Feedback control II

Fast Robots, ECE4160/5160, MAE 4190/5190

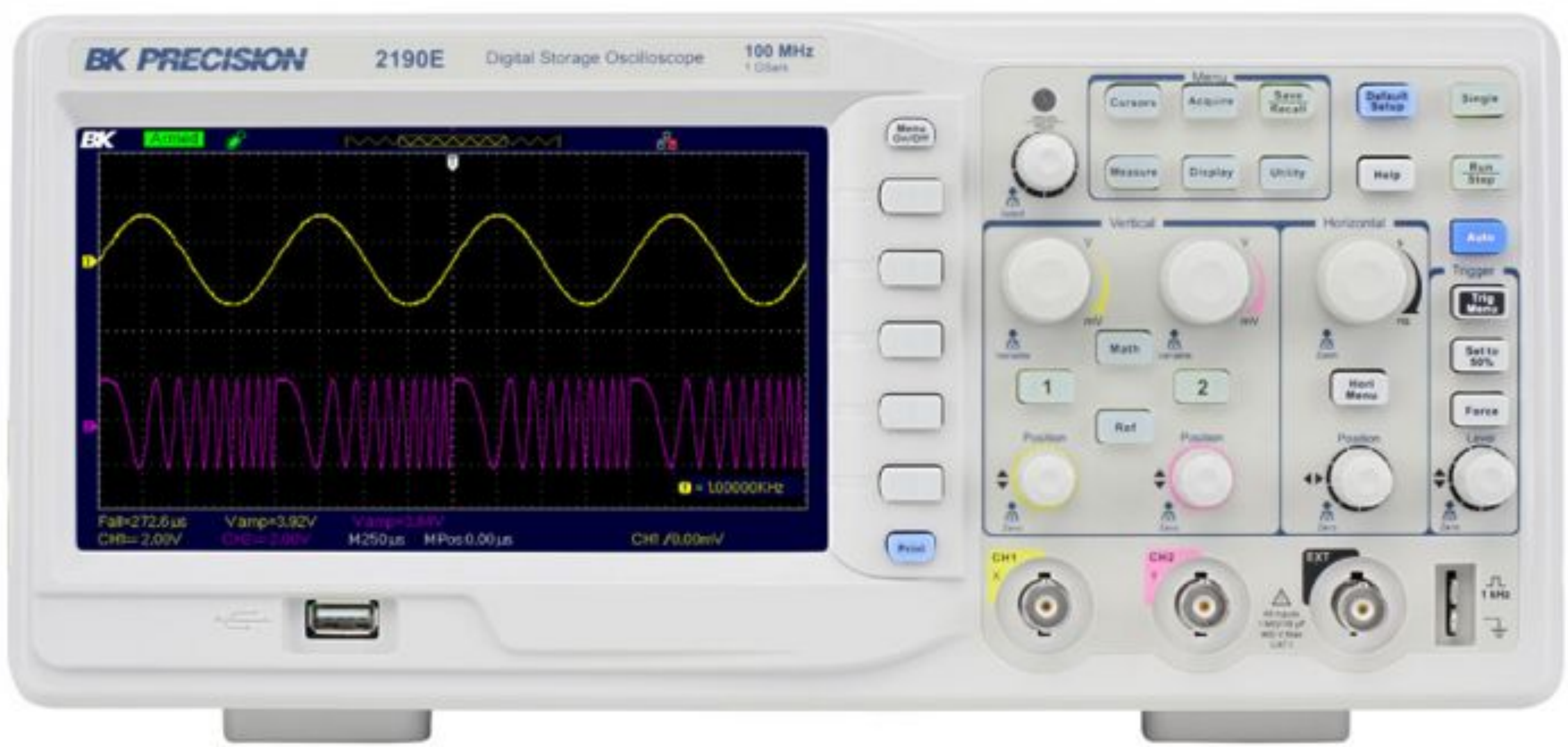
E. Farrell Helbling, 2/13/25

Class Action Items

- Please check our open hours if you need to go back to the lab to solder!
  - We will have some open hours over February break, check the google calendar for the most up-to-date lab times.
- Reminder: there is no lab next week and lab 3 is not due until Feb. 25-26. If you used a slip week for lab 2, this is still due next week!
- Lab 4 also has a significant soldering component. If you can, work on this early (i.e., next week after February break).
- Find a method for debugging code that works for you!

