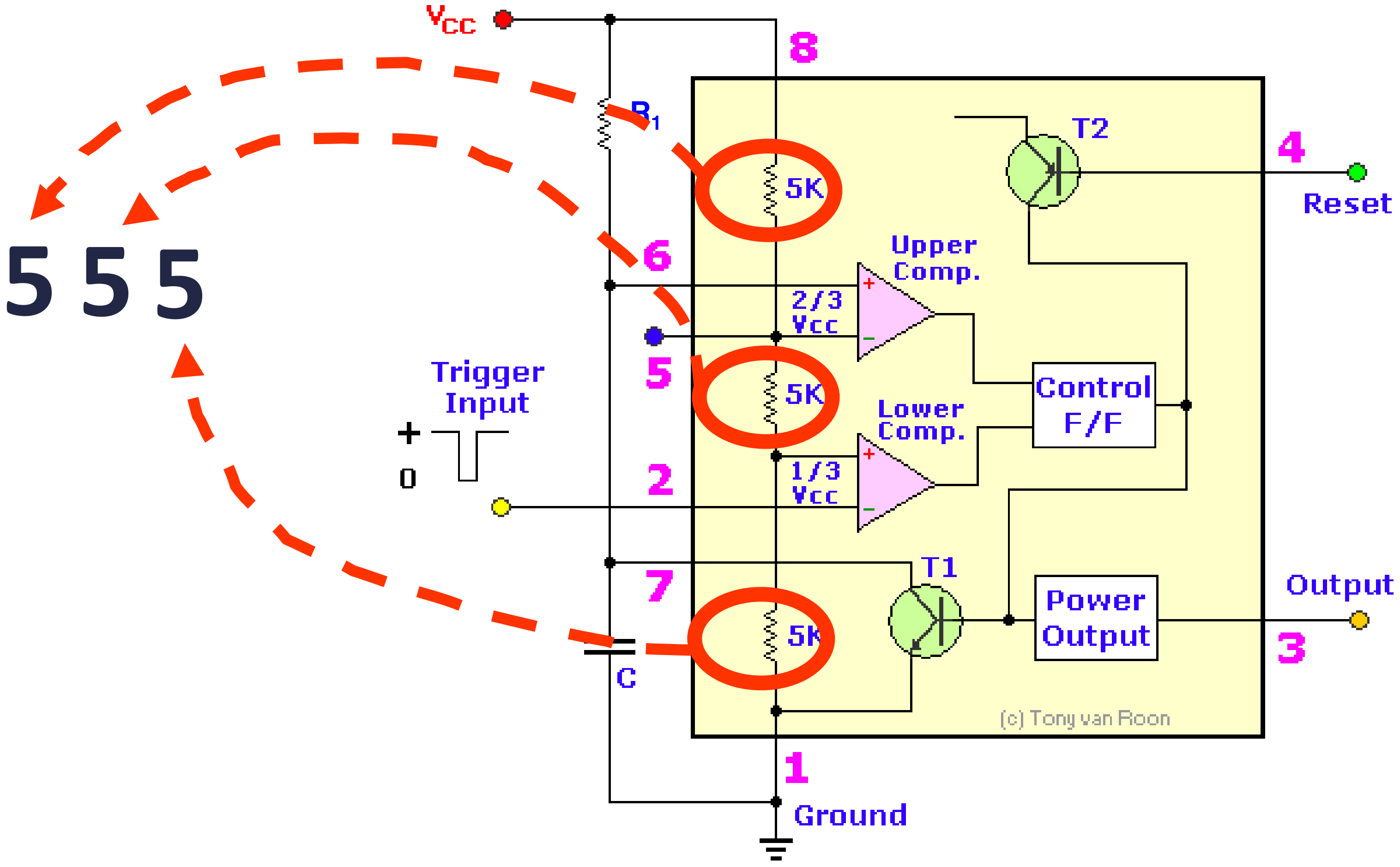
- Highly stable device for generating accurate time delay or oscillation.
- Not programmable.
    - Controlled by resistors and capacitors.
- Applications
    - Pulse generation
    - PWM
    - Time delay generation



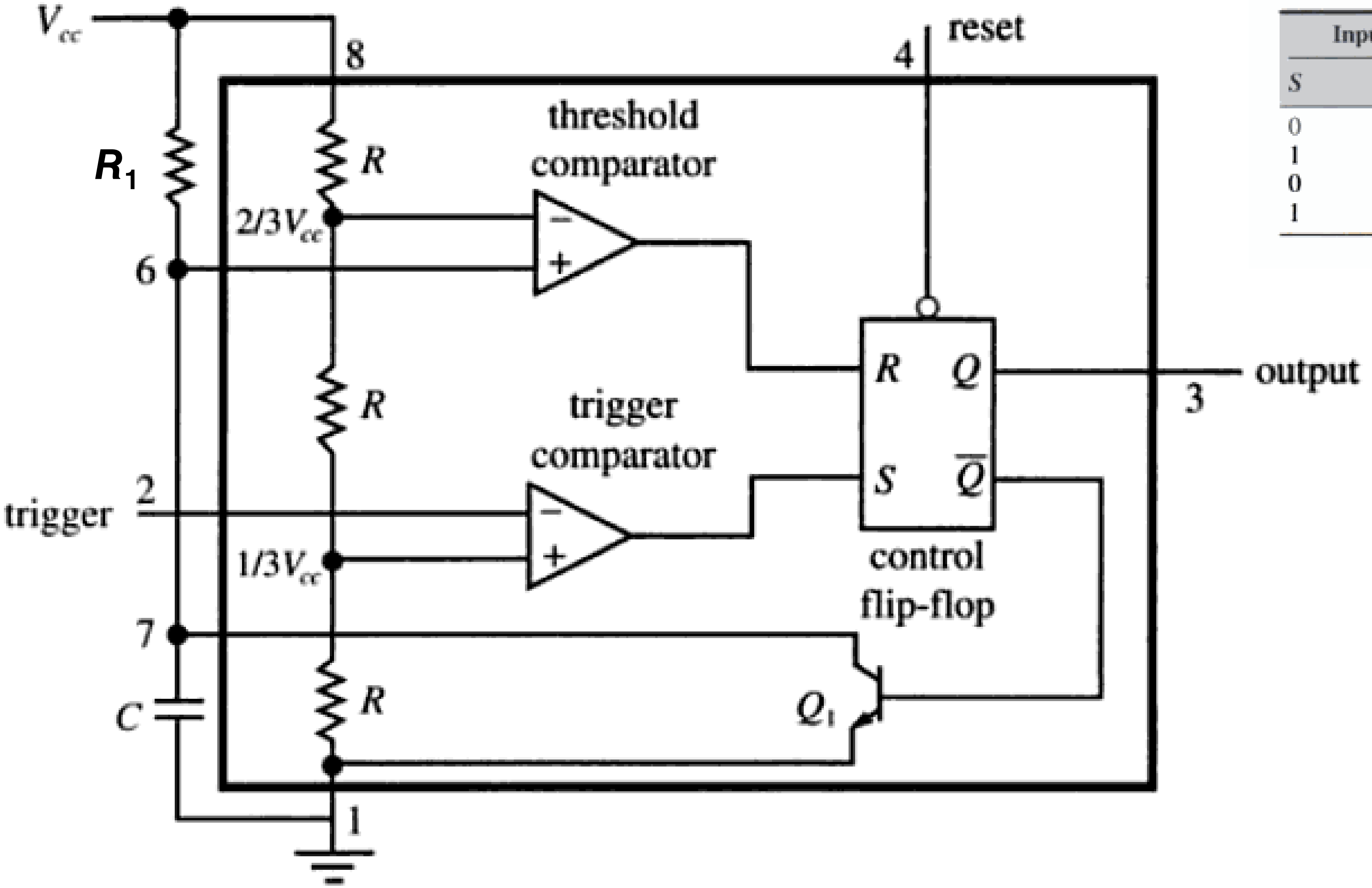
Pinout Diagram

555 Timer: Block Diagram

- Contains **control flip-flop**
    - Same truth table as **SR Latch**
- Voltage divider formed by three 5K ohm resistors
- Two comparators
- Two transistors



