Lecture 07

Comparators
Rotary Encoders

Agenda

00. Teensy USB-print
01. Comparators
02. Rotary Shaft Encoders
03. Resistor Colors

Misc. stuff

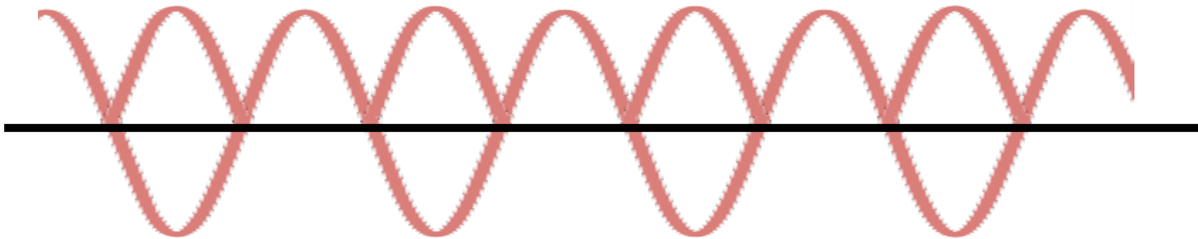
- Check off for Labs. If you are sick (or don't feel well) check off can be done via Zoom. Make arrangements with TAs.
- Lab 3 will involve laser cutting. You need to be trained.

1. Use CAD system to create DWG files
2. Watch video
3. Take quiz
4. Go to RPL for staff training – sign up info for MEAM510 will be announced on piazza.

https://meamlabs.seas.upenn.edu/rapid-prototyping-lab/training/

Lab 2

- 60Hz or 120Hz

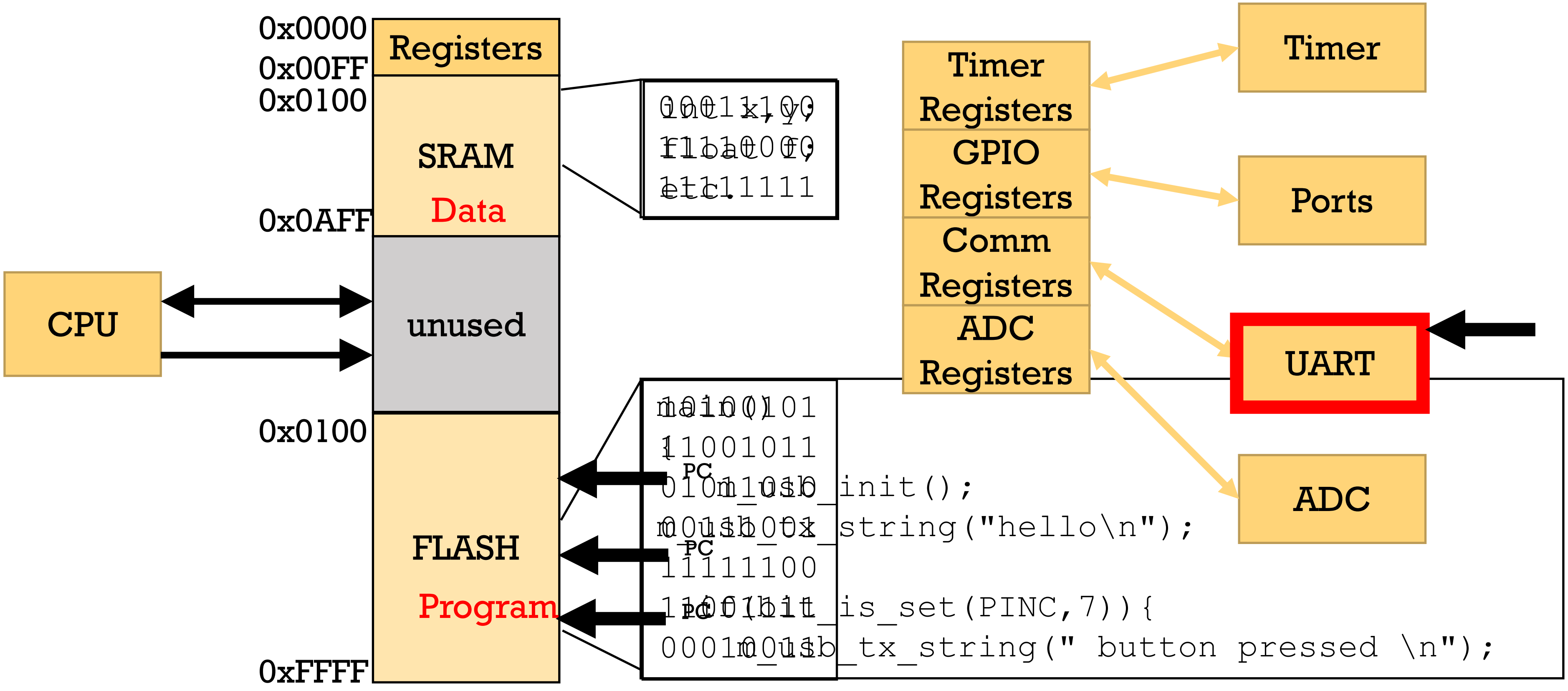


- Dealing with analog values on Teensy (LVTTL logic levels)
  - Above 1.9V is considered logic high $V_{IH} = 1.9V$
  - Below 0.9V is considered logic low $V_{IL} = 0.9V$

Print statements are slow

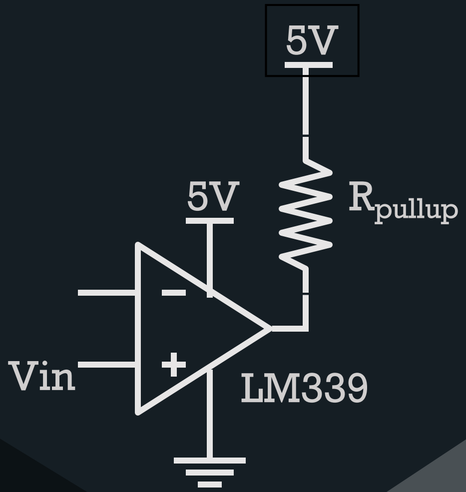
```
#include "teensy_general.h"
#include "t_usb.h"

#define PRINTNUM(x) m_usb_tx_uint(x); m_usb_tx_char(10); m_usb_tx_char(13)

int main(){
  m_usb_init(); // init USB for print statements
  set(PORTC,7); // turn on pull up on PC7

  for (int i=0; i<100;i++)  {
    teensy_wait(100);
    PRINTNUM(i);
    PRINTNUM(bit_is_set(PINC,7)); // print state of PC7
  }

  m_usb_tx_string("ended\n");
}
```

Peripherals run concurrent with main code



01

Comparators



Comparator

Looks like an opamp,

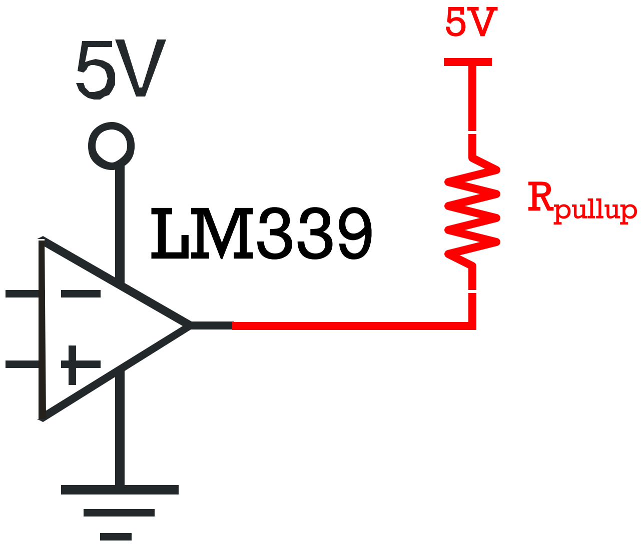
but it's a comparator

Acts like an opamp

but designed for driving output to a rail not linearity.

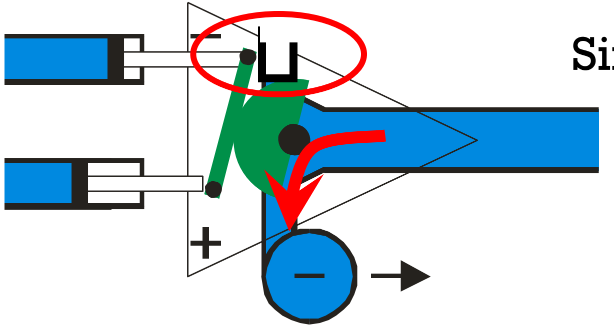
Compares the two inputs

swings output to negative rail or pulled up voltage.

