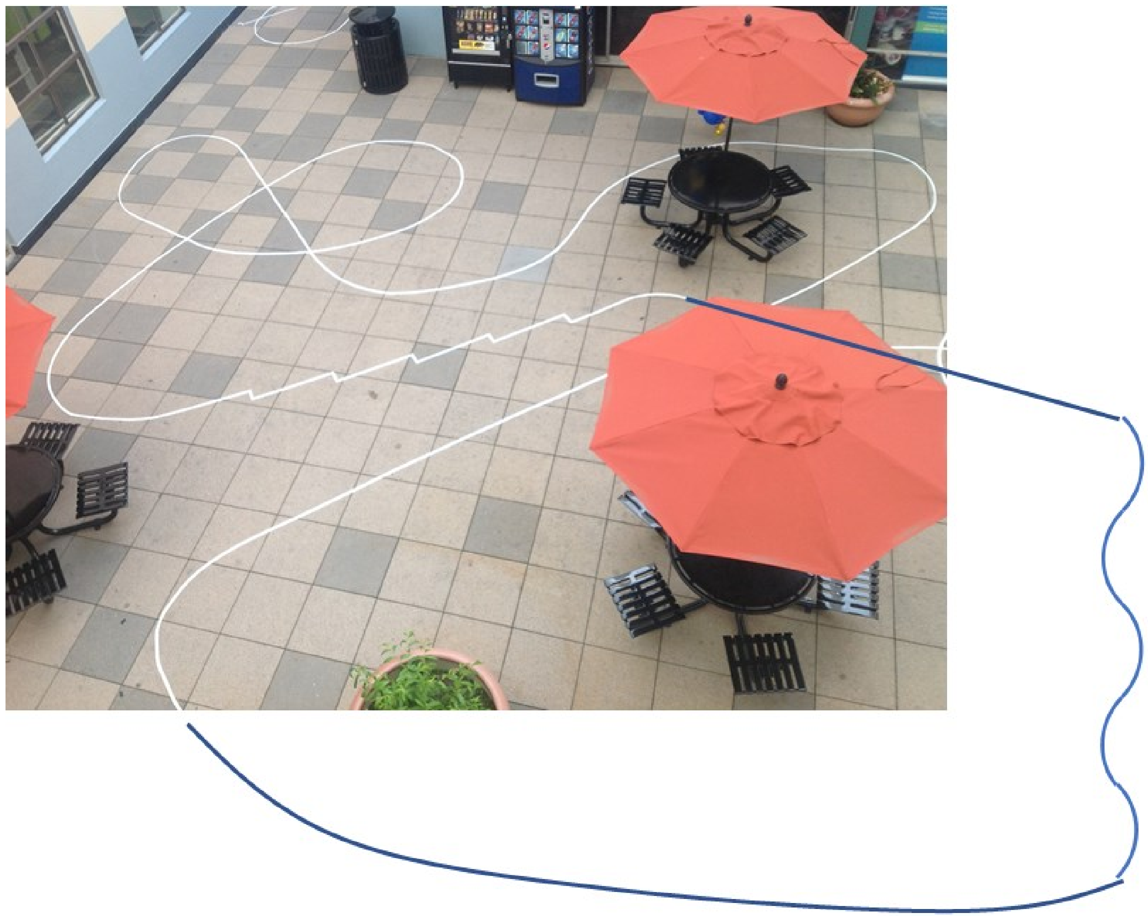
EECS192 Lecture 10
Power and Control
Mar. 30, 2021

Topics

- Checkpoint 8: Step+ telemetry
- HW 2 Simulation (due Fri 4/2 6 pm)
- Progress report (due Fri 4/9 8 pm)
- ESP32 A/D Issues
- Quiz3- MOSFET 3/30
- Motor Drive- details
- Control Fundamentals

Planned Cory Courtyard Track

Thu and Friday 2-4 pm, supervised by staff member David Au.
All Covid protocols to be followed.
Details on Piazza when set up.



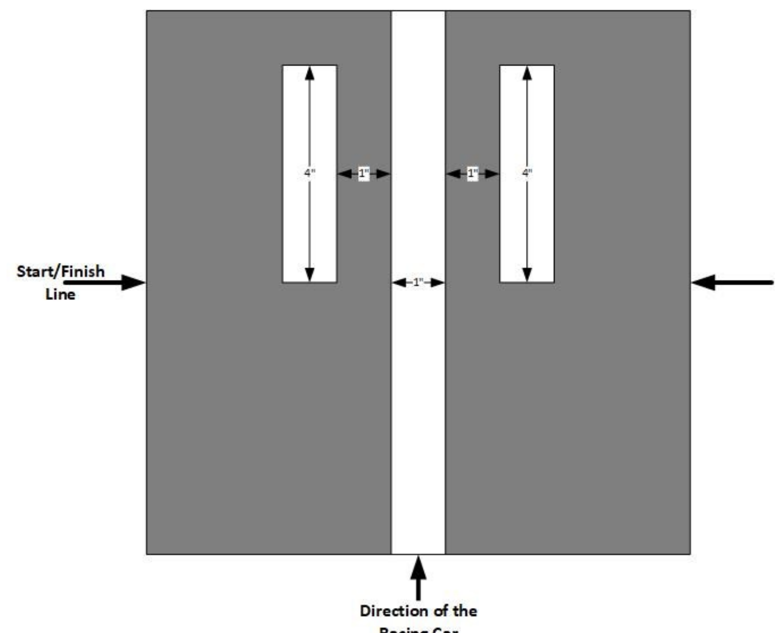
All curves minimum radius 3 feet (bigger radius is fine)
(use 3 foot string and mark circle with chalk)

Checkpoint 8: Stopping (Fri 4/9)

Set up a straight or curved track with length sufficient for car to accelerate to (ideally) 2 m/sec or better and stop when it sees the stop pattern.

Checkoff Procedure

- C8.1 Show car driving on track and then doing emergency stop from remote command.
- C8.2 Show car driving on track and doing emergency stop when it crosses NATCAR stop marking of parallel lines. Natcar Finish Line
- C8.3 Show telemetry plot of speed and other relevant parameters.
- C8.4 All members must fill out the checkpoint survey before the checkoff close. Completion is individually graded.