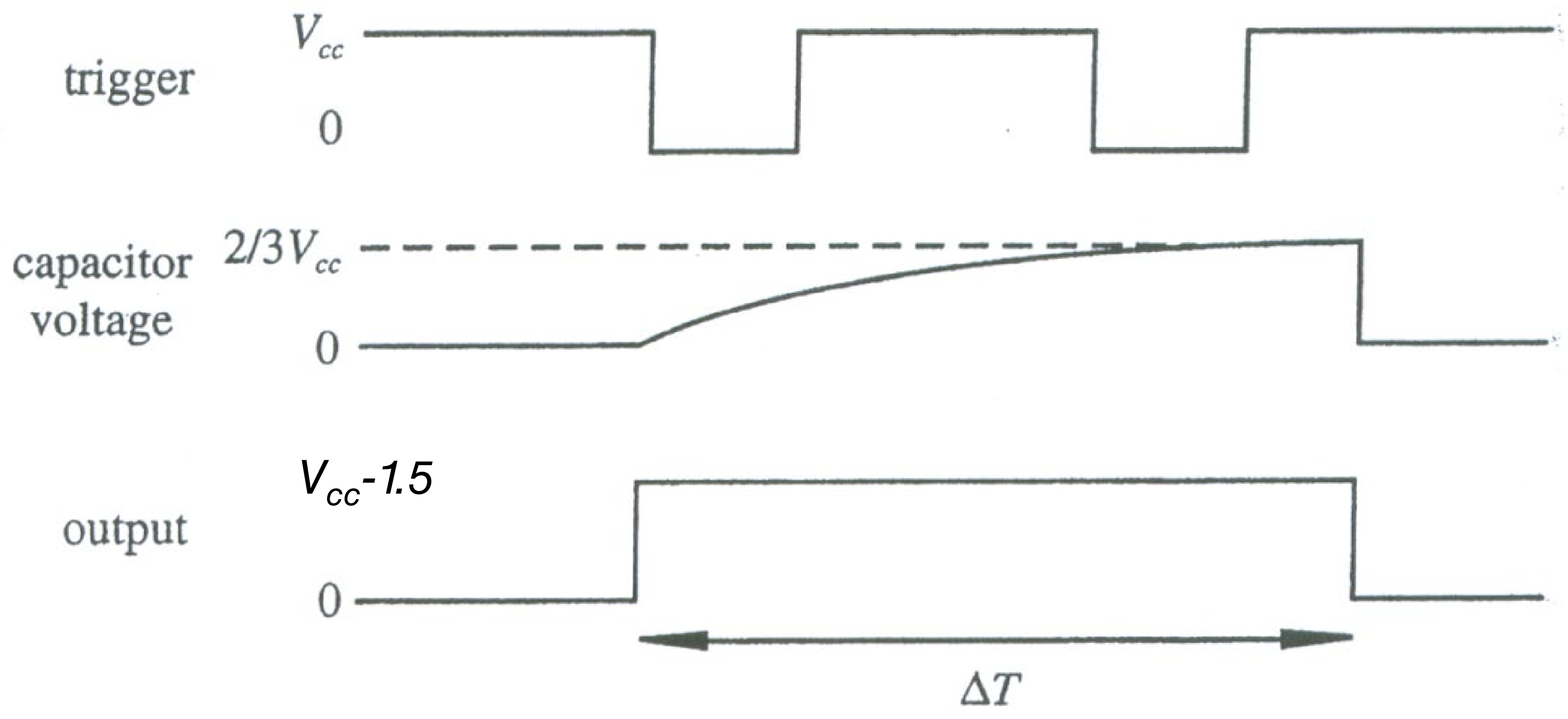
555 Timer: Monostable Mode Implementation



Truth table for the RS flip-flop

Inputs		Outputs	
S	R	Q	$\overline{Q}$
0	0	Q_0	$\overline{Q}_0$
1	0	1	0
0	1	0	1
1	1	NA	

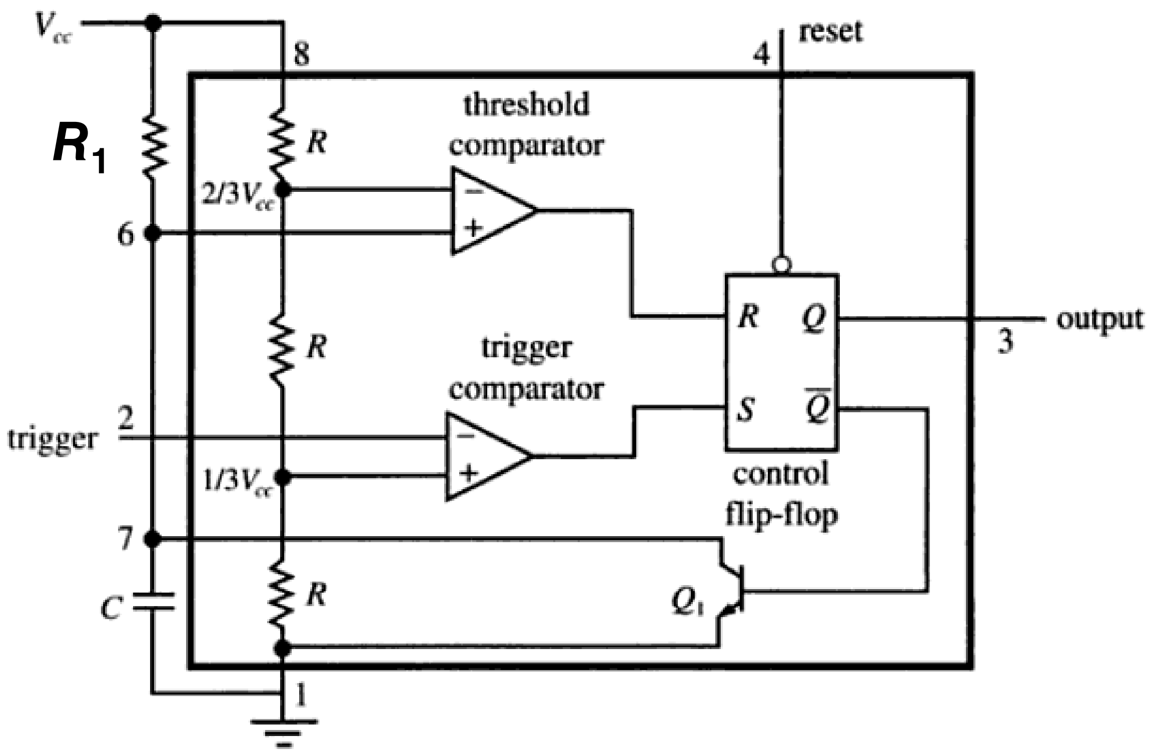
555 Timer: Monostable Mode Output



One-shot timing.

555 Timer: Monostable Circuit Operation

- On power-up or after reset: Q=low → output low, $\overline{Q}$ =high → transistor Q_1 in saturation → capacitor C is shorted
  - o Threshold comparator: $V_-=(2/3)V_{cc}$ and $V_+=0$ → comparator o/p low (R=0)
  - o Trigger comparator: V_-=High and $V_+=(1/3)V_{cc}$ → comparator o/p low (S=0)
  - o R=0, S=0 → Q and $\overline{Q}$ maintain their initial state



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Inputs		Outputs	
S	R	Q	$\overline{Q}$
0	0	Q_0	$\overline{Q}_0$
1	0	1	0
0	1	0	1
1	1	NA	

- S: set i/p
- R: reset i/p
- Q, $\overline{Q}$ complementary o/ps

555 Timer: Monostable Circuit Operation

- When trigger pulse goes low (below $(1/3)V_{cc}$), momentarily,
  - o Trigger comparator: V_{-}=low and $V_{+}=(1/3)V_{cc} \rightarrow$ comparator o/p high (S=1)
  - o Threshold comparator: $V_{-}=(2/3)V_{cc}$ and V_{+}=voltage across capacitor which charges from 0V initial state towards $(2/3)V_{cc} \rightarrow$ comparator o/p low (R=0)
  - o R=0, S=1 $\rightarrow$Q =1 (output high) and $\overline{Q}=0$ transistor stops conducting
  - o This state persists until threshold comparator: $V_{+}=(2/3)V_{cc}$ then R=1 and S=0 (since trigger goes low only momentarily) $\rightarrow$Q=0 (output low) and $\overline{Q}=1$ so transistor conducts again and causes the capacitor to be shorted.
  - o Note that the capacitor charges from 0V initial state towards $(2/3)V_{cc}$ with time constant R_1C

555 Timer: Monostable Circuit Operation

- This circuit has only one stable state.
- The o/p resets at 0V, until a negative-going trigger pulse is applied to the trigger lead: pin 2.
- After trigger pulse is applied, the o/p will go high (around V_{cc}-1.5V) for the duration set by R_1C network.
- The width of the high output pulse is:

