Op-Amps & 555 Timers

ECE 401 Senior Design I

Week #4

Please visit Bison Academy for corresponding lecture notes,
homework sets, and videos
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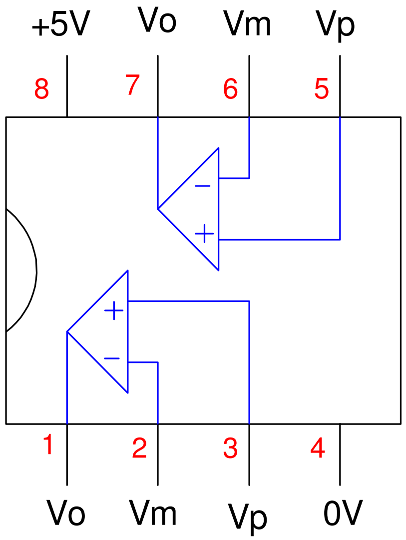
Operational Amplifiers (Op-Amps)

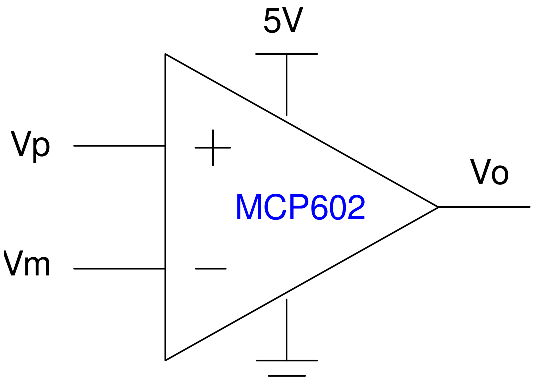
One of the requirements for your 401 project is it must include an integrated circuit (IC). Usually, this is an op-amp, a 555 timer, or a PIC processor.

Op-amps are really useful devices that can do all sorts of things. With op-amps, you can build

- Comparitors
- Schmitt Triggers
- Half-wave and full-wave rectifiers,
- Envelope detectors
- Amplifiers
- Filters

to name just a few. Op-amps are just darn useful.

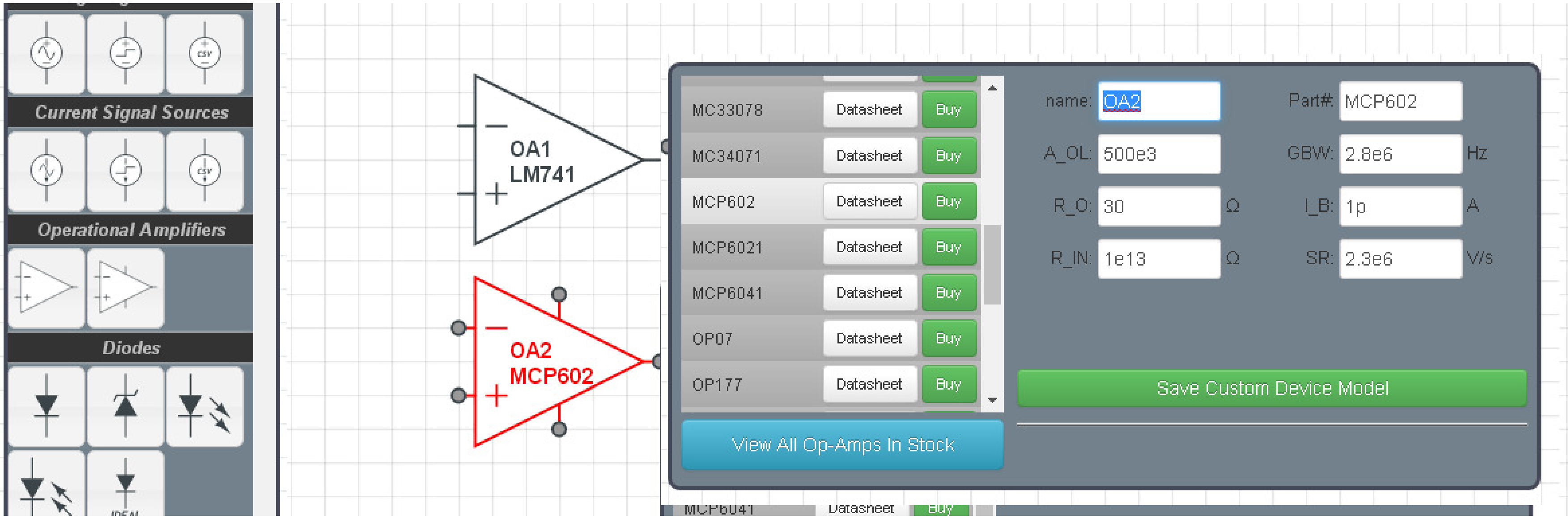




Op-Amps in CircuitLab

Two types of op-amps are available

- No power supply
  - Use for analog circuits (filters, amplifiers, etc)
- +/- Power Supply
  - Use for digital circuits (Comparitors, Schmitt Triggers)



MC33078	Datasheet	Buy
MC34071	Datasheet	Buy
MCP602	Datasheet	Buy
MCP6021	Datasheet	Buy
MCP6041	Datasheet	Buy
OP07	Datasheet	Buy
OP177	Datasheet	Buy

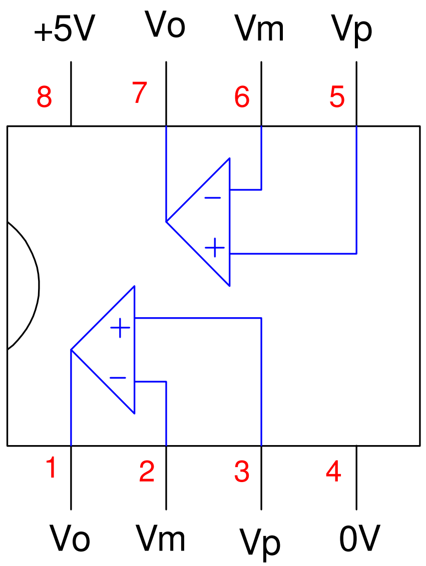
name: OA2
Part#: MCP602
A_OL: 500e3
GBW: 2.8e6 Hz
R_O: 30 Ω
I_B: 1p A
R_IN: 1e13 Ω
SR: 2.3e6 V/s

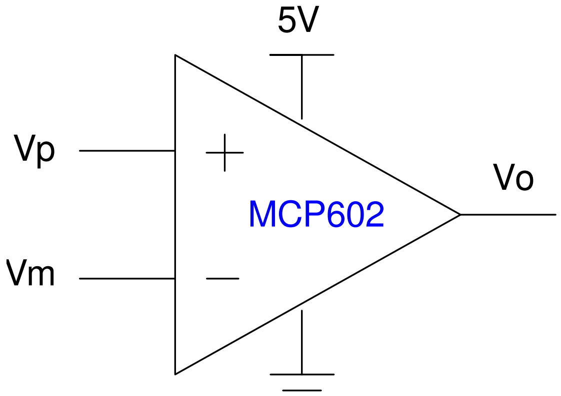
MCP602 Op-Amp

- The heart of a comparitor

Use an MCP602:

- It can operate from a single 5V power supply
  - range is 3V to 6V
- It's a rail-to-rail op-amp.
  - Output can go all the way up to 5.00V
  - Output can go all the way down to 0.00V
- It's a dual op-amp
  - you get two op-amps in each IC





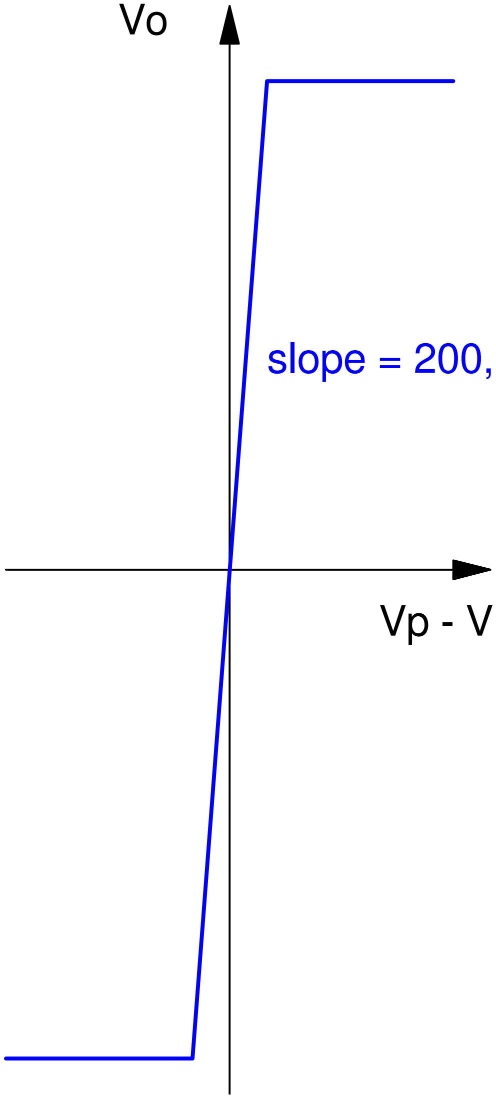
The MCP602 is a high-gain differential amplifier, where

$$V_o = 200,000(V_p - V_m)$$

What this means is

- Vp > Vm
  - The output rails at the upper power supply (5V)
- Vp < Vm
  - The output rails at the lower power supply (0V)

This allows you to build several different circuits.