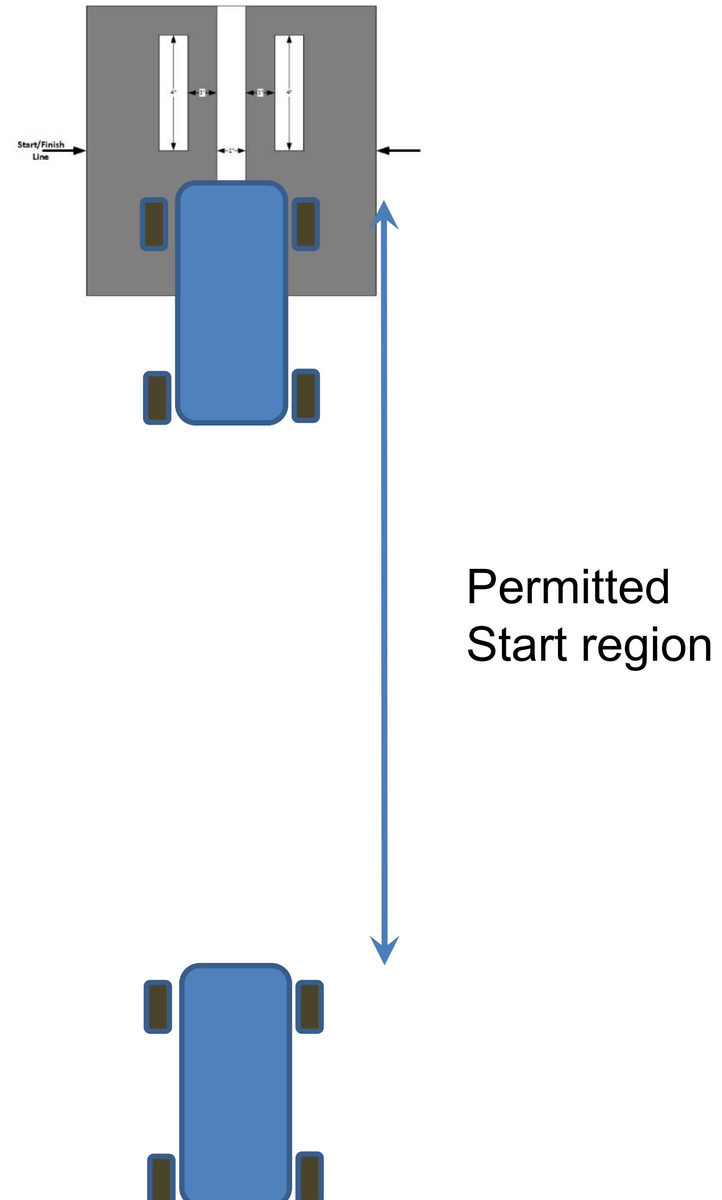
NATCAR Notes

1. Car can start in region shown (running start or avoid seeing stop line…) up to ``several feet" behind start/stop line

2. A running car can continue running for consecutive laps. If car is doing multiple laps without stopping, 4 second penalty is applied to intermediate laps.

The car must automatically stop within 6 feet of the finish line after finishing the race.

A penalty of 4 seconds will be added to the lap time for any car that does not automatically stop within the required region.



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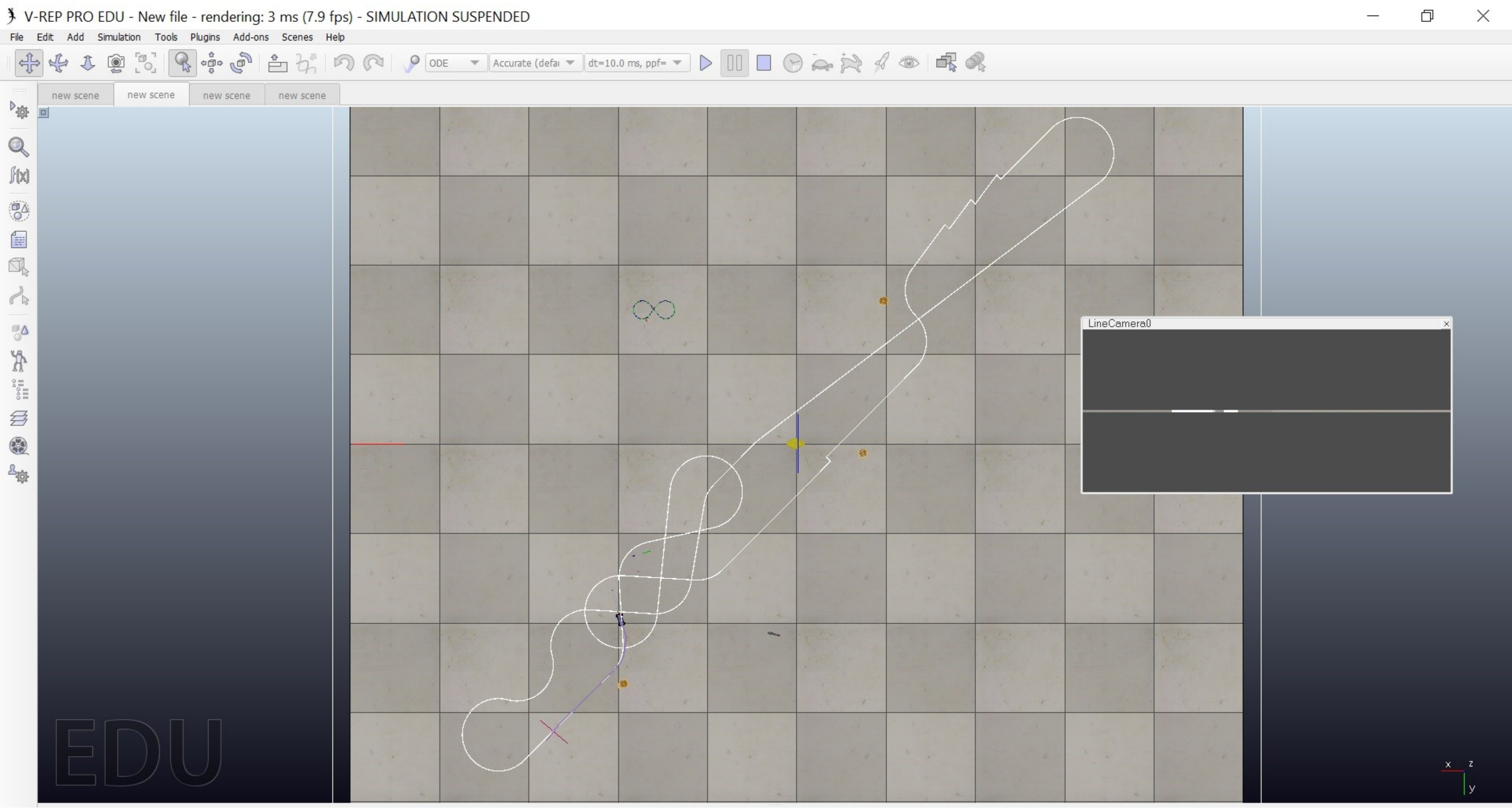
V-rep simulation- HW2 (due 6 pm Fri 4/2)



demo

Progress Report Due Fri 4/9 (8 pm)