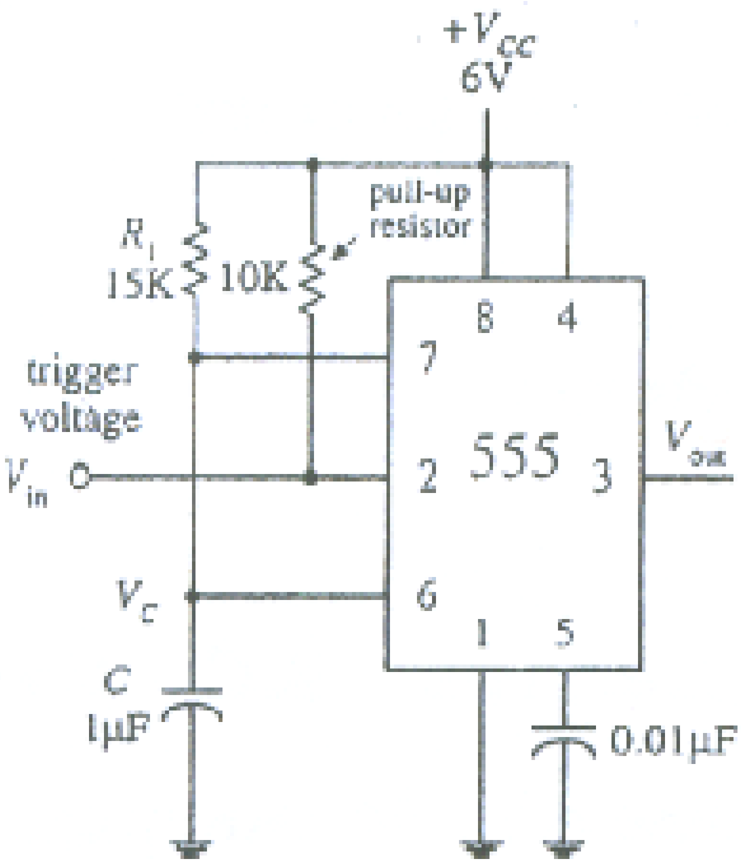
$$V_c(t) = V_{cc}(1 - e^{-t/\tau})\,|_{t=1.1\tau}$$

$$V_c(1.1\tau) = \frac{2}{3}V_{cc}$$

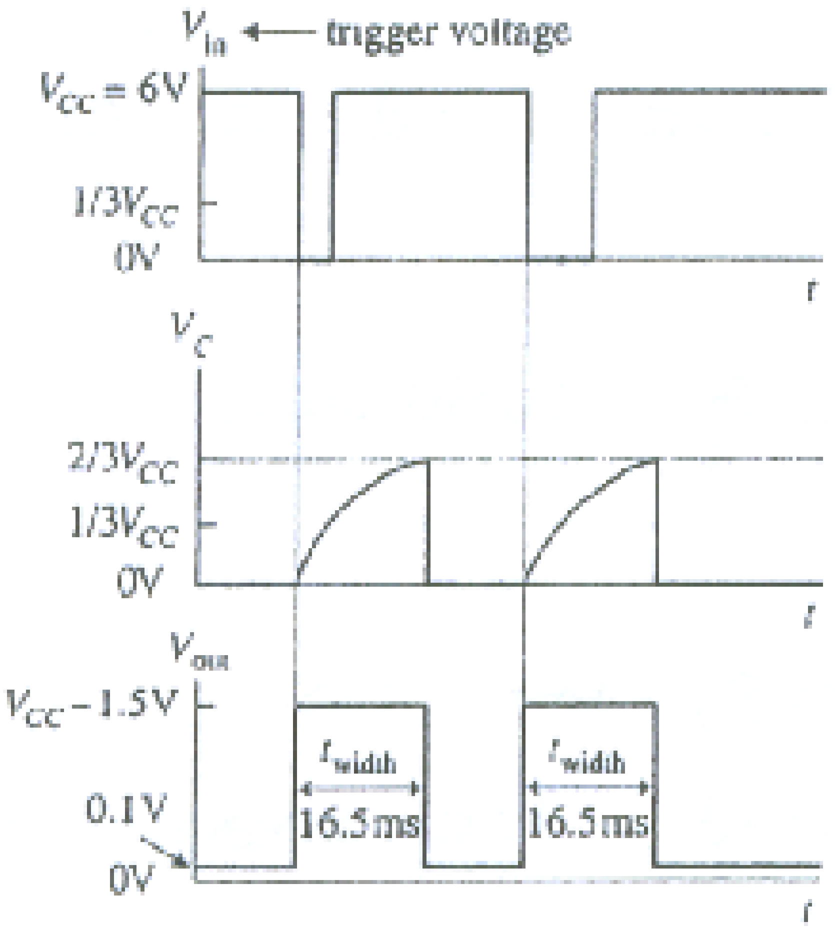
$$t_{width} = 1.10 R_1 C$$

- For reliable operation, R_1 should be between 10kW and 14MW and the capacitor should be from around 100pF to 1000mF.

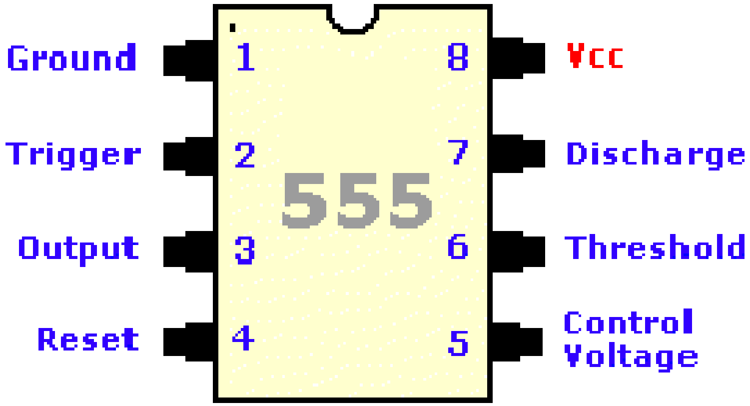
555 Timer: Monostable Circuit Operation—IV



$t_{width} = 1.10\, R_1 C$
$t_{width} = 1.10\,(15K)(1\mu F) = 16.5ms$



- Note capacitor at pin 5
  - Buffer to stabilize voltage at the pin
- In general, pin 5 is used to override voltage of 2/3 Vcc

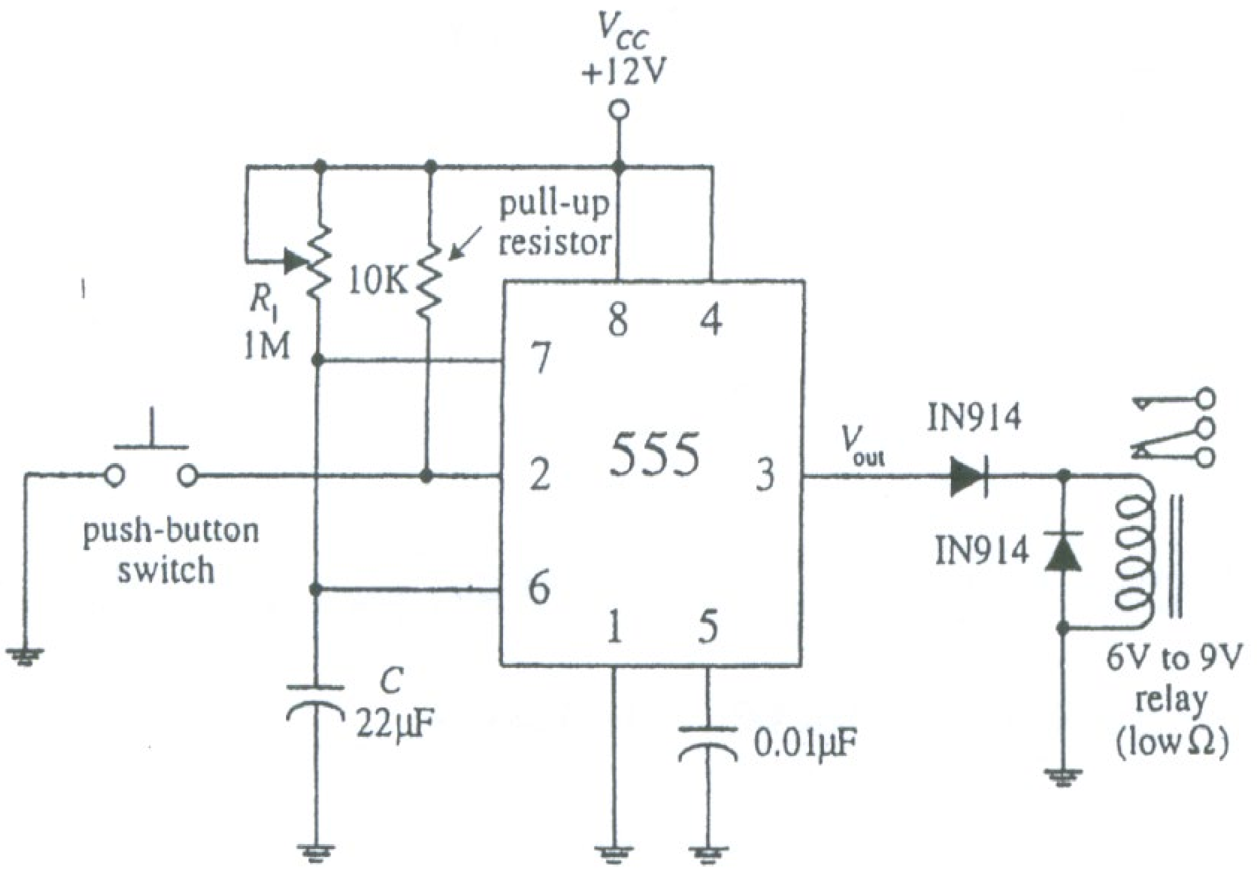


555 Timer: Monostable Mode Application: Delay Timer for Relay

- Delay timer to actuate a relay for a given duration
- When the push-button is momentarily closed, the 555 begins its timing cycle; the output goes high (in this case, ~10.5V) for a duration of