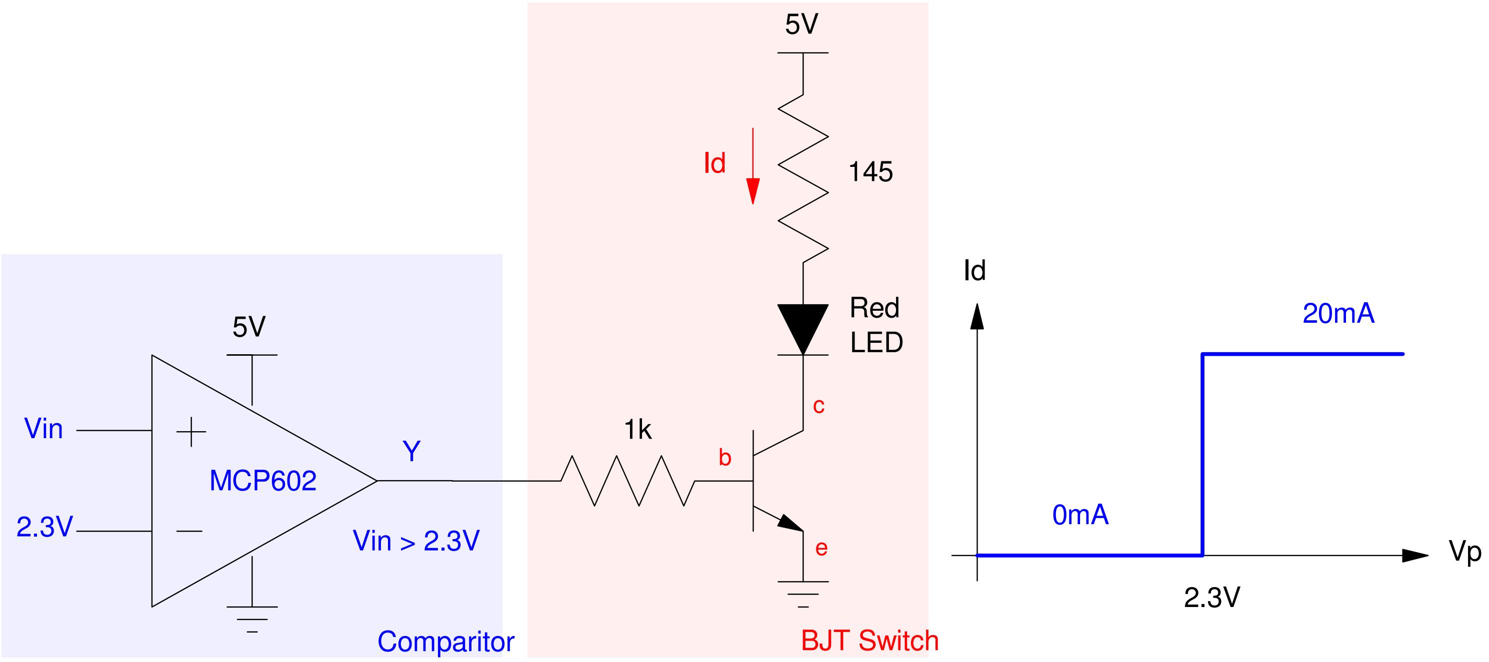


Comparitor: Y = (Vin > 2.3V)

Turn on an LED when Vin > 2.3V

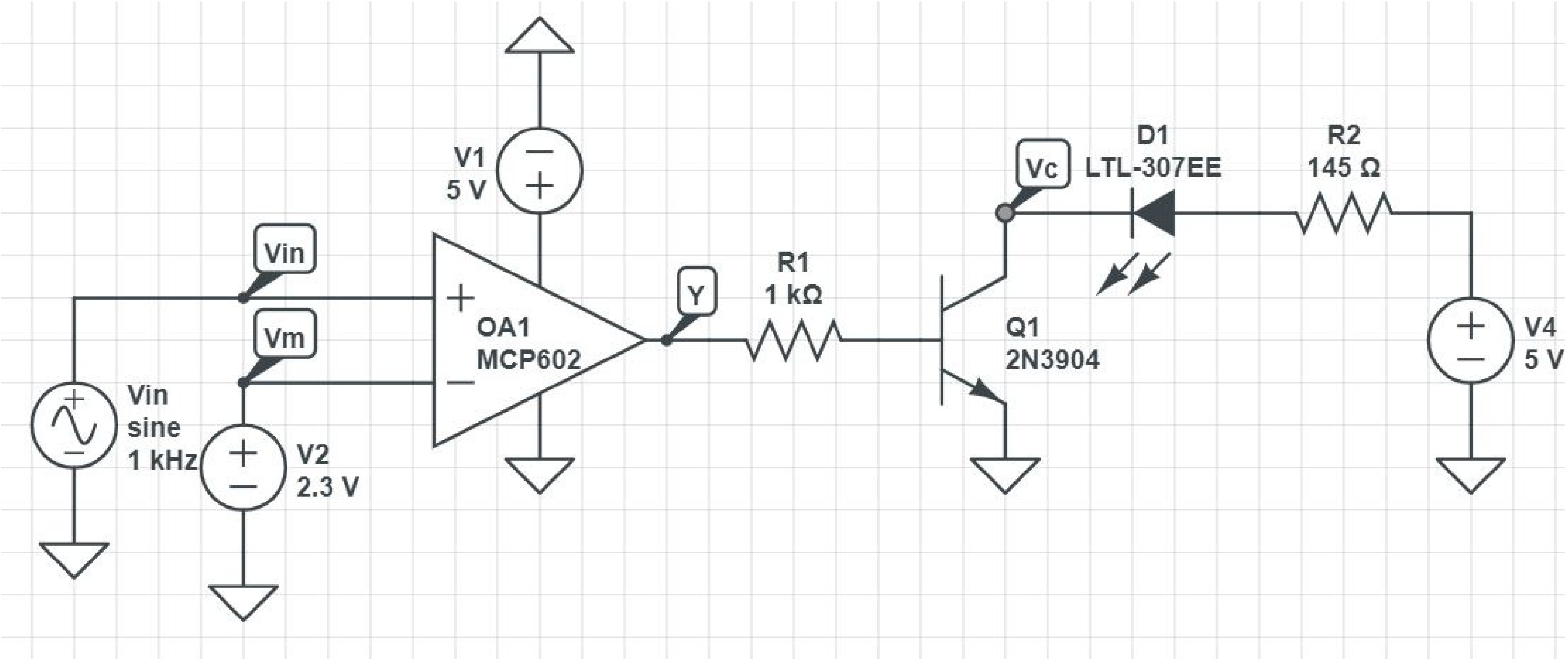
- Connect Vin to Vp
- Connect 2.3V to Vm
- This produces the function: Y = Vin > 2.3V

If you swap Vp and Vm, you get the opposite (Vin < 2.3V)



Checking in CircuitLab

- Use an op-amp with the voltage inputs
  - Tells CircuitLab what is logic 1 (5V) and 0 (0V).
- Use an AC input for Vin.
  - When Vin > 2.3V, Y slams to 5V.
  - When Vin < 2.3V, Y slams to 0V