https://inst.eecs.berkeley.edu/~ee192/sp21/docs/progrpt.pdf

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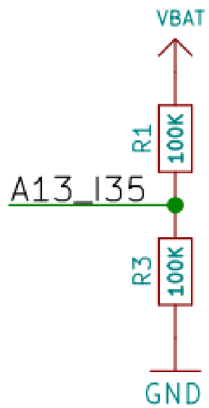
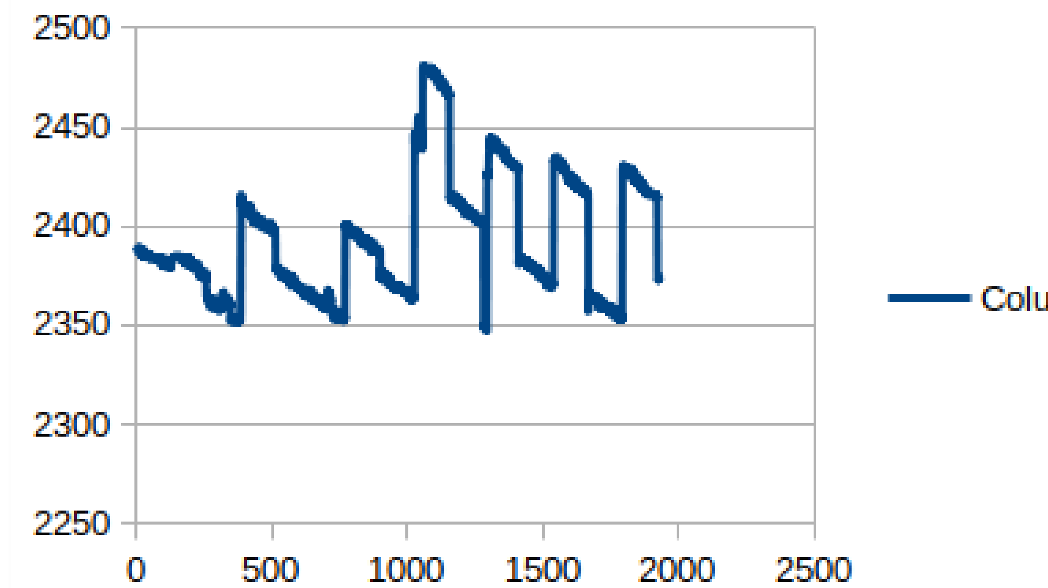
ESP32 A/D Issues





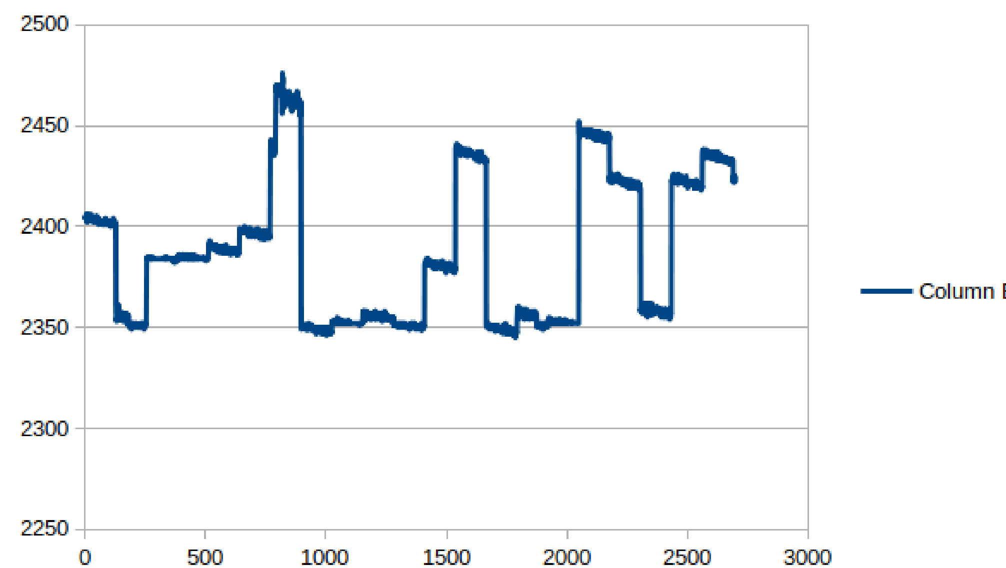
static const adc_channel_t channel = ADC_CHANNEL_7;

128 reads are done at 51 us for `adc1_get_raw()`

and

128 reads are done at 12.2 us for `local_adc1_read()`

Then there is a 5 second delay before reading the A/D again. A lot of drift is noticeable.

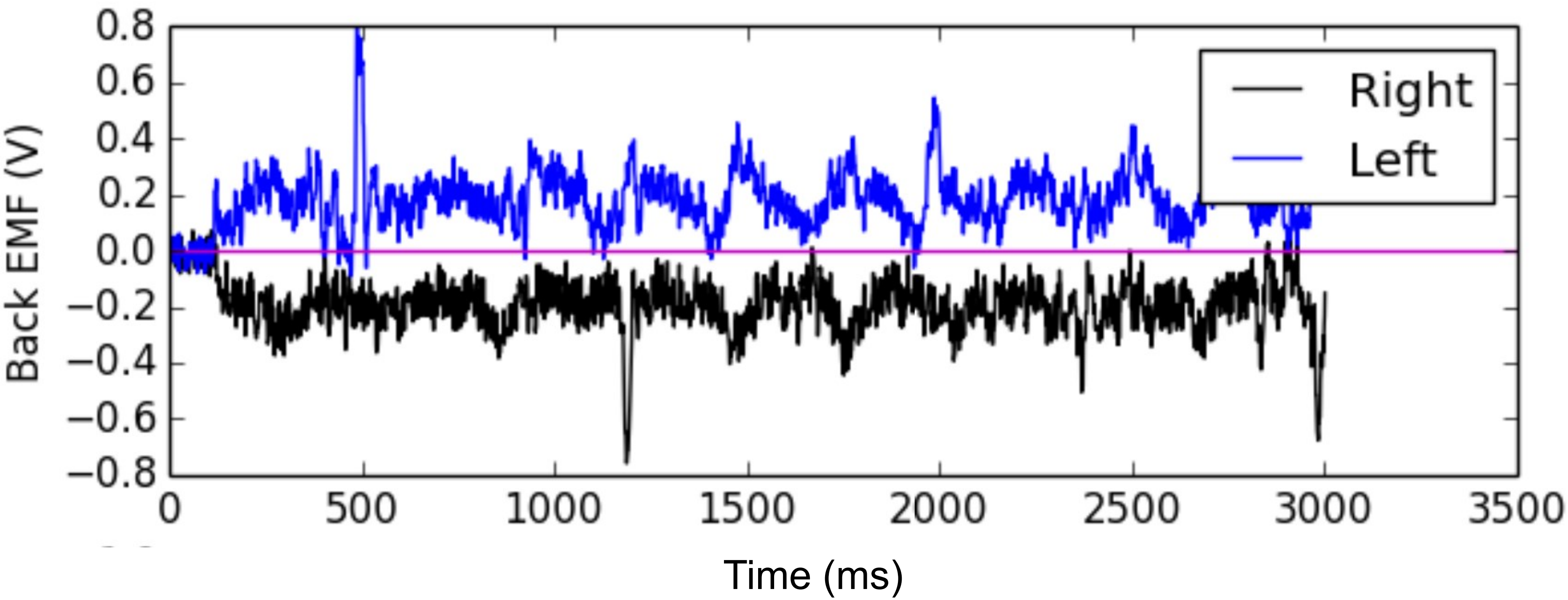


Digital Filtering

- Moving average
  - $y1[n] = (y[n-2]+y[n-1]+y[n])/3$
- Median filter (outlier rejection)
  - median(7,10,11,12,16,200,205)=?
- Notch filter (mechanical vibration)
  - $y[n] = (x[n-2]+2x[n-1]+x[n])/4$
- Model based filtering (or Kalman filter)

