Mechatronics (ROB-GY 5103 Section A)

- **Today's lecture:**
    - Midterm
    - Comparator
    - Buttons/Switches
- (See Topics #4 and #6 from Main Text for details)

Midterm

- Midterm covers all lecture slides and in-class activities so far (**including today**)
- Midterm consists of two parts:
  - **Written Section:**
    - Individual
    - Closed-book/closed-notes short answer questions
  - **Hands-on portion:**
    - Groups
    - Only resource allowed is the **BASIC Stamp Syntax and Reference Manual Version 2.2**

Written Section: Sample Question

- **What is the difference between forward bias and reverse bias?**
- *When a diode is forward biased current is allowed to flow through it once it overcomes the minimum voltage required to move through the PN junction. In reverse bias mode the diode does not allow current to flow. In a zener diode when in reverse bias mode, current is allowed to flow but the voltage will remain constant at the device's rating. This makes it good for voltage regulation.*
  - Demonstrates that you paid attention in class:
    - You know the context of forward/reverse bias (diodes)

Written Section

- Goal is to test basic understanding.
- Answers can be brief (1–3 sentences) and still be awarded full-credit
  - You will not be penalized for writing more, but you may be penalized for writing information that is **inaccurate** or **unclear**.
- Midterm Exam Preparation Materials folder on Brightspace contains a study guide for the individual written section
  - Try to answer the questions by yourself without referring to the solutions
- **Format: 5 questions (25 minutes)**

Hands-on Section

- **Each group is responsible for bringing a laptop, BS2, and *all* circuit components used so far.**
- Including the components we will use in class today!
- You should have finalized your groups by now
- You will download **BASIC Stamp Syntax and Reference Manual Version 2.2** before the exam and keep Wi-Fi turned off for the duration of the exam.

- **Guaranteed to use LEDs and buttons (today's topic).**
- **Format: 2 exercises (1 hour each).**
  - **Performance is graded on the spot.**

Philosophy

- Post-Modern Philosophy
  - *Simulacres et Simulation* (Jean Baudrillard, 1981)

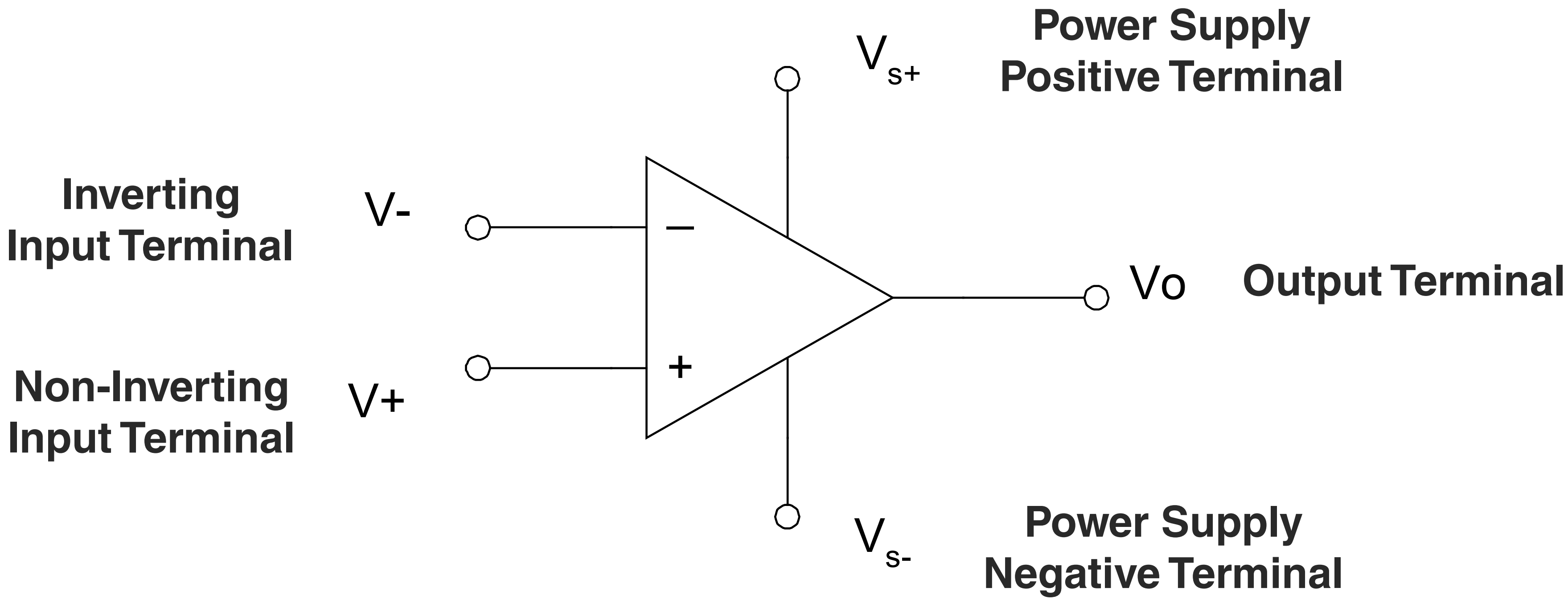
Philosophy

- **Semiconductor Physics:** A PN junction allows current to flow in one direction due to the depletion voltage
- **Engineering:** A diode is a device that allows current to flow in one direction
- **More engineering:** An LED is a diode that emits light when current flows in one direction
- **Final Application:** An LED is an indicator of when the power is turned on

Logic Circuits

Comparator

- **Note:** this looks like an **operational-amplifier** (we will cover that next week)
- Like a transistor, a **comparator** is an **active** or **powered** device (resistors, capacitors, etc. are **passive** devices that are **not powered**)



Comparator

- Given a voltage difference between input voltage terminals:

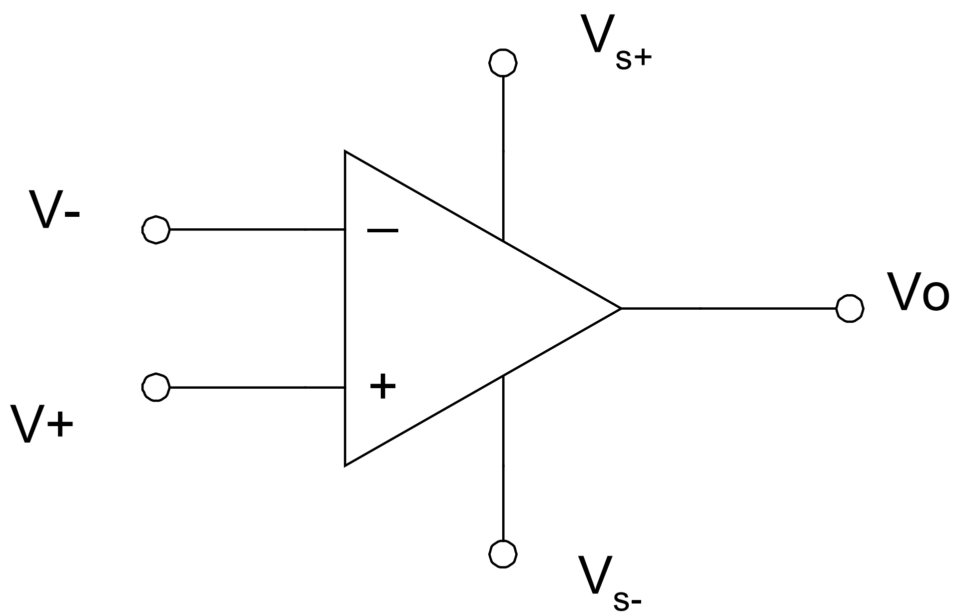
$$\varepsilon \triangleq V_{+} - V_{-}$$

- If $\varepsilon > 0 \Rightarrow V_o = V_{up}$

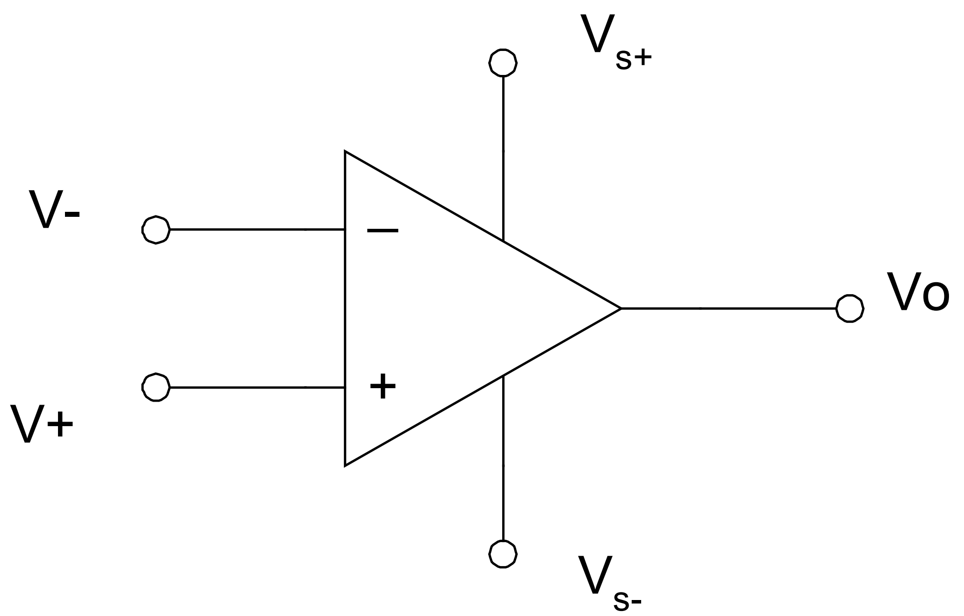
  V_{up} is the **upper saturation limit** at output ($\approx V_{s+}$).

- Else $\varepsilon < 0 \Rightarrow V_o = V_{low}$

  V_{low} is the **lower saturation limit** at output ($\approx V_{s-}$).



Comparator



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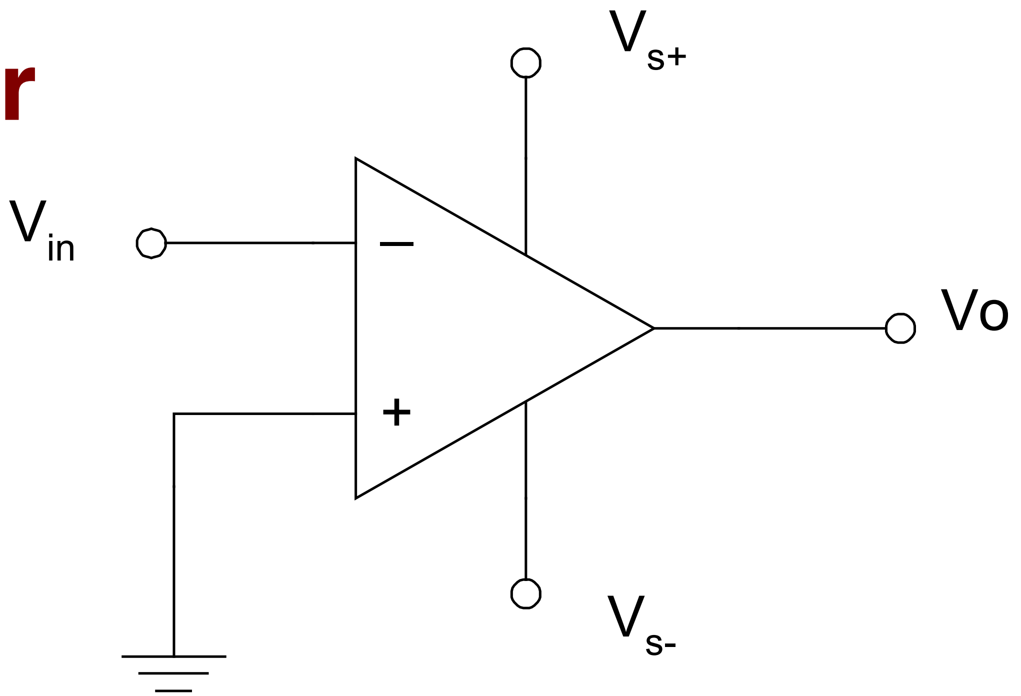
- Else $\varepsilon < 0 \Rightarrow V_o = V_{low}$

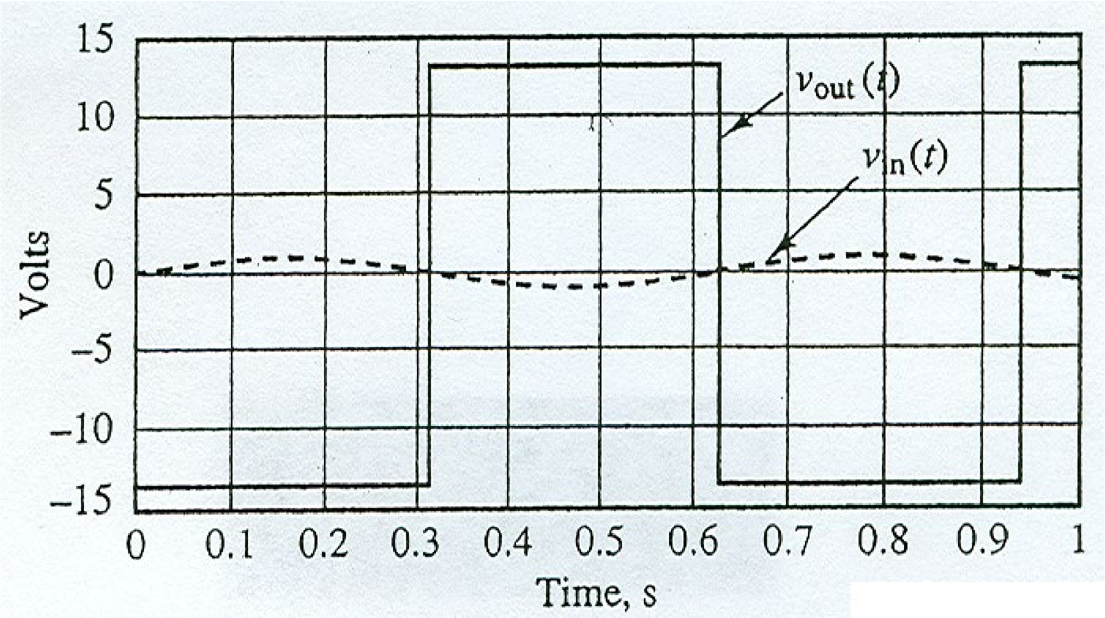
  V_{low} is the **lower saturation limit** at output ($\approx V_{s-}$).