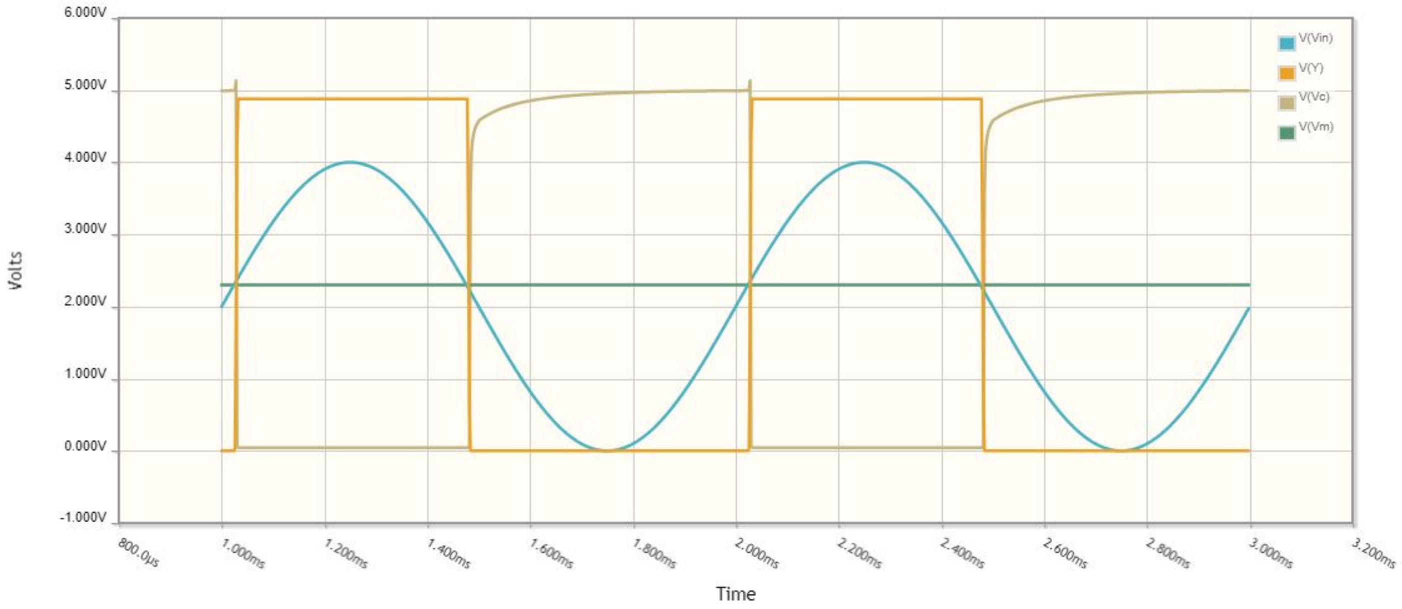
Time-Domain Simulation

When Vin > 2.3V

- V(Y) = 5V (on)
- Vc = 0.2V (the transistor is saturated)

When Vin < 2.3V

- V(Y) = 0V (off)
- Vc = 5V (off)



Comparitor: Y = (T > 20C)

First, convert temperature to resistance

$$R = 1000 \cdot \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\Omega$$

Convert resitance to voltage

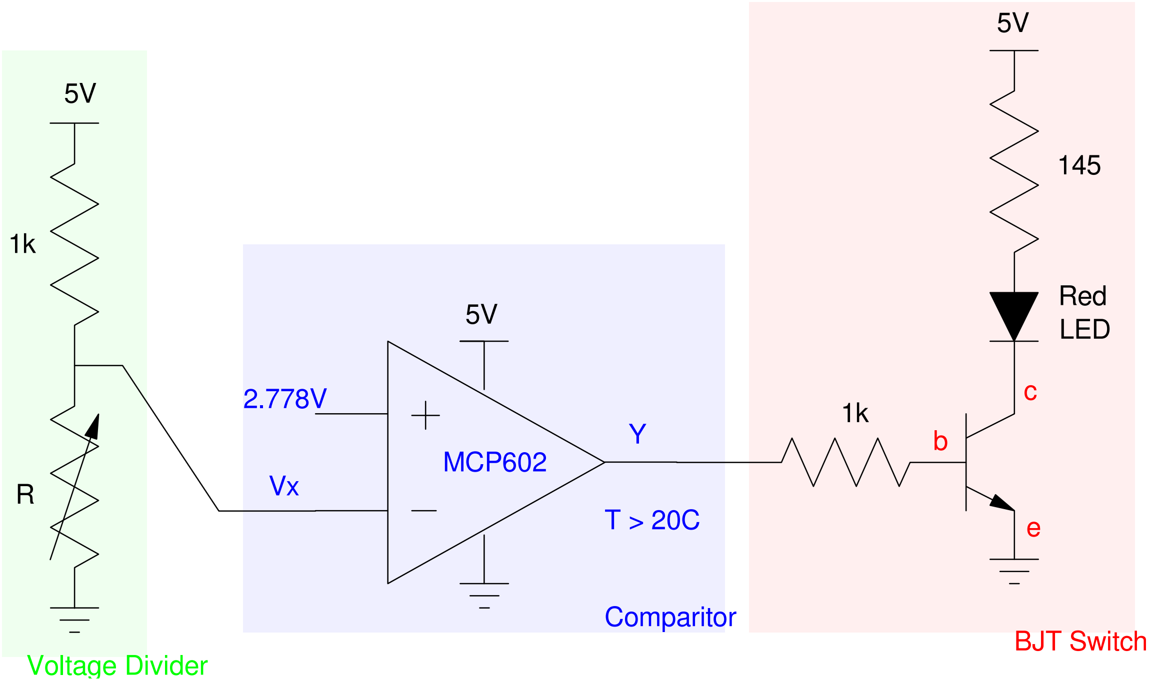
$$V_x = \left(\frac{R}{R+1000}\right)5V$$

Connect Vx to Vm

- As T goes up
- R goes down
- Vx goes down
- Y goes up

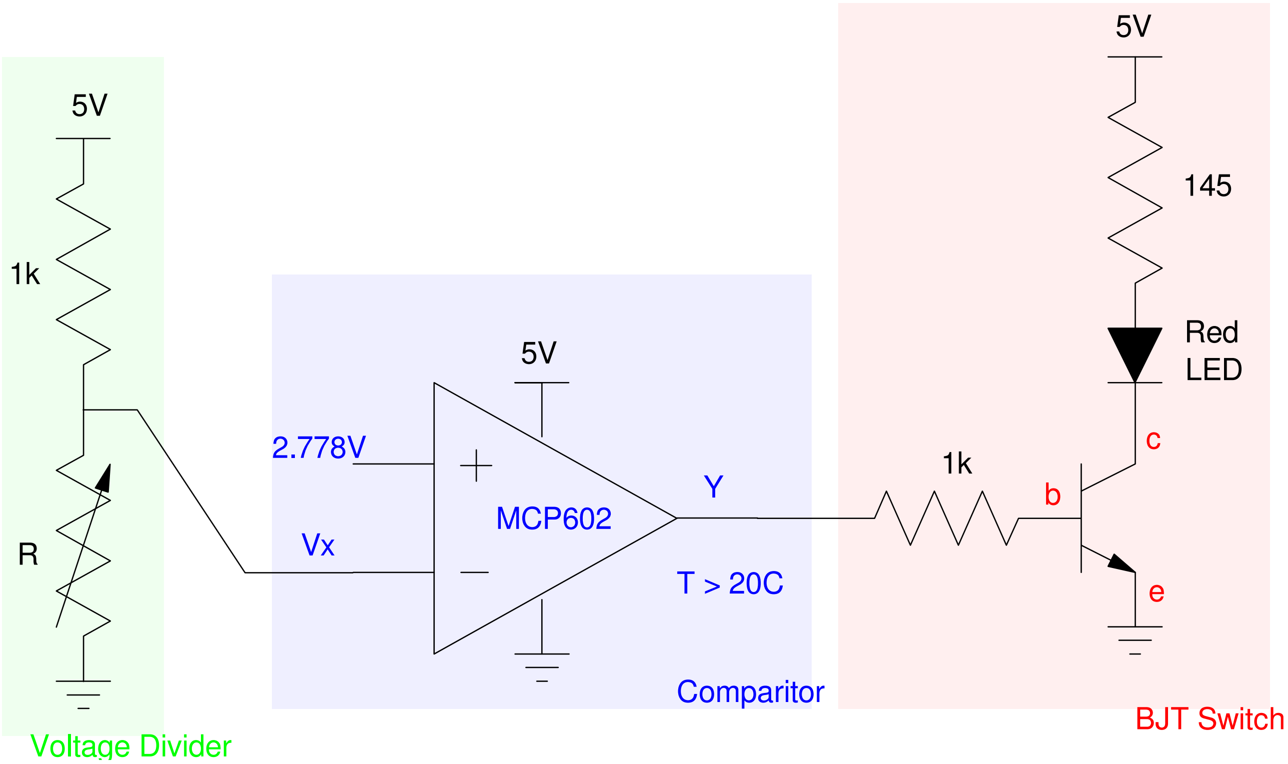
Connect Vp to Vx(20C)