Moving Average vs. Median Filter

Example: motor brush noise, back EMF measurement



{0,2,-1,4,0,2,1,1,20,1,0,2} ➔

{0,2,-1,2,0,1,1,1,1,1} 3 element median filter

{0,2, 0.3,1.7, 2, 1,1.3, 7.3, 7.3, 7,1…} 3 elem MA

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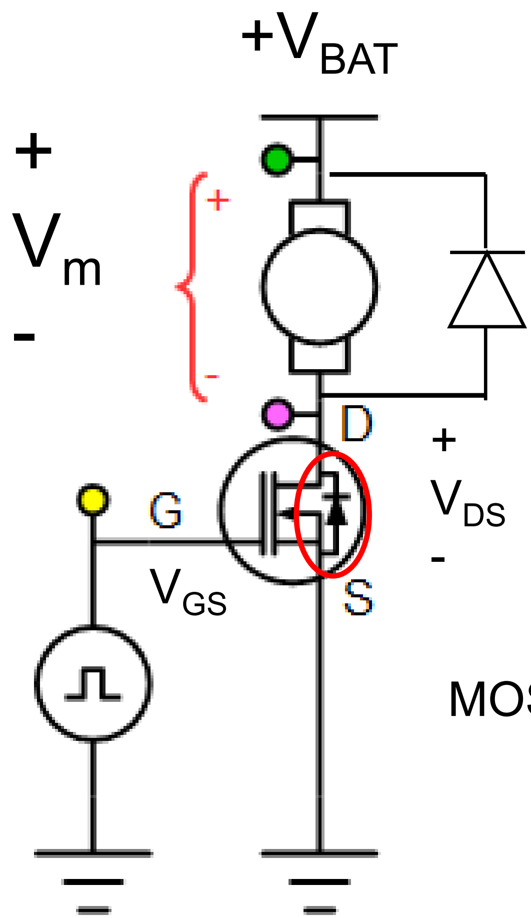
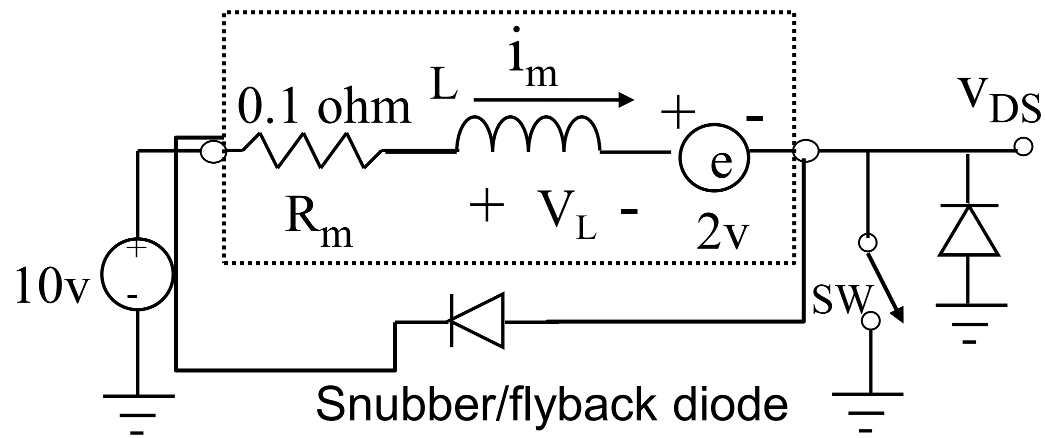
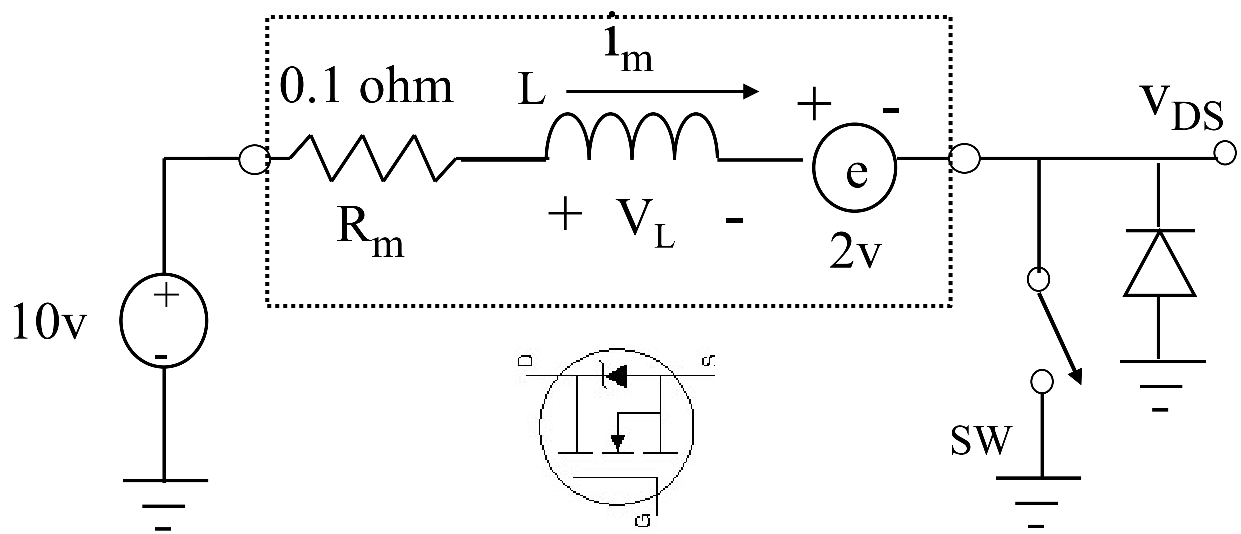
Low side motor drive

What about motor inductance?