- ***Analog*** **inputs** to ***digital*** **outputs**

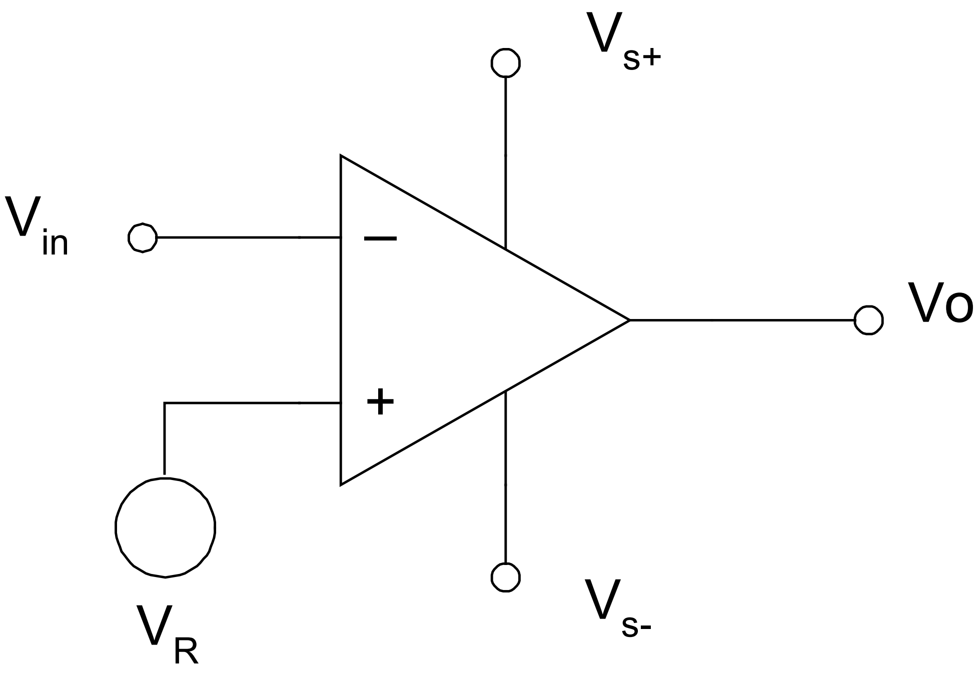
Zero Detecting Comparator



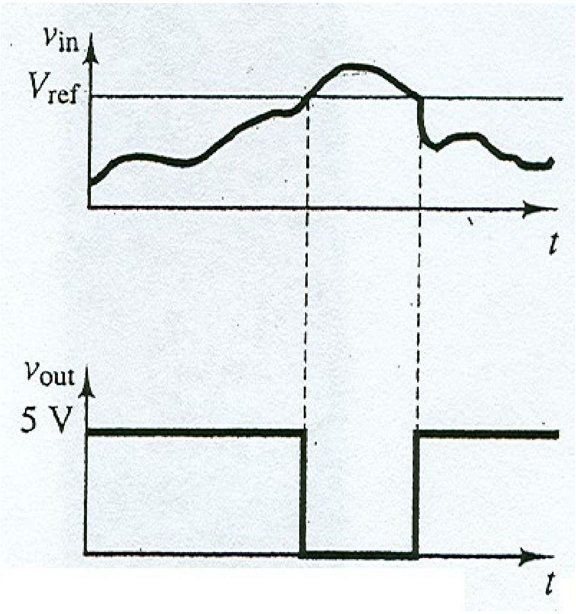
- Connect input signal at the inverting input of the comparator.
- Connect the noninverting terminal of the comparator to ground.
- With $V_{-} > 0 \rightarrow V_o = V_{low}$.
- With $V_{-} < 0 \rightarrow V_o = V_{up}$.
- Here V_{s+}=15V and V_{s-}= –15V.



Comparator with Offset

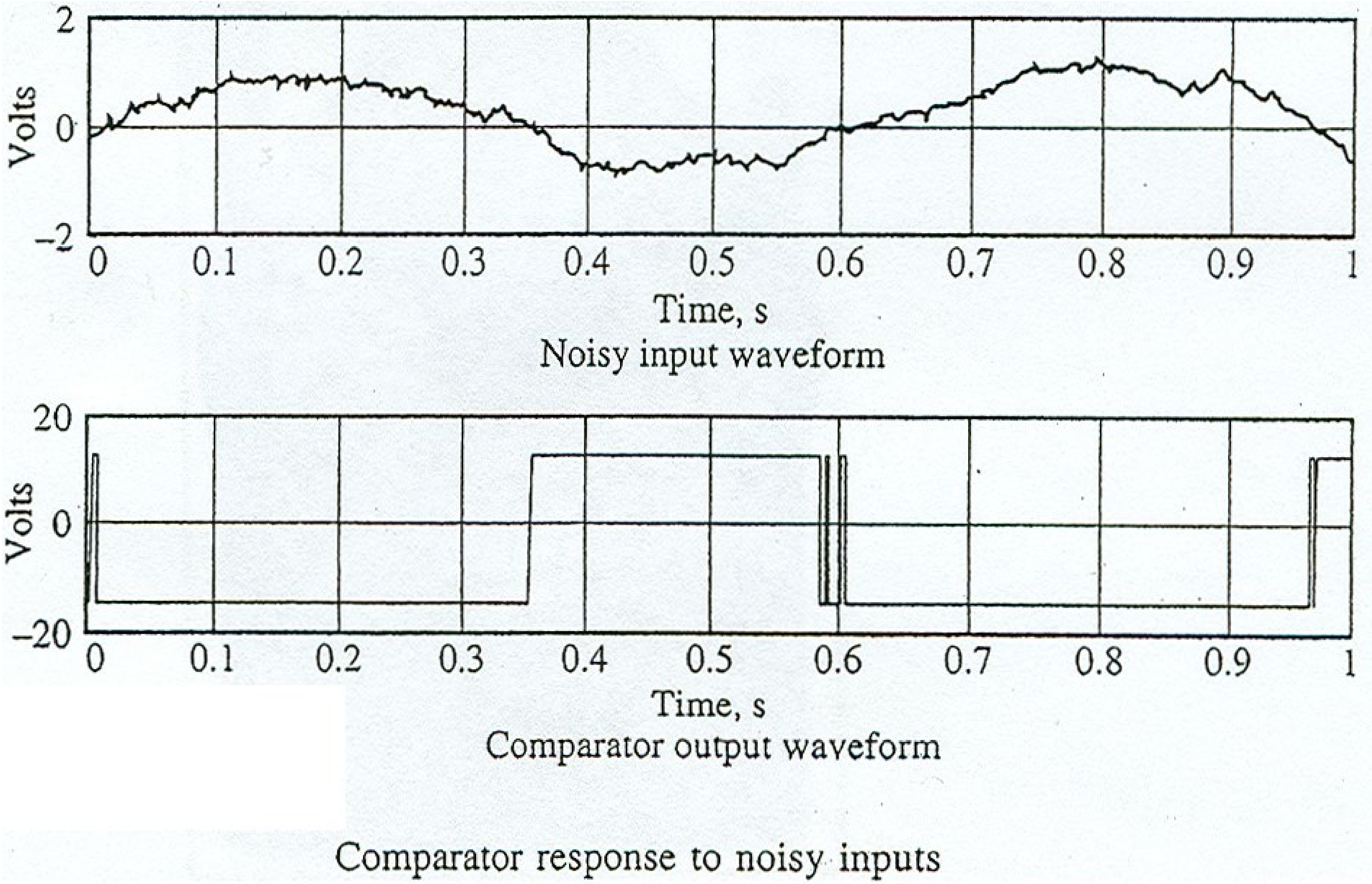


- Connect input signal at the inverting input of the comparator.
- Connect the noninverting terminal of the comparator to a nonzero reference voltage V_R.
- $V_- > V_R \rightarrow V_o = V_{low}$
- $V_- < V_R \rightarrow V_o = V_{up}$
- Here V_{s+}=5V and V_{s-}=0V.



Chattering at the Comparator Output

- If V_{in} is noisy, the output V_o will **chatter**!



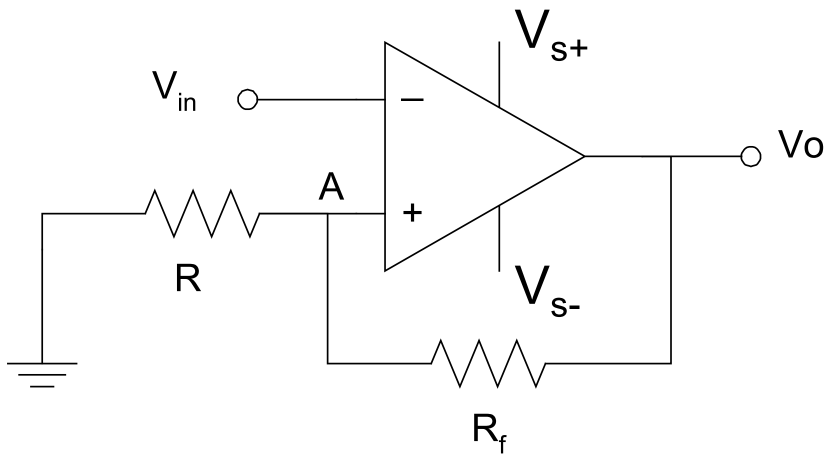
Noisy input waveform

Comparator output waveform

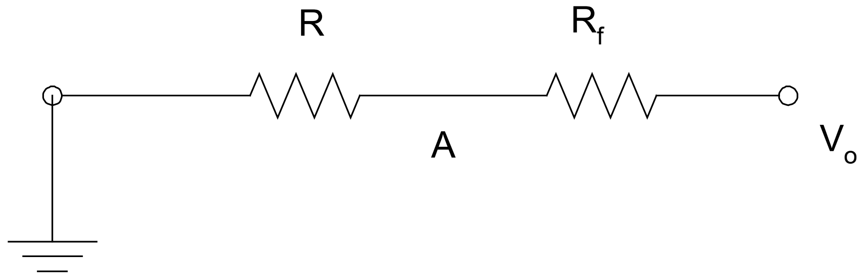
Comparator response to noisy inputs

Comparator with Positive Feedback

- Use **positive feedback** to prevent chattering at the comparator output



- Use of positive feedback introduces **hysteresis** (system **state** depends on its ***history***).
- The voltage at A can be found by considering the following circuit and using the law of voltage division.



$$V_A = \frac{R}{R + R_f} V_o$$

Comparator with Positive Feedback

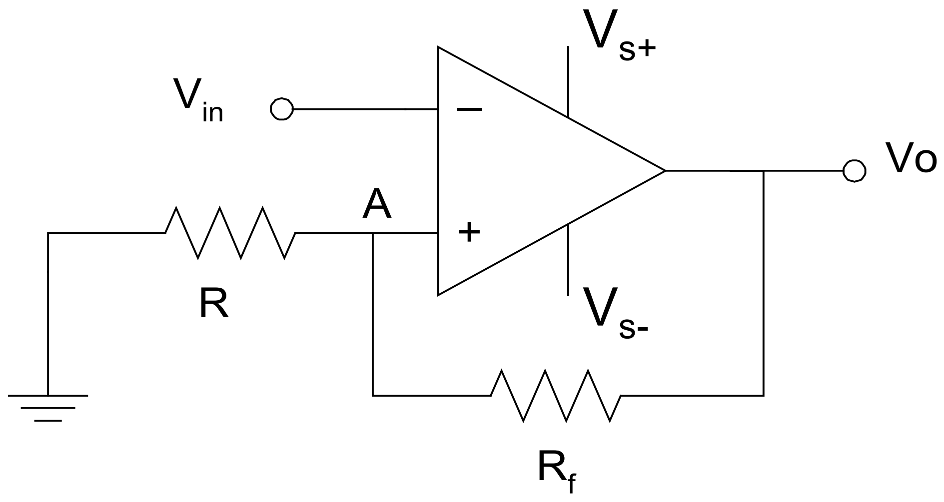
- Assume $V_o = V_{up}$. In this case:

$$V_+ = V_A = \frac{R}{R+R_f} V_{up}$$

- This condition will hold to be true until $V_- < V_+$ (with V_+ given above).
- Thus, we define an upper threshold voltage as follows.

$$V_{UT} \triangleq \frac{R}{R+R_f} V_{up}$$

- If V_- becomes larger than V_{UT} then V_o switches from V_{up} to V_{low}.