- R = 1250.59 Ohms
- Vx = 2.778V



Note

- If you swap Vp and Vm, you get the opposite (light is on when T < 20C).
- If you change R to a light sensor, the LED turns on and off with light level
- If you change R to a magnetic field sensor, the LED turns on and off with magnetic field strength



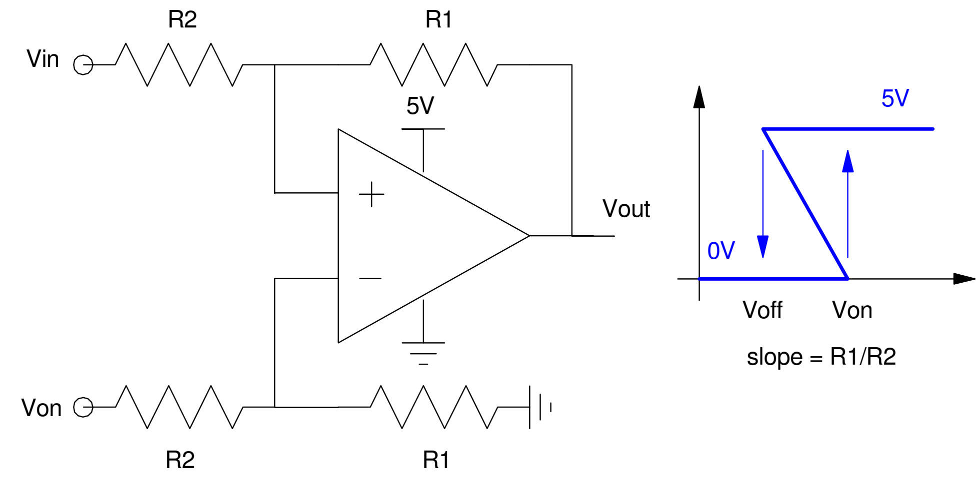
Schmitt Triggers

Add hysteresis to avoid chatter

- Add positive feedback

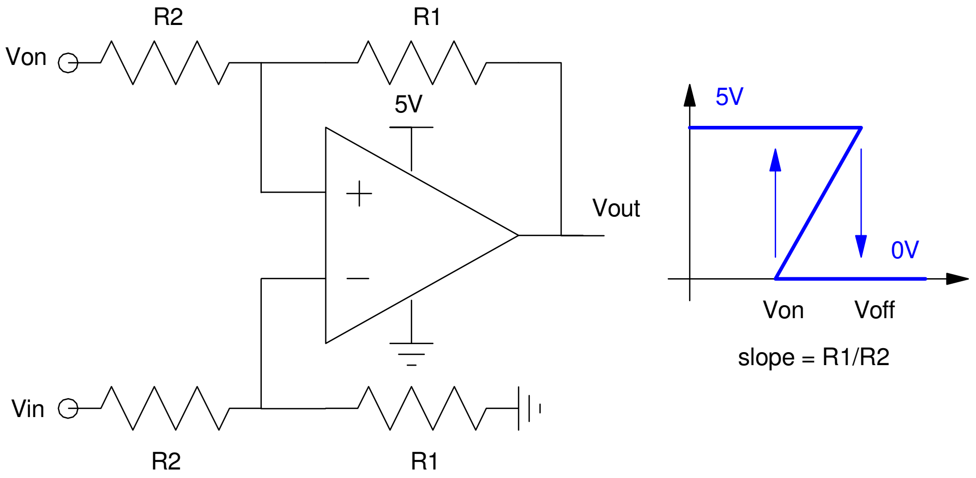
V(on) > V(off)

- Connect Vin to the plus input



V(on) < V(off)

- Connect Vin to the minus input



The offset is V(on) in both cases

Example: design a circuit which turns an LED

- On when T > 25C and
- Off when T < 20C

When 20V < T < 25C, the LED remains unchanged (on or off).

Step 1: Convert temperature to resistance

- Use a thermistor

$$R = 1000\exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\Omega$$

Step 2: Convert resistance to voltage

- Use a votlage divider with a 1k resistor

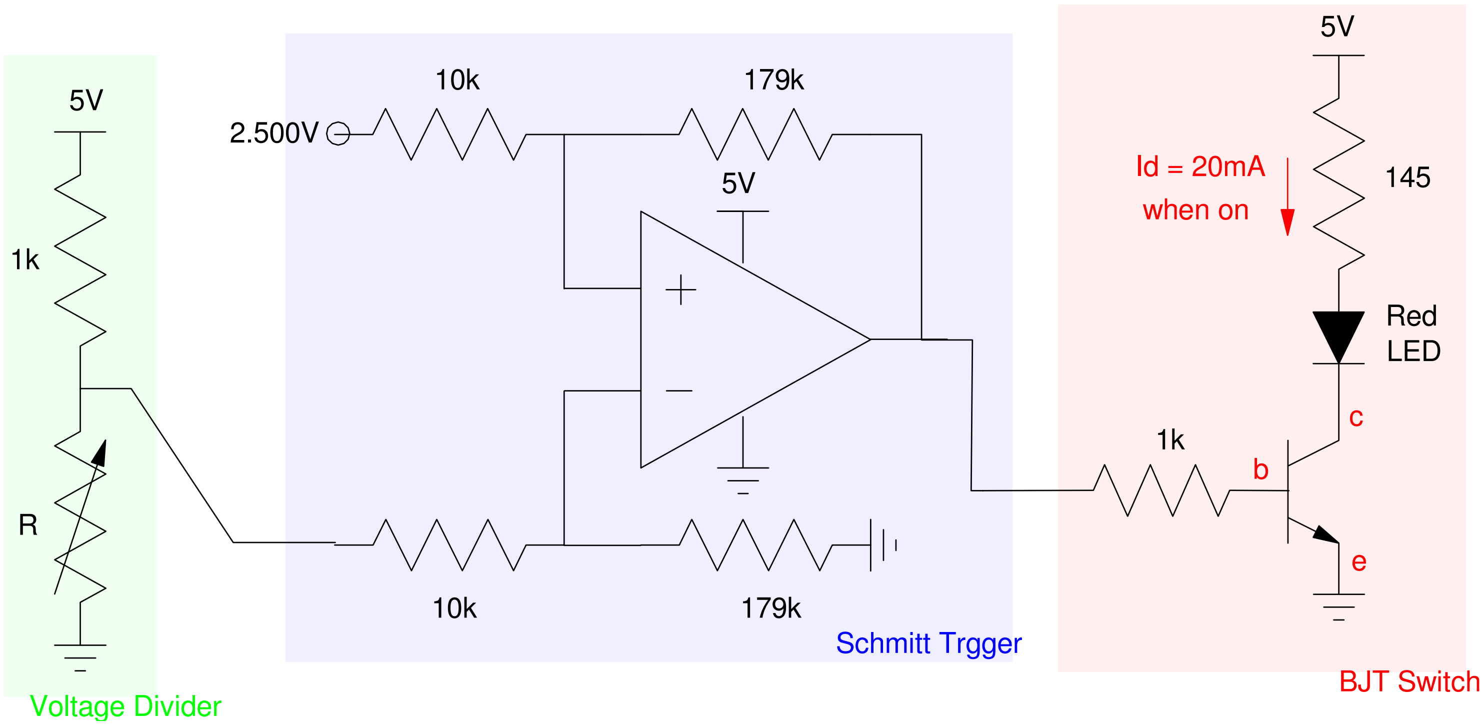
$$V_x = \left(\frac{R}{R+1000}\right)5V$$