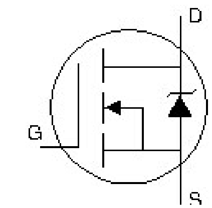


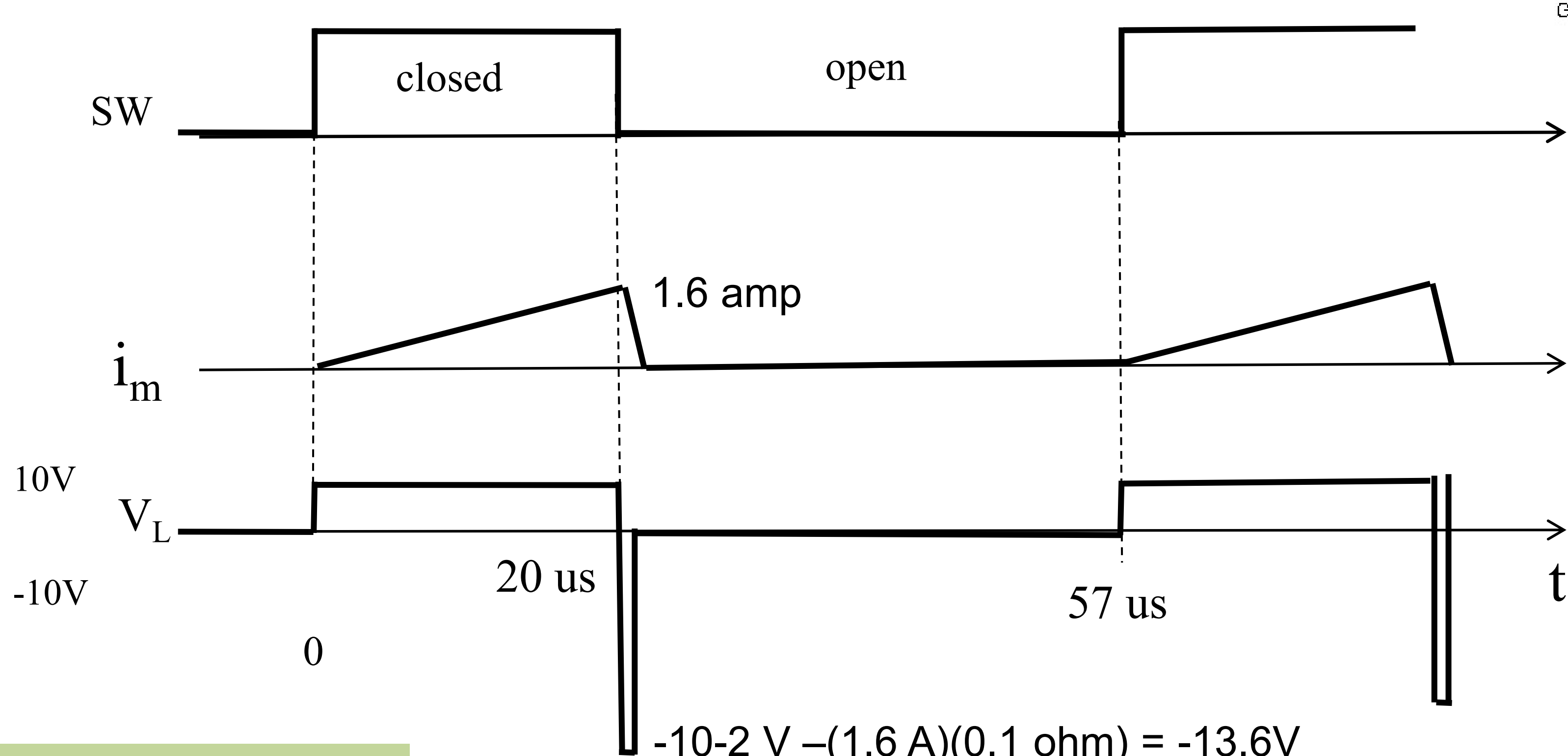


MOSFET body diode



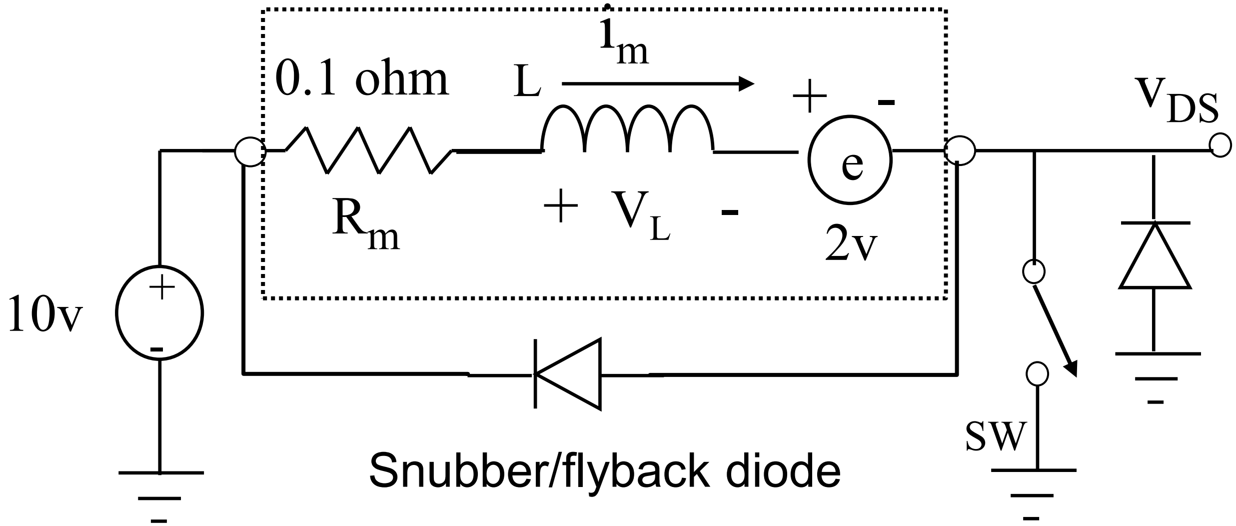
Assume ideal diode,
17 kHz
ideal switch, L= 100 μH.
Time constant τ = 1 ms.
Steady state,
constant velocity.
Initial rate:
V/L= +8x10[4] amp/sec