Comparator with Positive Feedback

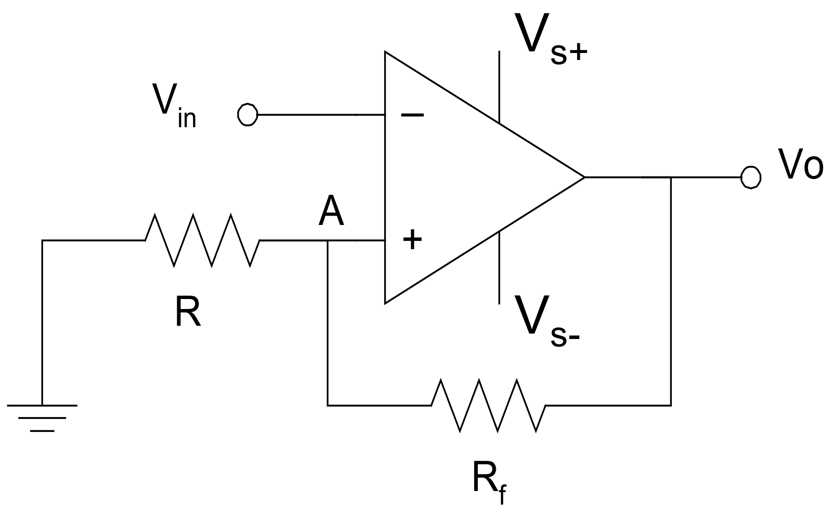
- Assume $V_o = V_{low}$. In this case:

$$V_+ = V_A = \frac{R}{R + R_f} V_{low}$$

- This condition will hold true until $V_- > V_+$, (with V_+ given above).
- Thus, we define a lower threshold voltage as follows.

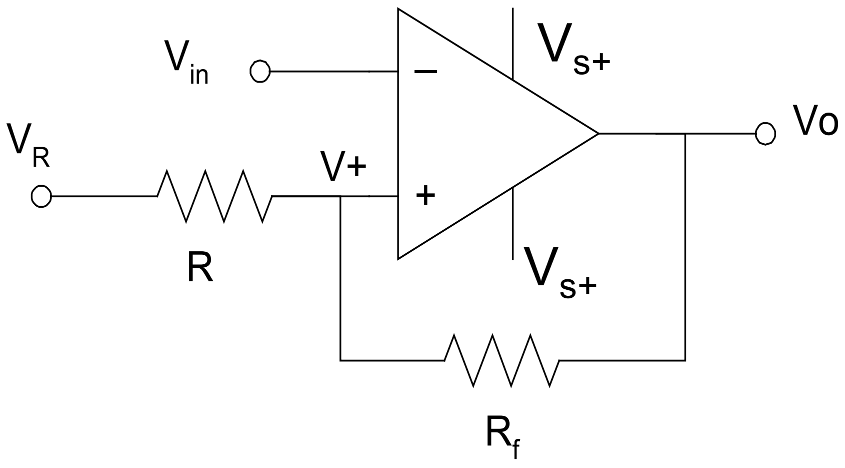
$$V_{LT} \triangleq \frac{R}{R + R_f} V_{low}$$

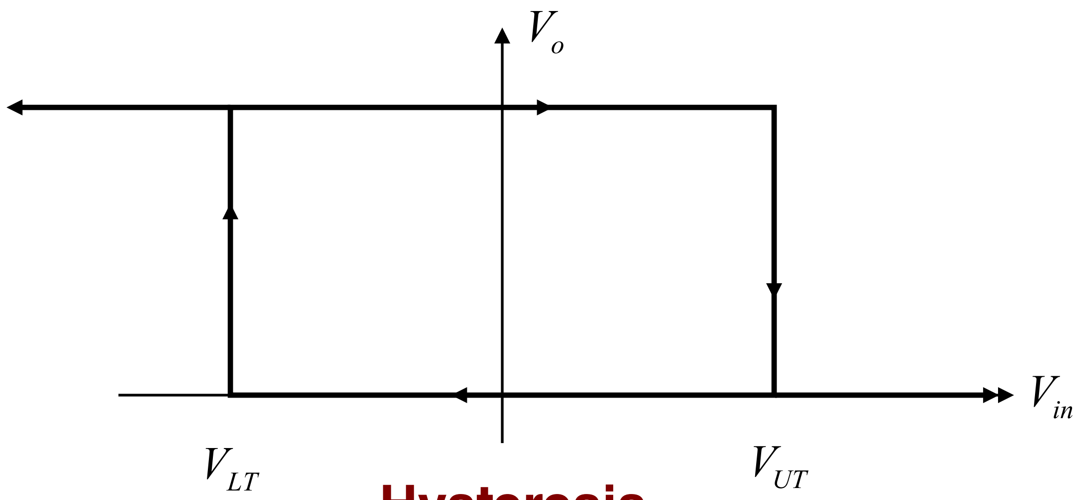
- If V_- becomes lower than V_{LT} then V_o switches from V_{low} to V_{up}.



Comparator with Positive Feedback

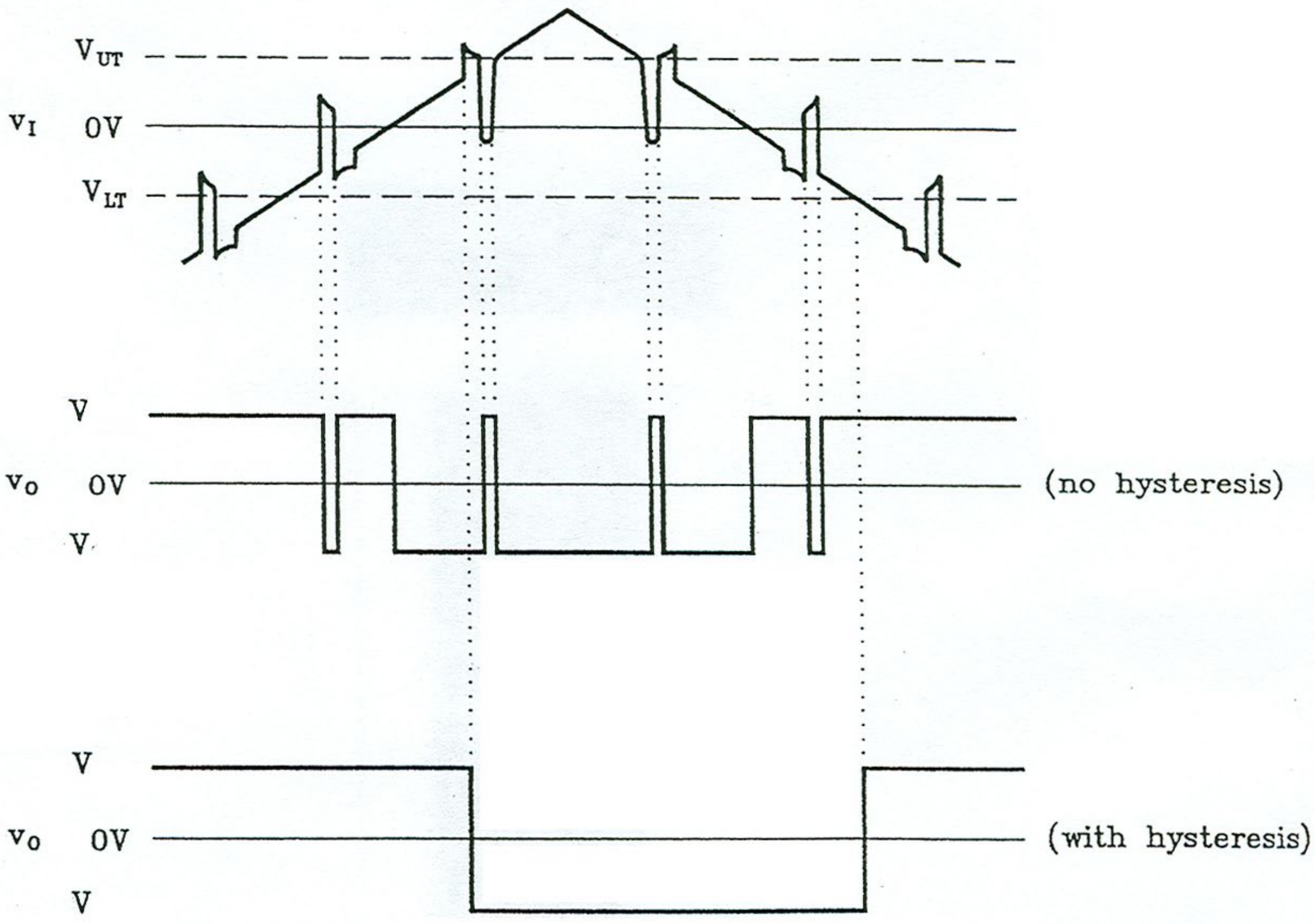
- Recall: If V_{in} becomes larger than V_{UT} then V_o switches from V_{up} to V_{low}.
- Recall: If V_{in} becomes lower than V_{LT} then V_o switches from V_{low} to V_{up}.





Hysteresis phenomenon

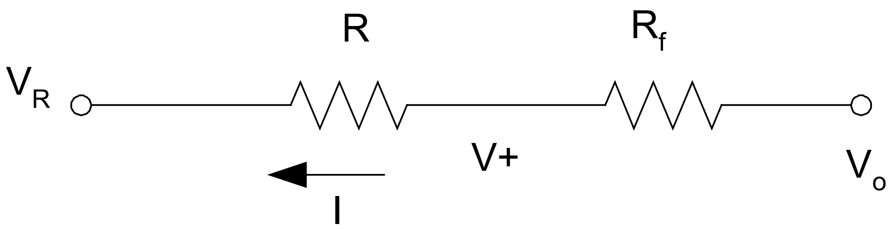
Zero Crossing Detector with Positive Feedback



Hysteresis makes the zero-crossing detector less sensitive to noise.

Comparator with Positive Feedback: Example

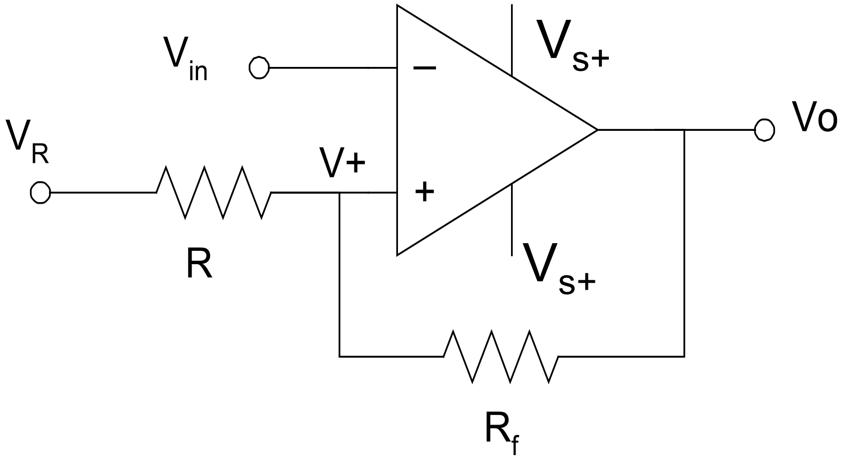
- Consider the given circuit.



- Note $I = \dfrac{V_o - V_R}{R + R_f}$ and

$$V_o - V_+ = IR_f \Rightarrow V_+ = V_o - IR_f$$

$$V_+ = V_o - \frac{V_o - V_R}{R + R_f} R_f = \frac{V_o R + V_R R_f}{R + R_f}$$



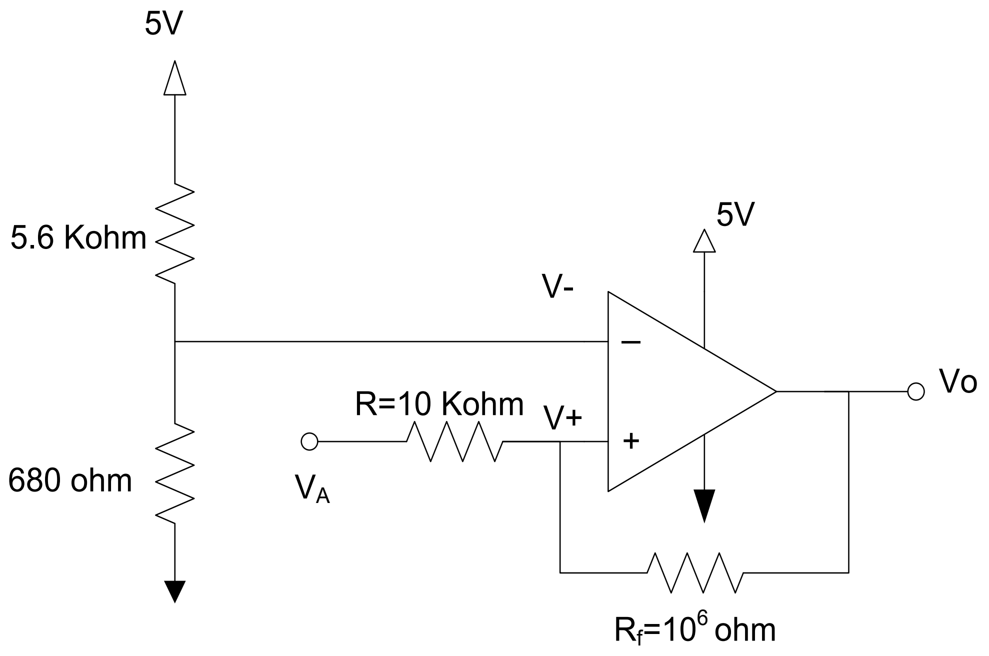
- Now, assume $V_o = V_{up}$. In this case $V_+ = \dfrac{V_{up} R + V_R R_f}{R + R_f} \leftarrow V_{UT}$

- Similarly, assume $V_o = V_{low}$. In this case $V_+ = \dfrac{V_{low} R + V_R R_f}{R + R_f} \leftarrow V_{LT}$

Comparator with Positive Feedback: Example

- Consider the circuit given below.
- Using voltage division on the series combination of 5.6 KΩ and 680Ω resistors we obtain:

$$V_{-} = \frac{5 \times 680}{680 + 5600} = 0.541V$$



Comparator with Positive Feedback: Example

- For a comparator with offset and hysteresis: $V_+ = \frac{V_o R}{R+R_f} + \frac{V_A R_f}{R+R_f}$

- Now with V_o=V_{up}=5V, if $V_+ = \frac{V_{up} R}{R+R_f} + \frac{V_A R_f}{R+R_f} < V_- = 0.541$

  – then, V_o will switch from V_{up} to V_{low}.