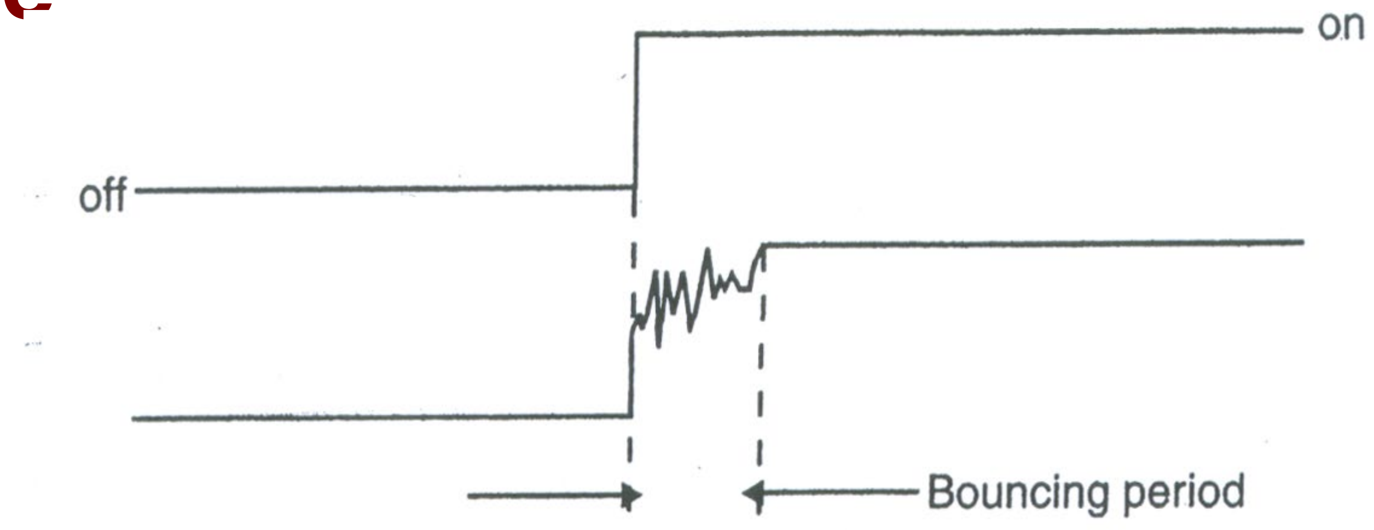
$$t_{width} = 1.10 R_1 C$$

- The relay is actuated for the same time duration.
- Diodes prevent inductive kickback from damaging the 555 IC and the switch contacts of relay

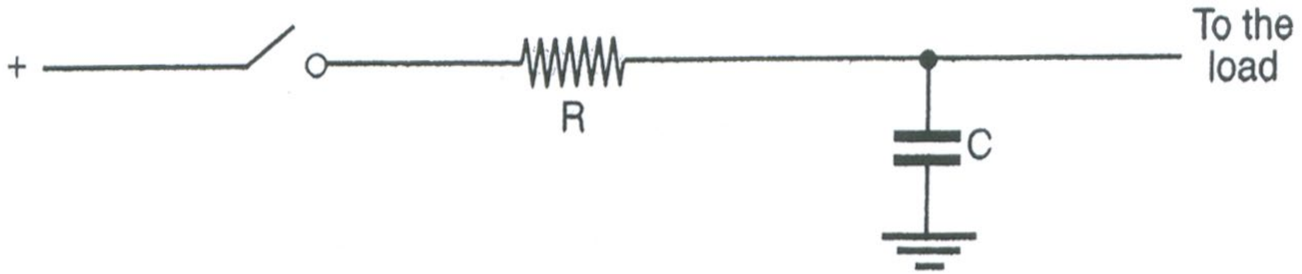


Recall: Switch Bounce

- Mechanical switches often suffer from switch bounce.
    - switch chatters with multiple low-high transitions
- ***Debouncing*** removes bounce
    - **Hardware:** RC circuit can be used
    - **Code:** BS2 command “Button” can be used to eliminate switch bounce in software (needs 250 μsec)



Contact bounce when turning on a switch.



Simple debouncing.

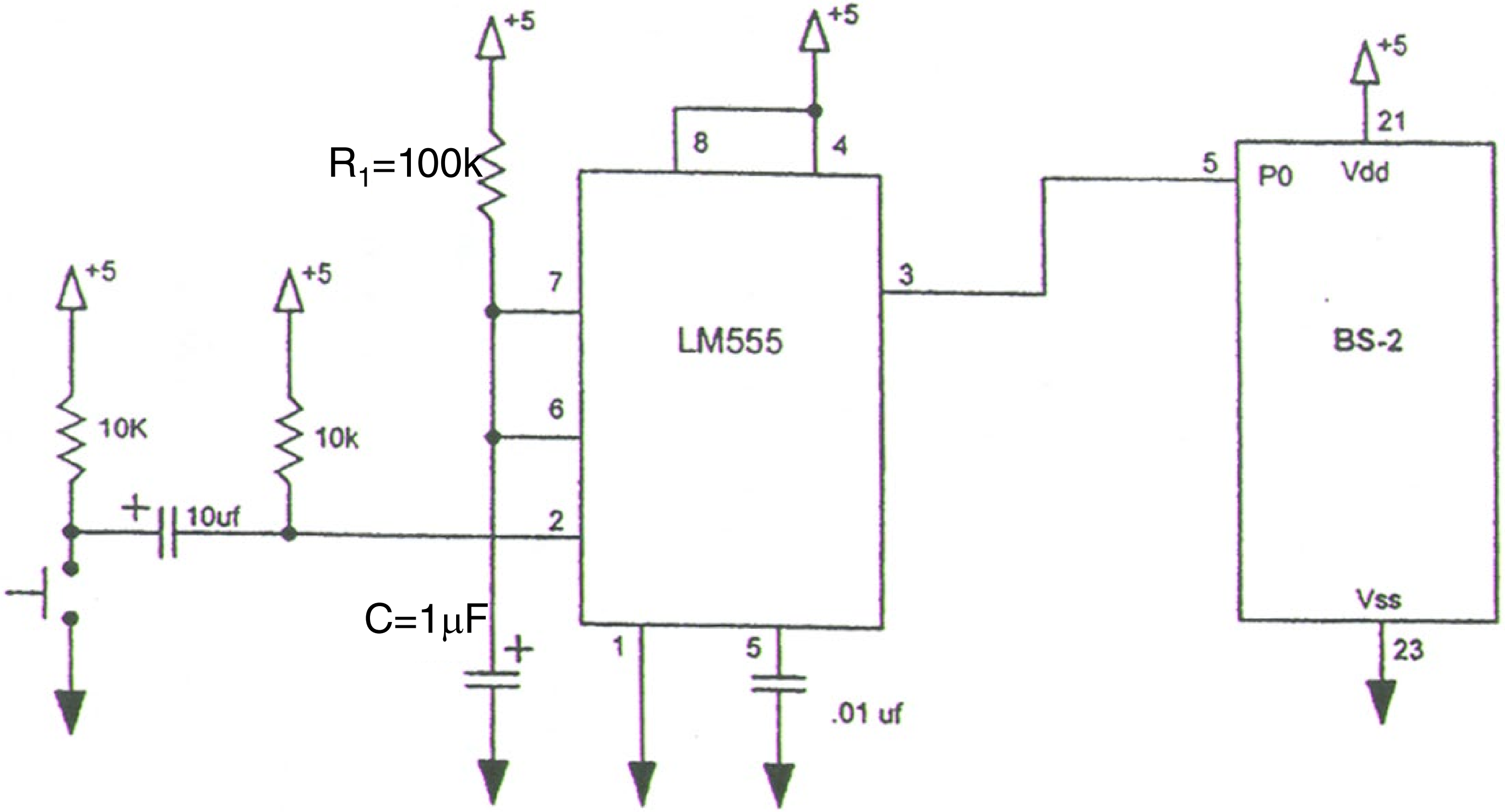
This circuit may cause time delay.