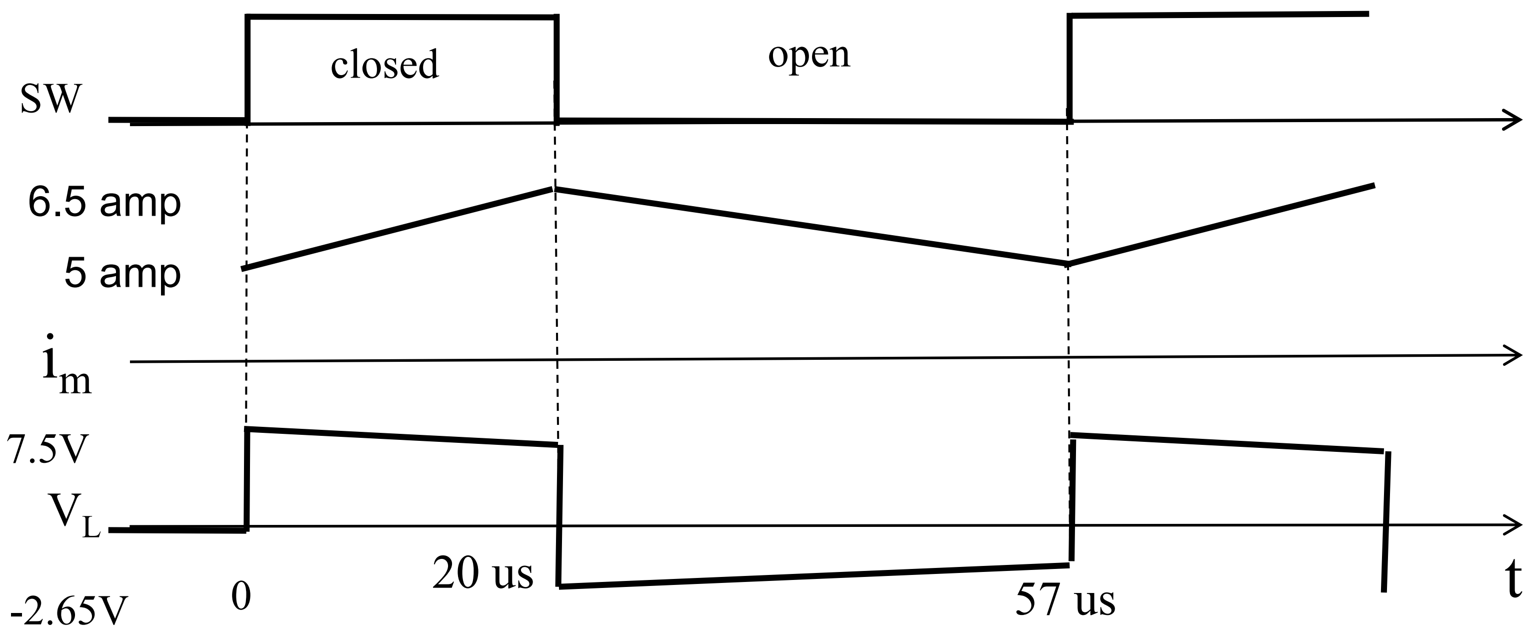


Motor+flywheel diode

Motor+flywheel diode

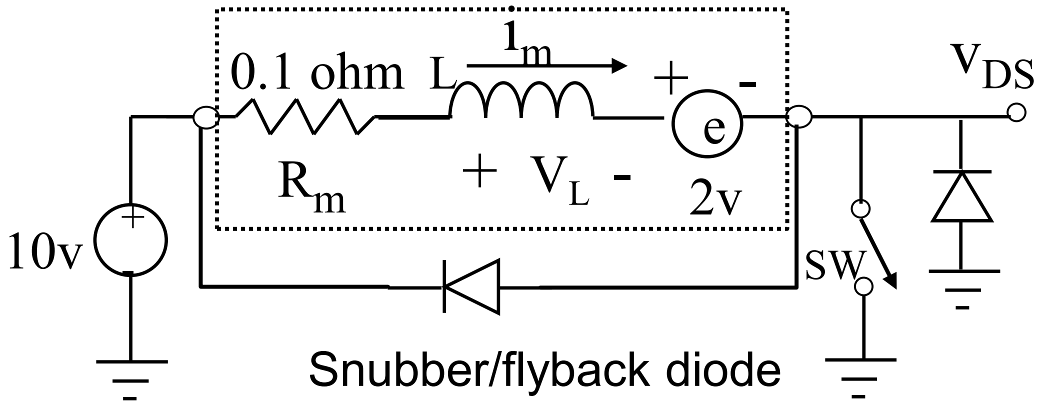


Assume ideal diode, ideal switch, L= 100 μH.
Time constant τ = 1 ms.
Steady state, constant velocity.
Assume i_{min} = 5 amp



L di/dt = 7.5V   L di/dt = -2.65V

Note: 25 kHz PWM reduces peak current



$$V_{DS} = 10V - V_{DIODE}$$

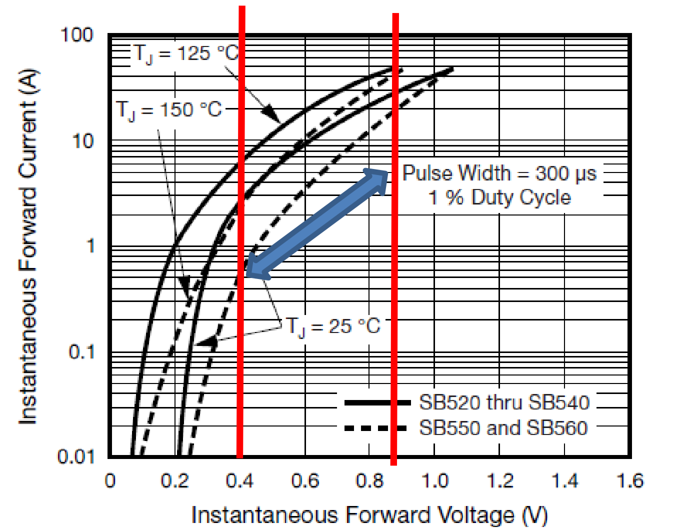
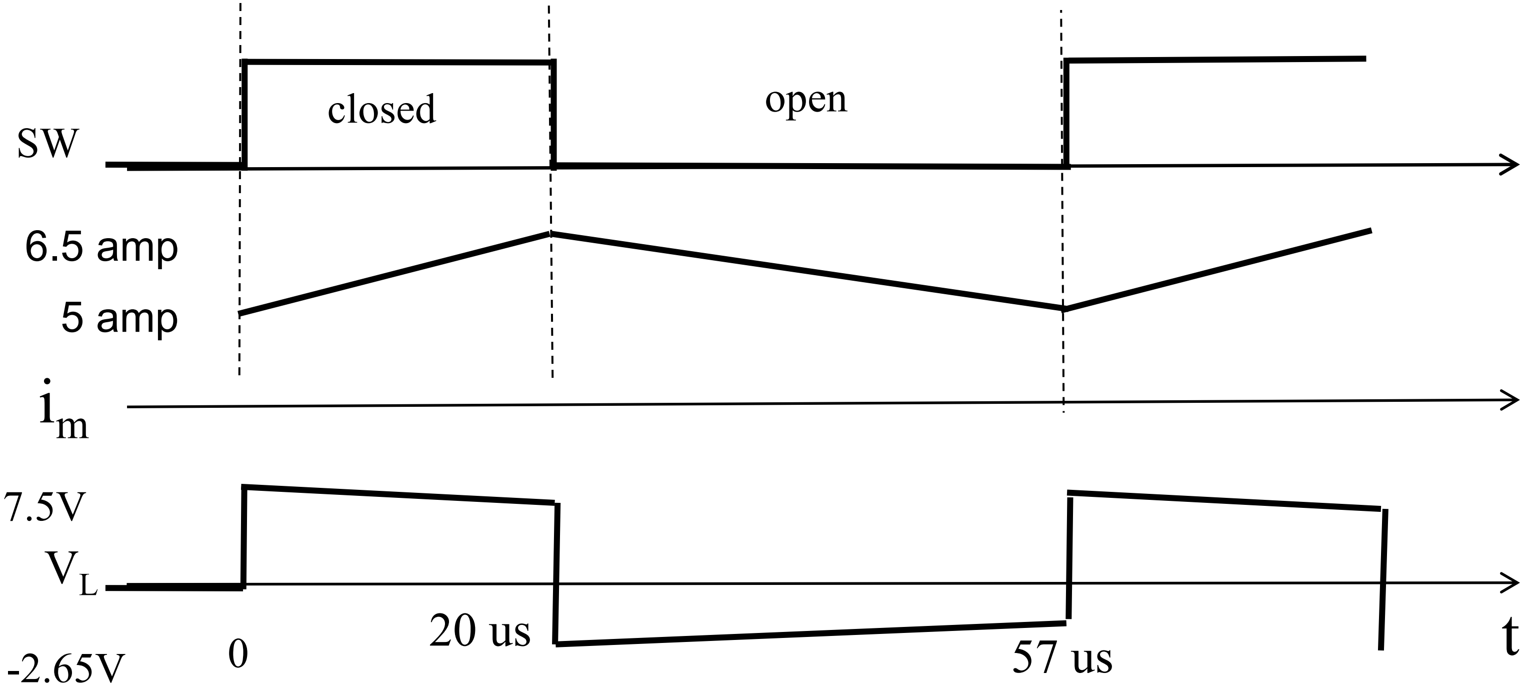