20C	25C
R = 1250 Vx = Voff = 2.778V	R = 1000 Vx = Von = 2.500V

Since Von < Voff, connect to the minus input

$$gain = \left(\frac{\text{change in output}}{\text{change in input}}\right)$$

$$gain = \left(\frac{5V - 0V}{2.778V - 2.500V}\right) = 17.96$$



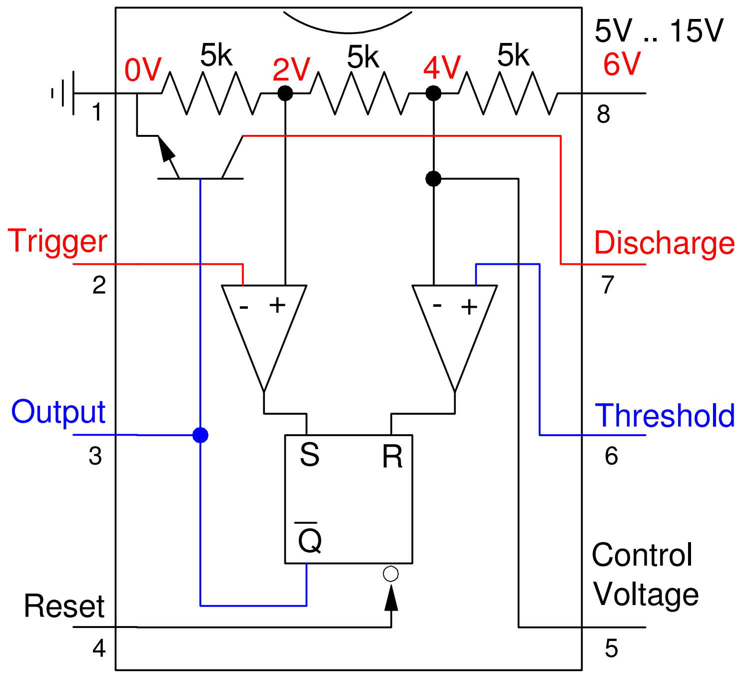
555 Timers

Really useful IC that can make

- An oscillator
  - Keep track of time, make lights blink, etc.
- An light controlled oscillator
  - Frequency varies with light level
  - Or temperature, magentic field strength,etc.
- A voltage-controlled oscillator
  - Allowing you to make siren noises, and
- A one-shot
  - Output a single pulse

This course looks at an oscillator

- See ECE 320 for other circuits

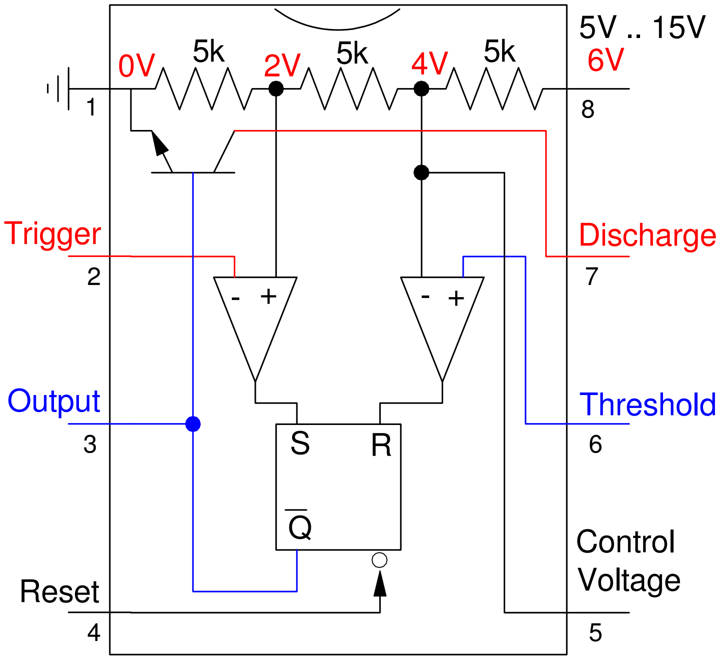


555 Timer:

Name comes from three 5k resistors

Funciton of Pins:

- Power and Ground: 0V and 5V
- Trigger: Set the SR flip-flop > 2V
- Threshold: Clear the SR flip-flop when > 4V
- Control Voltage: Change the thresholf voltage
- Discharge:
  - When the output is low, Discharge is shorted to ground through a transistor.
  - Otherwise, Discharge is a floating pin.



555 Oscillator (take 1):

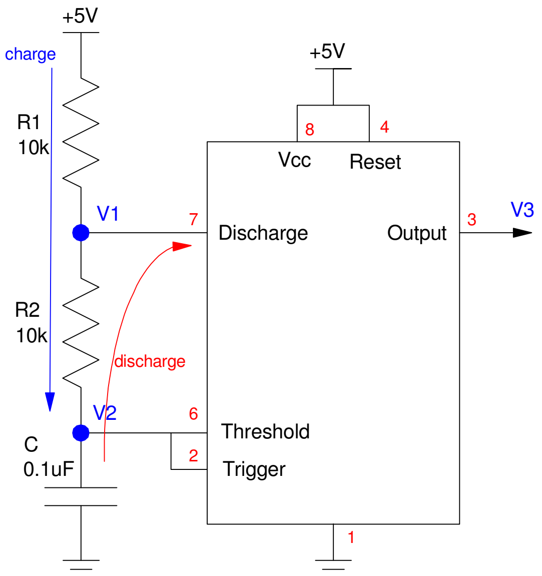
When V2 reaches 1/3 of 5V

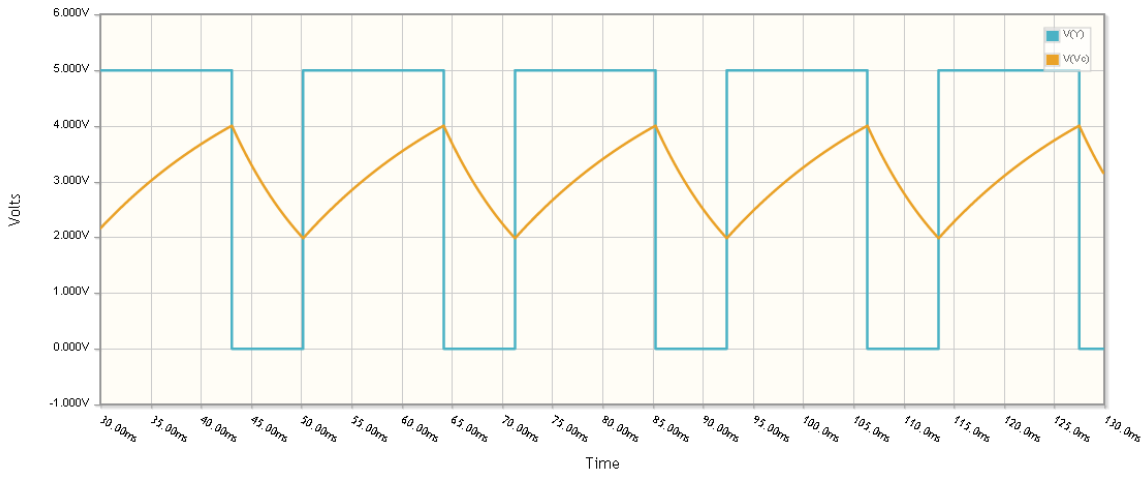
- Discharge is floating,
- C charges up to 2/3 of 5V through R1 and R2.