Another Hardware Solution for Debouncing

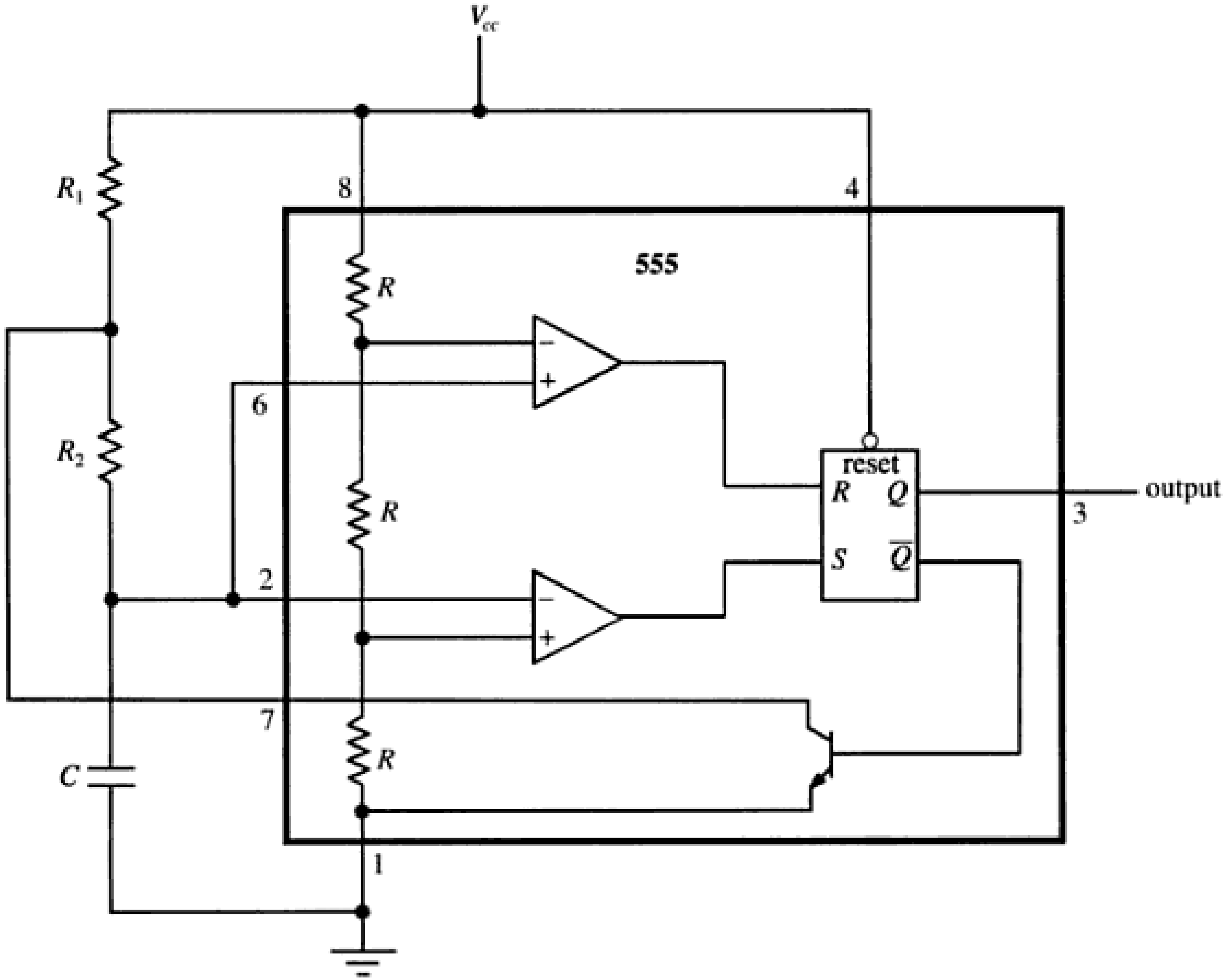
- **Monostable** circuit (**one-shot** circuit)
  - Function is to produce a single output pulse which goes from low to high and back to low once the switch is pressed
    - If a switch closing happens too quickly for BS2 to register, then the monostable circuit can be quite useful
  - Duration for high pulse output is controlled by appropriate selection of R and C
  - not useful for monitoring the current state in real time

555 Timer: Monostable Mode Application: Debouncing

- Uses a **555 timer**

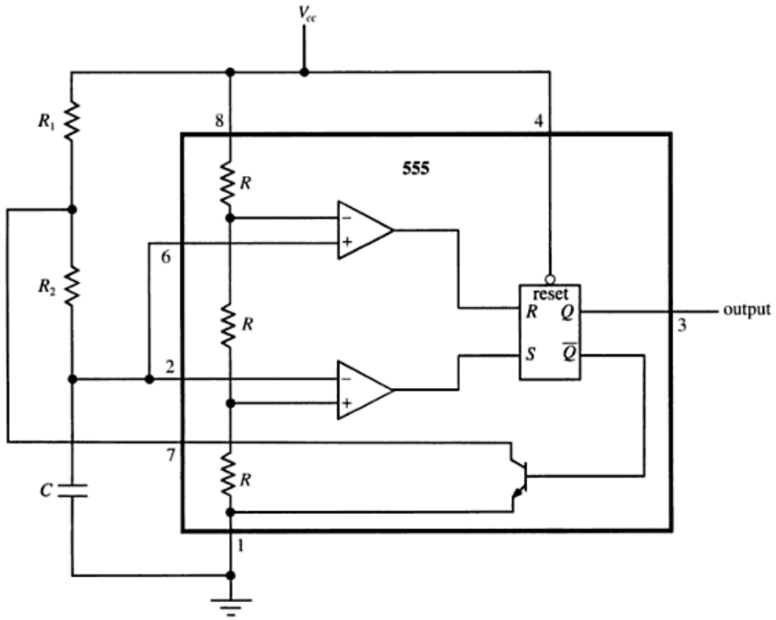


555 Timer: Astable Mode



555 Timer: Astable Mode Operation

- On power-up: C is discharged, so pin 2 is low (0V), Comp2: V_-=0, V_+=(1/3)Vcc → S=1, Comp1: V_+=0, V_-=(2/3)Vcc → R=0, So → Q =1 and $\overline{Q}$ = 0 → output is high, transistor not conducting, capacitor C charges via R_1+R_2
  - o Capacitor gets to (1/3)V_{CC}, Comp2: V_-= (1/3)V_{CC}, V_+=(1/3)Vcc → S=0, Comp1: V_+= (1/3)V_{CC}, V_-=(2/3)Vcc → R=0, So → Q and $\overline{Q}$ do not change, output is high, transistor not conducting, capacitor C charges via R_1+R_2
  - o Capacitor gets to (2/3)V_{CC}, Comp2: V_-= (2/3)V_{CC}, V_+=(1/3)Vcc → S=0, Comp1: V_+= (2/3)V_{CC}, V_-=(2/3)Vcc → R=1, So → Q =0 and $\overline{Q}$ = 1 → output is low, transistor conducts, capacitor C discharges via R_2