Fig. 3 - Typical Instantaneous Forward Characteristics



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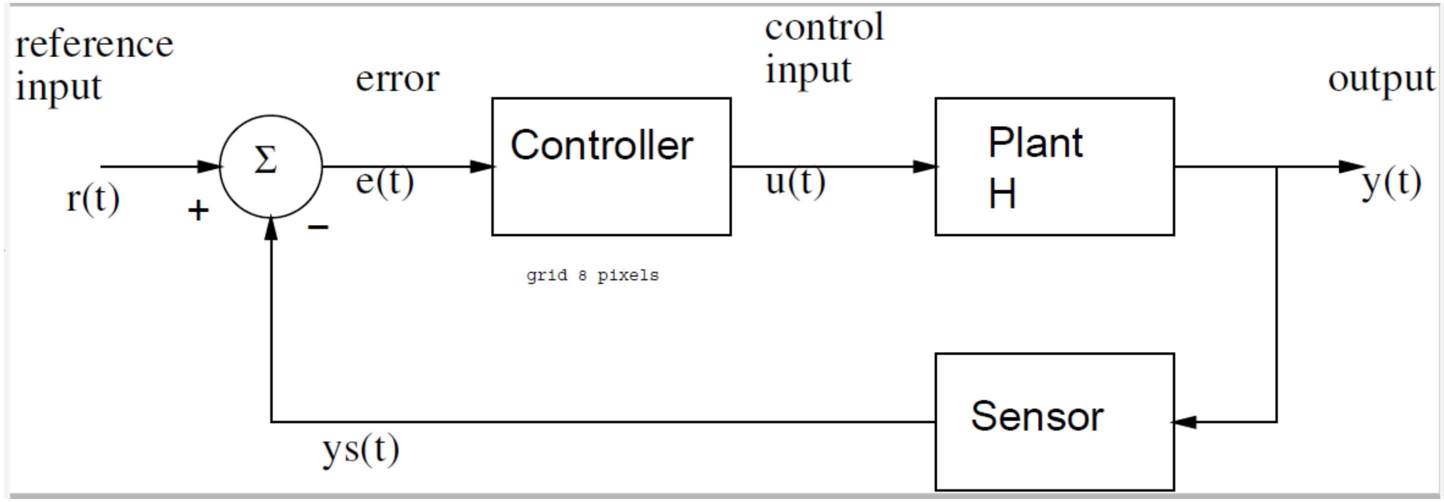
Control Synopsis



State equations: $$\dot{x}(t) = ax(t) + bu(t)$$

Output equations: $$y(t) = cx(t) + du(t)$$

Control Law (P): $$u(t) = k_p e(t) = k_p(r(t) \; - \; y(t)).$$

Control Synopsis

Control Law (P): $u(t) = k_p e(t) = k_p(r(t) \ - \ y(t)).$

New state equations:

$$\dot{x} = ax + bk_p e(t) = ax + bk_p(r - x) = (a - bk_p)x + bk_p r.$$

Zero Input Response (non-zero init condx):

$$x(t) = x(0)e^{(a-bk_p)t} \quad for \quad t \geq 0.$$

$a' = a - b\,k_p$ $\qquad$ $b' = b\,k_p$

Total Response (non-zero init condx) by convolution:

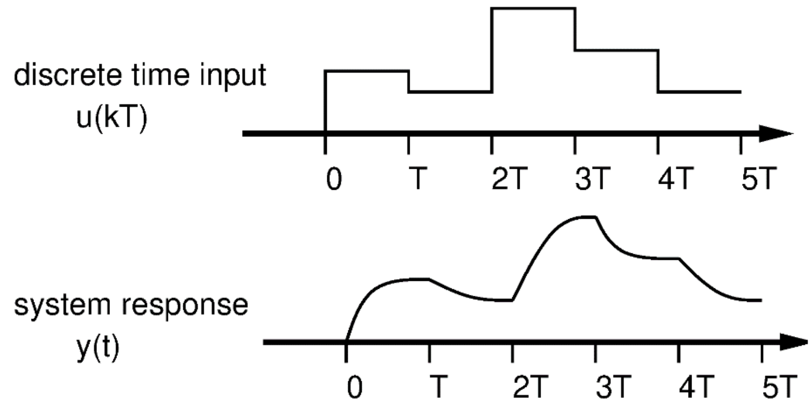
$$x(t_o) = e^{a' t_o} x(0) + \int_0^{t_o} e^{a'(t_o - \tau)} b' r(\tau) d\tau \ . \qquad (10)$$

Step Response (zero init condx) by convolution:

$$x(t_o) = b' \int_0^{t_o} e^{a' t_o} e^{-a'\tau} d\tau \ = \ \frac{-b' e^{a' t_o}}{a'} e^{-a'\tau}|_0^{t_o} \ = \frac{b'}{a'}(1 - e^{-a' t_o}) \ . \qquad (11)$$

Control Synopsis- Discrete Time

Superposition of Step Responses



$$x((k+1)T) = e^{a(k+1)T}x(0) + e^{a(k+1)T}\int_0^{(k+1)T} e^{-a\tau}bu(\tau)d\tau \ . \qquad (15)$$

$$x(kT) = e^{akT}x(0) + e^{akT}\int_0^{kT} e^{-a\tau}bu(\tau)d\tau \ . \qquad (14)$$

$$x((k+1)T) = e^{aT}x(kT) + e^{a(k+1)T}\int_{kT}^{(k+1)T} e^{-a\tau}bu(\tau)d\tau \ = e^{aT}x(kT) + \int_0^T e^{a\lambda}bu(kT)d\lambda \ , \quad (16)$$