- In this case,

$$\frac{5\times10^4}{10^4+10^6} + \frac{V_A\times10^6}{10^4+10^6} < 0.541$$

$$V_A < \frac{0.541\times101\times10^4}{10^6} - \frac{5\times10^4}{101+10^4}$$

$$V_A < 0.4969 \approx 0.5 volts$$

- Thus, if we start with some V_A value such that V_o=V_{up}= 5.0V and then bring V_A down to 0.5V, V_o will switch to V_o= V_{low}= 0V.

Comparator with Positive Feedback: Example

- Let $V_o = V_{low} = 0$V.
- To make V_o switch to V_{up}, the following must happen:

$$V_+ = \frac{V_o R}{R+R_f} + \frac{V_A R_f}{R+R_f} > 0.541$$

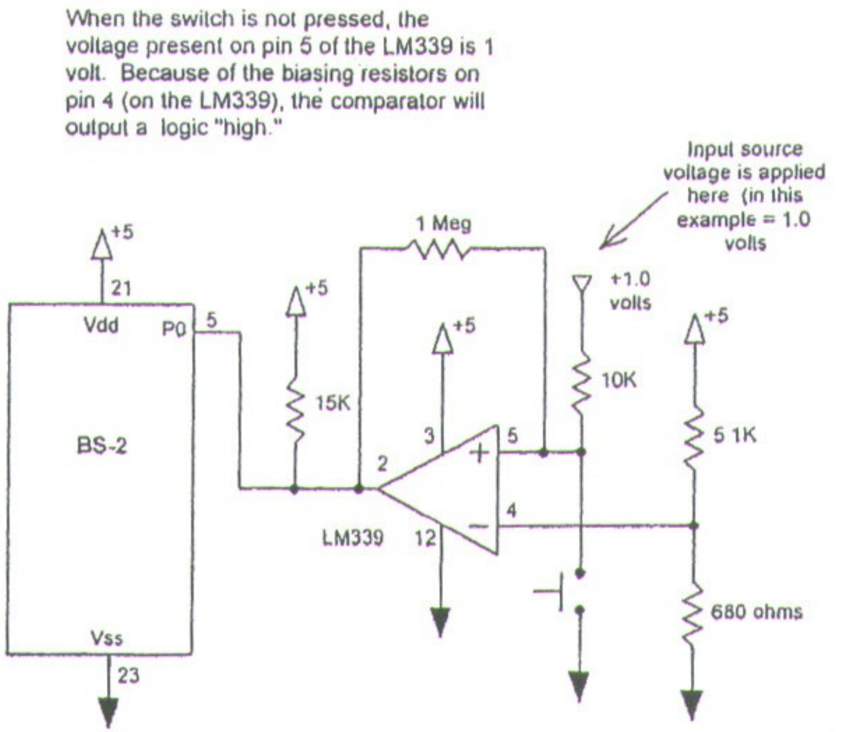
$$\Rightarrow \frac{0\times 10^4}{10^4+10^6} + \frac{V_A\times 10^6}{10^4+10^6} > 0.541$$

$$V_A > 0.546V$$

- Conclusion:
  - If $V_A > 0.546$V, then V_o will output high.
  - $V_A < 0.5$V, then V_o will output low.
- When $V_A \approx 1$V, the comparator will output 5V and when $V_A \approx 0$V, the comparator will output 0V. Hence, this technique can be used to scale up a digital input that switches between 0V and 1V so that it can be interfaced to BS2.

Upward Shift in Signal Level Using a Comparator

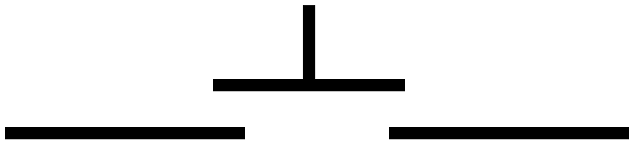
- When a sensor outputs 0V (off) and 1V (on), a comparator can be used to interface the sensor to BS2.
- Comparator outputs a digital signal and works as follow.
  - When voltage input at comparator's noninverting terminal (V_+) is higher than voltage input at comparator's inverting terminal (V_-), comparator output is equal to its upper saturating voltage.
  - When $V_+ < V_-$, comparator output is equal to its lower saturating voltage.
  - Positive feedback in a comparator introduces a hysteresis behavior in its I/O relationship and eliminates chattering (as just detailed).



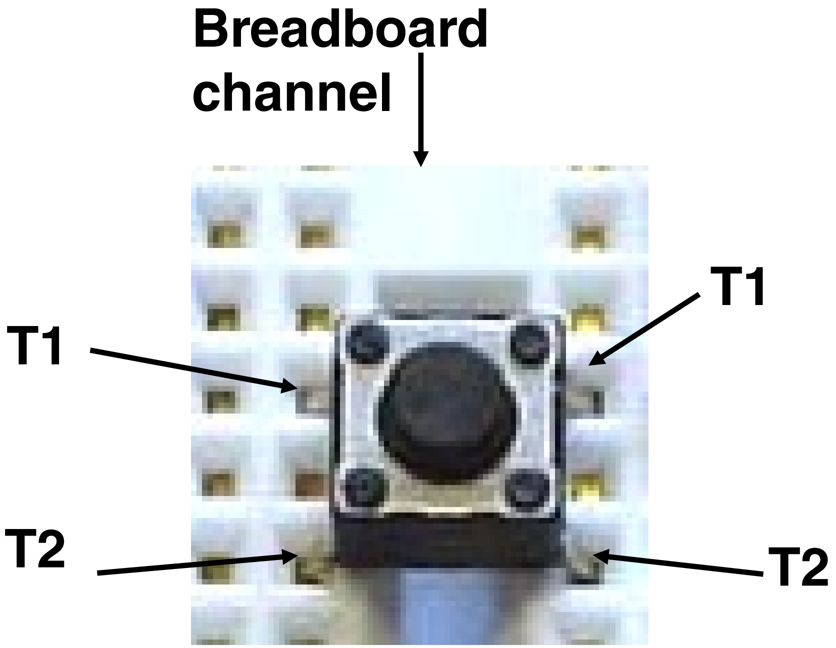
– V_+>0.59, o/p high, V_+<0.55, o/p low
– LM339 has an open collector output. To get a valid logic level, a 15K pull-up resistor is included at the output of LM339.

Digital Inputs

Buttons/Switches

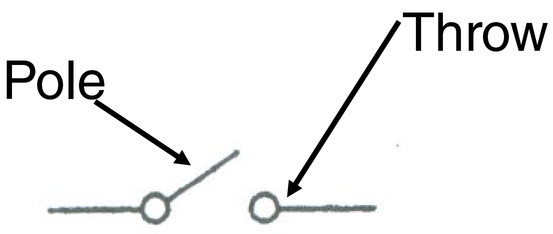


Symbol



Buttons/Switches: Classification

- SPST switches



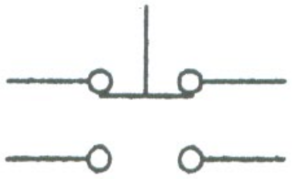
Throw switch

Normally open push-button

Normally closed push-button

- SPDT switches

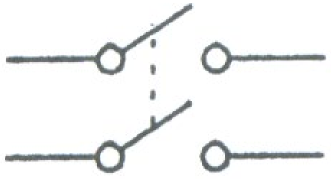
Throw switch



Normally open/closed push-button

Buttons/Switches: Classification

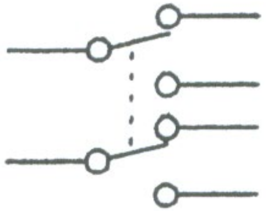
- DPST switches



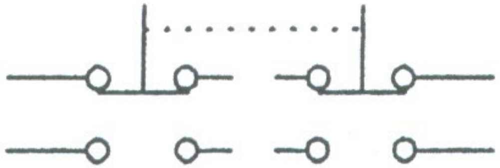
Throw switch

Normally open
push-button

- DPDT switches



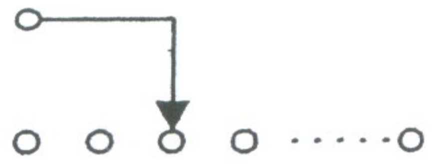
Throw switch



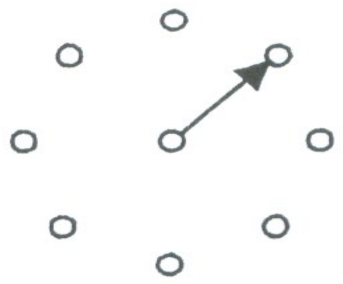
Normally open/closed
push-button

Buttons/Switches: Classification

- SP(n)T switches

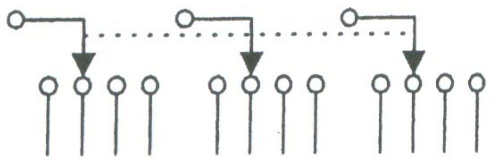


Multiple contact slider
switch

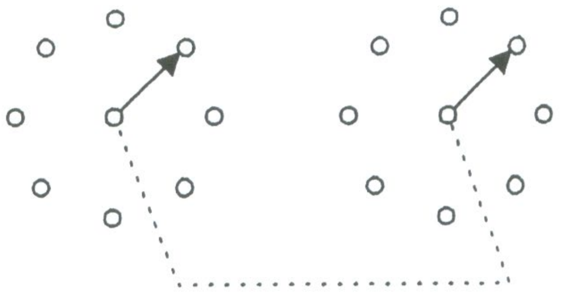


Multiple contact rotary
switch
(SP8T)

- (n)P(m)T switches



3P4T



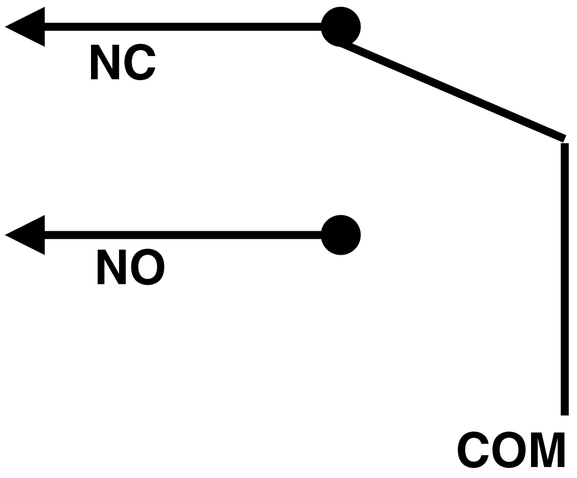
2-deck rotary
(DP8T)

Buttons/Switches: Further Classification

- Two major categories:
  - **Momentary switch:** its state is altered only during it actuation.
  - **Permanent switch:** its state is altered and maintained after it is actuated.

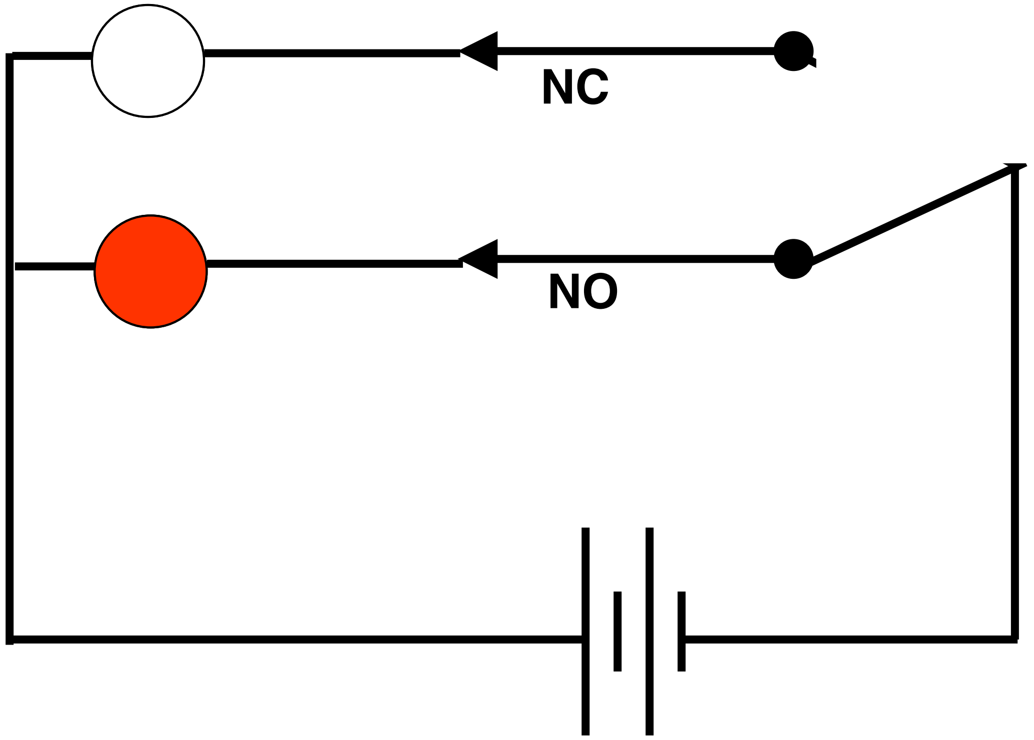
- **"Make-before-break"** and **"Break-before-make"** (more common) switches:
  - Suppose you have a make-before-break switch with contacts A, B, and C.
  - Let B be the common terminal and let A be connected to +5V supply and C to the ground.
  - When the switch is moved from C to A, for a brief moment C and A are connected before connection to C is broken.
  - We get an unintended momentary short circuit!