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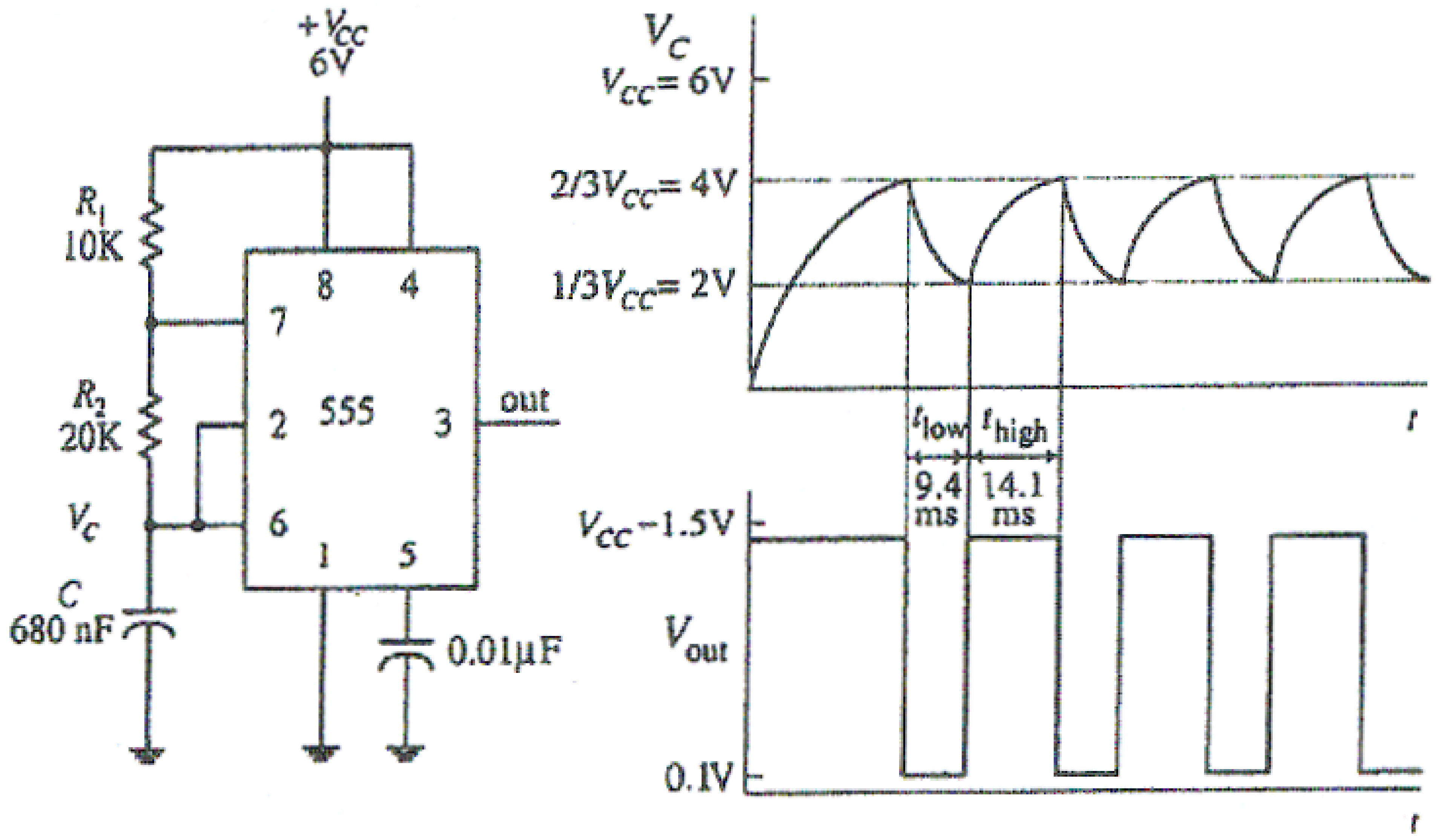
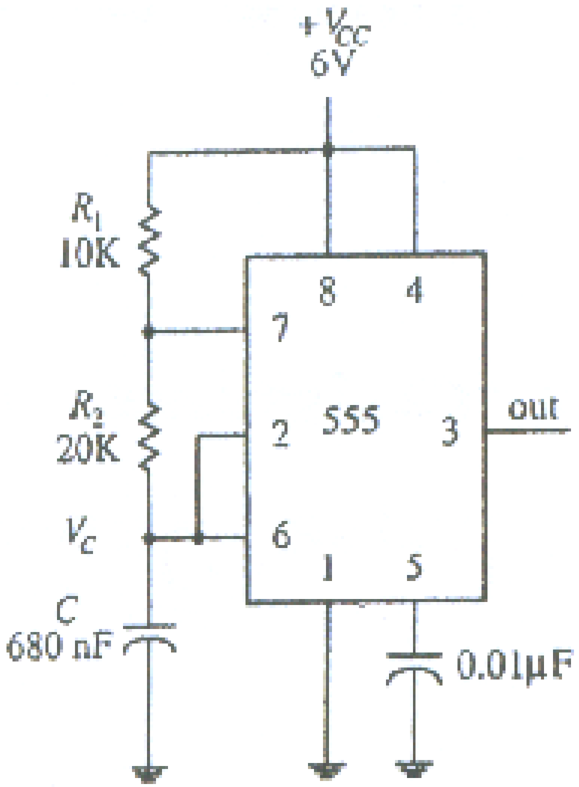
555 Timer: Astable Mode Output