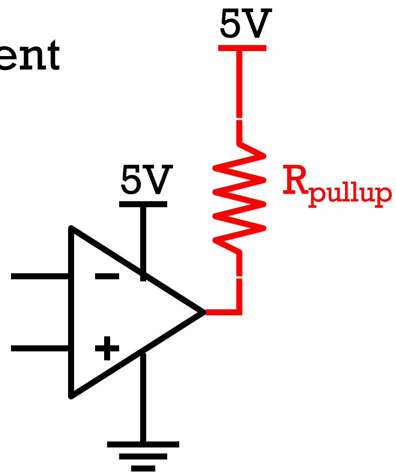


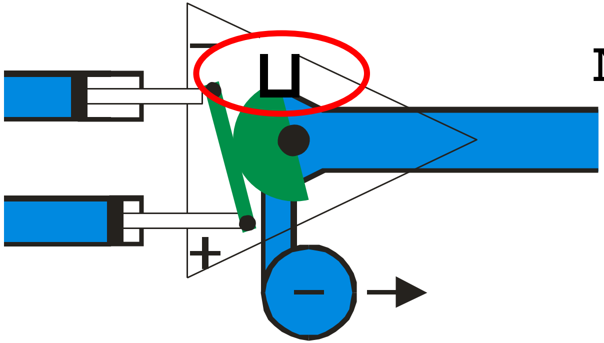
Output is often "open collector" or "open drain." (need pull-up resistor)

Two states of open collector comparator



Sinking current





No flow

Output is "floating"

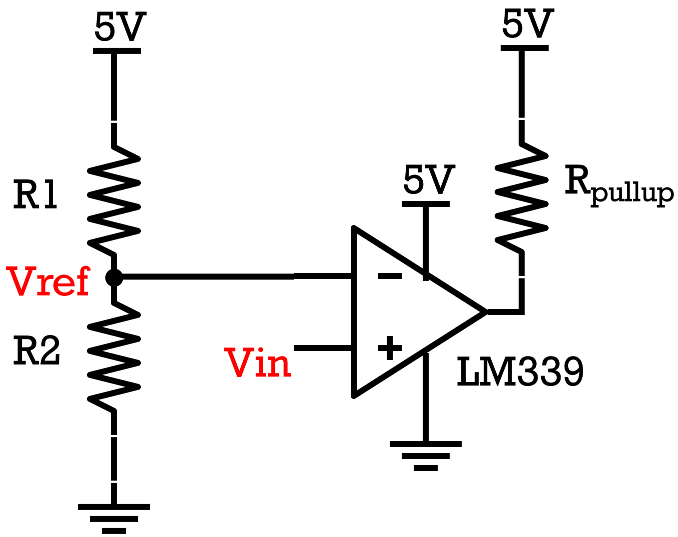
High impedance state

How do you use a comparator?

R1 and R2 are a voltage divider setting a reference voltage

Input	Output
V+ < V-	driven LOW
V+ > V-	pulled HIGH

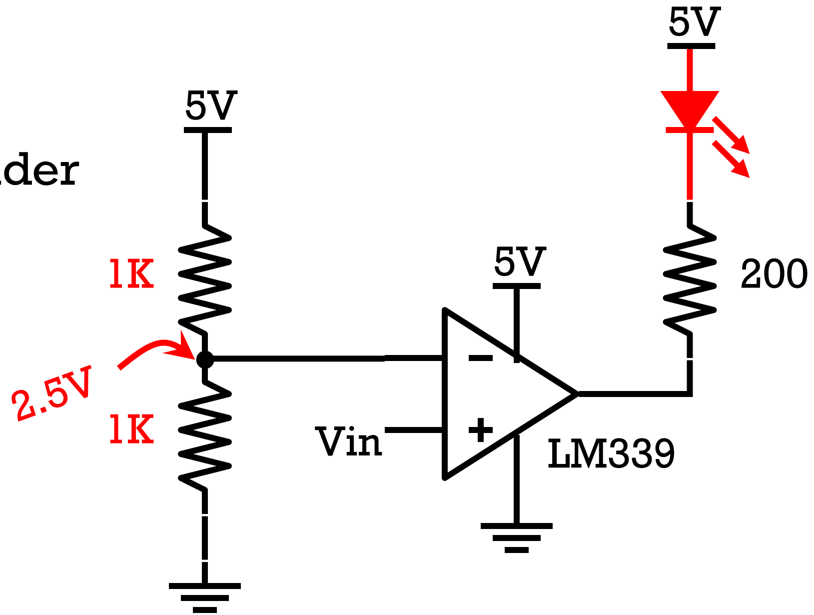
Non-inverting



What would this do?

R1 and R2 are a voltage divider setting a reference voltage

Input	Output
V+ < V-	driven LOW
V+ > V-	pulled HIGH

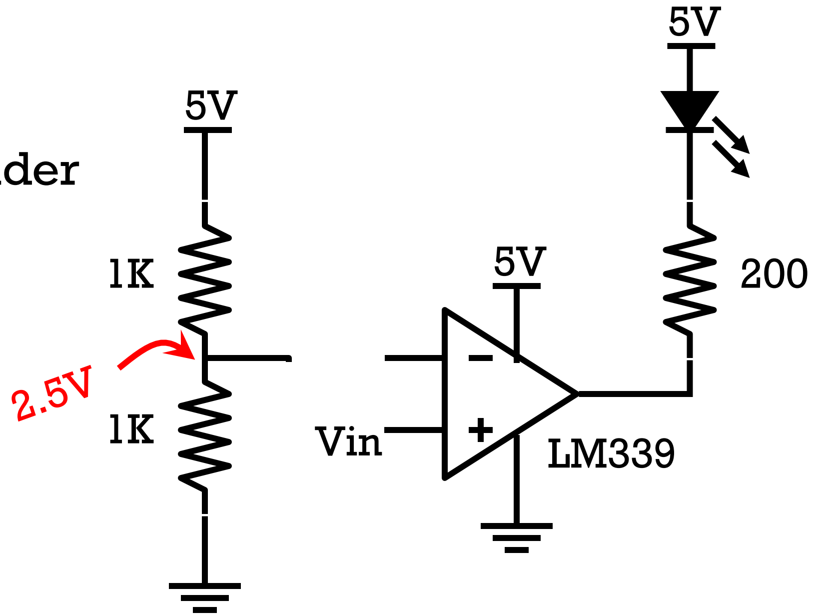


Non-inverting

Q1: in chat: What happens to the LED if Vin is 1.5V?

What would this do?