Limit Switch



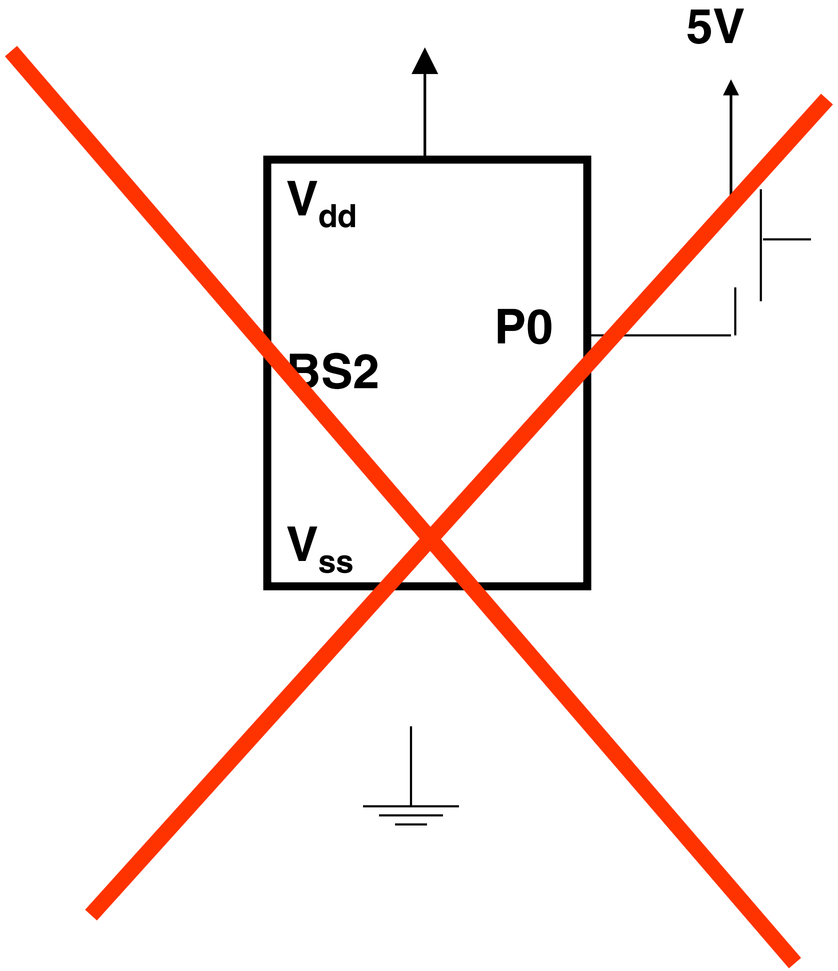
SPDT Limit Switch

Limit Switch



Wrong Button Connection—I

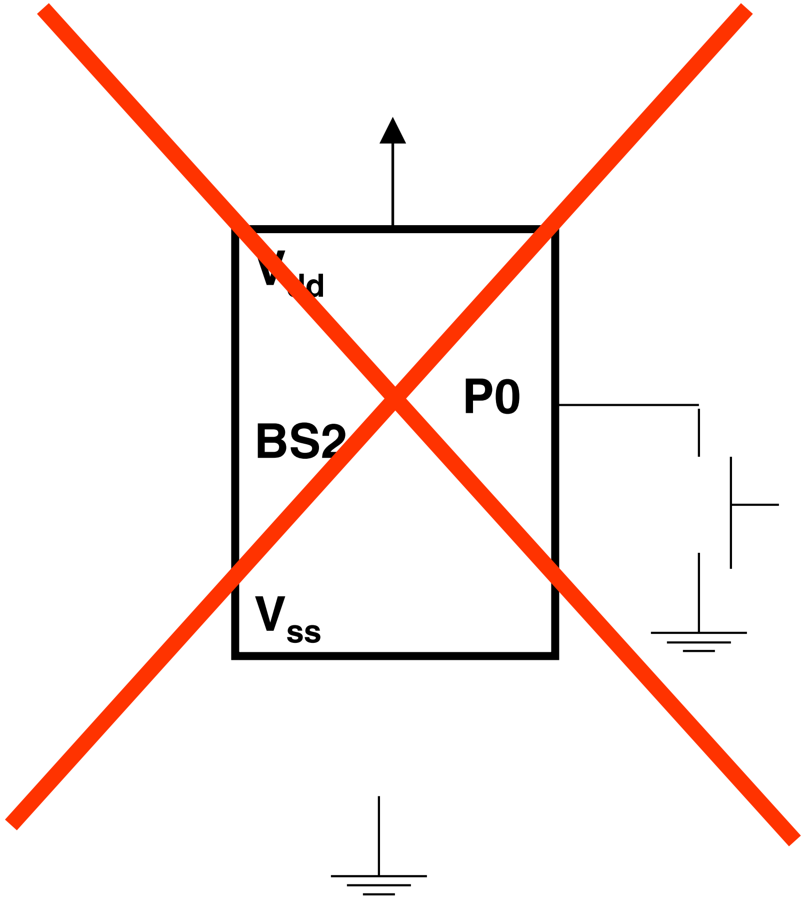
- Floating input condition when button is not pressed!
- When button is pressed, P0 is driven high.
- When button is pressed and erroneously one makes P0 output a low, then 5V is in short with ground → BS2 may be damaged!



Wrong

Wrong Button Connection—II

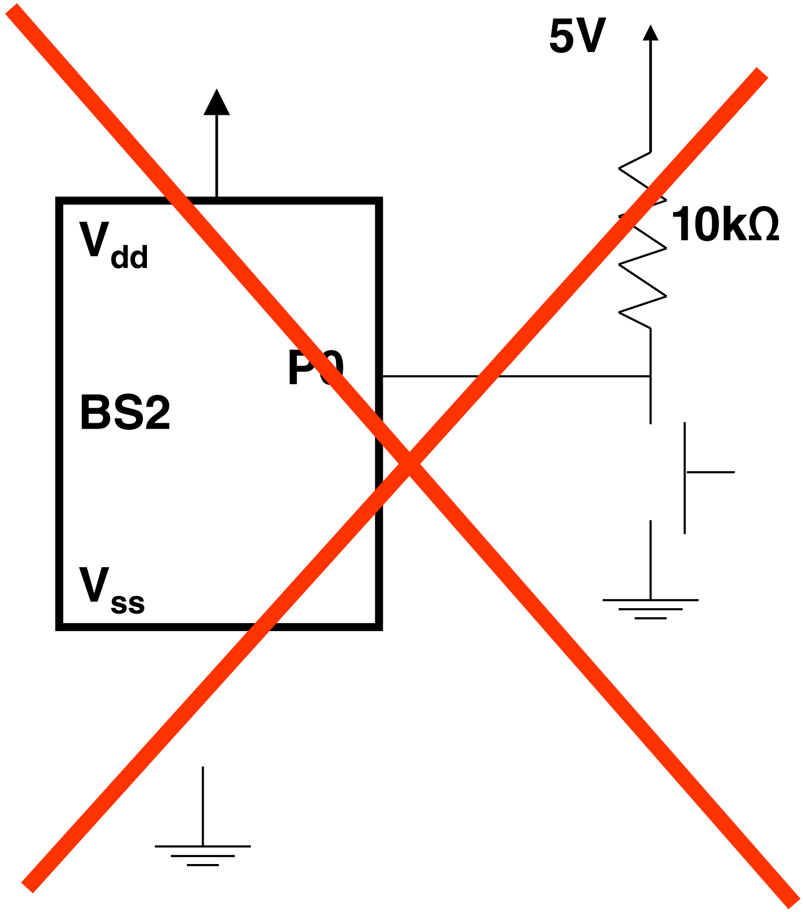
- Floating input condition when button is not pressed!
- When button is pressed, P0 is driven low.
- When button is pressed and erroneously one makes P0 output a high, then 5V is in short with ground → BS2 may be damaged!



Wrong

Wrong Button Connection—III

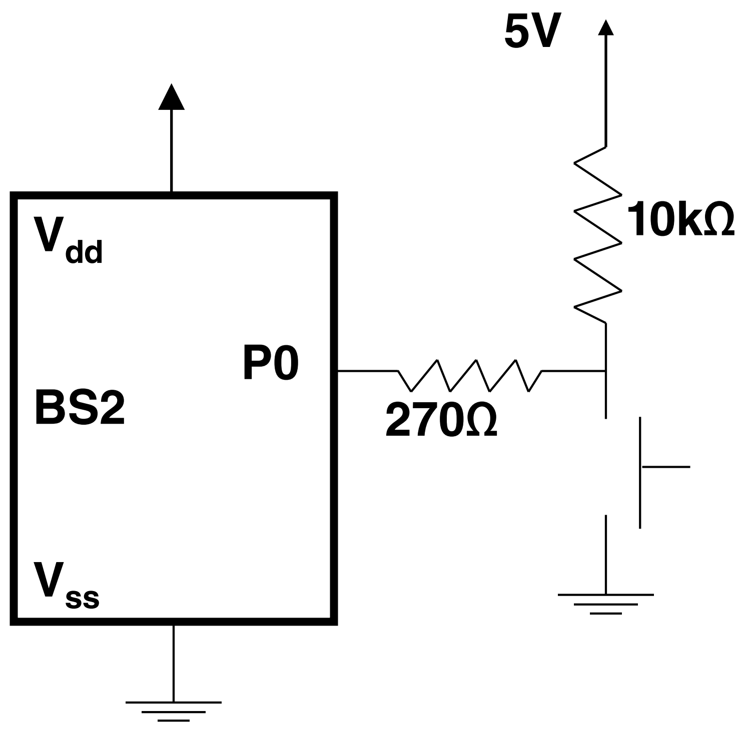
- Button is pressed, P0 is pulled down to ground.
- Button is not pressed, the 10kΩ resistor pulls P0 high.
- When button is pressed and erroneously one makes P0 output a high, then 5V is in short with ground → BS2 may be damaged!



Wrong

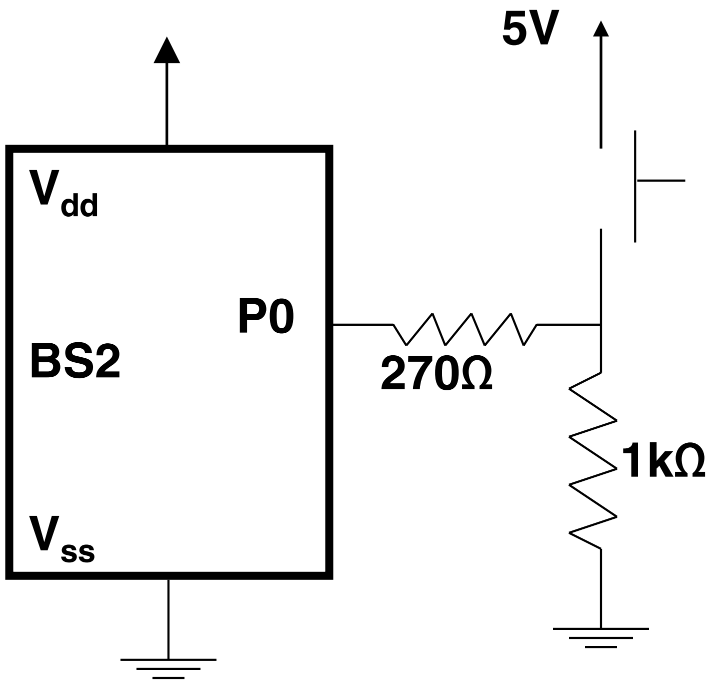
NO Active Low Button Connection

- SPST normally open switch installed as an active low device:
  - P0 high → open switch (10K pull-up resistor).
  - P0 low → closed switch (switch is activated).
  - 270Ω is for protecting I/O pin