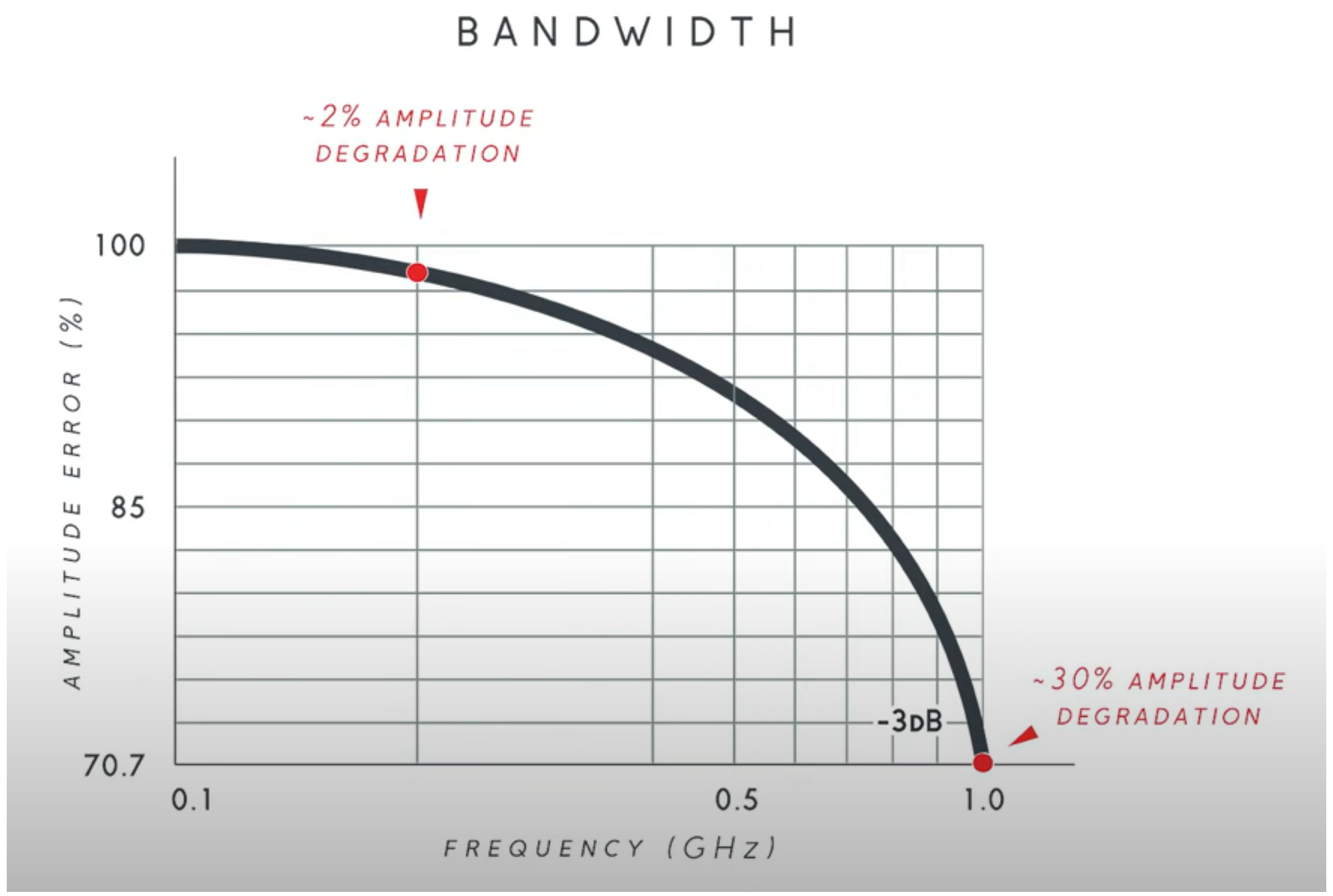
Oscilloscopes

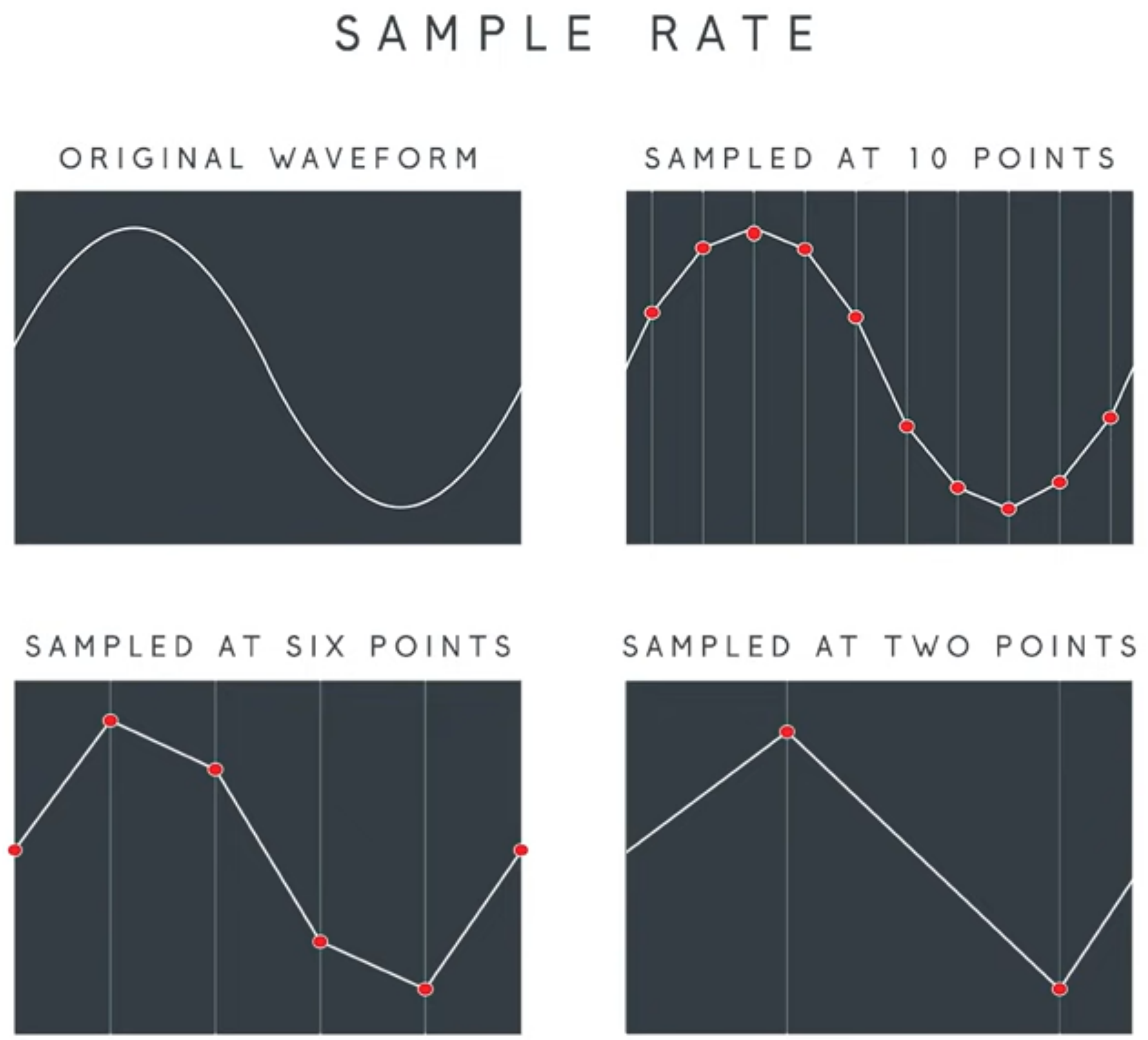
Oscilloscope setup



Oscilloscope setup

- Bandwidth
- Sample rate
- Resolution

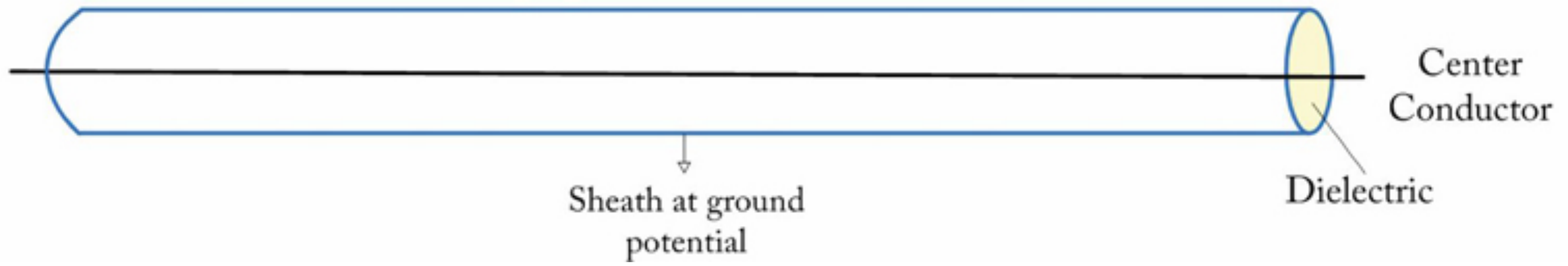




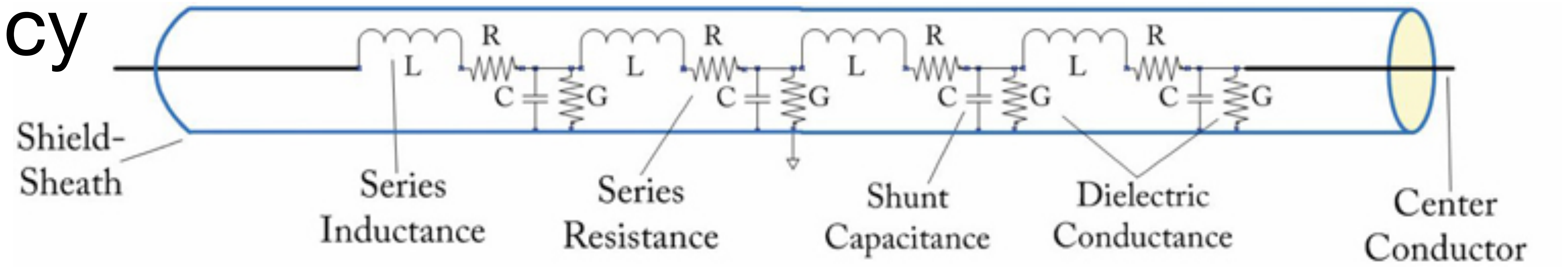
Oscilloscope Probes

- Scope inputs resemble a 16pF capacitor in parallel with a 1MOhm resistor
- At high frequencies the coax cable acts as a low pass filter