When V2 reaches 2/3 of 5V

- Discharge is grounded
- C discharges down to 1/3 of 5V throuth R2

Repeat





Calculations:

$$T_{on} = (R_1 + R_2) \cdot C \cdot \ln(2)$$

$$T_{off} = R_2 \cdot C \cdot \ln(2)$$

$$T = Period = T_{on} + T_{off} = (R_1 + 2R_2) \cdot C \cdot \ln(2)$$

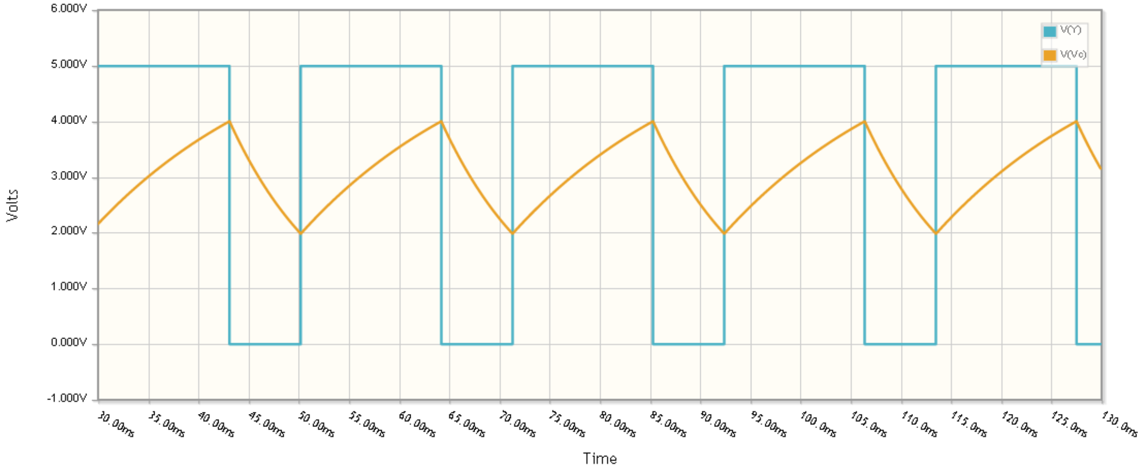
For the values given, this works out to

$$T_{on} = 1.386ms$$

$$T_{off} = 0.693ms$$

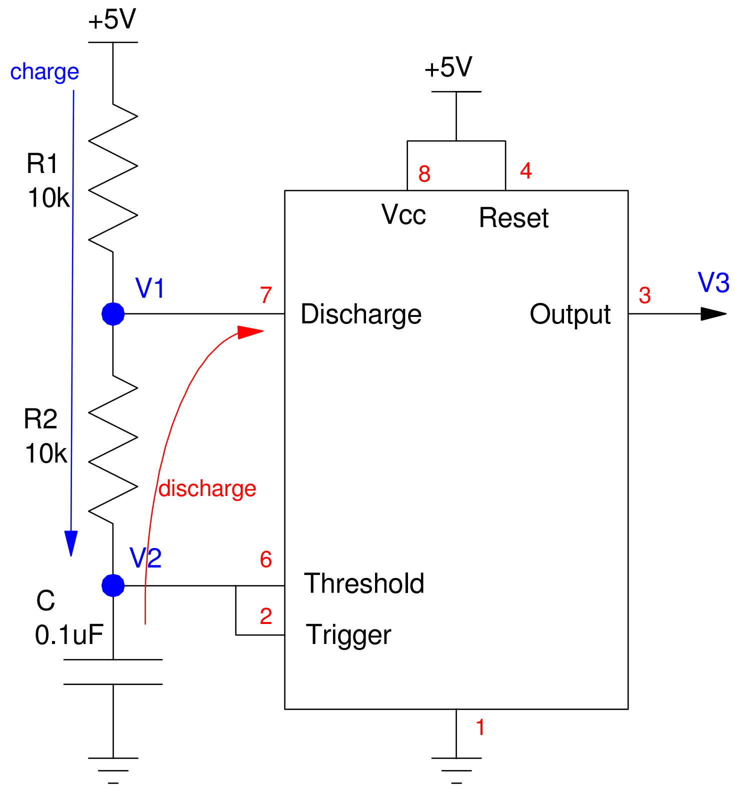
$$T = Period = 2.079ms$$

$$f = \frac{1}{T} = 480.9Hz$$



Note

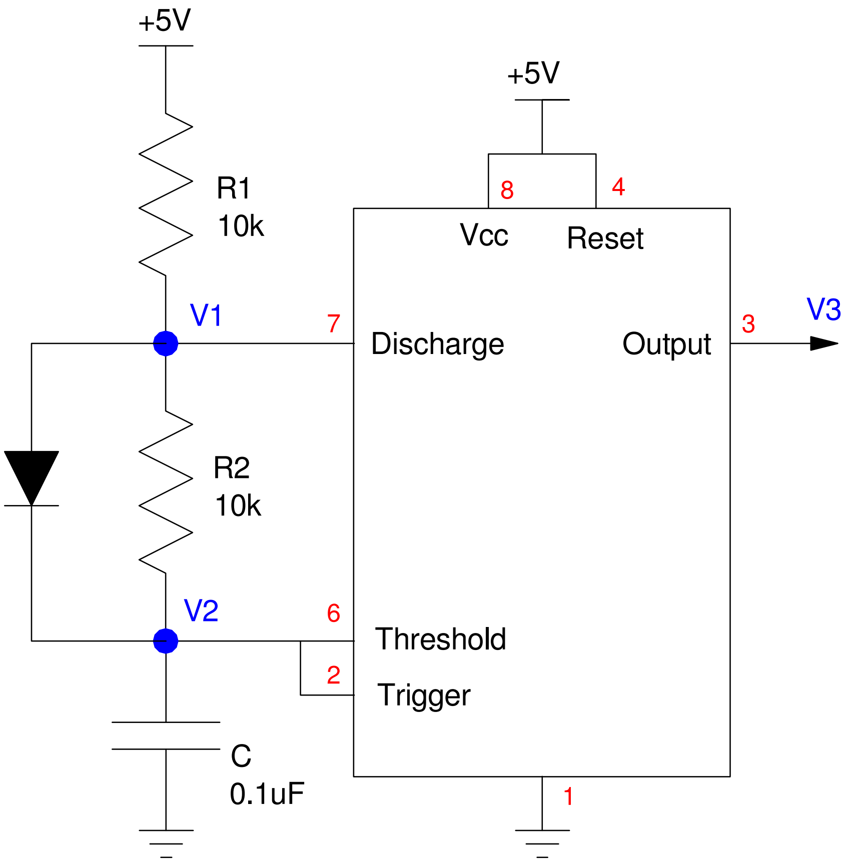
- The on time is twice as large as the off time. This is due to C charging through R1 and R2, while discharging through R2.
- If you replace either resistor with a thermistor or a photo-resistor, the period (and frequency) will change with temperature or light.



555 Oscillator (take 2):

A slight improvement is to add a diode as follows. This results in

- C charging through R1 (R2 is bypassed by the diode), and
- C discharging through R2 (when pin 7 of the 555 timer is grounded).