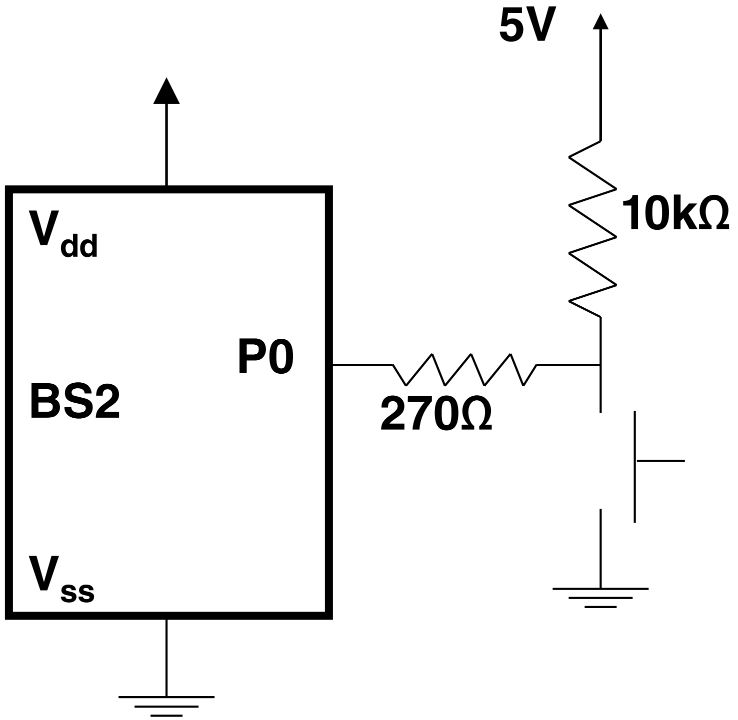
NO Active High Button Connection

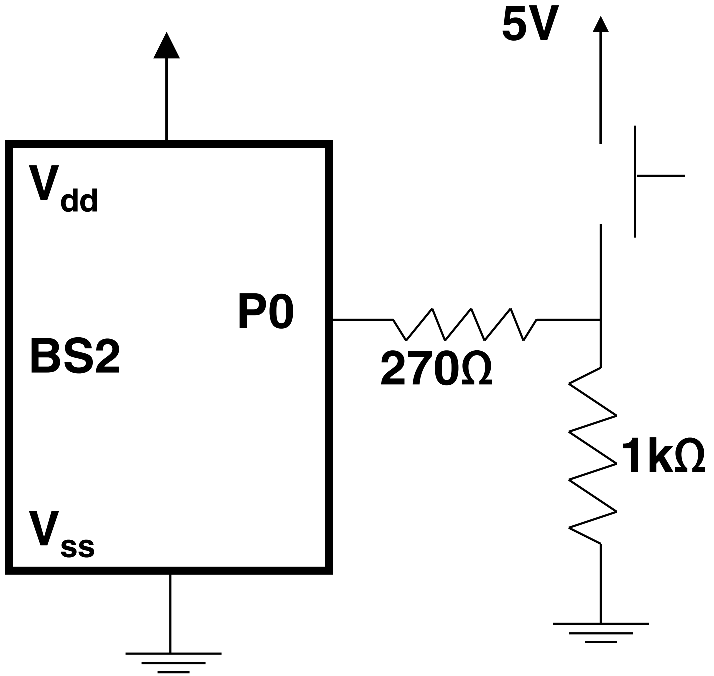
- SPST normally open switch installed as an active high device:
  - P0 high → closed switch (switch is activated).
  - P0 low → open switch (1K pull-down resistor).
  - 270Ω is for protecting I/O pin



NO Button Connection Preference

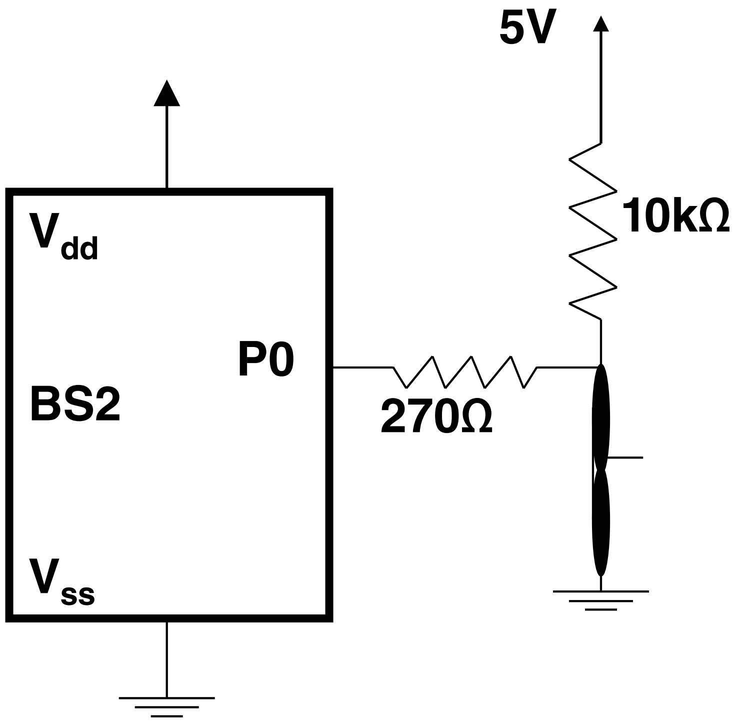
- **NO active low circuit** is preferred as it yields better **noise immunity**.
  - Low state detection threshold is 1.4V. In order for this circuit to incorrectly report switch closure, a noise level of –3.6V is needed at the 5V supply.
- In a **NO active high circuit**, a noise level of 1.4V at the ground of the supply will incorrectly report an open switch as a closed switch.





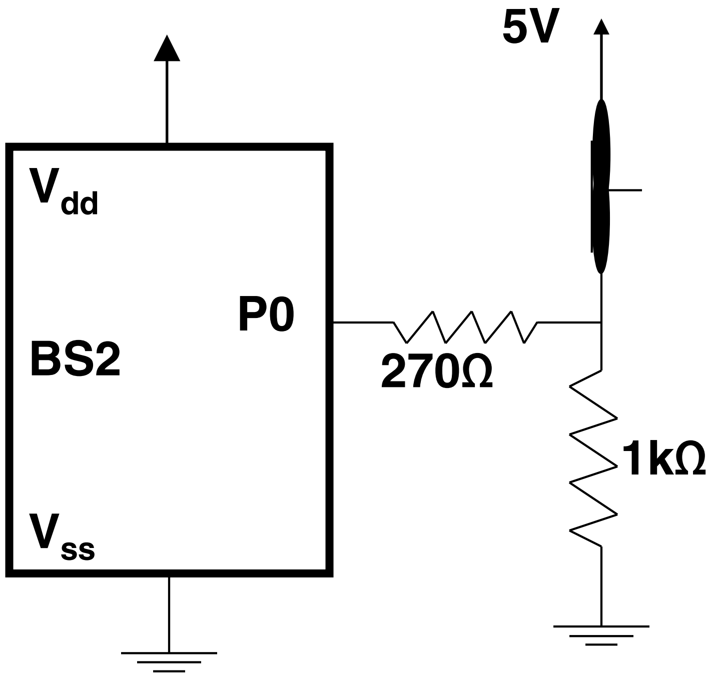
NC Active High Button Connection

- SPST normally closed switch installed as an active high device:
  - P0 low → closed switch (switch is not activated).
  - P0 high → open switch, switch is activated (10K pull-up resistor).

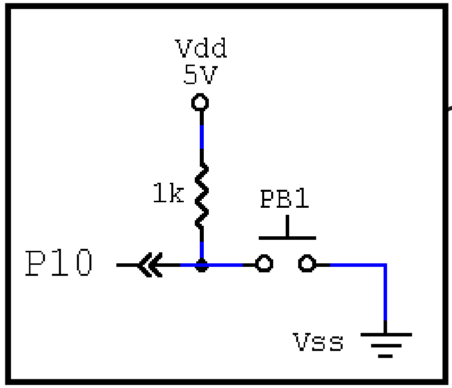


NC Active Low Button Connection

- SPST normally closed switch installed as an active high device:
  - P0 high → closed switch (switch is not activated).
  - P0 low → open switch, switch is activated (1K pull-down resistor).
  - 270Ω is for protecting I/O pin



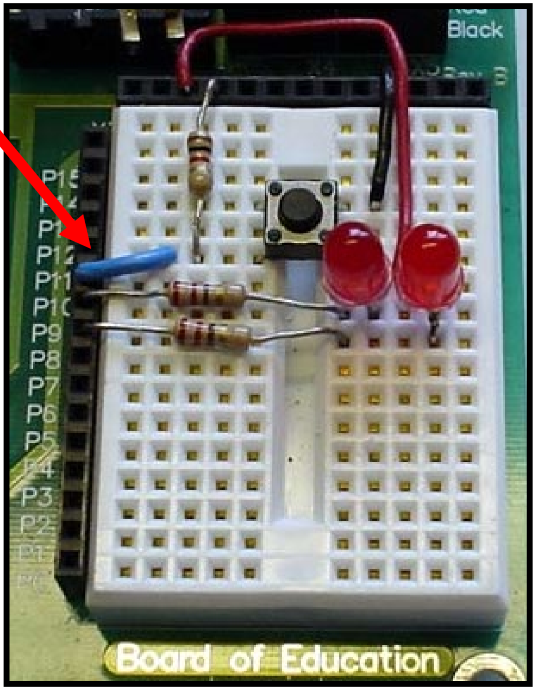
Illustrative Button Connections on a BS2



The push-buttons used here have 4 terminals. 2 are electrically connected on one side of the button, and the other 2 on the other side. By wiring to opposing corners we ensure the proper connection independent of button rotation.

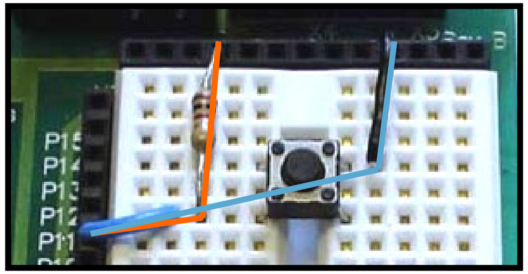
n:

Use a 270 Ω resistor



- This push-button is a momentary normally-open (N.O.) switch. When the button IS NOT pressed (open), P10 will sense Vdd (5V, HIGH, 1) because it is *pulled-up* to Vdd.

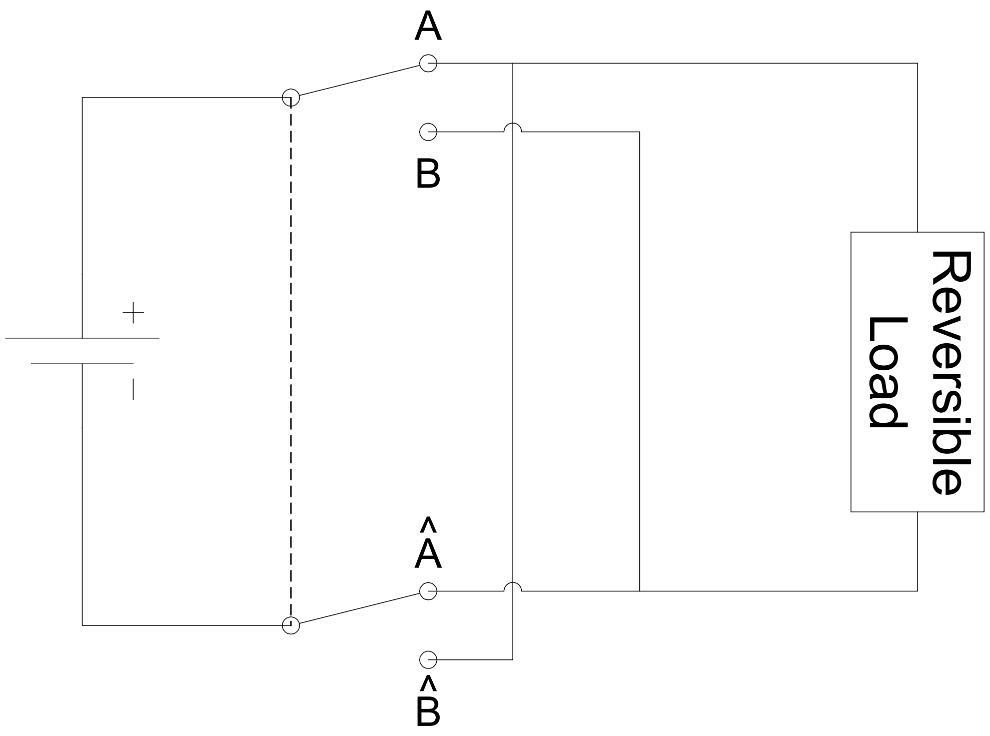
- When PB1 IS pressed (closed), P10 will sense Vss (0V, LOW, 0) making it *Active-Low*.