R1 and R2 are a voltage divider setting a reference voltage

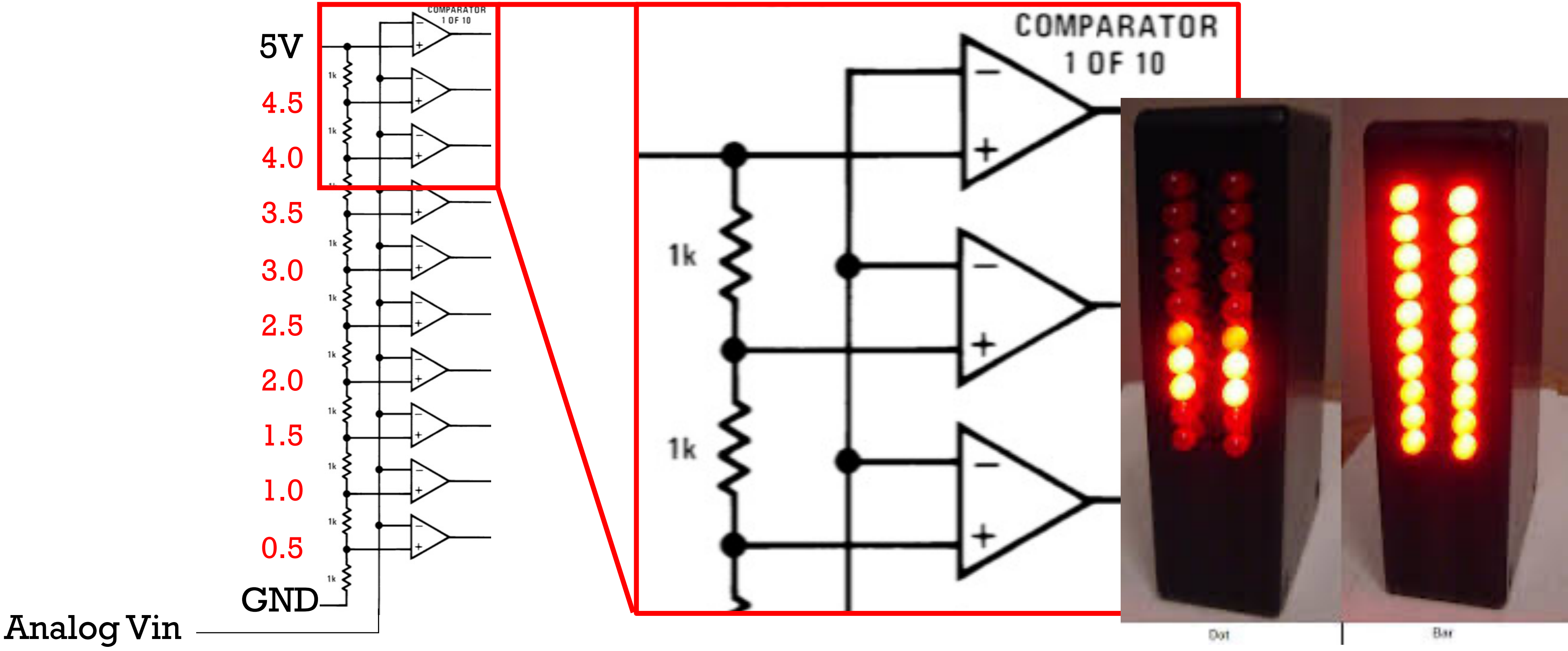


If Vin < 2.5V? LED on

If Vin > 2.5V? LED off

Inverting configuration

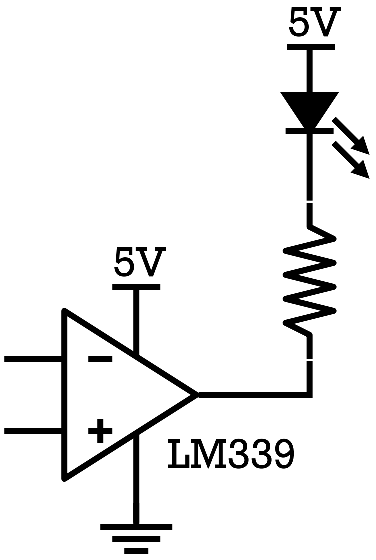
How does this circuit behave?



LM339

- Driving LED's with LM339A? What do we need to know?

Q2: Draw and hold: Circle the important value on this spec sheet.



Electrical Characteristics for LMx39 and LMx39A (continued)

at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

	PARAMETER	TEST CONDITIONS[1]		T_A[2]	LM239 LM339			LM239A LM339A			UNIT
					MIN	TYP	MAX	MIN	TYP	MAX	
I_{OH}	High-level output current	V_{ID} = 1 V	V_{OH} = 5 V	25°C		0.1	50		0.1	50	nA
			V_{OH} = 30 V	Full range			1			1	μA
V_{OL}	Low-level output voltage	V_{ID} = –1 V,	I_{OL} = 4 mA	25°C		150	400		150	400	mV
				Full range			700			700	
I_{OL}	Low-level output current	V_{ID} = –1 V,	V_{OL} = 1.5 V	25°C	6	16		6	16		mA
I_{CC}	Supply current (four comparators)	V_O = 2.5 V,	No load	25°C		0.8	2		0.8	2	mA

When would you use a comparator?

- Converting analog to digital. Most digital input are high impedance (e.g. draw much less than LED <<1mA)
- You need to set an input analog threshold for a digital signal.

Q3: in chat: Can you use this in Lab 2 ? Which part?

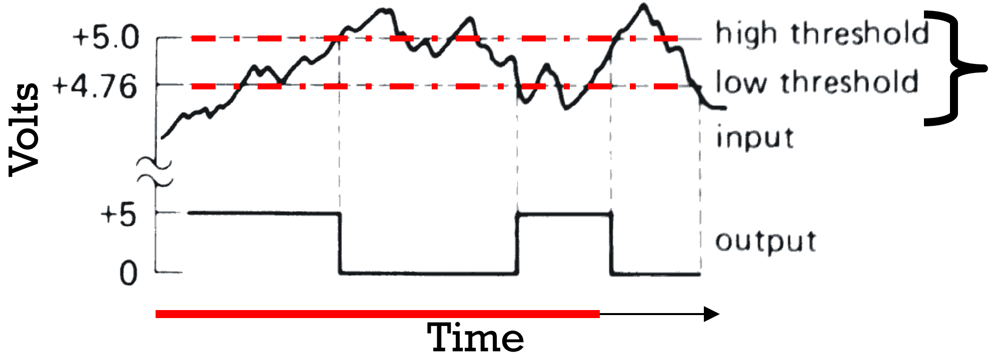
Versus Op amp with very high gain?

- When you need fast signals (input or output in uS)
- When you want to tie many outputs together (wired OR)
- When you have large voltage swing output requirements.
- Op amps designed for negative feedback, not railed output, may have stability issues (e.g., MCP6044)

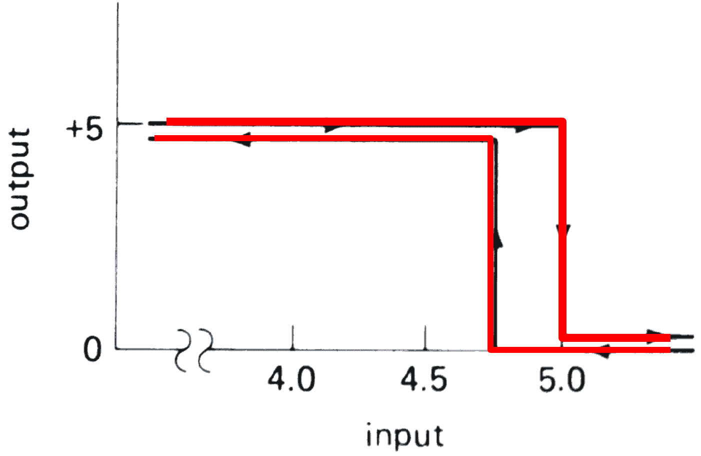
01a

Comparators Hysteresis

Hysteresis like Schmidt trigger

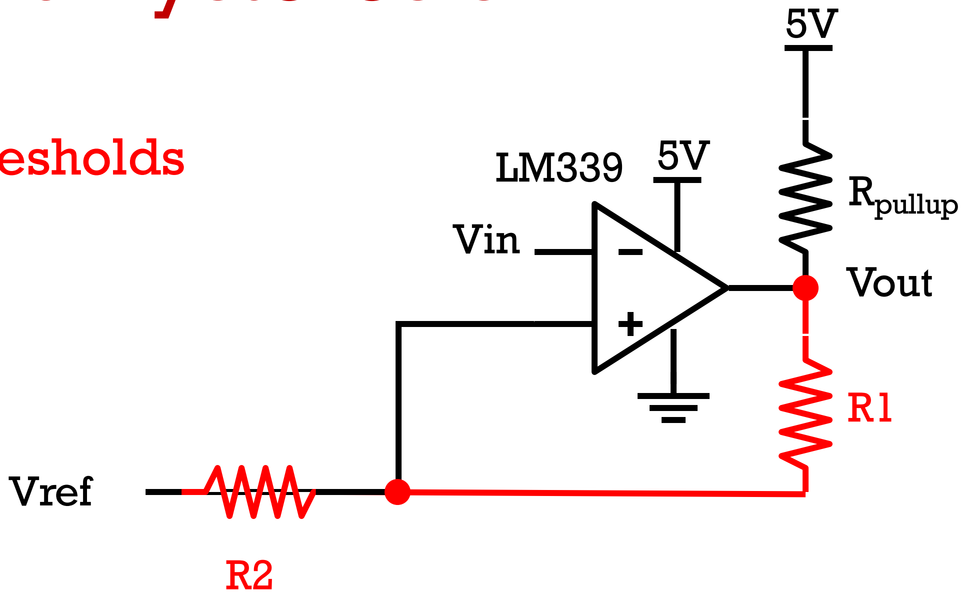


Two Thresholds, Which one applies depends on past history



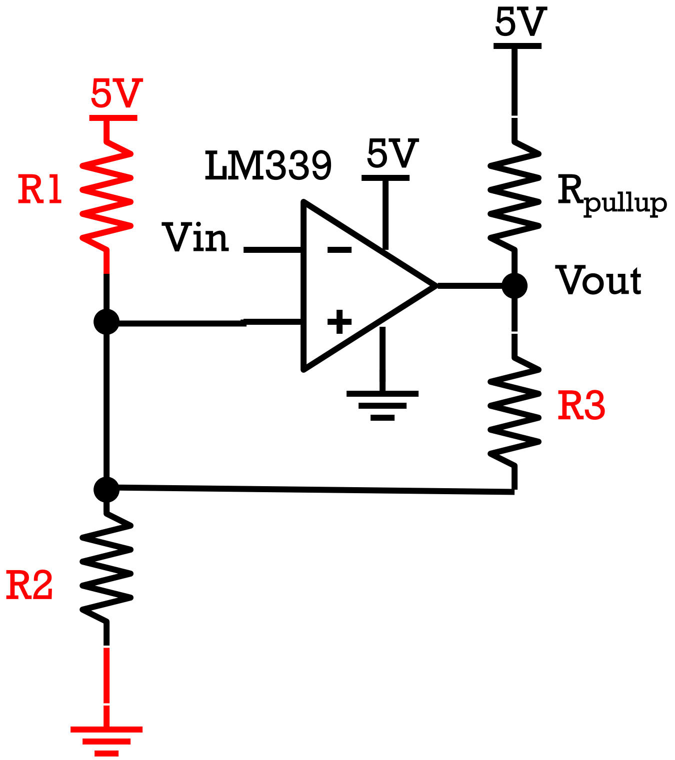
How do you add hysteresis?