Calculations

$$T_{on} \approx R_1 \cdot C \cdot \ln(2)$$

$$T_{off} = R_2 \cdot C \cdot \ln(2)$$

If R1 = R2 = 10k

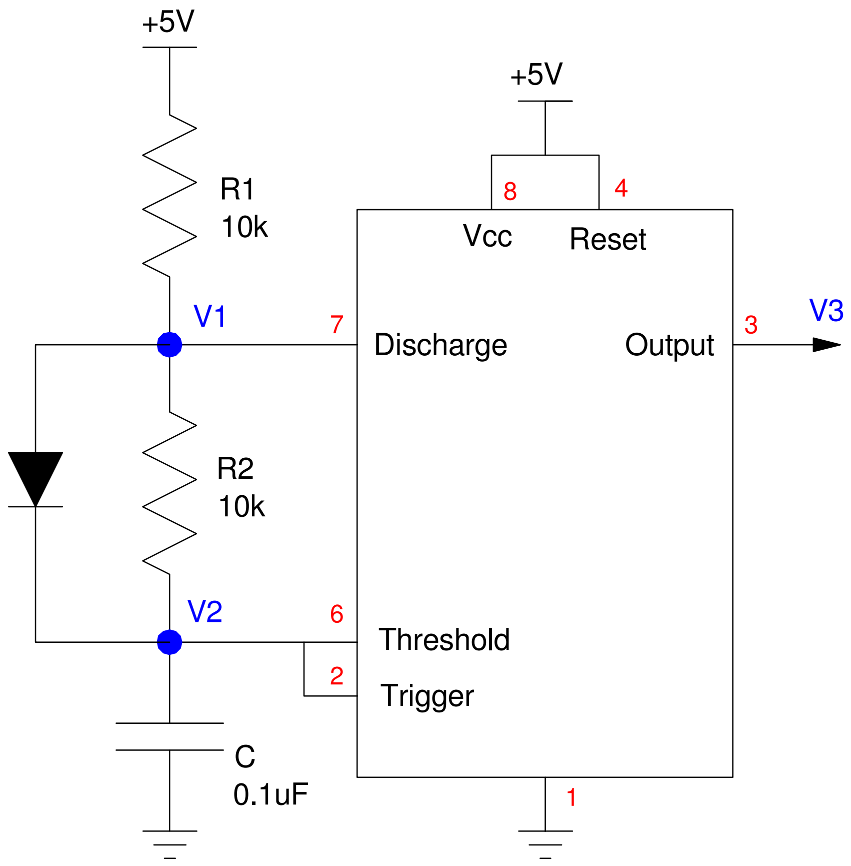
$$T_{on} \approx 0.693ms$$

$$T_{off} = 0.693ms$$

$$T = T_{on} + T_{off} = 1.386ms$$

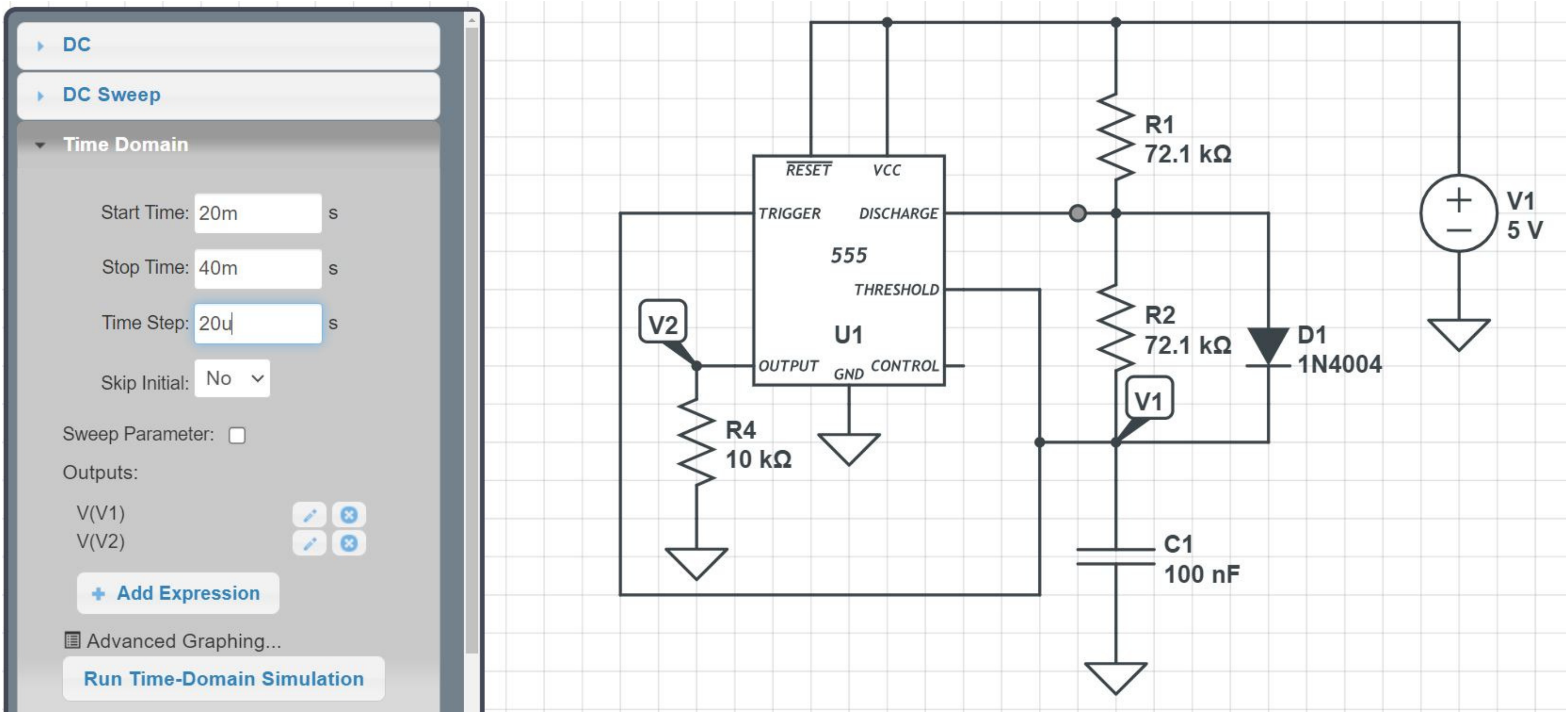
$$f = \frac{1}{T} = 721.3Hz$$

note: T(on) is approximate due to ignoring Vd in the calculations for Ton



Checking in CircuitLab

Build the circuit and do a time-domain simulation:



Start Time: 20m s

Stop Time: 40m s

Time Step: 20u s

Skip Initial: No

Sweep Parameter: ☐

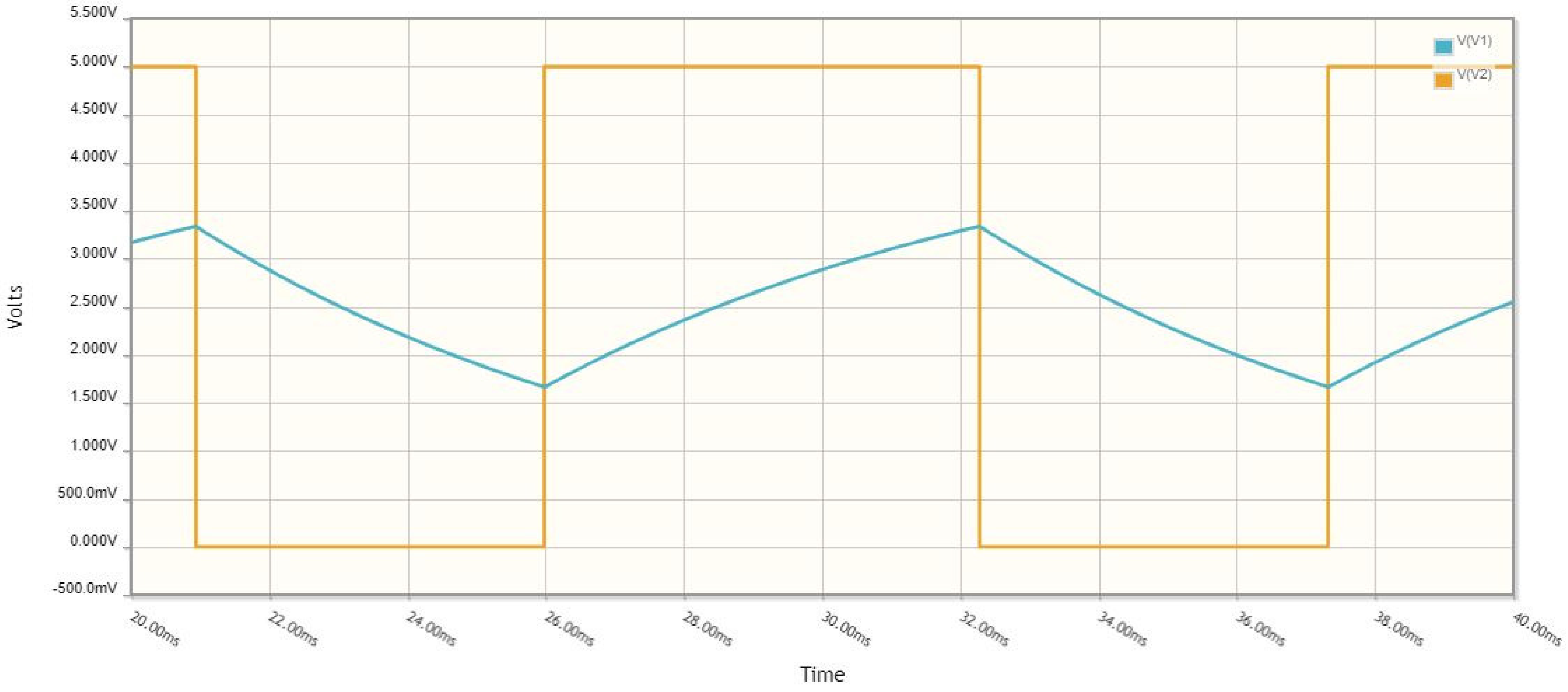
Outputs:

V(V1)

V(V2)

Measure the on/off times

- T(on) = 6.824ms
- T(off) = 5.04ms
- Not quite 5.00ms due to the diode when charging (Ton)