Button alone

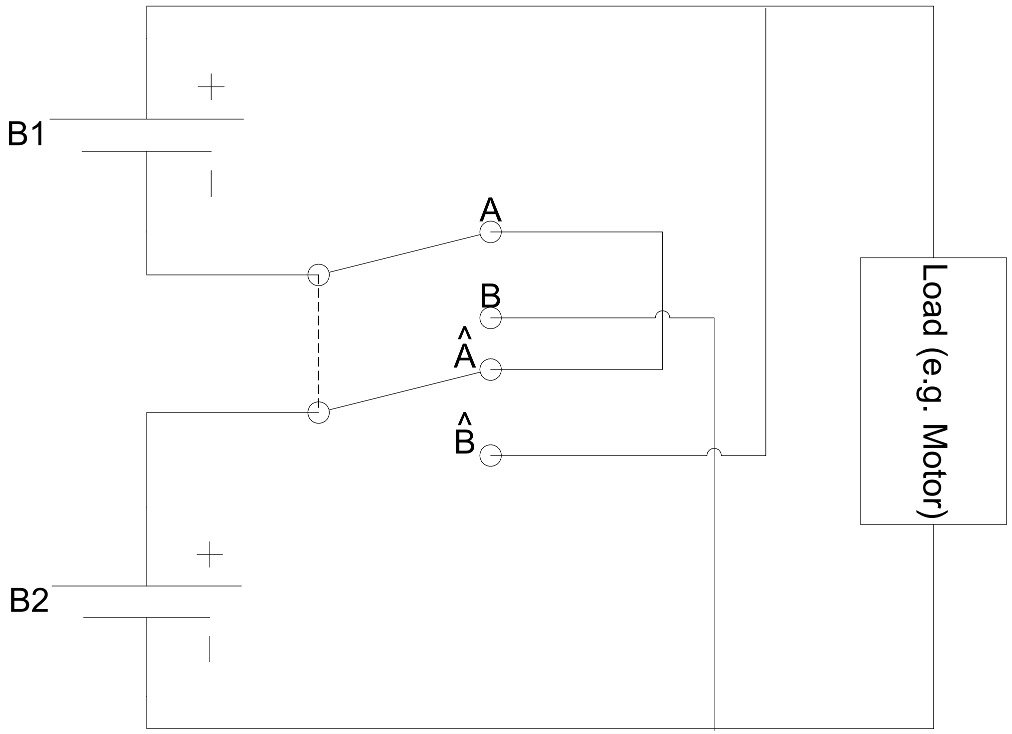
Button Applications: Load Reversal

- DPDT switch used to reverse a load (e.g., a motor).
- When switch makes contacts with A and $\hat{A}$, load runs in forward direction.
- When switch makes contacts with B and $\hat{B}$, load runs in reverse direction.

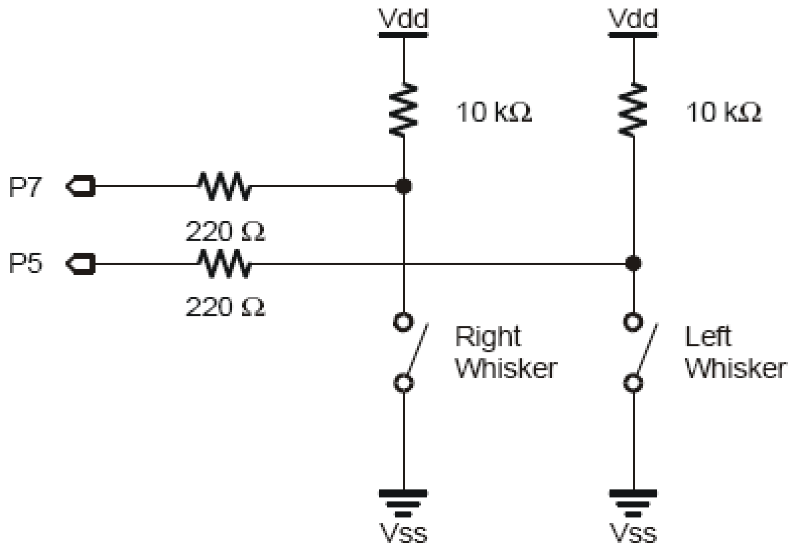


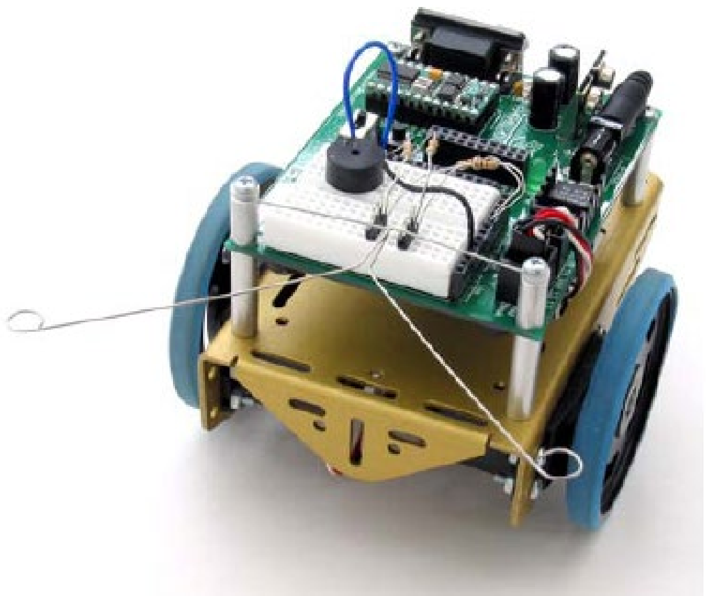
Button Applications: Series/Parallel Connection

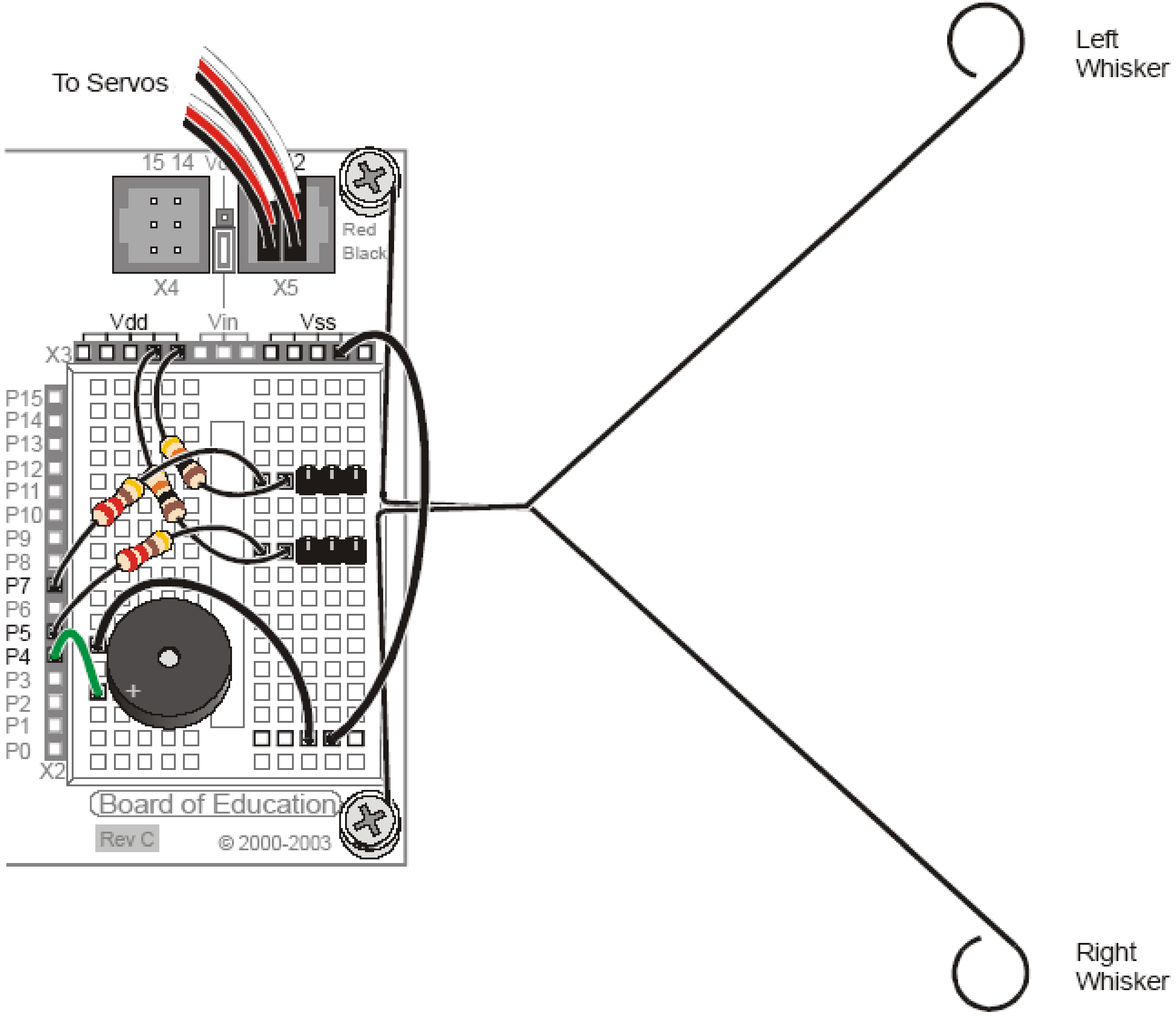
- Series-Parallel connection of power sources using DPDT switch.
- When switch makes contact with A and $\hat{A}$, B1 and B2 are in series and supply $2V_B$ volts (each battery provides V_B volts).
- When switch makes contact with B and $\hat{B}$, B1 and B2 are in parallel and can supply a larger current.



Button Applications: Tactile Sensing

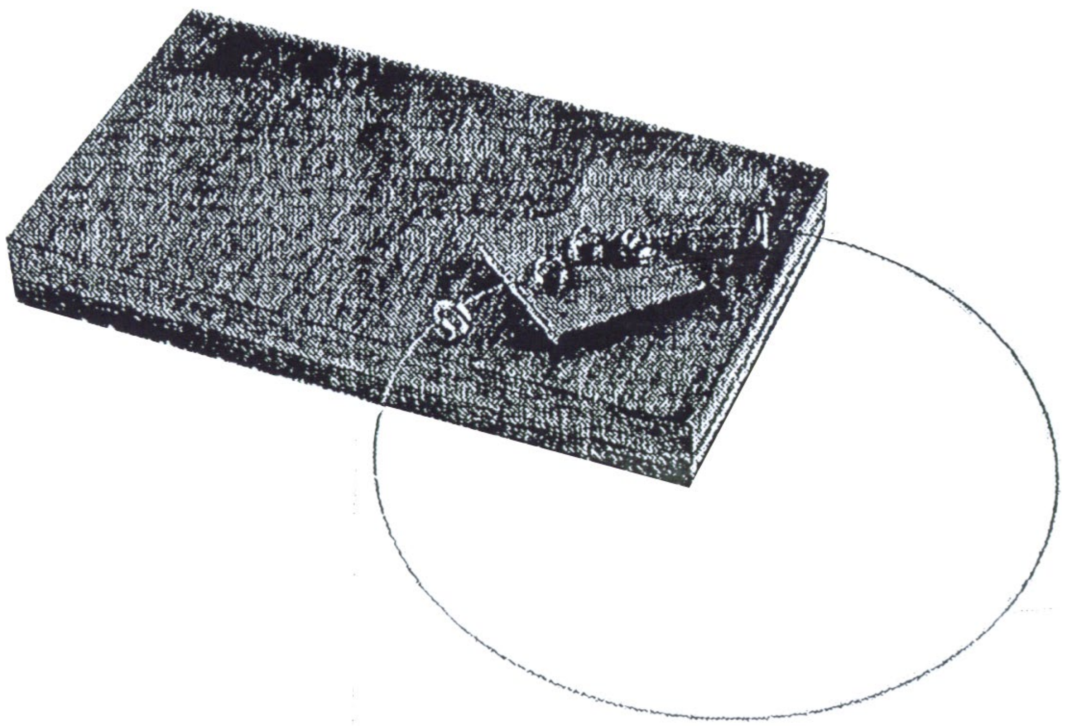




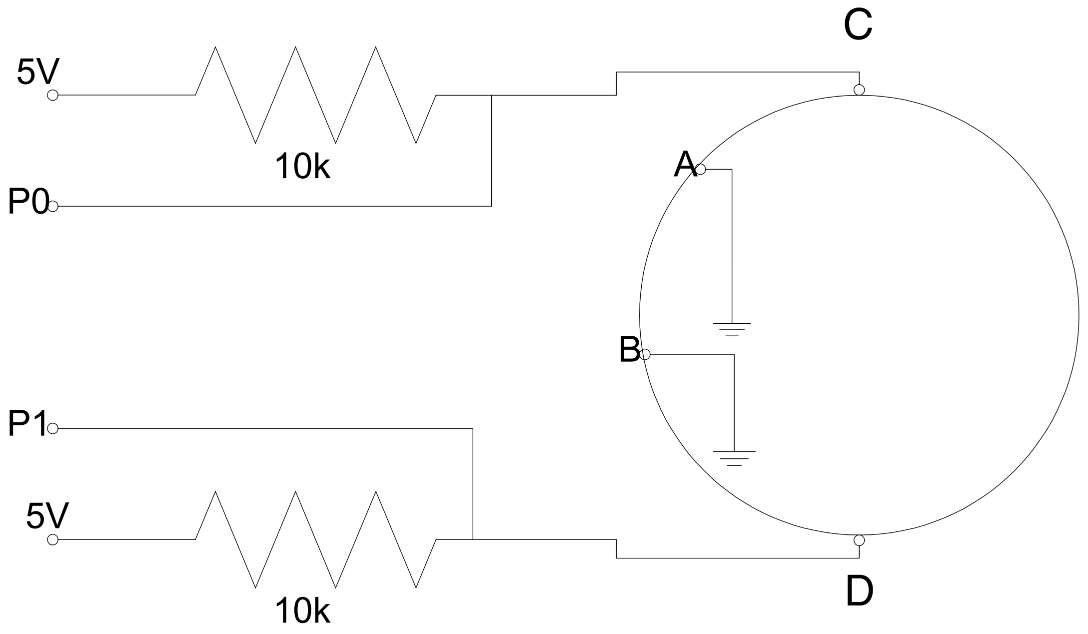


Button Applications: Tactile Sensing

- Tactile sensing using guitar string looped through the center of a pair of small screw-eyes.