Two states of Vout gives mechanism to have 2 thresholds



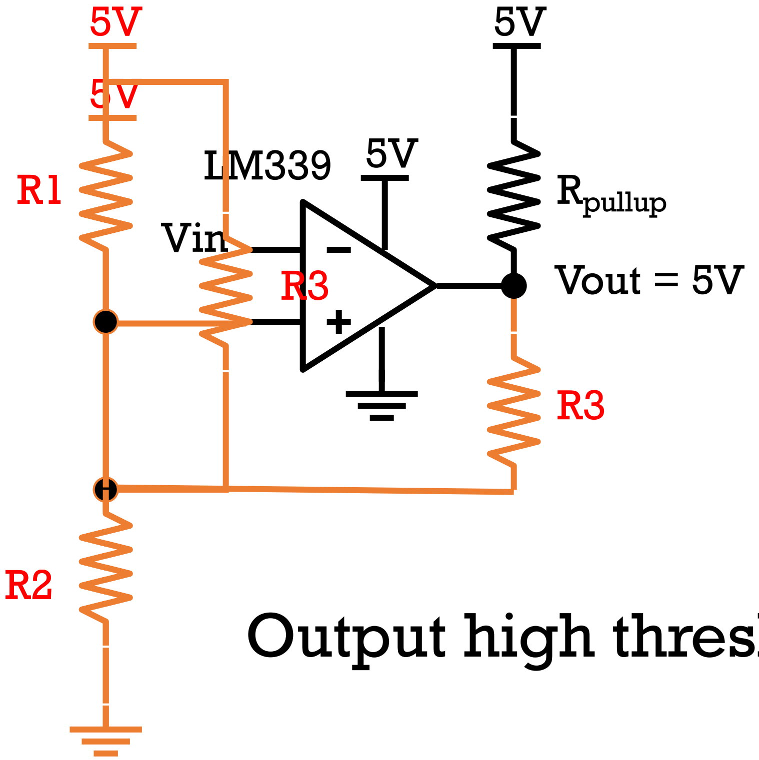
Hysterisis is about Vout R2/R1

V_{REF} with voltage dividers



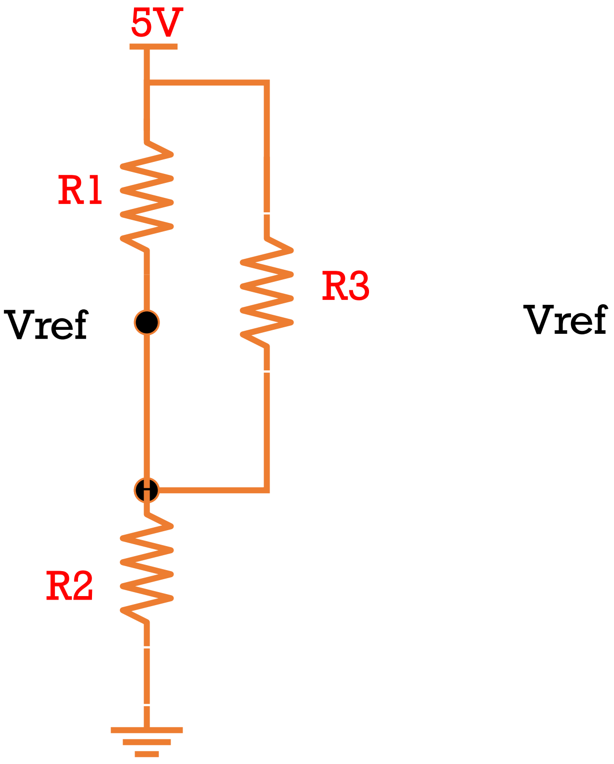
V_{REF} with voltage dividers

Vref

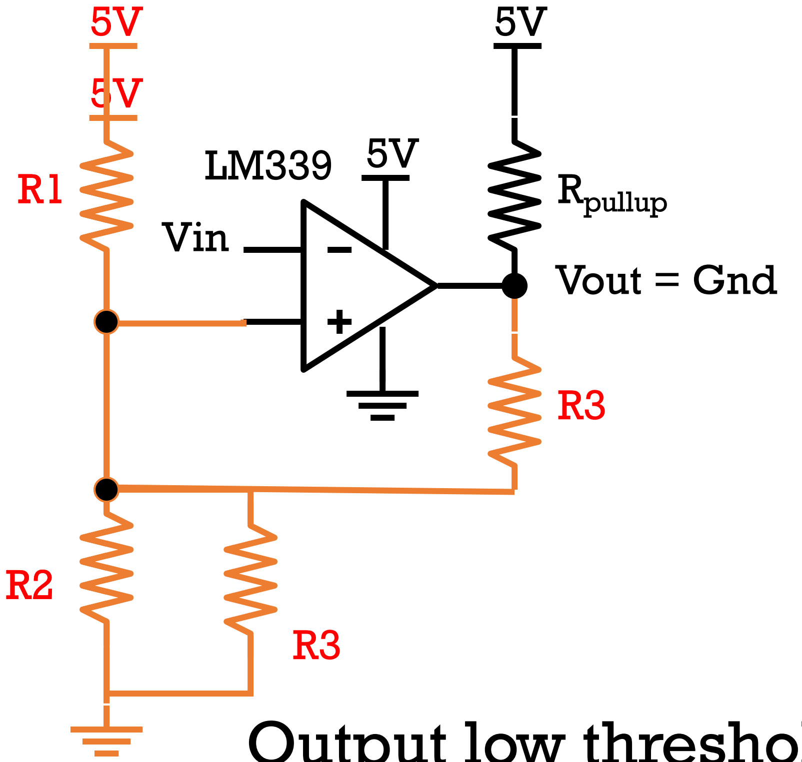


Output high threshold

V_{REF} with voltage dividers

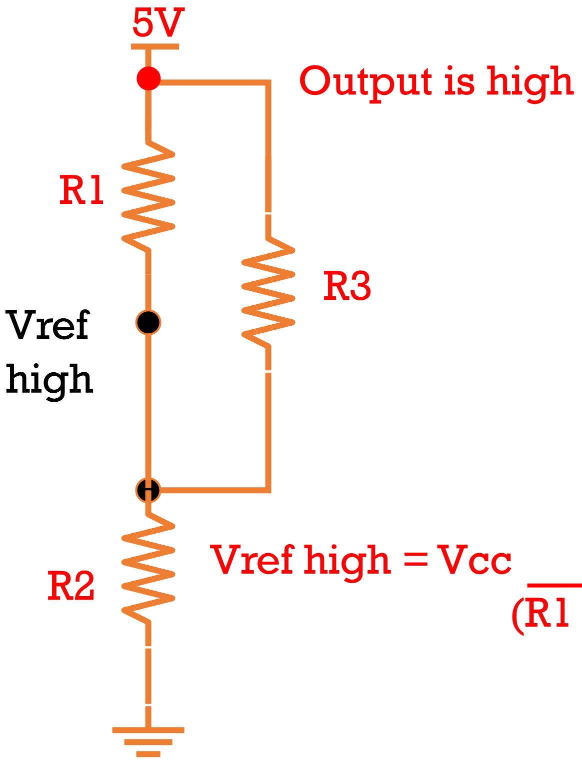


Output high



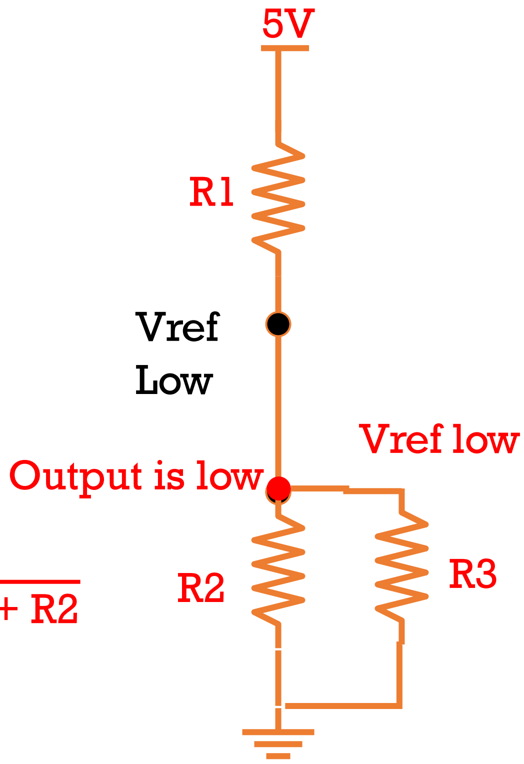
Output low threshold

What are the two thresholds?