Adjust R1 to bring T(on) to 5.00ms

Iteration #1

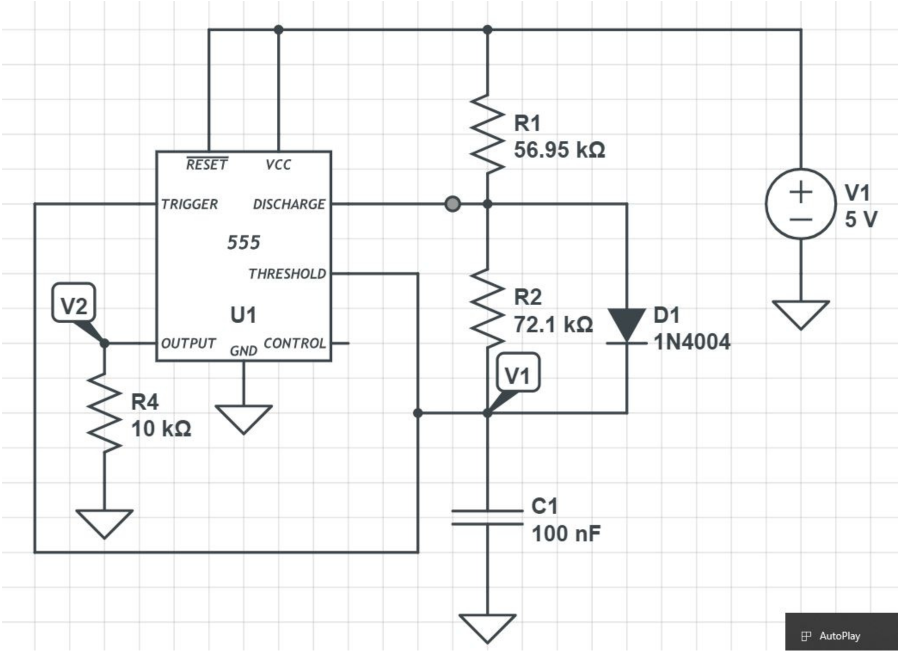
$$R_1 \rightarrow \left(\frac{5ms}{6.824ms}\right)72.13k = 52.85k\Omega$$

Rerun the simulation and you get T(on) = 4.64ms. Iterate again...

$$R_1 \rightarrow \left(\frac{5ms}{4.64ms}\right)52.85k\Omega = 56.95k\Omega$$

T(on) = 5.04ms

- C = 0.1uF
- R1 = 56.95k
- R2 = 72.13k



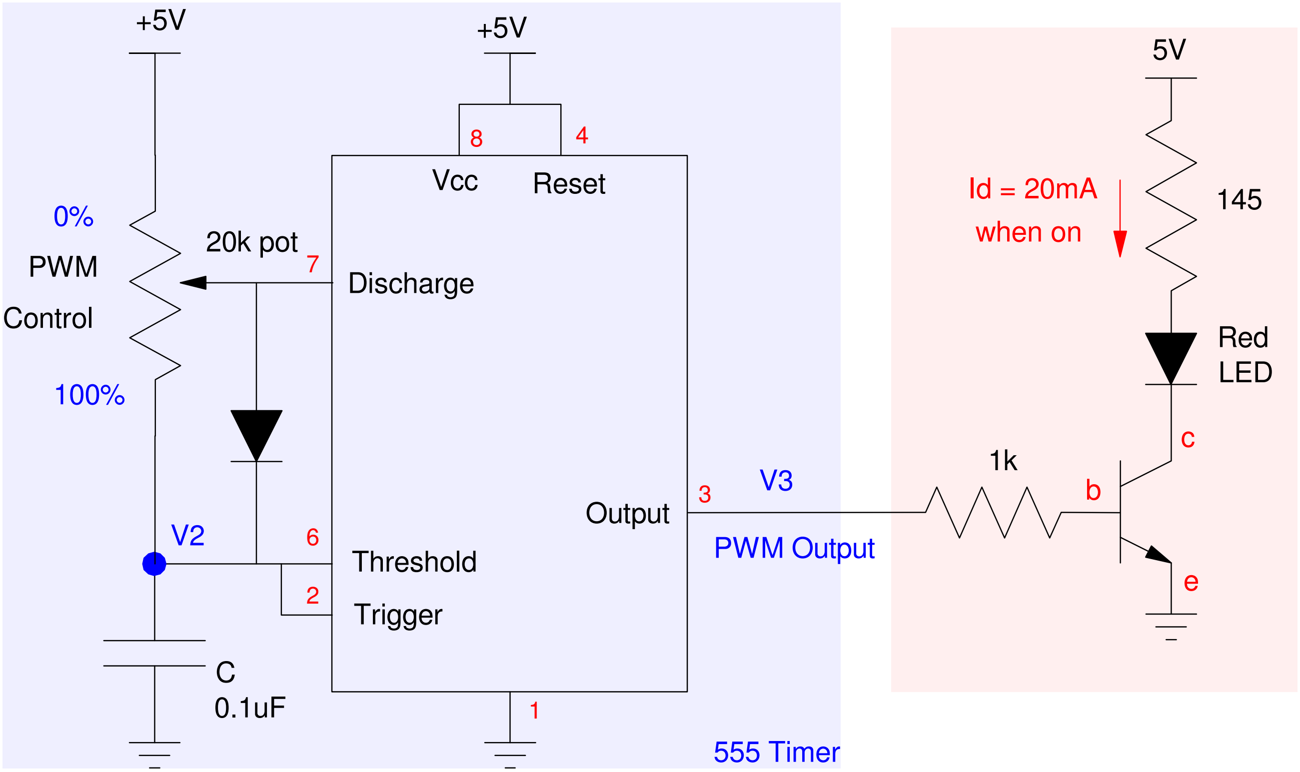
Note:

- Calculations get you close
- You may need to tweak values

LED Brightness Control

Vary R1 and R2 to change the on / off times

- Replace R1 and R2 with a potentiometer allows adjustment of the duty cycle



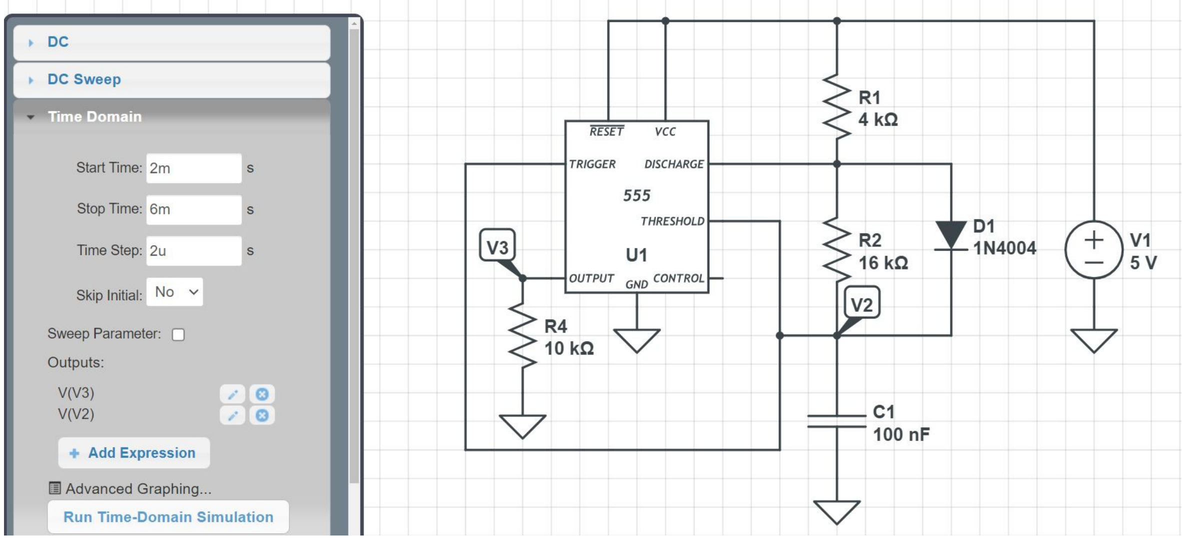
Example: 20% Duty Cycle

- 20k potentiometer
- R1 = 20% of 20k (4k)
- R2 = 80% of 20k (16k)

CircuitLab Results

- Period = 1.486ms
  - 1.386ms calculated
- T(on) = 0.374ms
  - 25.2%
- T(off) = 1.112ms
  - 74.8%

Adjusting R1 and R2 can get you to 20% on



Start Time: 2m s
Stop Time: 6m s
Time Step: 2u s
Skip Initial: No
Sweep Parameter: ☐
Outputs:
V(V3)
V(V2)