555 Timer: Astable Mode Duty Cycle

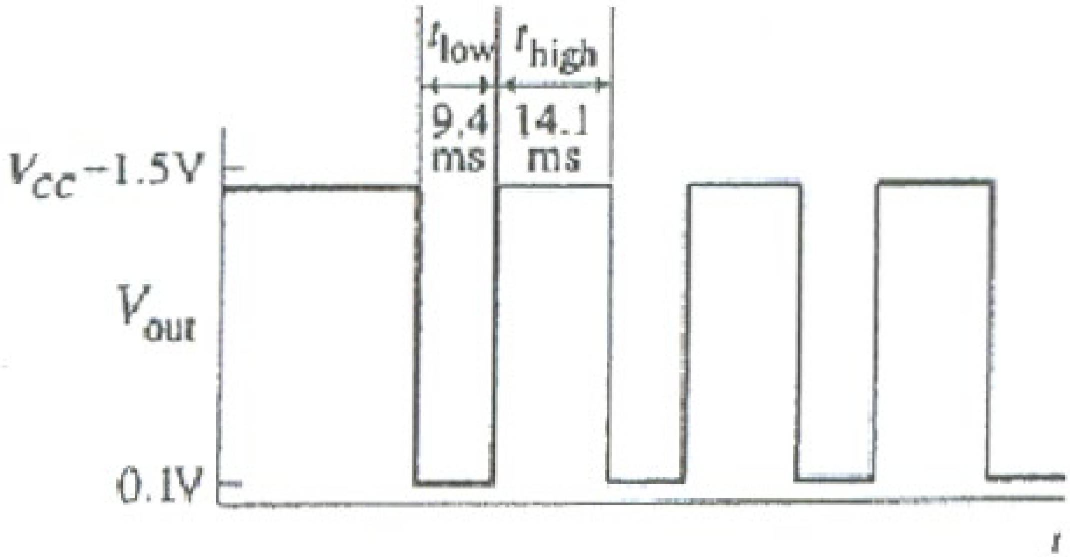


$$t_{low} = 0.693 R_2 C$$

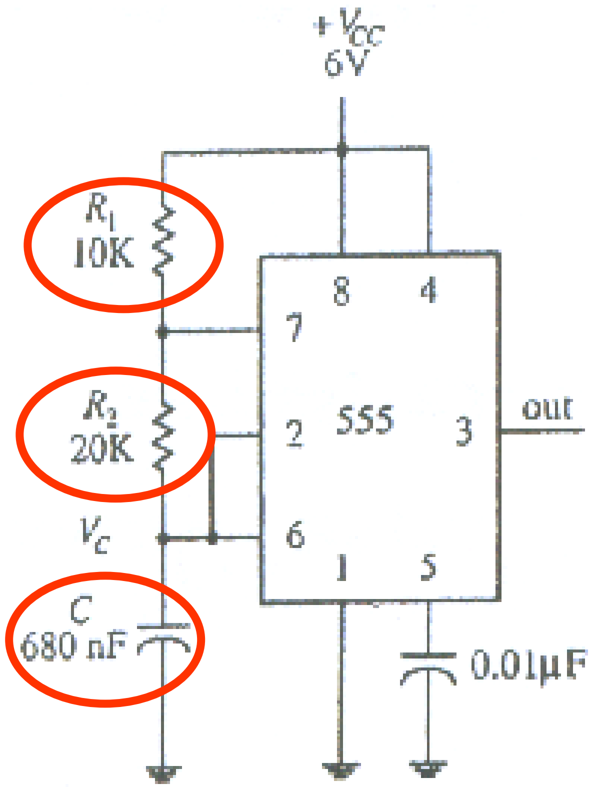
$$t_{high} = 0.693(R_1 + R_2)C$$

$$Duty\ cycle = \frac{t_{high}}{t_{high} + t_{low}}$$

$$f = \frac{1}{t_{high} + t_{low}}$$



555 Timer: Astable Mode Duty Cycle



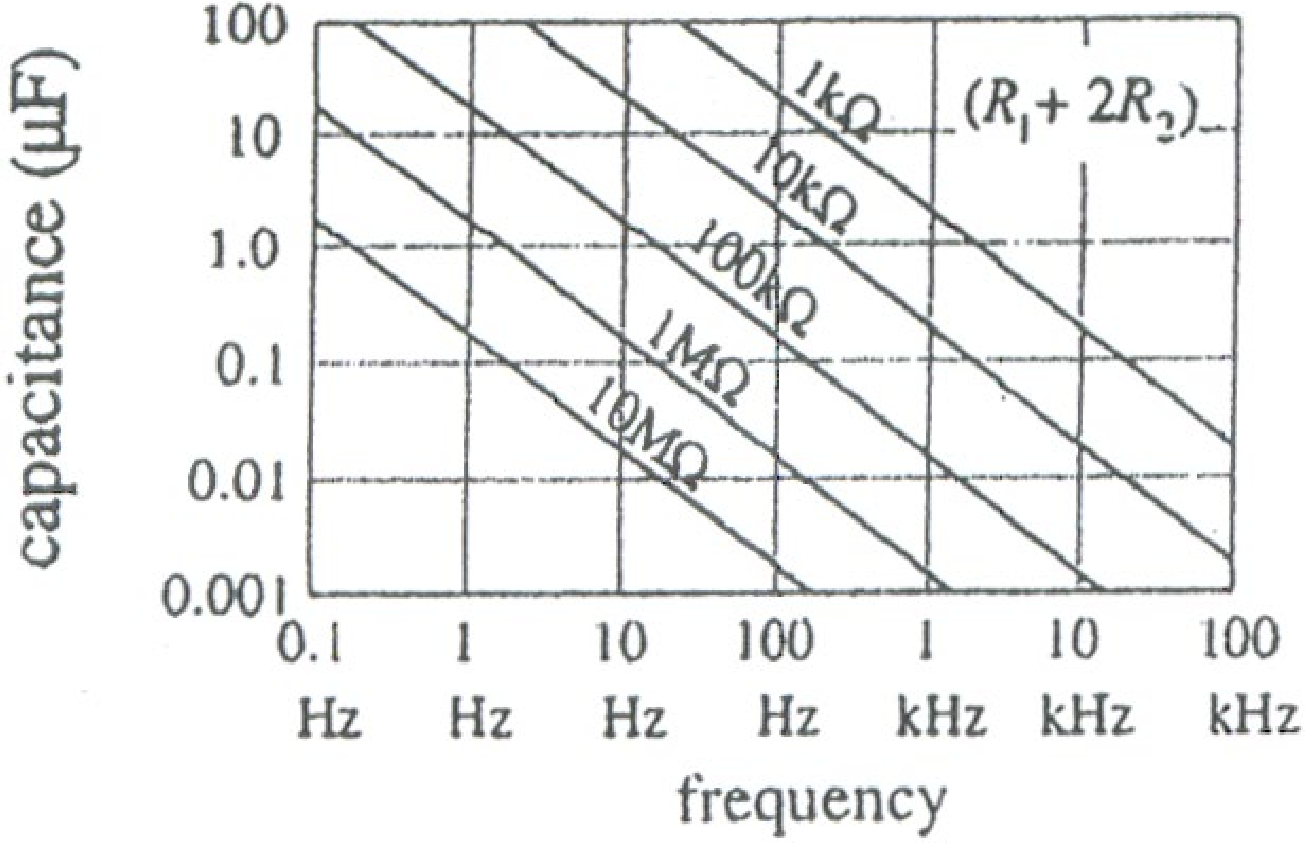
$$t_{low} = 0.693\,(20K)\,(680nF) = 9.6ms$$

$$t_{high} = 0.693\,(10K + 20K)\,(680nF) = 14.1ms$$

$$Duty\ cycle = \frac{14.1ms}{14.1ms + 9.6ms} = 0.6$$

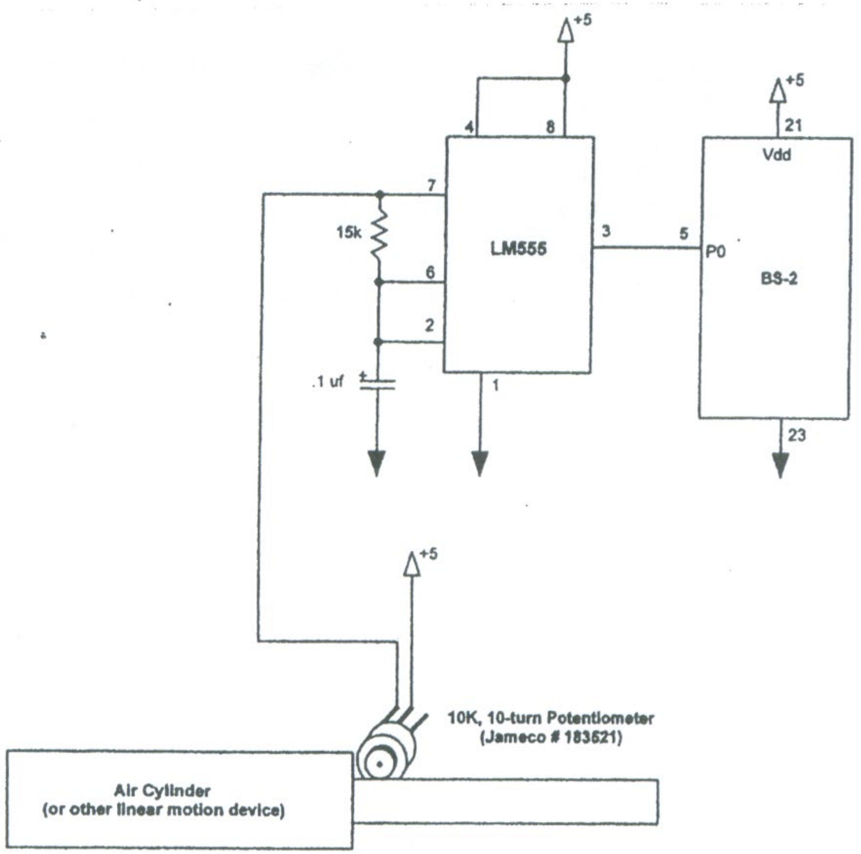
$$f = \frac{1}{14.1ms + 9.6ms} = 42Hz$$

555 Timer: Astable Mode Frequency vs. C, R_1, and R_2



Measuring an Analog Value using Astable LM555 Timer

- The astable LM555 timer and the pulsin command of BS2 can be employed to measure the linear travel of a machine tool slide
- A pot is mechanically coupled to the arm undergoing linear motion via a rubber wheel.
- The translation motion of the arm changes the pot resistance.
- The pot resistance forms the "R1" resistor of the astable LM555 timer.
- Time duration of high pulse by 555 timer $\propto$ Pot resistance $\propto$ Linear travel of slide.



Figure

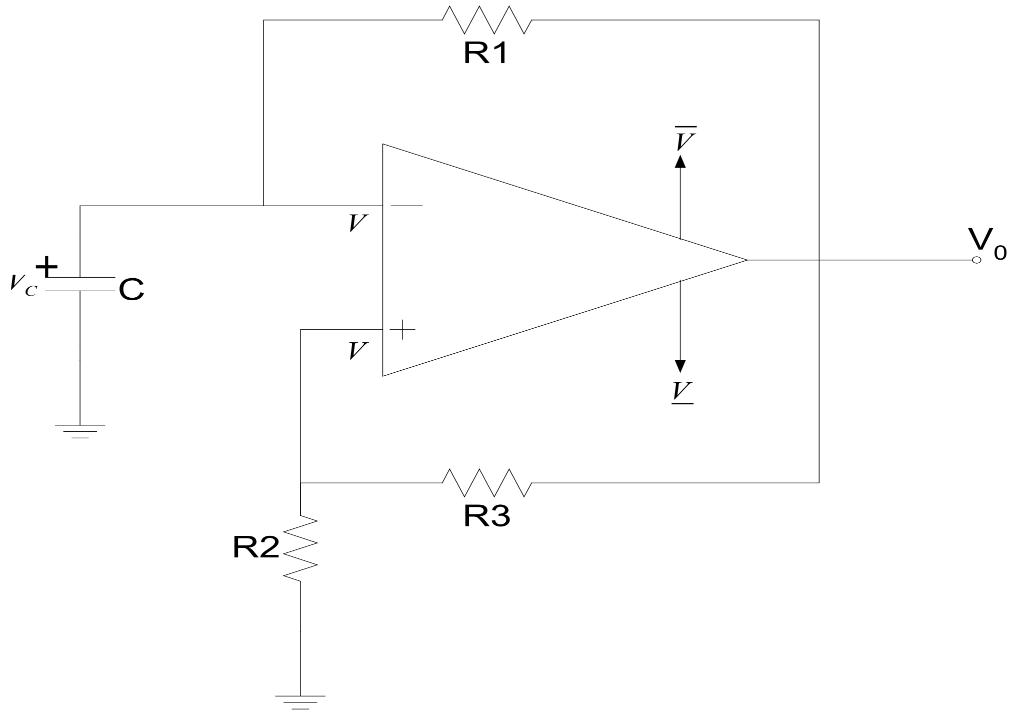
Using pulse-width modulation for linear movement detection

Pulsin 0, 1, Highdura

Will give time over which 555 outputs "high" pulse.