$$\text{Vref high} = \text{Vcc}\,\frac{R2}{(R1\ ||\ R3) + R2}$$

Output high



$$\text{Vref low} = \text{Vcc}\,\frac{R2\ ||\ R3}{(R2\ ||\ R3) + R1}$$

Output low threashold

Inverting Comparator Design Procedure

1) $R_{pullup} << R_{load}$

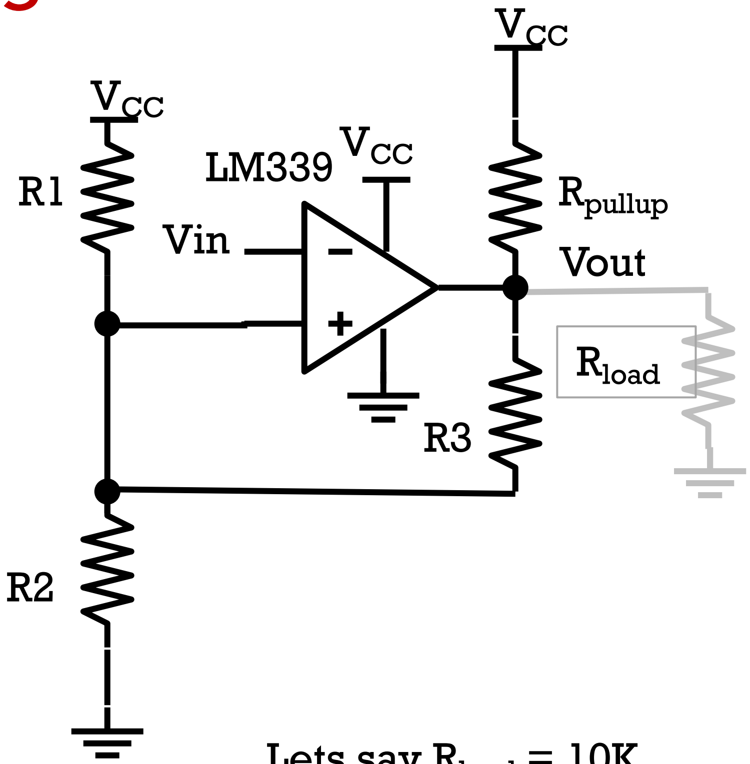
2) $R3 >> R_{pullup}$

3) Choose thresholds

   $\Delta V = \text{Vref high} - \text{Vref low}$

4) $$R1 = \frac{R3\ (\Delta V)}{\text{Vref low}}$$

5) $$R2 = \frac{R1\ ||\ R3}{(Vcc/\text{Vref high}) - 1}$$



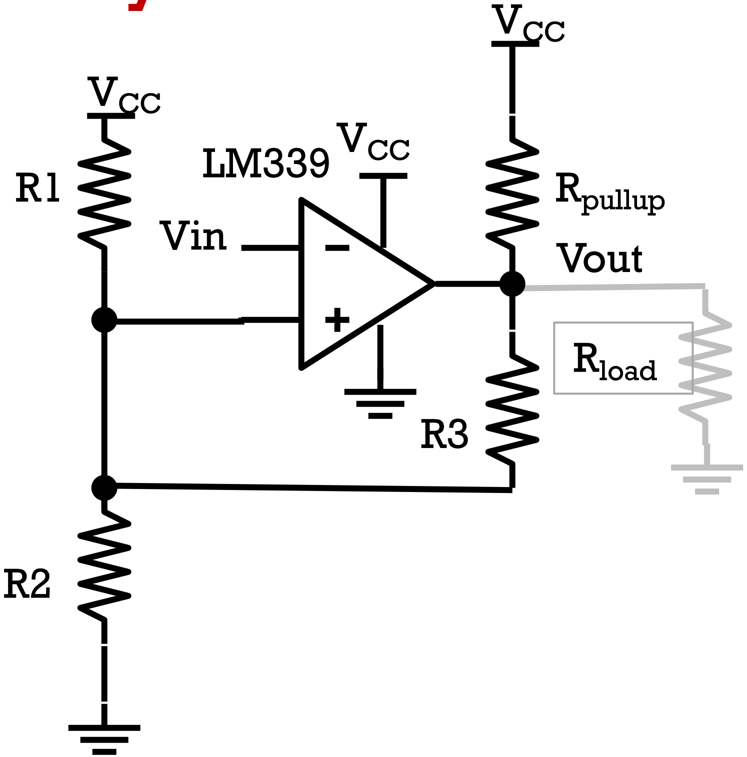
Lets say R_{load} = 10K

Start with R_{pullup} = 1K,

R3 = 1.0M

Example comparator with hysteresis

- Conditions: VCC = 5V; Impedance is for CMOS input (Rload ~= 10K)
- Choose Vref high = 2V, Vref low = 1V.
- Choose pullup of 1kΩ
- Choose R3 = 100KΩ



4) $R1 = 100K\Omega \, \Delta V / Vref\ low$

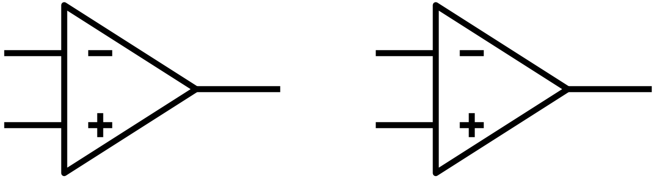
$R1 = 100K\Omega$

5) $R2 = \dfrac{100K\Omega \,||\, 100K\Omega}{(5V/2V) - 1} = \dfrac{50K\Omega}{1.5}$

$R2 = 33K\Omega$ Q4: What is R1 if we change Vref high = 1.1V;

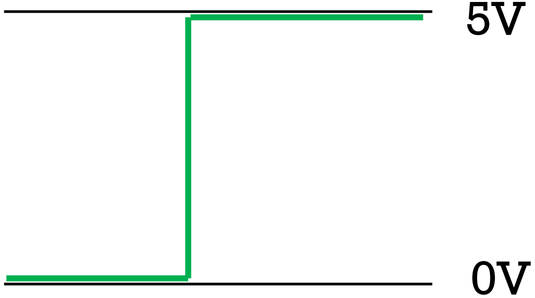
Comparators vs opamp summary

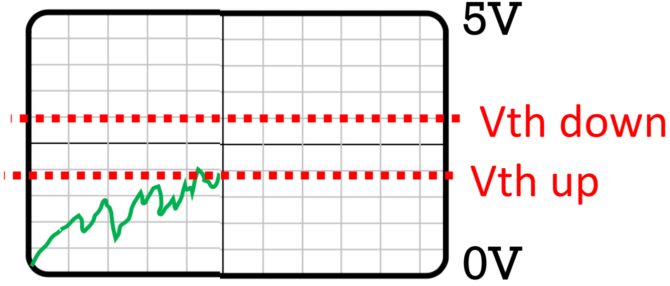
opamp symbol comparator symbol



- High gain difference amp - Like an opamp
- Comparators need pullup, opamps don't
- Op amps not designed to be at rails (only subset of opamps are rail-to-rail)
- The TLV272 is rail-to-rail and could theoretically be used as comparator even with hysteresis
- LM393 and LM339 available in GM lab

(LM393 is dual, LM339 is quad)