- 1x attenuation for low amplitude, low frequency signals
- 10x attenuation for load-sensitive circuits, high-frequency or high-amplitude signals

Low frequency coax cable



High frequency circuit



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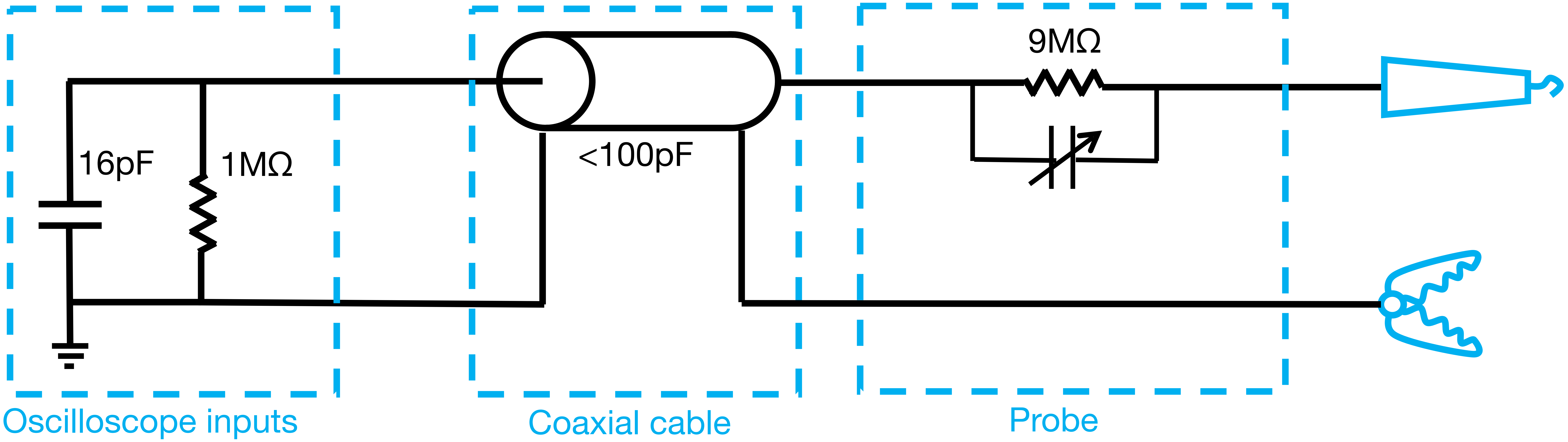
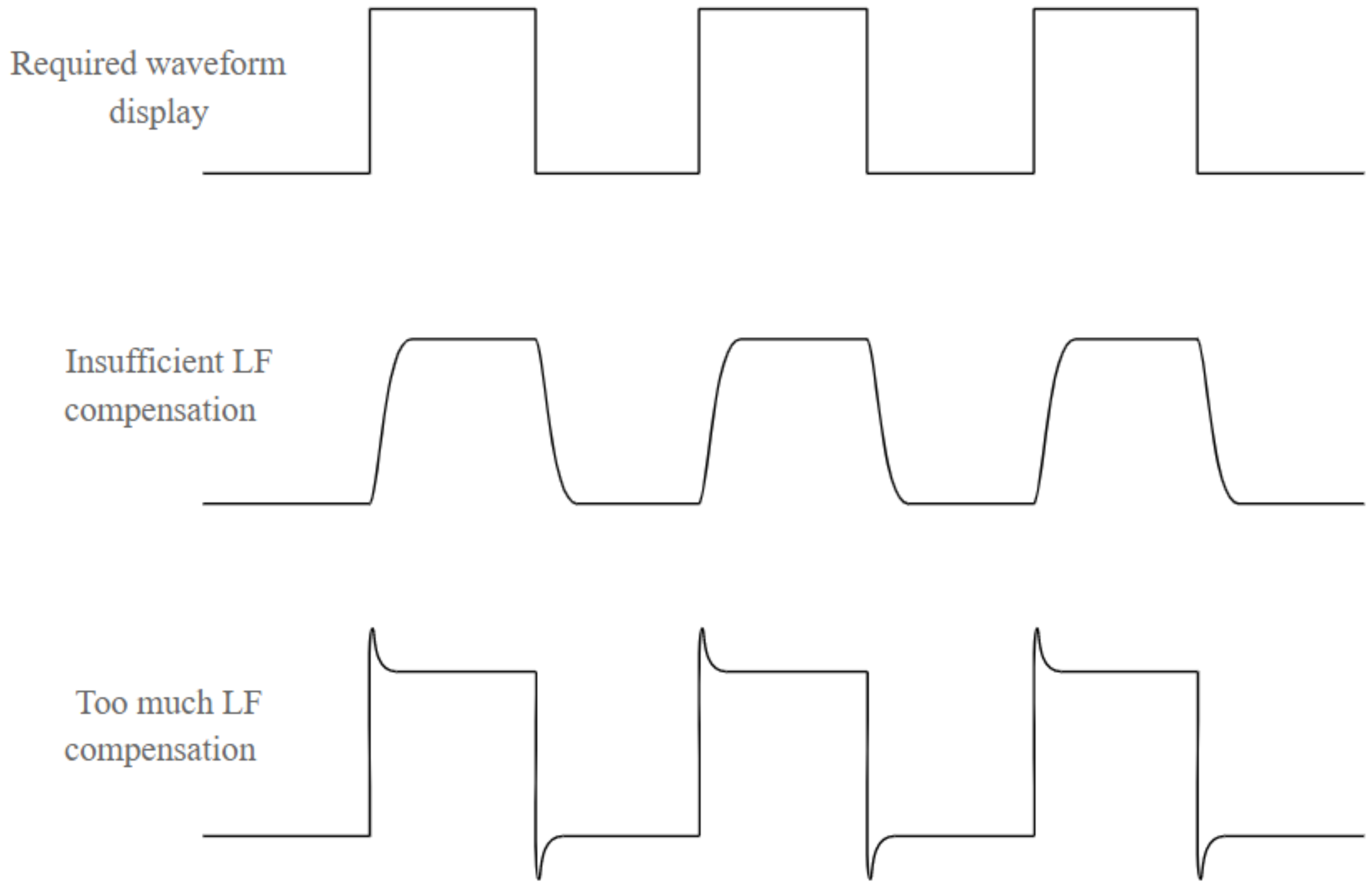
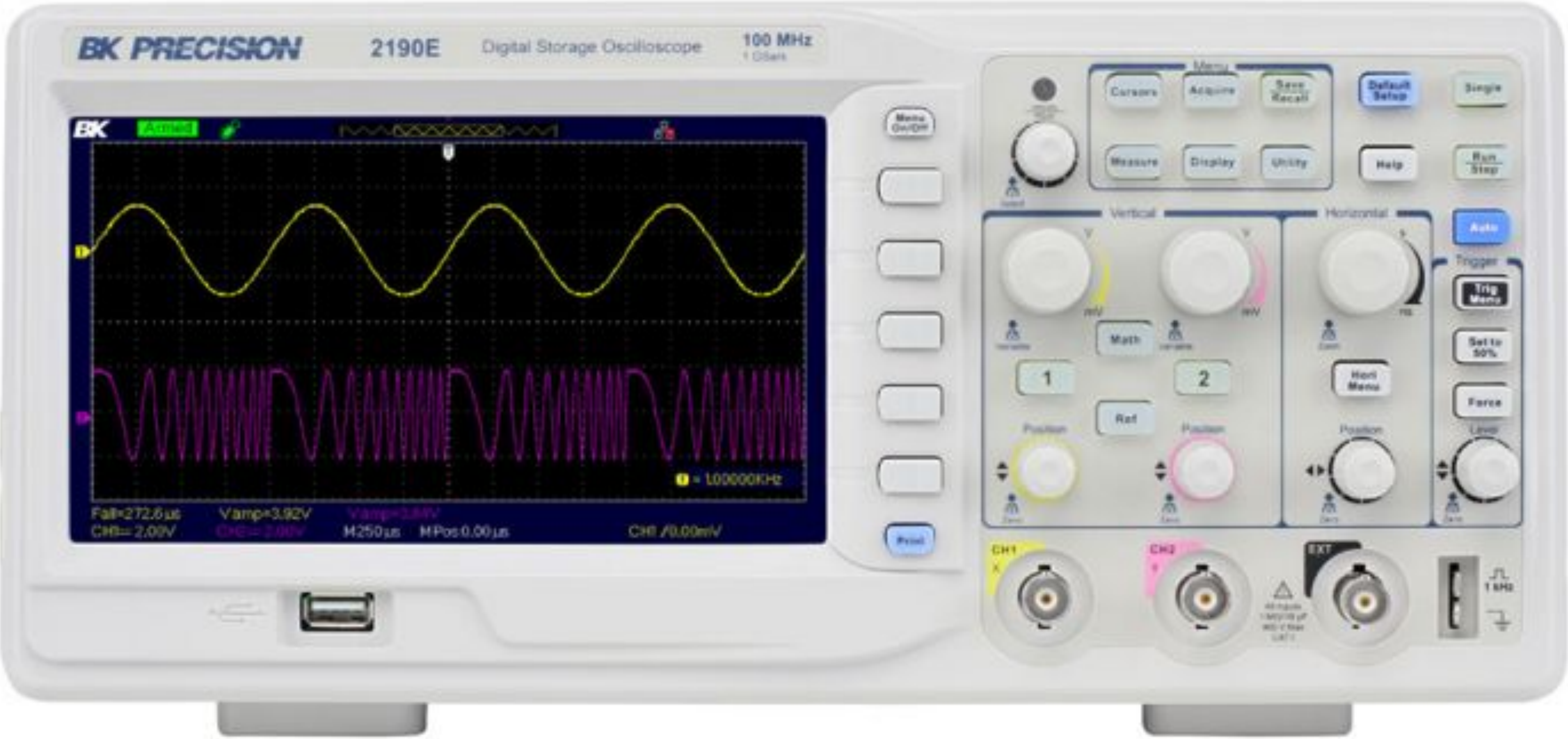