Simple Multivibrator

- Consider a comparator with the given schematic.
  - Both positive and negative feedback
  - RC circuit that generates the inverting input V-.



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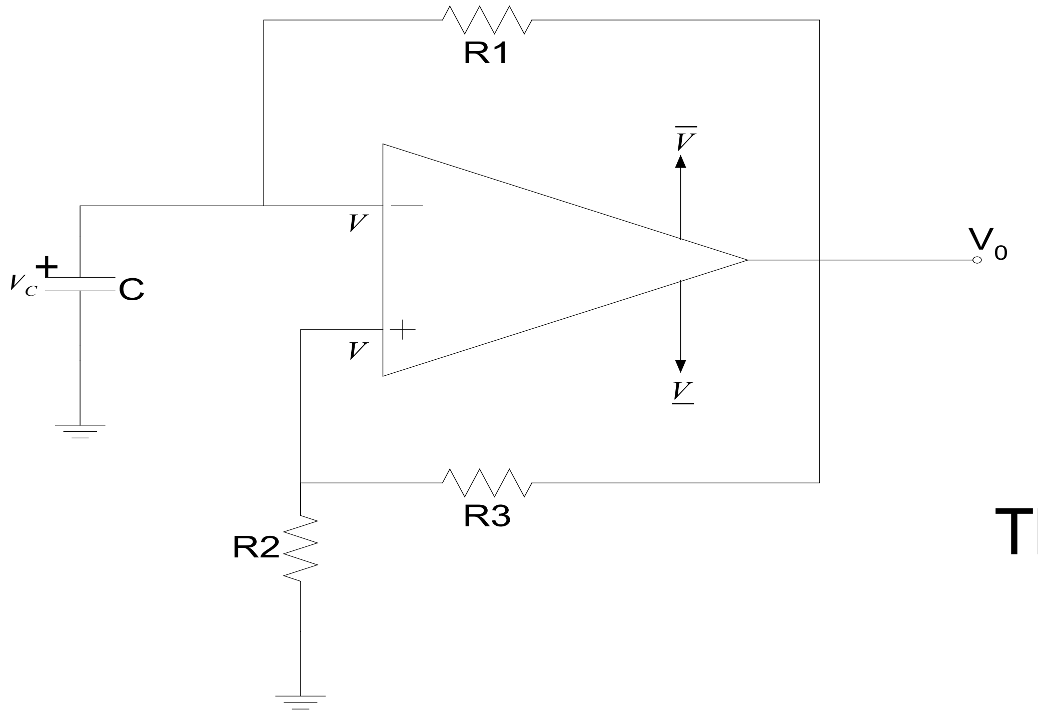
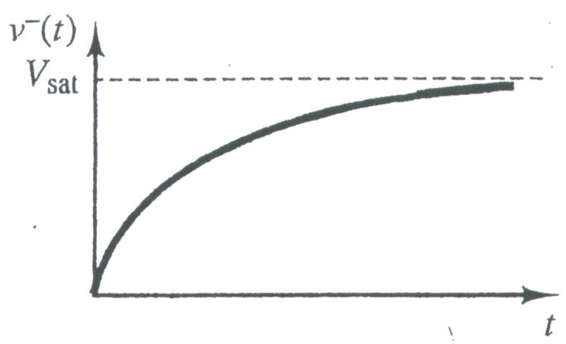
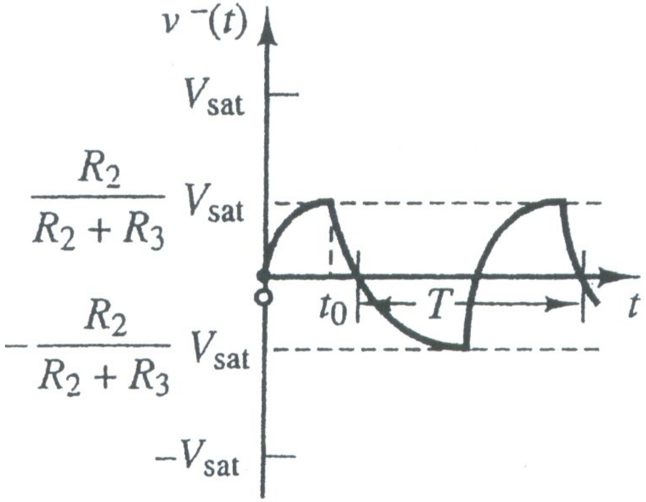


This is an **astable** multivibrator

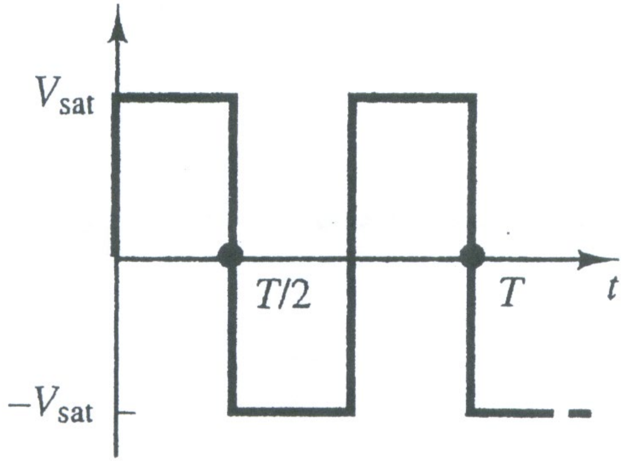
Simple Multivibrator Output



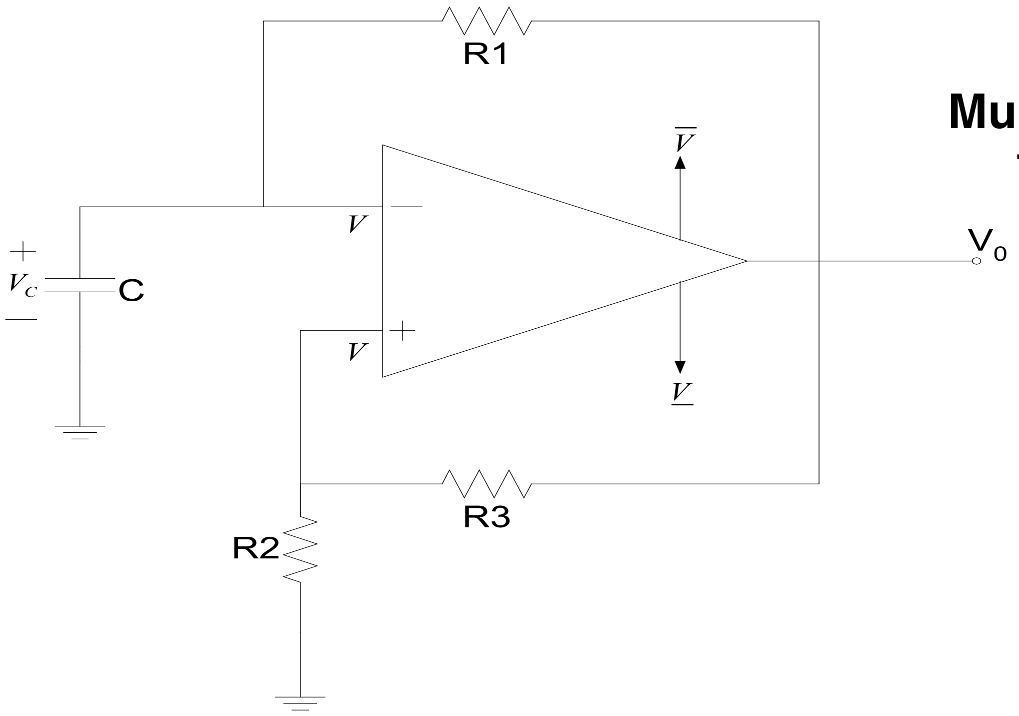
Capacitor charging



Multivibrator inverting terminal voltage



Multivibrator output waveform



Additional Reference

- **Mathematical Details:** Topic 4 of main text details the computations for resistances and capacitances required for exact timing
- https://www.youtube.com/watch?v=qfWIjb48mjE

Hands-on Exercises: Digital Input

BASIC Stamp Syntax and Reference Manual 2.2 RCTIME	pp. 363 – 368
What's a Microcontroller? Potentiometer (Activities #1–#3)	Chapter 5
Basic Analog and Digital 555 Timer	Chapter 6