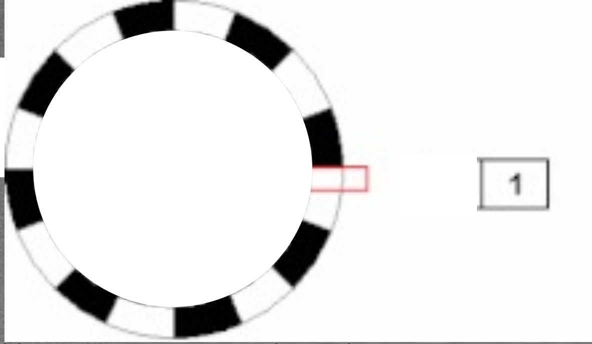




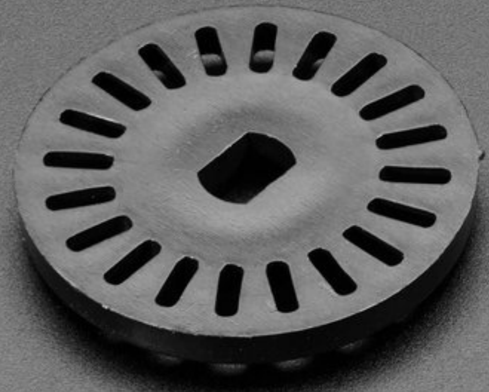
02

Rotary Position Encoders

Optical Shaft Encoders

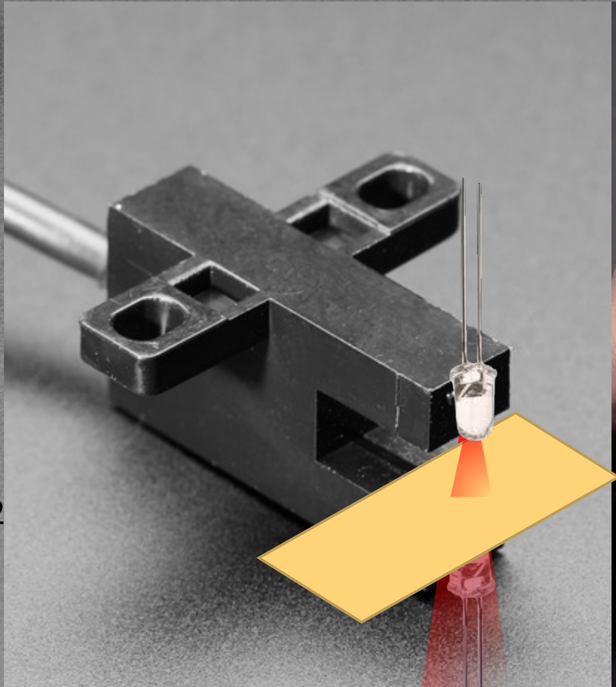


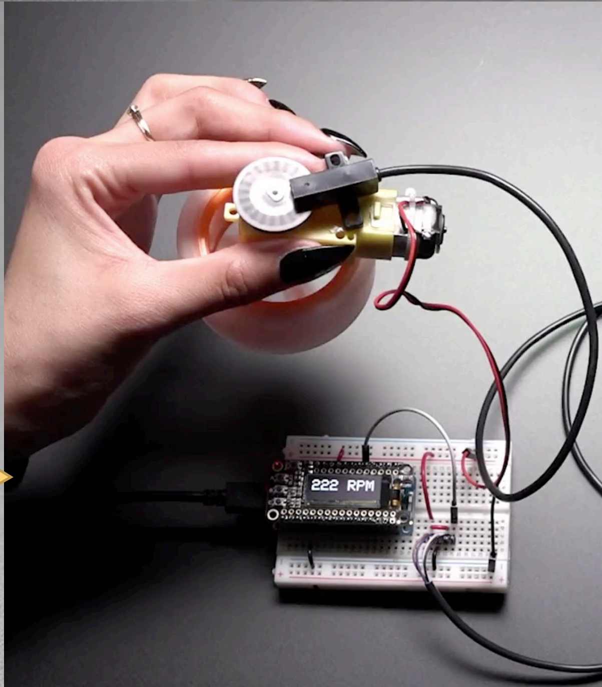
https://en.wikipedia.org/wiki/Rotary_encoder



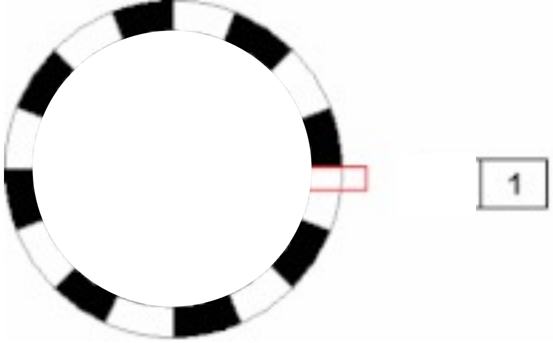
https://www.adafruit.com/product/3782

https://www.adafruit.com/product/3985



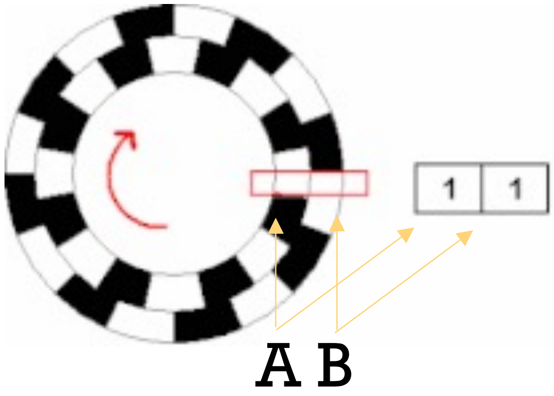


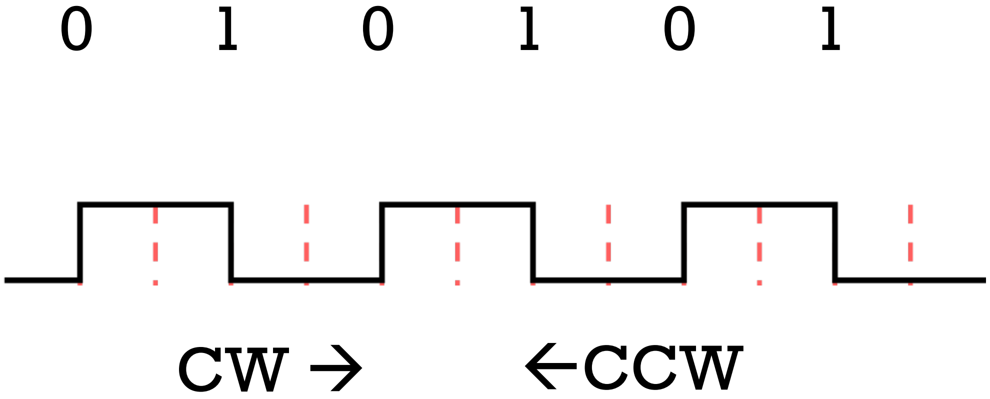
Quadrature



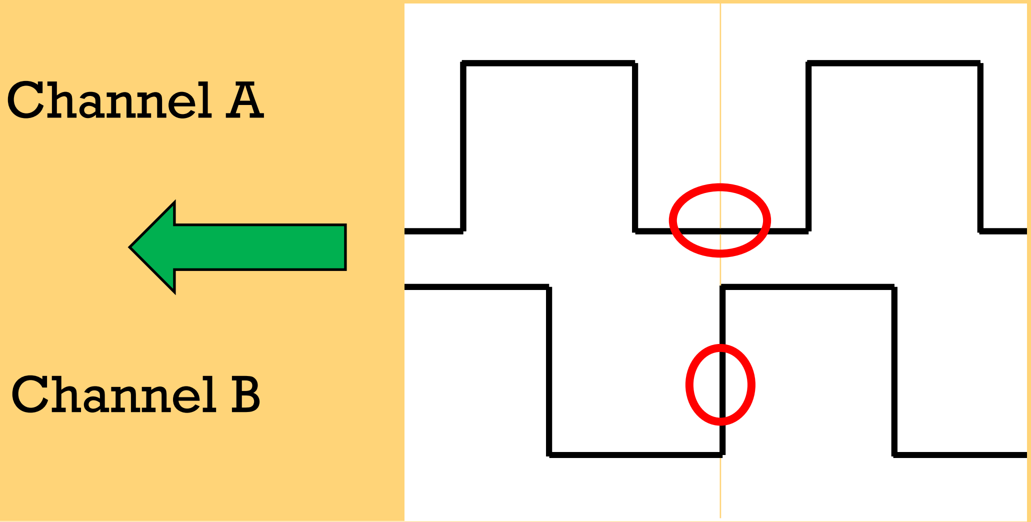
Q5: What is the sequence of logic level values for A for every rising edge of B as the time moves to the right CW?

- With one square wave, we cannot tell the direction the wheel spins
- With two square waves 90^{O} phase shifted, we can!