Oscilloscope Probes

- 10x probe calibration
  - Use the built-in square wave generator
  - Adjust capacitor until the square wave looks square!



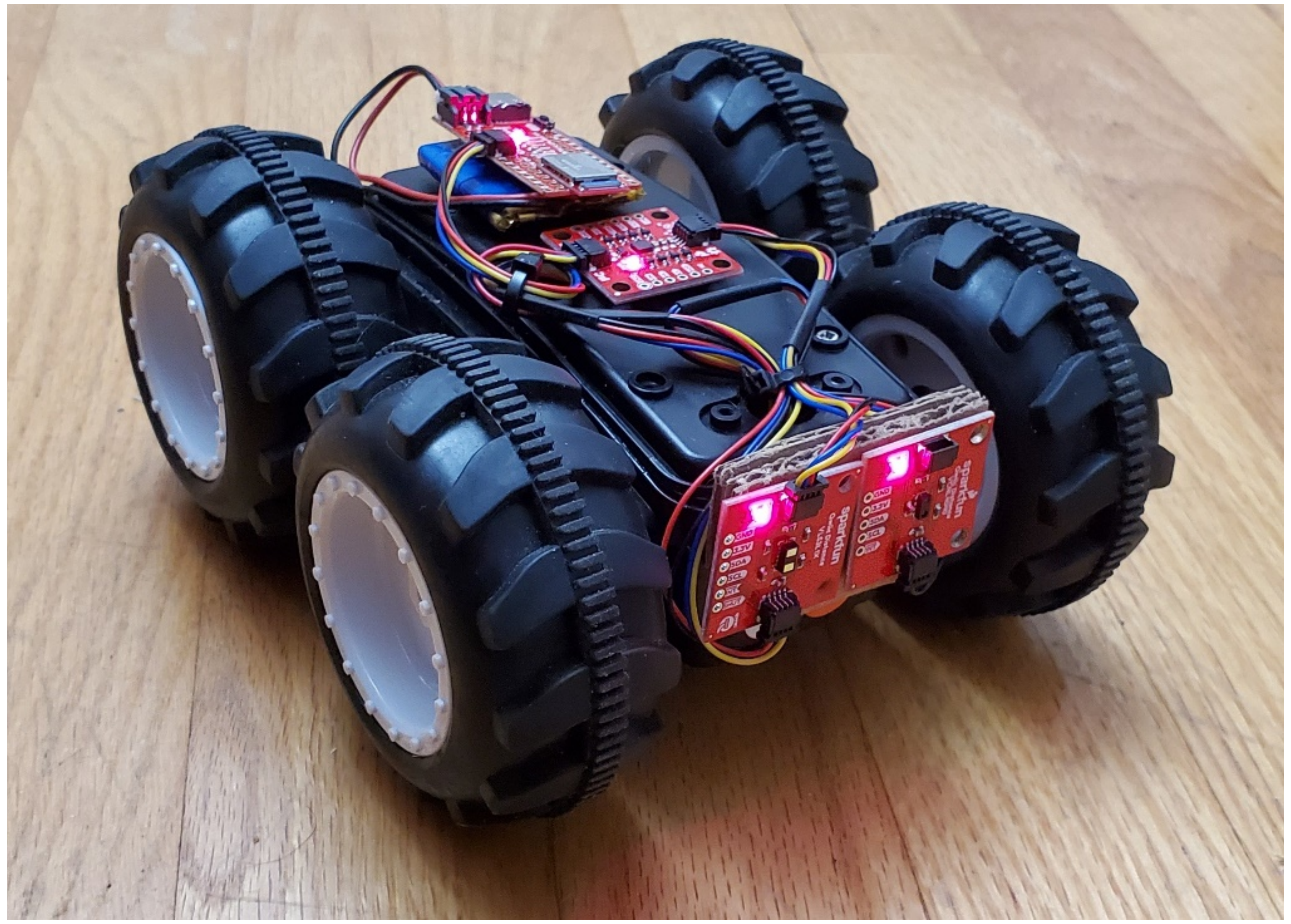
Oscilloscope setup

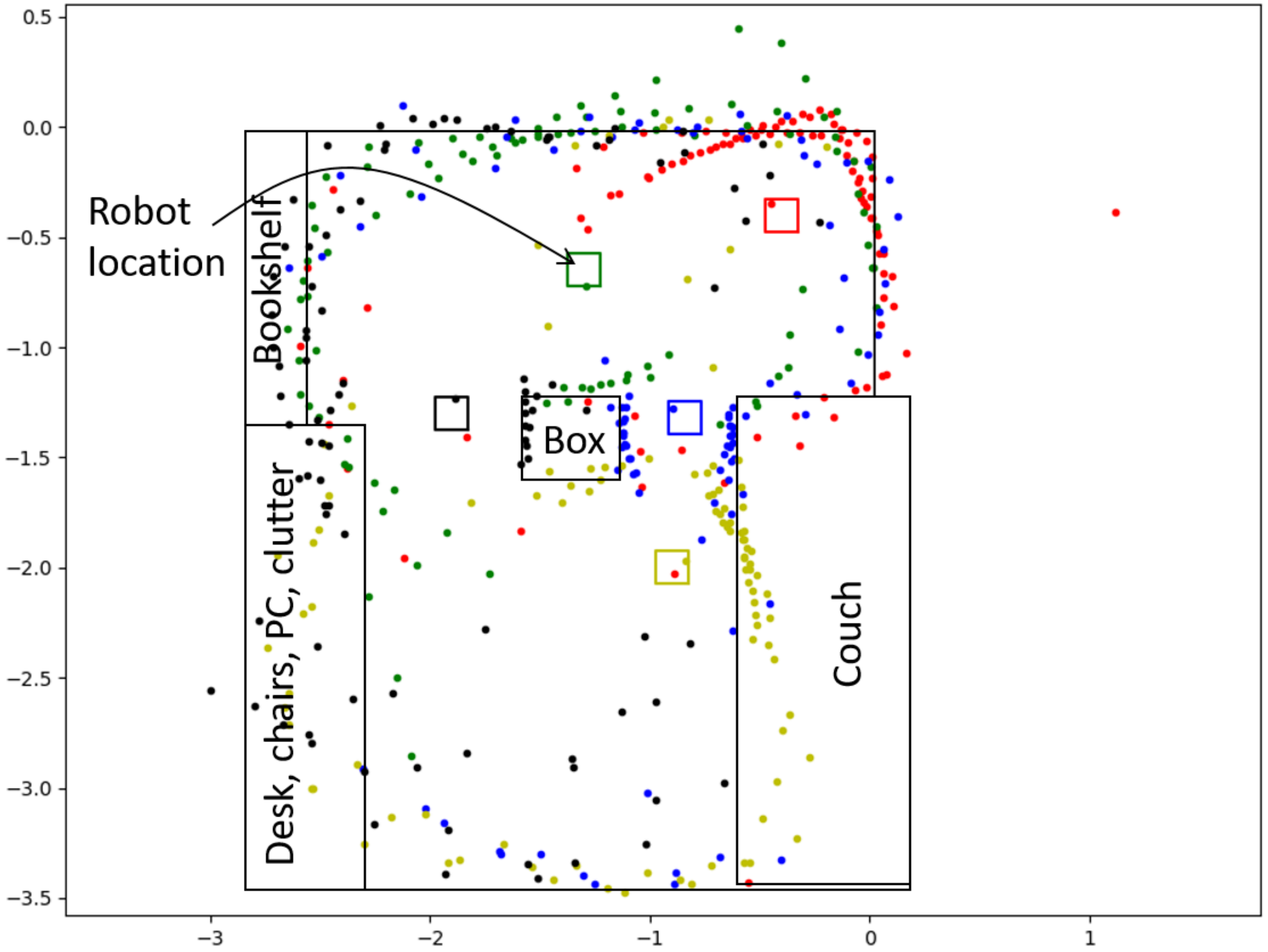


PID continued

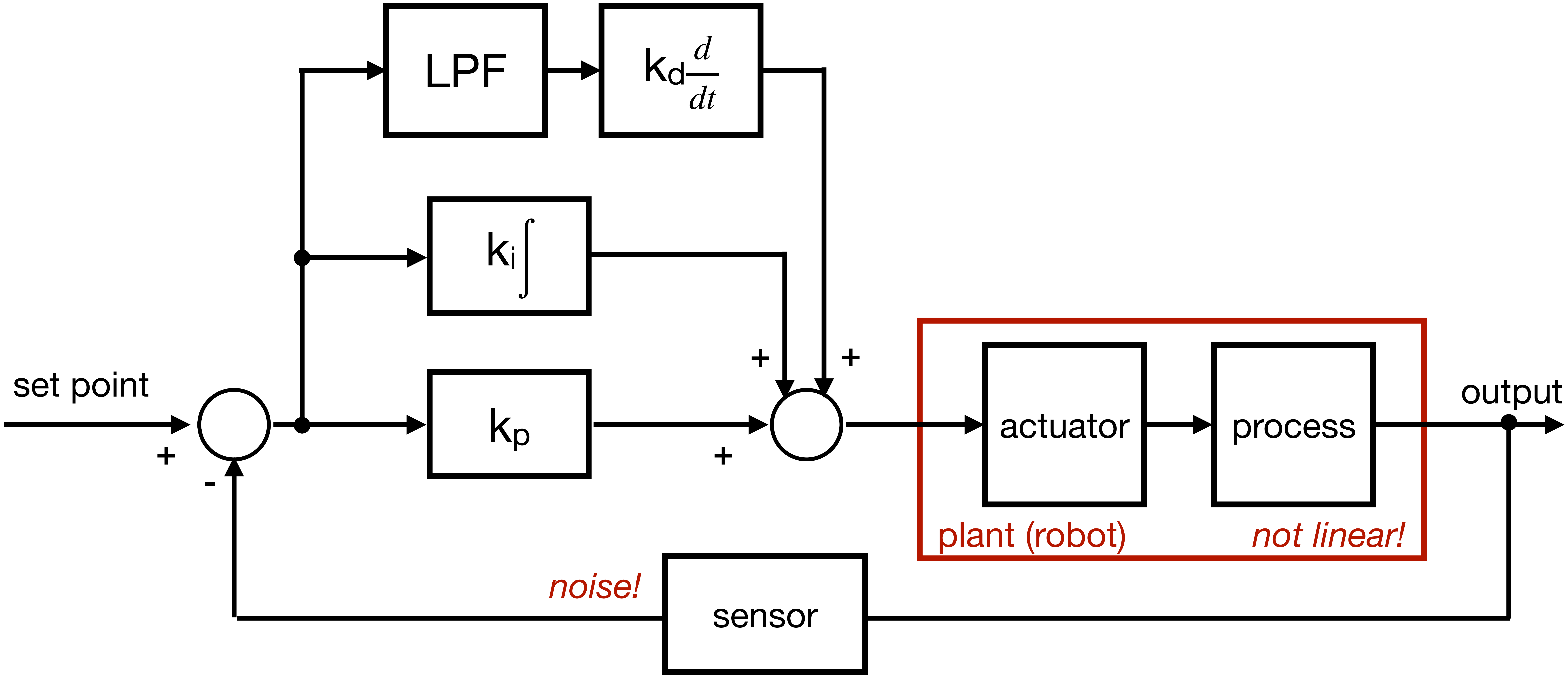
Feedback Control

- Stunts: maintain speed prediction at different battery levels, over different surfaces
- Mapping: evenly spaced out sensor readings
- Path execution: adhere to generated path plans