Use the usual current limiting safety resistors at P0 and P1

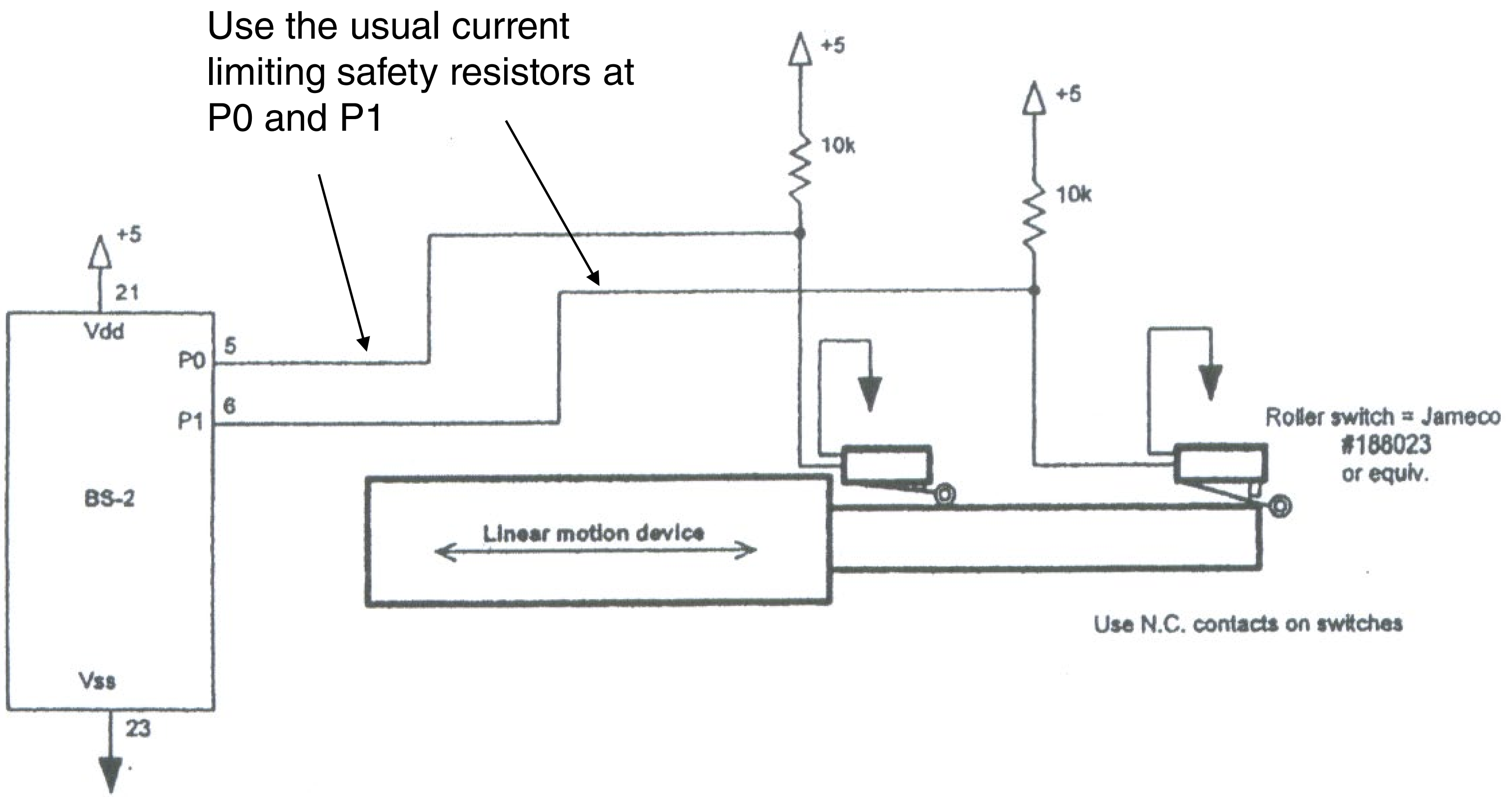


Button Applications: Tactile Sensing —IV

- A loop of guitar string is formed and connected to ground at A and B.
- Two screw eyes at C and D are used as switches. The guitar string loop is passed through C and D such that normally the string does not contact C and D. When the loop comes under pressure, the string will touch the screw eye either at C or D, thereby bringing C/D to ground.
- The two screw eyes are connected to BS2 pins P0 and P1 as shown and to 5V source via 10kΩ resistors.
- When the loop is under no pressure, P0 and P1 are pulled high by 10kΩ resistors.
- When the loop is deflected towards screw eye C/D, thereby bringing screw eye C/D to ground, switch C/D closes, bringing P0/P1 to low.

Switch Applications: Travel Limit Detection

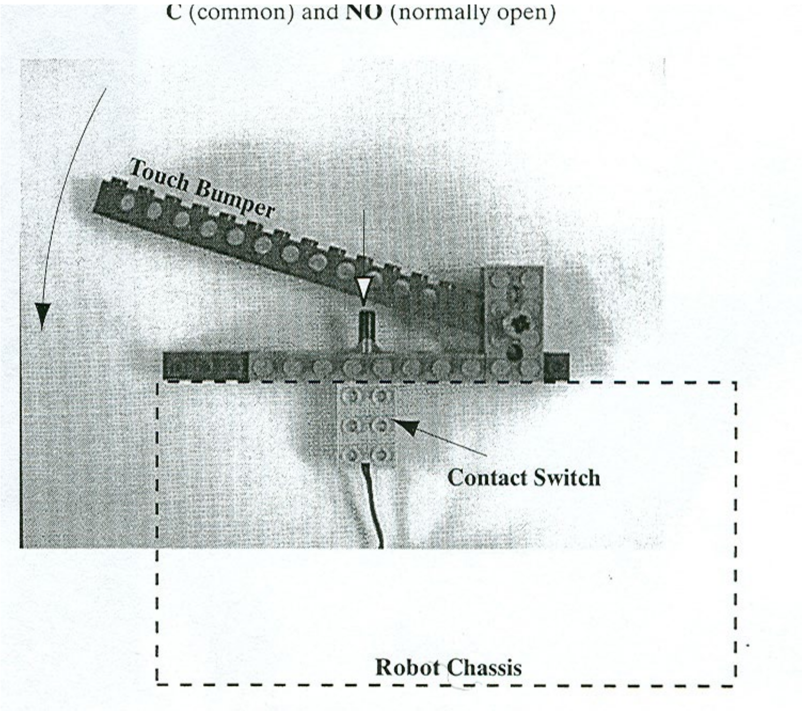
- Two limit switches detect the minimum and maximum position of travel in a mechanical system.



Switch Applications

Tactile Sensing

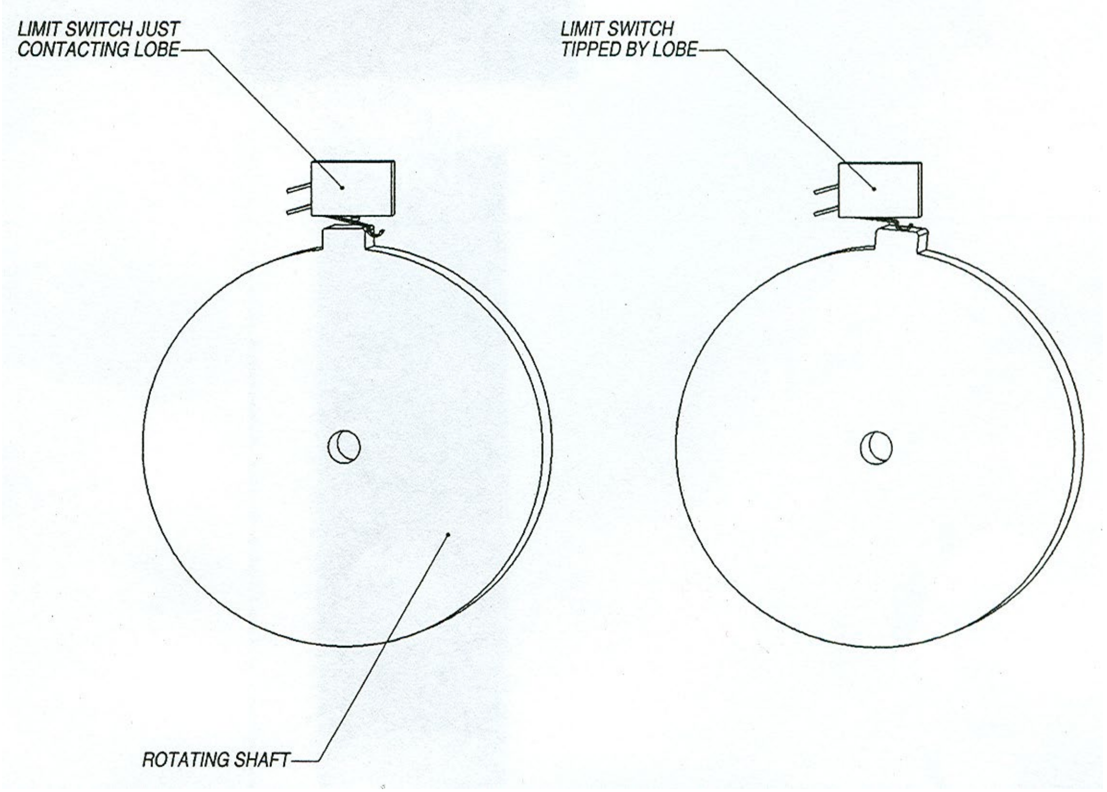
- Push button switch is actuated by a touch bumper whenever it runs into objects.



Pushbutton Switch Sensor

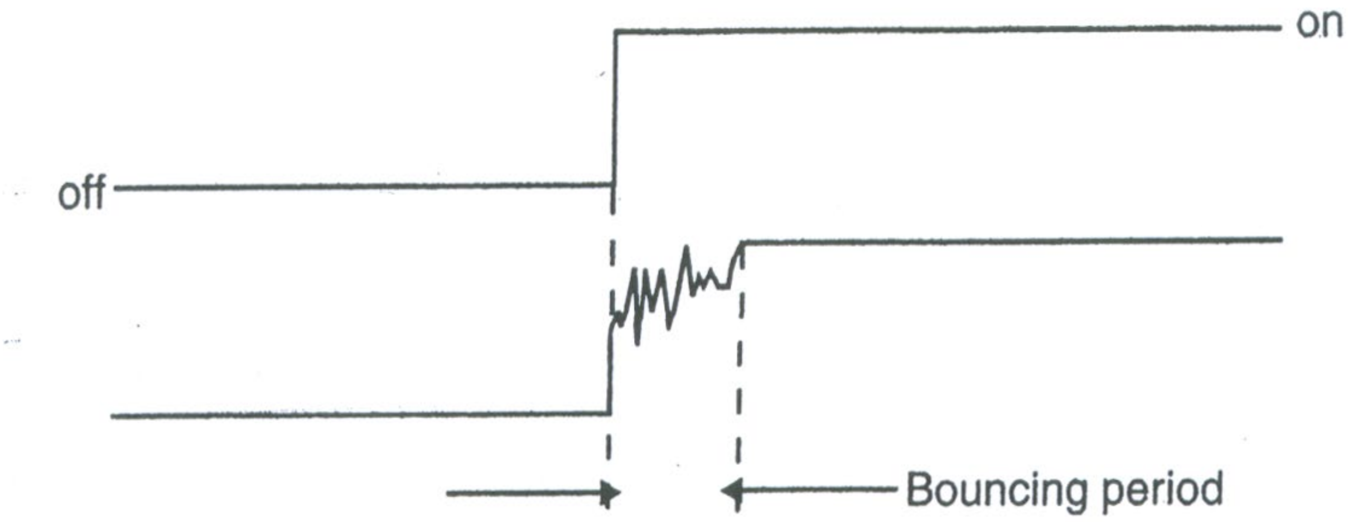
Rotation Sensing

- Limit switch closes once every revolution of the wheel.

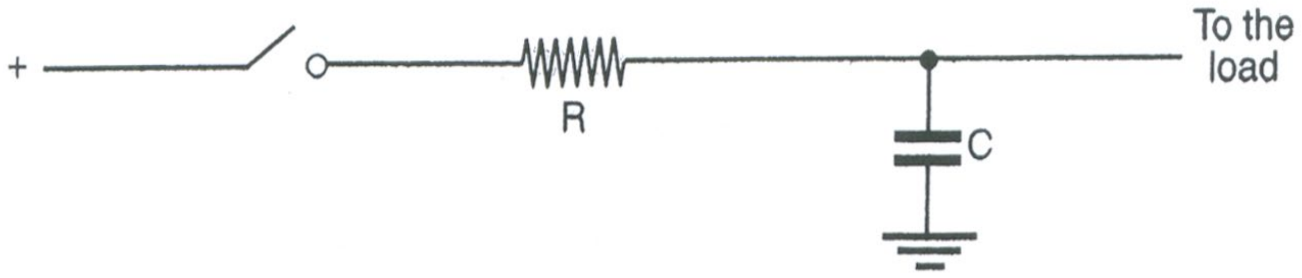


Switch Bounce

- 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.

Hands-on Exercises: Digital Input

What's a Microcontroller? Digital Input – Pushbuttons	Chapter 3
Activities #1 – #3	pp. 61-73
Activities #4 and #5	pp. 73-87
Basic Analog and Digital Analog Voltage and Binary States	Chapter 1