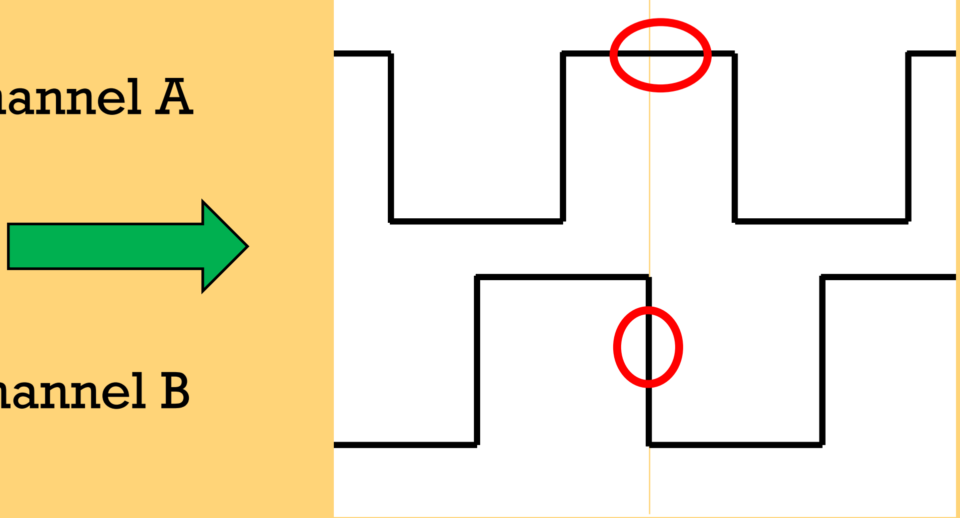
Quadrature intuition



Channel A is low on rising edge of B when moving left

Quadrature intuition

Channel A

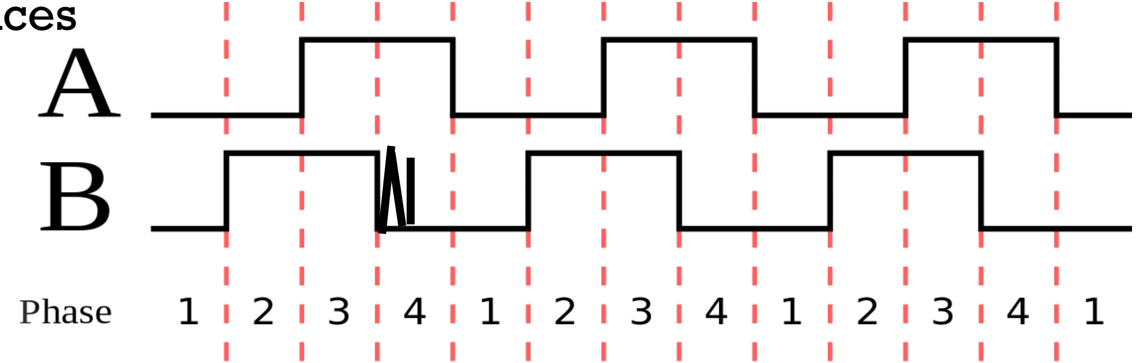


Channel B

Channel A is high on rising edge of B when moving right

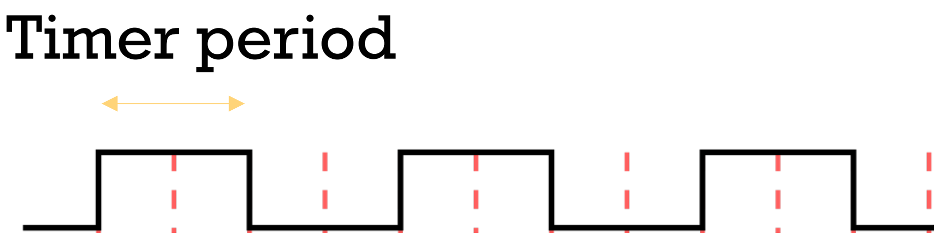
So what would code look like?

- Position Sensing – for incremental encoder
  - Periodically poll the state of A and B lines (need to do this faster than the highest expected frequency – e.g. 100RPM and resolution of 1024 = 102,400/60 = 1706 Hz). Polling digital lines can easily be done at >10kHz.
  - If there is a transition, then see which phase you are in. Can actually get 4x resolution by distinguishing between phases.
- Following phase transistions
  - More immune to bounces



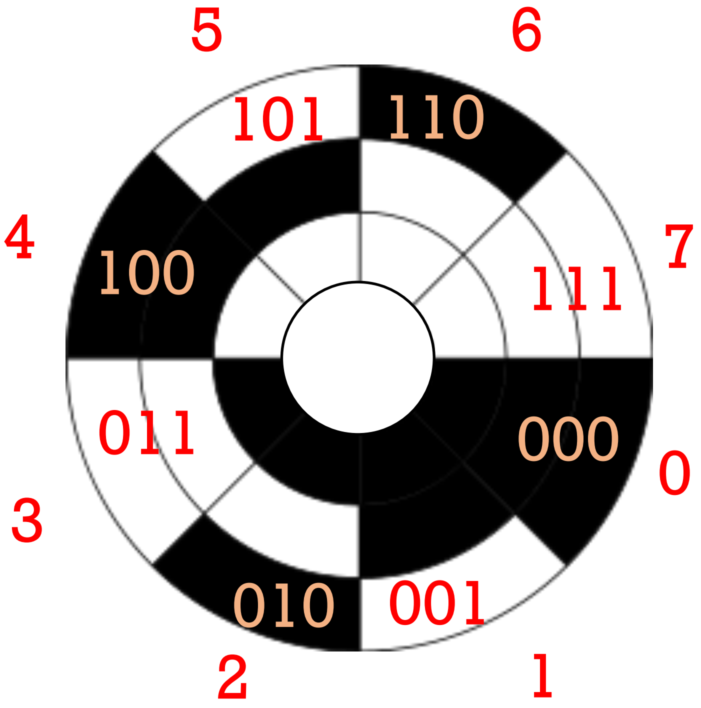
So what would code look like?

- Velocity Sensing – for incremental encoder
  - Can monitor position and difference based on timing.
  - Works well for fast velocities. Works poorly for slow velocities.
  - Instead use a timer to measure the pulse width. This can be done with interrupts to update a variable that stores the current velocity.
  - Need to handle the 0 velocity case as separate



Absolute Encoders

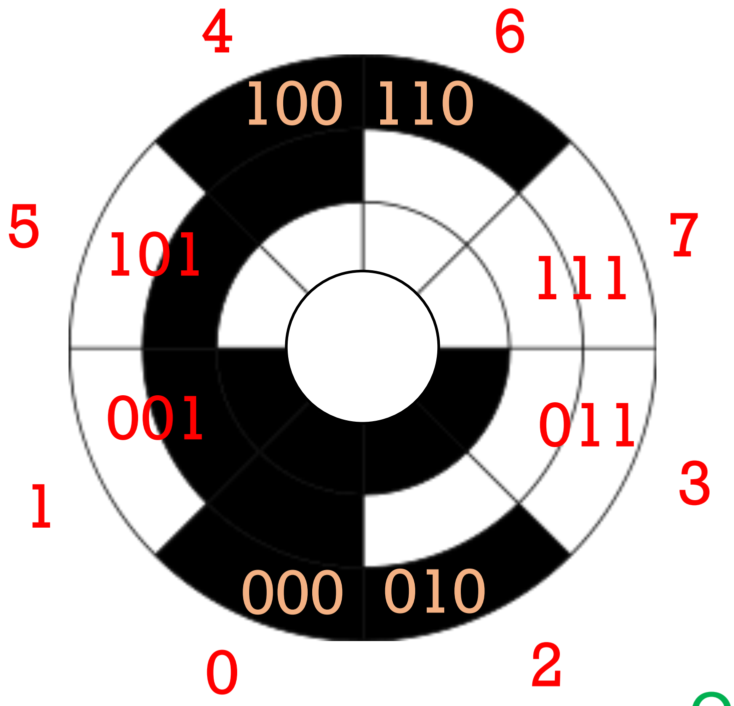
- Absolute encoders divide up the circle into unique codes for each sector.



Absolue Encoder
Binary encoding

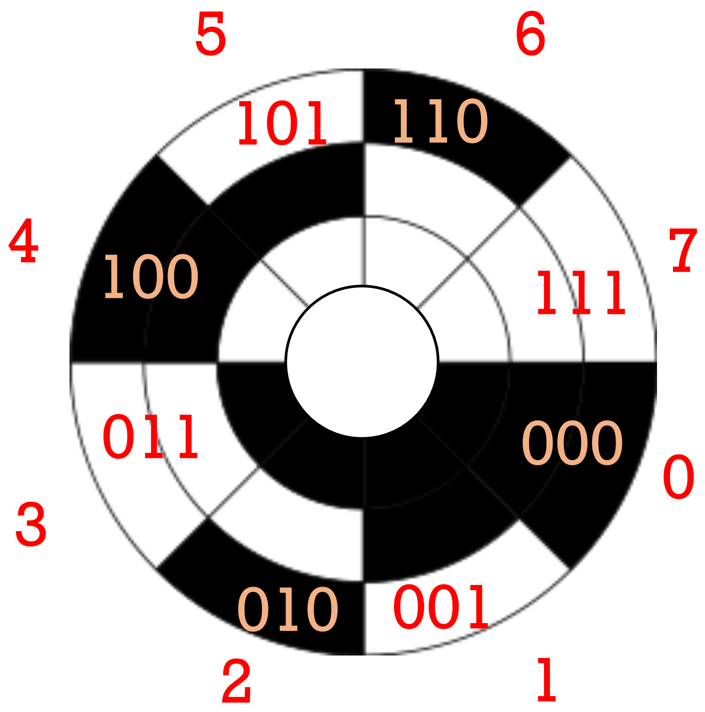
https://en.wikipedia.org/wiki/Rotary_encoder

Absolute Encoders



Absolue Encoder

Gray encoding



Q6: What is a feature of this new pattern that is different and why might it be useful?