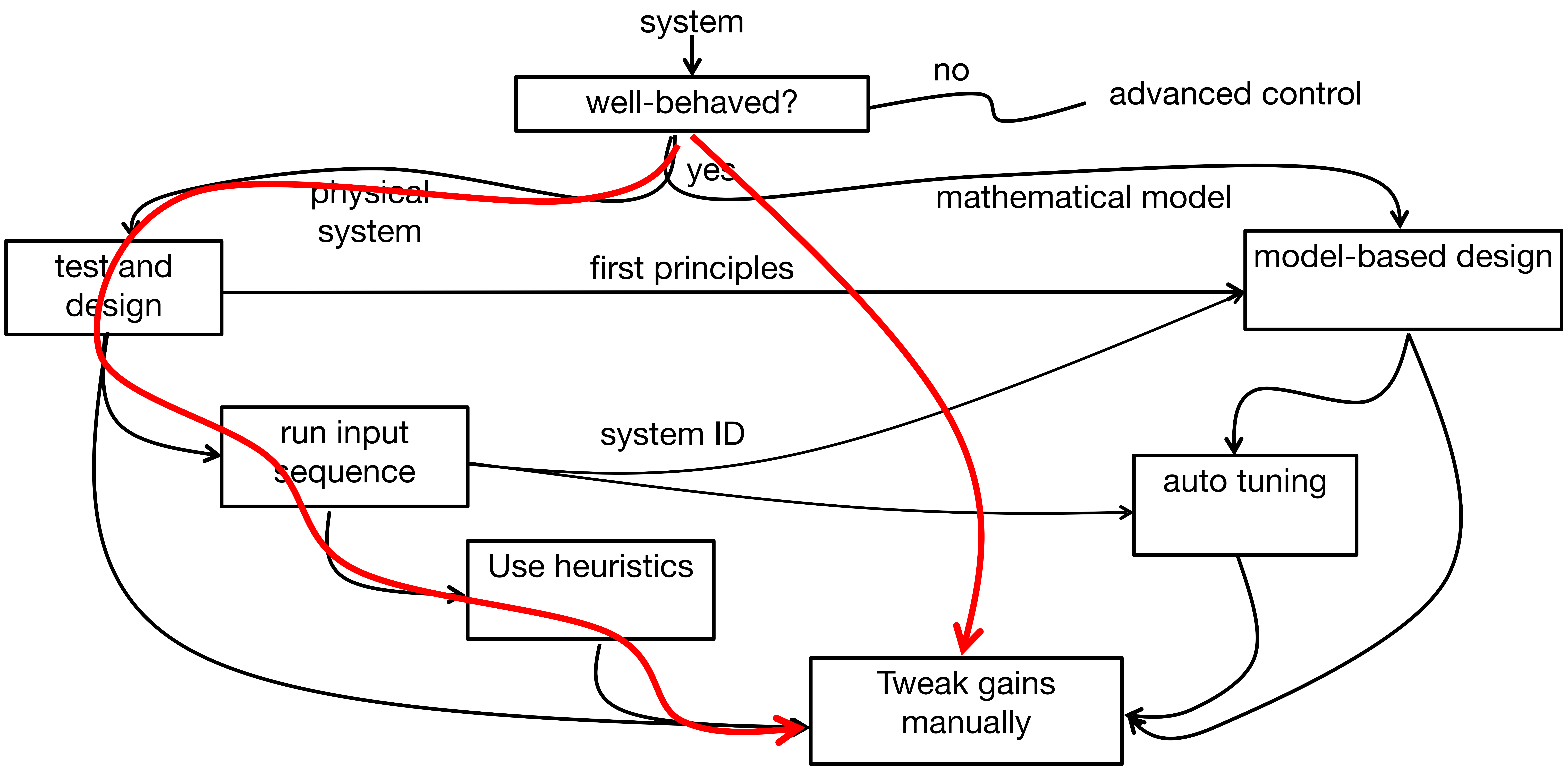




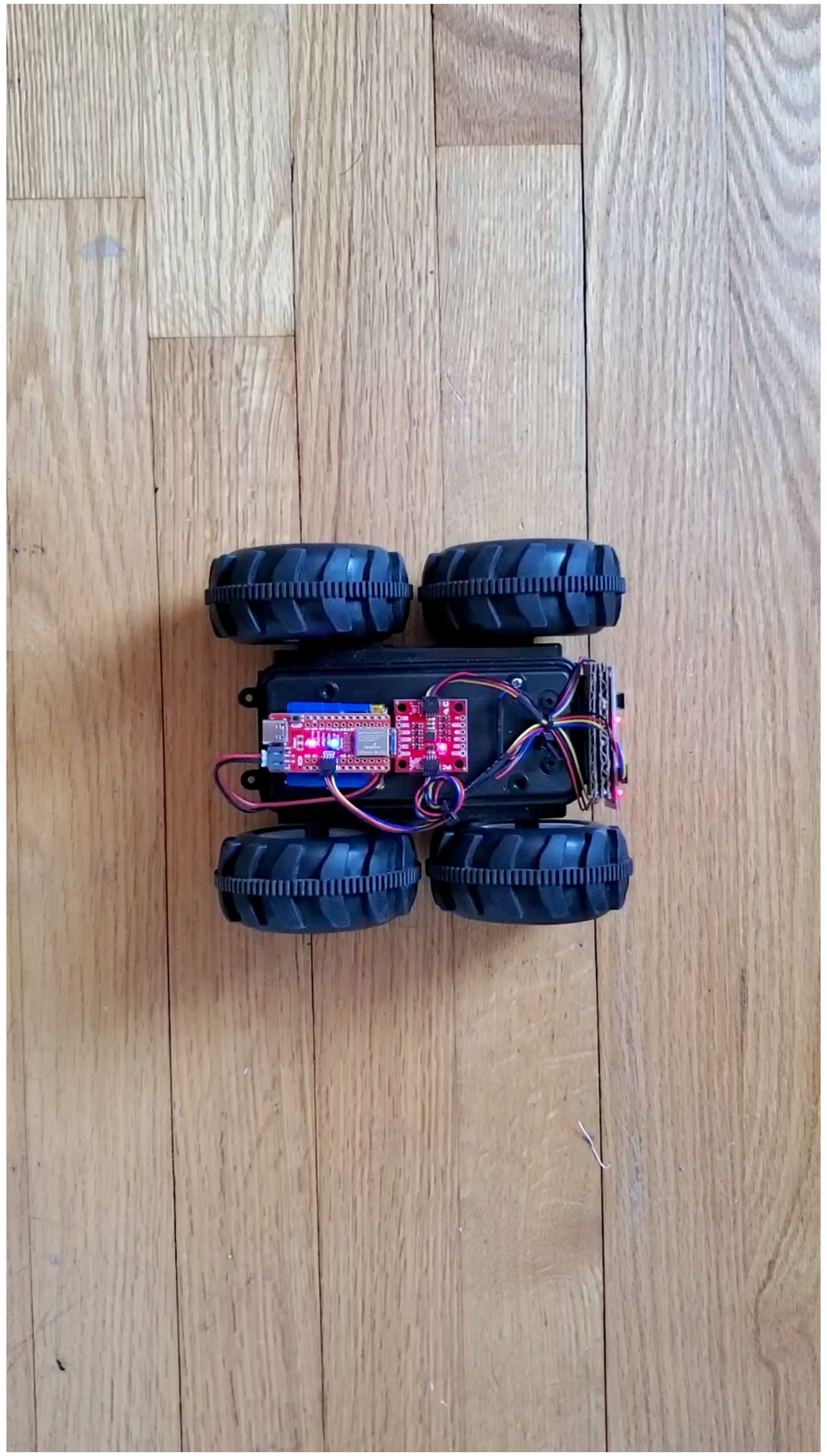
PID

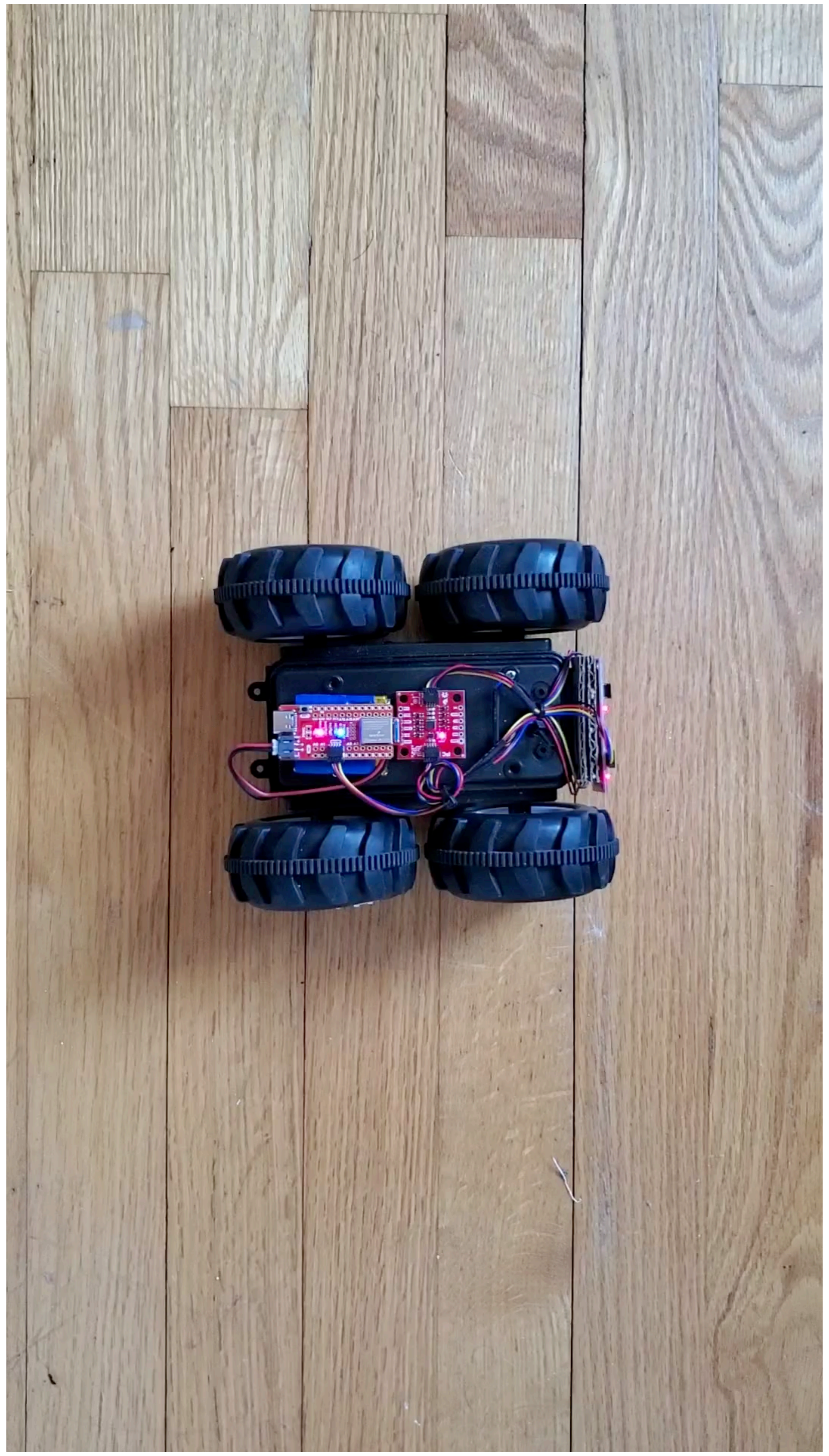

LPF
$k_d \frac{d}{dt}$
$k_i \int$
k_p
set point
+
-
+
+
+
actuator
process
output
plant (robot)
not linear!
noise!
sensor