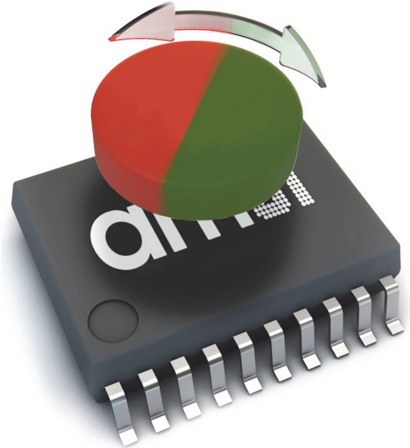
https://en.wikipedia.org/wiki/Rotary_encoder

https://en.wikipedia.org/wiki/Rotary_encoder

Other rotary sensors

- Encoders
  - Absolute
  - Incremental
- Analog
  - Potentiometer
  - Synchro
  - Resolver

Mount magnet on shaft

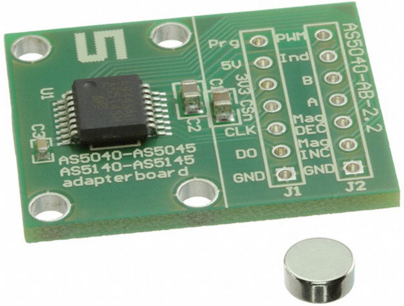


8.5 bit Magnetic encoders
[AS5030-ATST]() ~$6 on digikey

Absolue Encoder
Gray encoding

https://en.wikipedia.org/wiki/Rotary_encoder

Example encoders



Mechanical Encoder
CPR: ~ 5 to 20
Cost: ~$1
Vendor: Bournes

Optical Shaft Encoder
CPR: ~500 to 4000
Cost: ~$30-100
Vendor: Avago/Broadcom

Magnetic Encoder
CPR: ~300-2000
Cost: ~$8
Vendor: AMS

Rotary Shaft Encoders

Pros

- Robust to noise
- Quick to read
- Easy to make low res version
- Non contact (high life span)
- Very commonly used in industry

Cons

- Limited resolution
- Requires monitoring or losing position
- Expensive to make high res
- Sensitive to dust, impact.

Summary

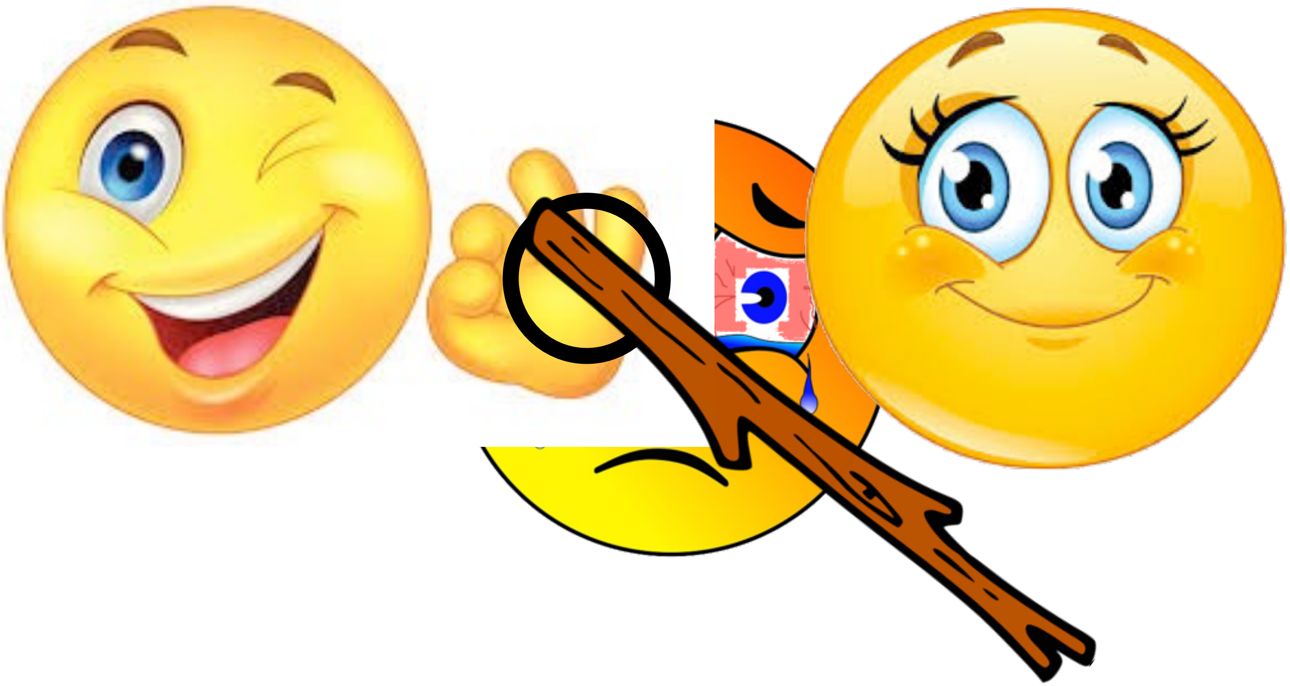
- Comparators can be used to output digital logic from analog thresholds to drive logic inputs.
- Positive feedback resistors can add hysteresis
- Rotary encoders can provide a robust digital signal for the angular position of a shaft.

03

Resistor Colors (a dumb story)

Sorting resistors

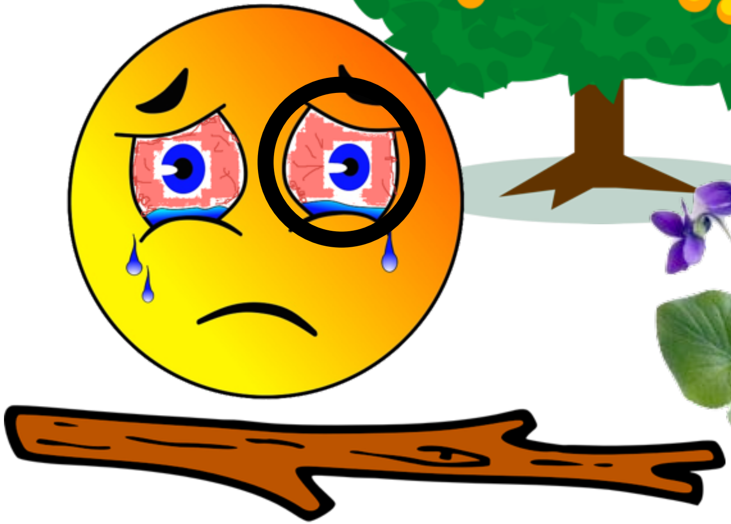
Resistor Colors



Resistor Colors

Resistor Colors

Resistor Colors



Resistor colors

- What number is?
  - grey
  - yellow
  - red
  - orange
  - green
- What color is
  - six
  - zero
  - nine
  - one
  - seven

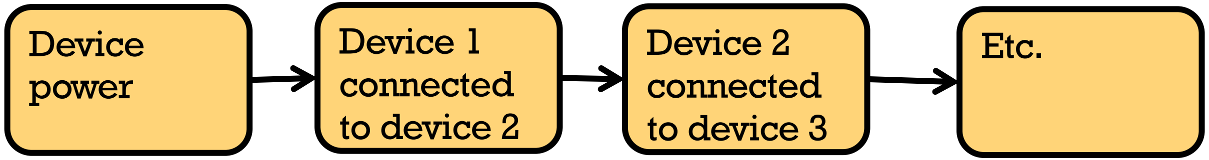
- What number is?
  - white
  - blue
  - brown
  - black
  - violet
- What color is
  - four
  - two
  - five
  - three
  - eight

Quiz Question

- Q8: What value is this resistor?

Debugging Electronics

- Hardware and Software piece - need to check both
- Break your system apart into pieces
    - viewed as linked via inputs and outputs
    - Ideally a chain of parts with 1 output from one part going to 1 input in the next part.



- Check known voltage at each part starting with power and ground.

Debugging Code

- If you feel you need help with C or programming in general.

  `https://www.onlinegdb.com/`

- Has an online debugger that lets you track the flow of code.
- Note: ATmega specific things won't work (PORTD, Timers etc.)
- Looking into setting it up so we can actually debug ATmega code (e.g. put includes and fake stubs so things can compile).

Answer in CHAT

Answer how you feel about each topic below with:

1. I don't understand this topic at all
2. I don't know now, but know what to do to get by
3. I understand some, but expect to get the rest later
4. I understand completely already

A. OpAmps
B. Comparators
C. Rotary encoders