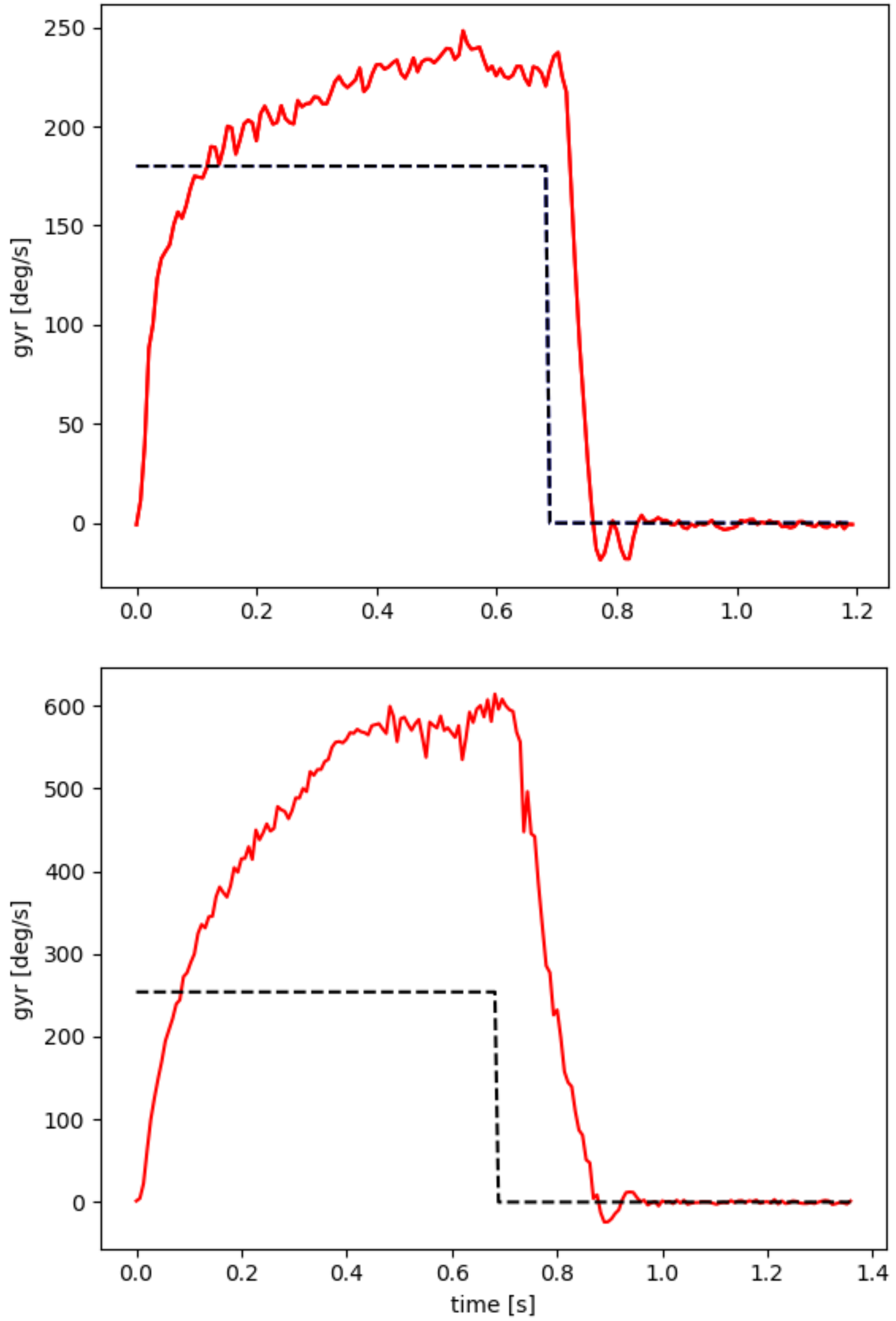
Tuning PID control



Tuning PID control







Tuning PID control

Chien, Hrones, and Reswick method

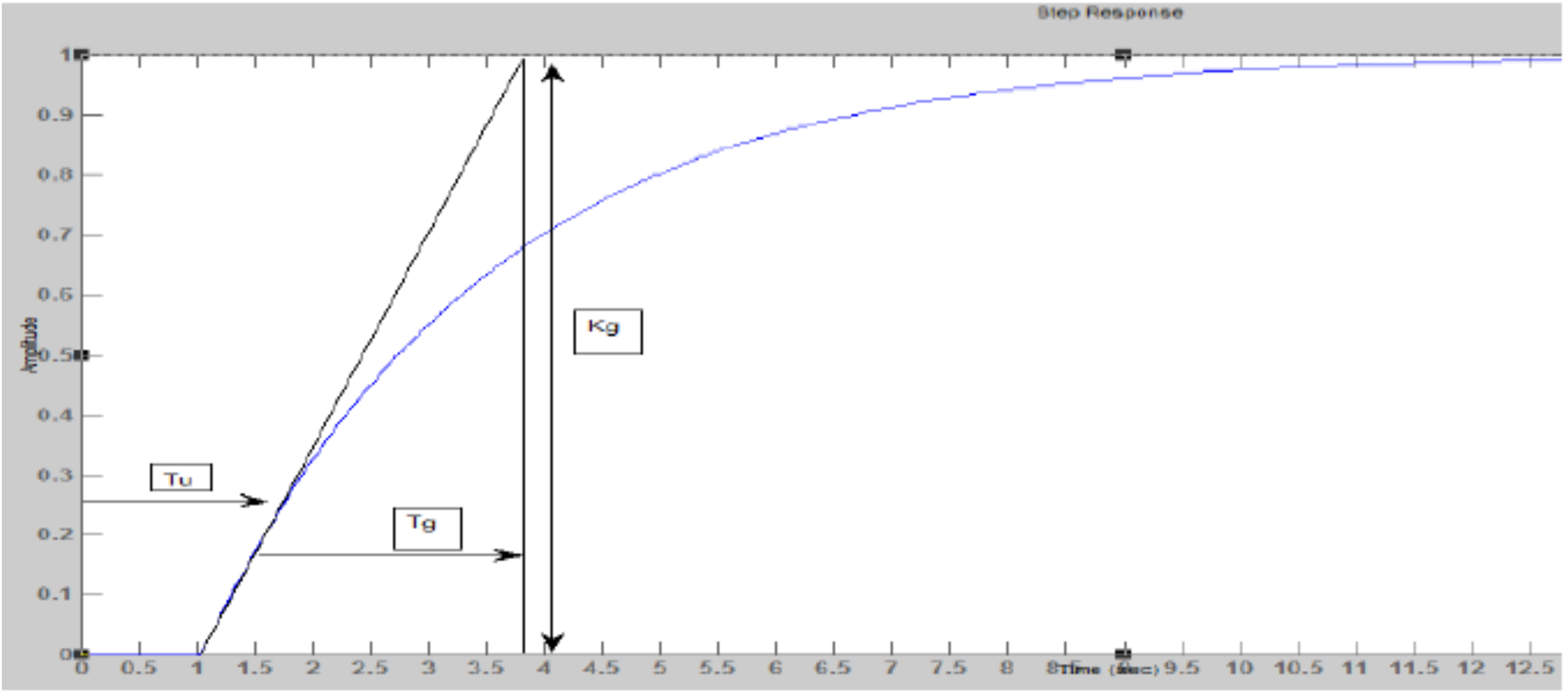
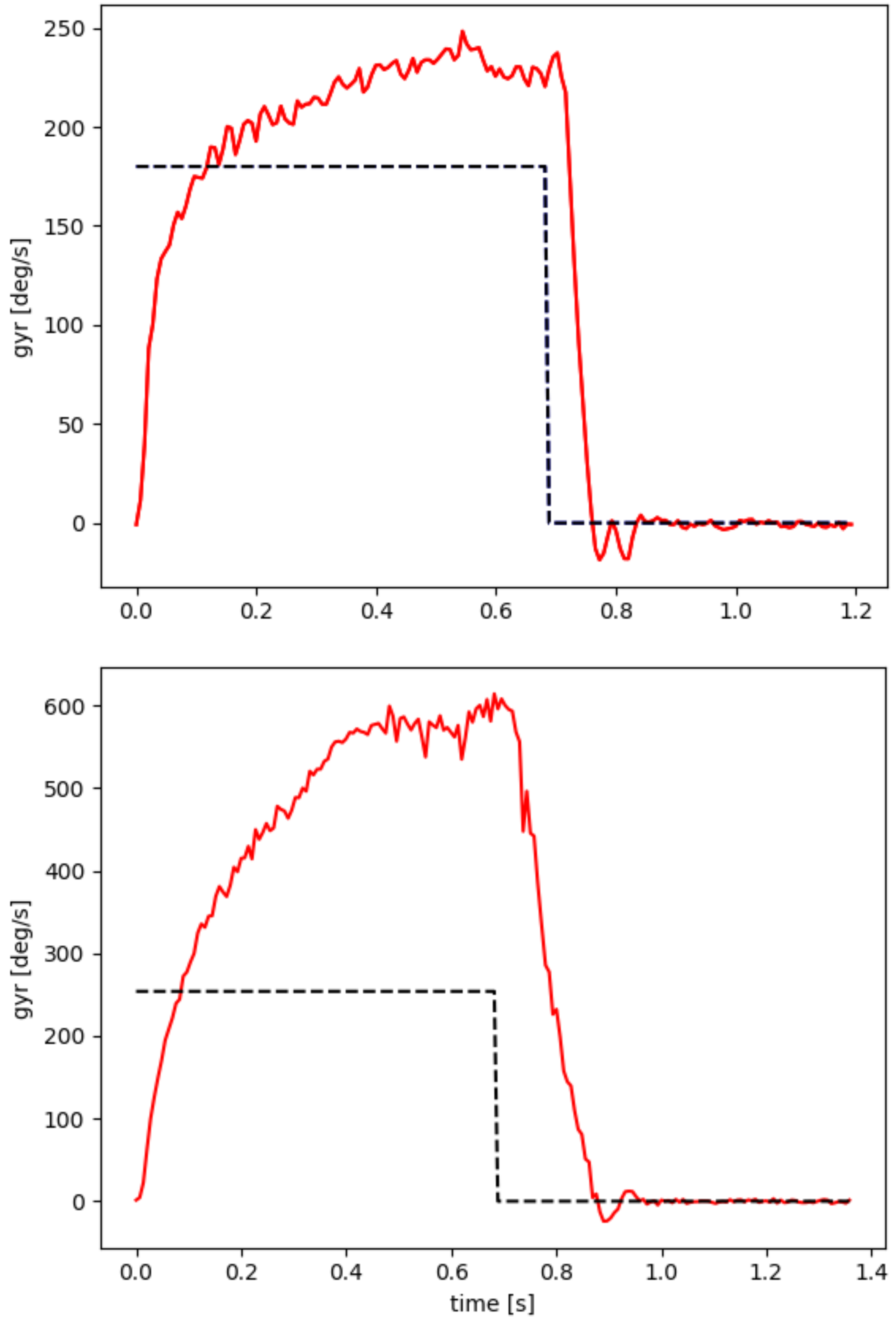


Fig.7. Open loop response of CHR method

Table.11. CHR Compensator

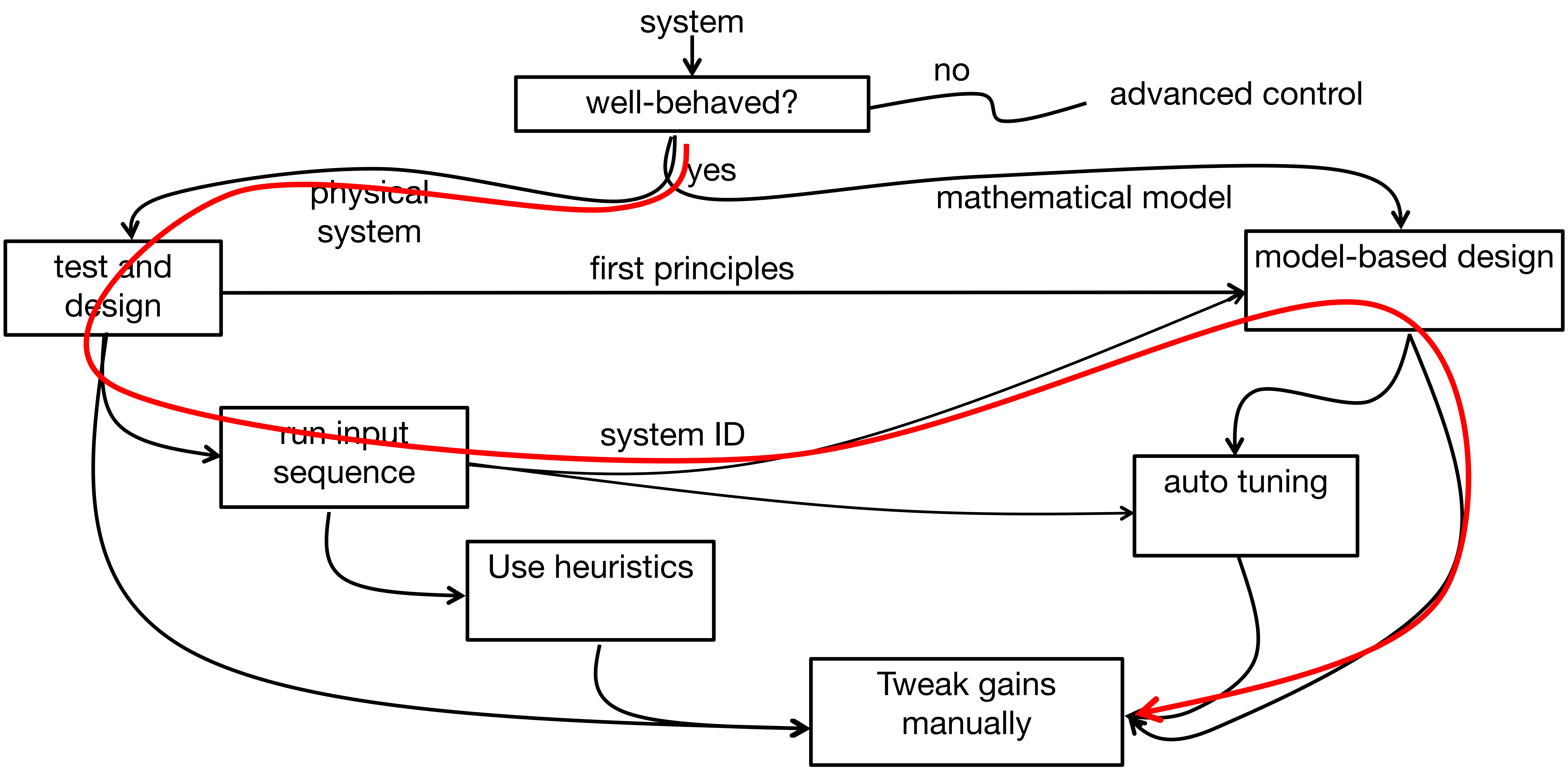
Type of controller	K_p	T_i	T_d
PID	$0.6T_g/T_uKg$	T_g	$0.5T_u$



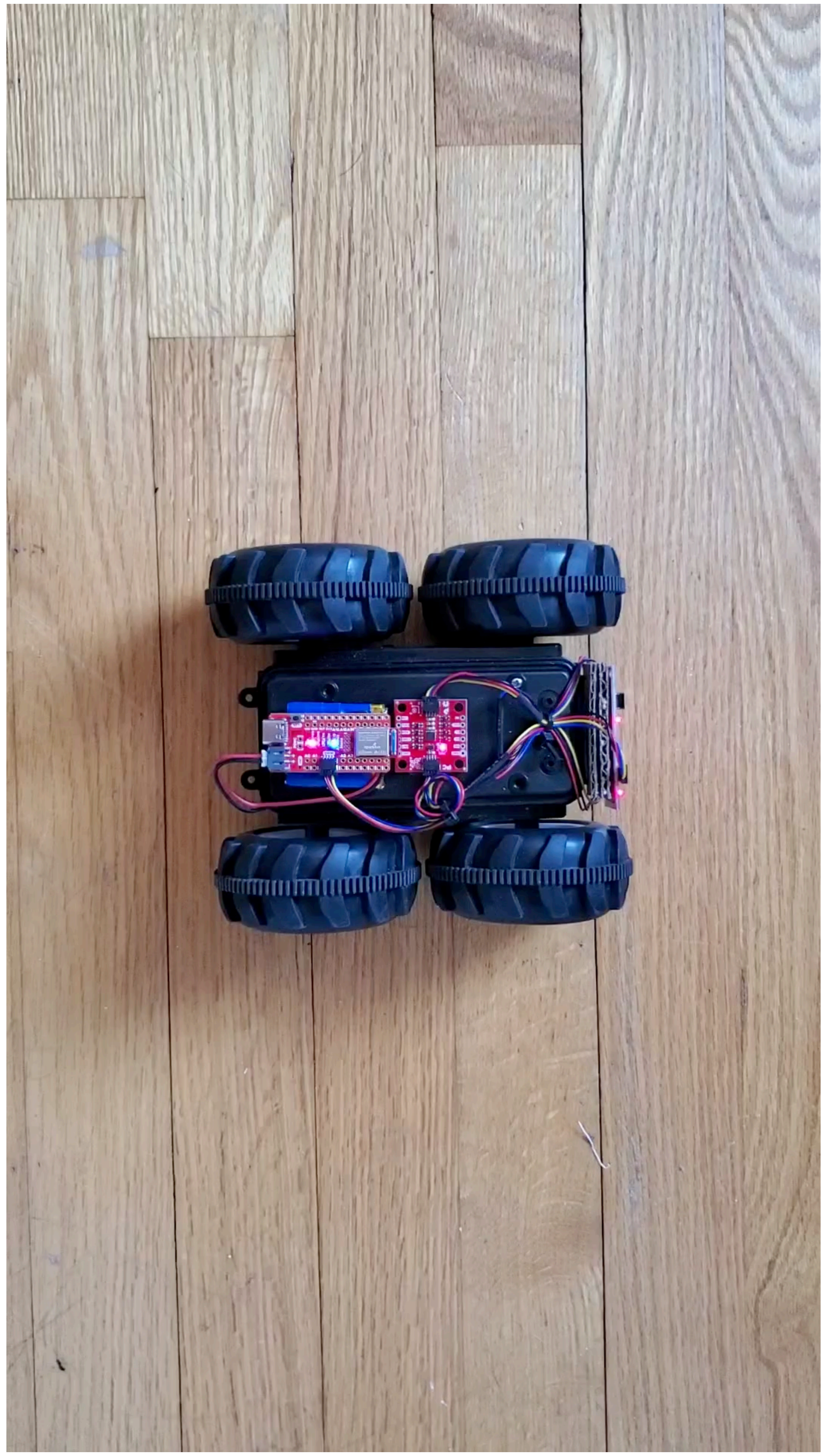
Tuning PID control

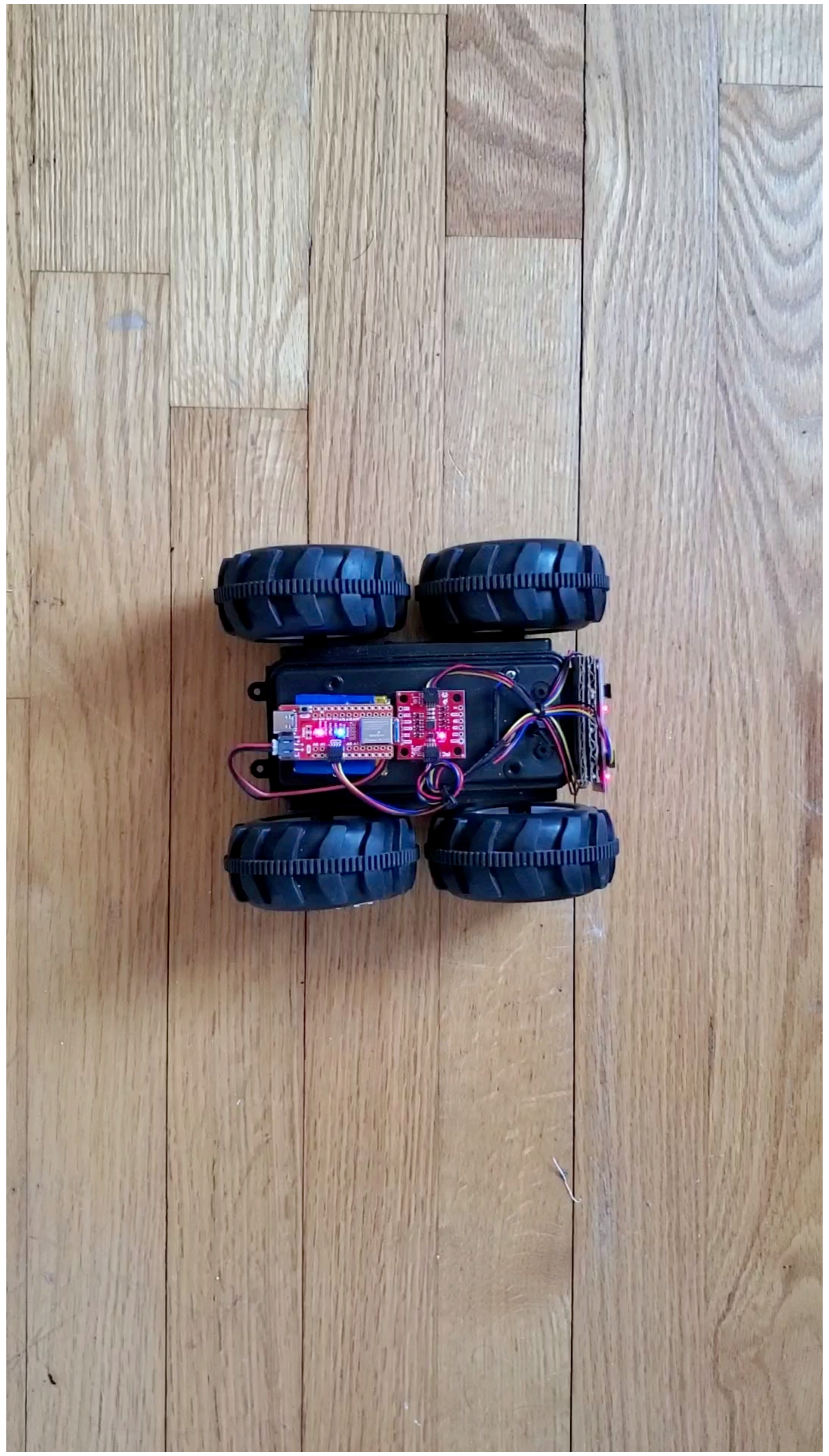
- Heuristic procedure #1:
  - Set k_p to small value, k_d and k_i to 0
  - Increase k_d until oscillation, then decrease by a factor of 2-4
  - Increase k_p until oscillation or overshoot, decreases by a factor of 2-4
  - Increase k_i until oscillation or overshoot
  - Iterate
- Heuristic procedure #2:
  - Set k_d and k_i to 0
  - Increase k_p until oscillation, then decrease by factor of 2-4
  - Increase k_i until loss of stability, then back off
  - Increase k_d to increase performance in response to disturbance
  - Iterate

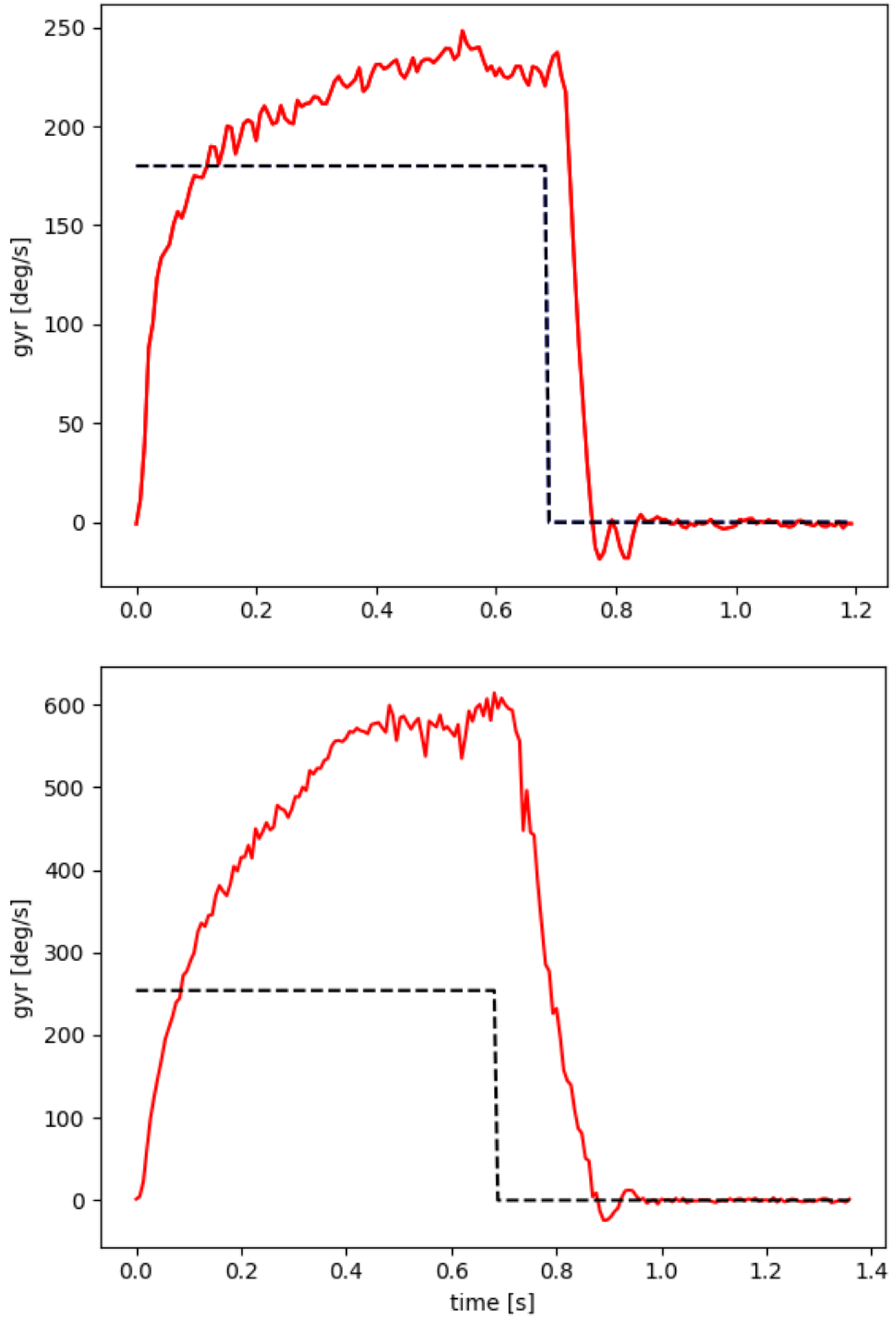
Tuning PID control



Simple model

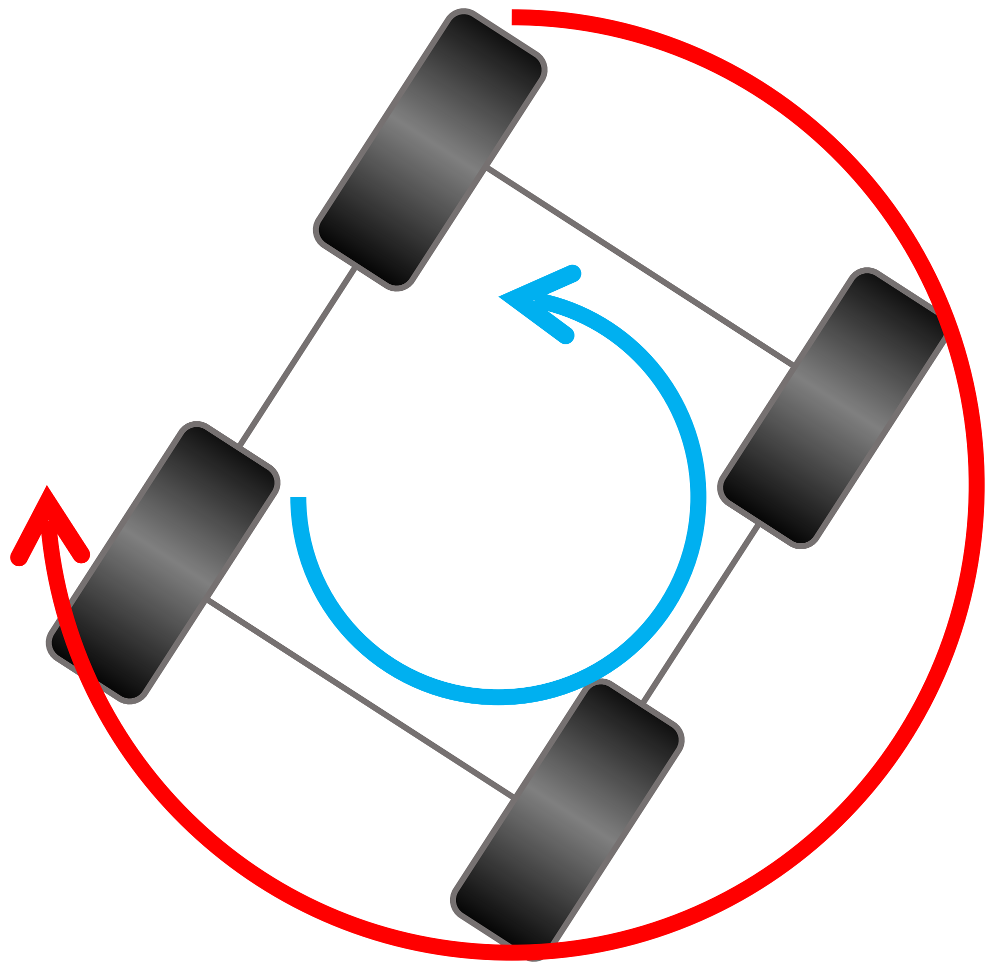






Equations of motion, angular speed

$$x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$$



$$F = ma$$

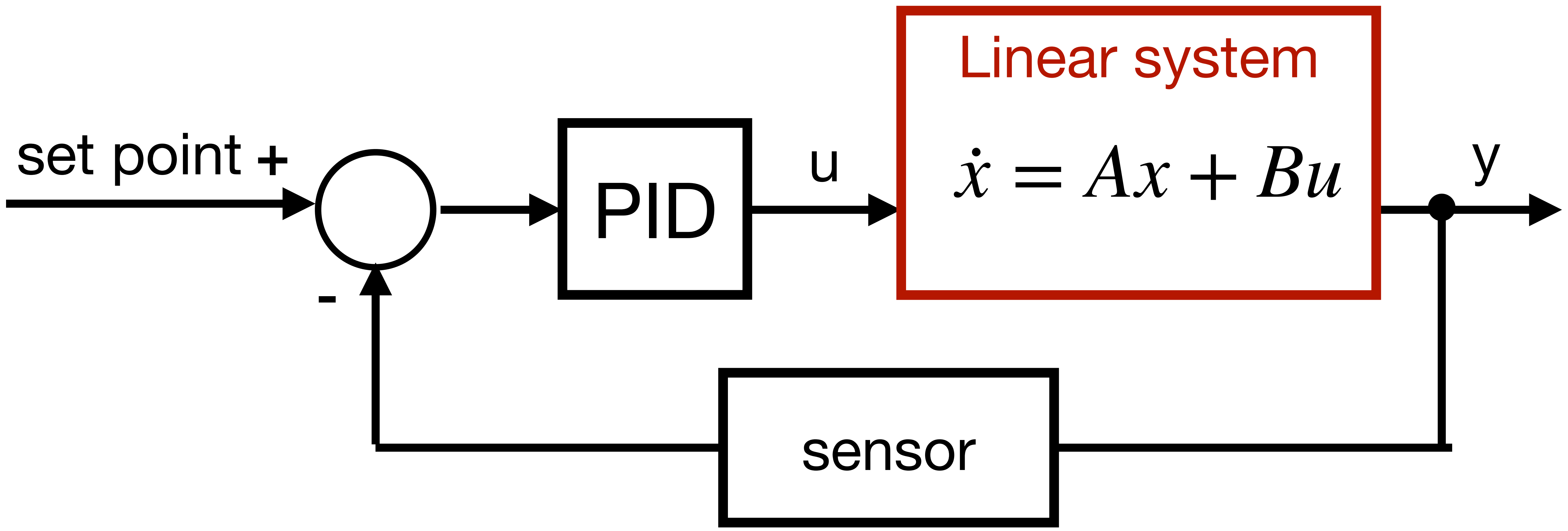
$$\tau = I\alpha$$

$$\tau = I\ddot{\theta}$$

$$u - \dot{\theta}c = I\ddot{\theta}$$

$$\ddot{\theta} = \left[\frac{-c}{I}\right]\dot{\theta} + \left[\frac{1}{I}\right]u$$

$$\boxed{\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 \\ 0 & \frac{-c}{I} \end{bmatrix}}_{A} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ \frac{1}{I} \end{bmatrix}}_{B} u}$$



PID control, angular speed

https://tinyurl.com/yc2wkckn

PID-FastRobots.ipynb

File Edit View Insert Runtime Tools Help

+ Code + Text

RAM
Disk

Gemini

Notebook for Designing PID controller. Minor formatting modifications from 2023, originally written by Prof. Kirstin Petersen.

```
from matplotlib import pyplot as plt
import numpy as np

'''
ECE 4160/5160, MAE 4190/5190: Designing a PID controller
Example: I=1, c=0.2
'''

class System:

  def __init__(self,
               A=[[0, 1],[0,-0.2]],
               B=[0,1],
               x0=[0, 0],
               sigma = 0,
               dt=0.005):

    self.x=np.array(x0)
    self.t=0
    self.dt=dt

    self.sigma = sigma

    self.A = np.array(A)
    self.B = np.array(B)

    self.x_hist=[x0]
    self.y_hist=[0]
    self.t_hist=[self.t]
    self.e_hist=[0]

    ...
```

PID control, angular speed

https://tinyurl.com/yc2wkckn

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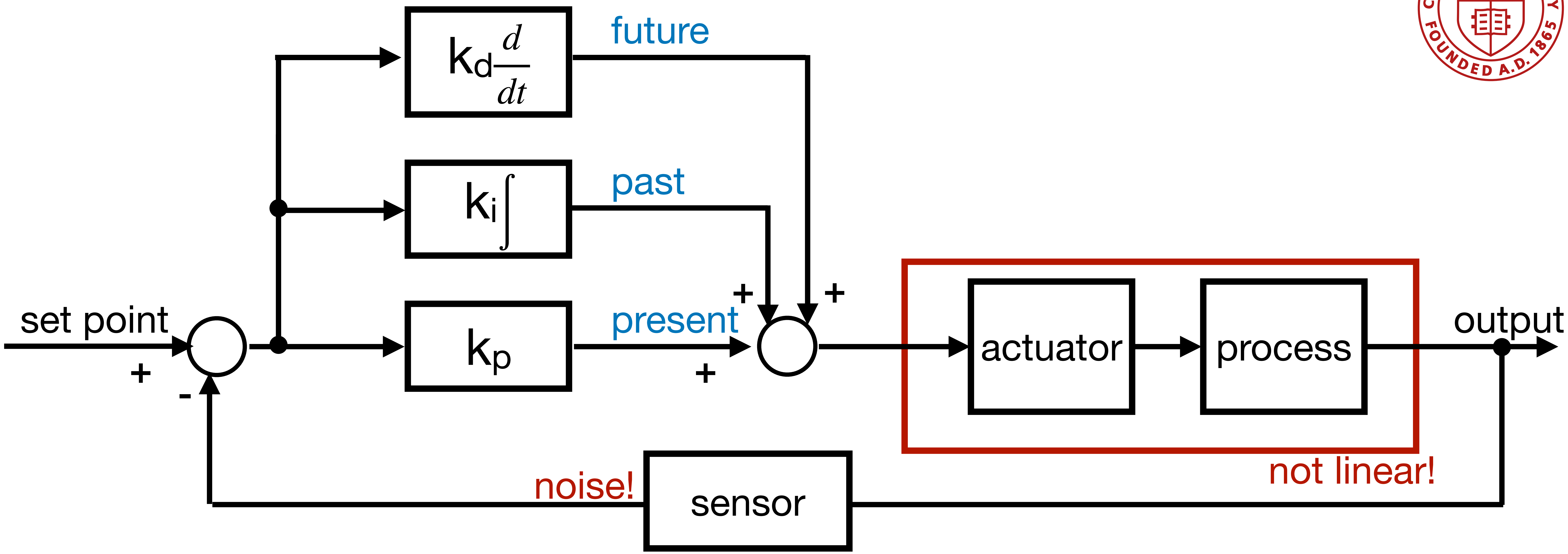
PID



- 1st order system: $$\begin{bmatrix}\dot{\theta}\\ \ddot{\theta}\end{bmatrix} = \begin{bmatrix}0 & 1\\ 0 & \frac{-c}{I}\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{I}\end{bmatrix}u$$
- 2nd order system: $$\begin{bmatrix}\dot{\theta}\\ \ddot{\theta}\end{bmatrix} = \begin{bmatrix}0 & 1\\ \text{const} & \frac{-c}{I}\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{I}\end{bmatrix}u$$

Labs 5 and 6 PID control

- Control for fast mode
  - Stunt: orientation
  - Stunt: speed control
- Control for slow mode
  - Mapping: angular sped
  - Path execution: position control

Biggest limitation:

- Sensor noise
- Sensor sampling time
- PID control is 5-10x faster than system
- Lab 7 kalman filter
- Lab 8 stunt

Next three lectures

Control theory

- Linear systems
- Eigenvectors
- Stability
- Controllability
- Observability
- Kalman filters

$$\dot{x} = Ax + Bu$$

These should look familiar from:

- MATH2940 Linear Algebra
- ECE3250 Signals and Systems
- ECE5210 Theory of Linear Systems
- MAE3260 System Dynamics
- and many others…