Control Synopsis- Discrete Time

$$G(T) \equiv e^{aT} \quad \text{and} \quad H(T) \equiv b \int_0^T e^{a\lambda} d\lambda \ . \tag{17}$$

State equations:

$$x((k+1)T) = G(T)x(kT) + H(T)u(kT) \tag{18}$$

Output equations:

$$y(kT) = Cx(kT) + Du(kT) \ . \tag{19}$$

Total Response (non-zero init condx) by convolution:

$$x(k) = G^k x(0) + \sum_{j=0}^{k-1} G^{k-j-1} H u(j) \ . \tag{23}$$

Control Synopsis- Discrete Time

Control Law (P): $U(kT) = k_p\,[r(kT) - x(kT)]$

New state equations:

$$x((k+1)T) = G(T)x(kT) + H(T)k_p(r(kT) - x(kT)) = [G - Hk_p]x(kT) + Hk_pr(kT)\ . \quad (24)$$

$$x((k+1)T) = [e^{aT} + \frac{k_p}{a}(1 - e^{aT})]x(kT) + Hk_pr(kT) \ = \ G'x(kT) + Hk_pr(kT)\ . \quad (25)$$

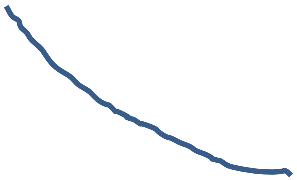
For stability:

$$|e^{aT} - \frac{k_p}{a}(e^{aT} - 1)| < 1. \quad (26)$$

Notes: stability depends on gain **and** T!

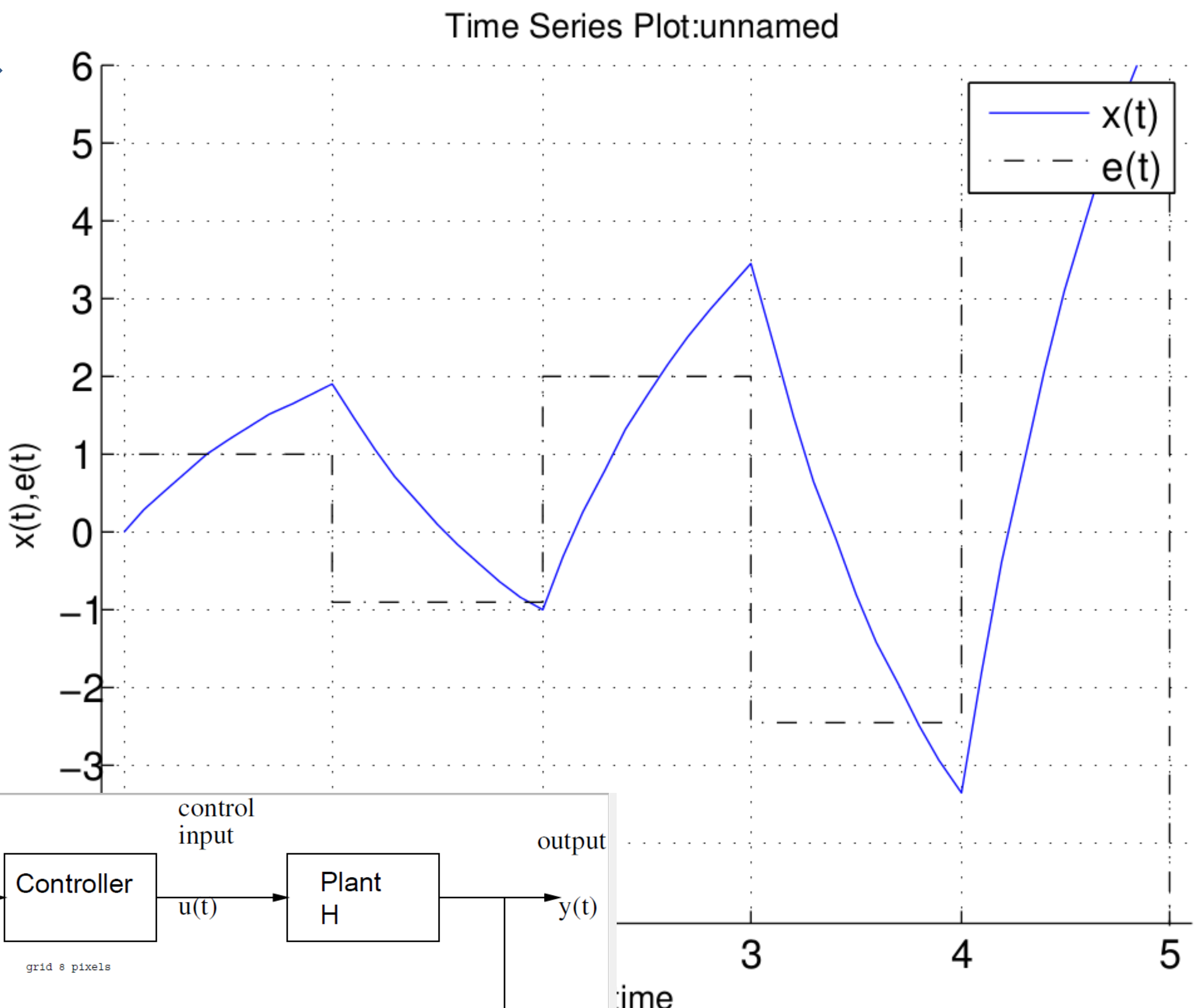
Discrete Time Control

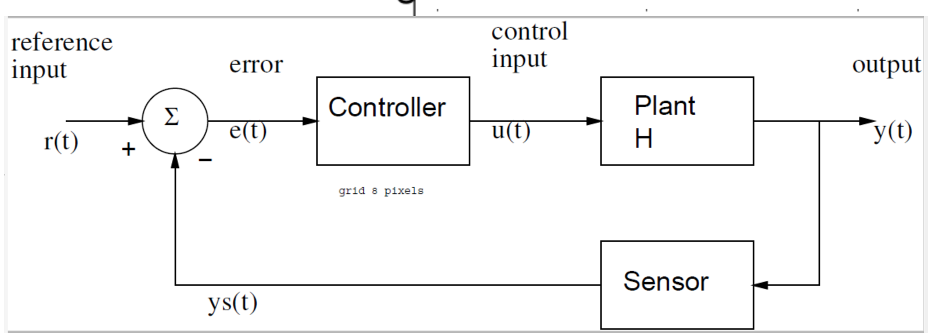
e(t), u=kp e(t)



$u[k] = kp*(r[k]-x[k])$

Let $x[k] = y[k]$





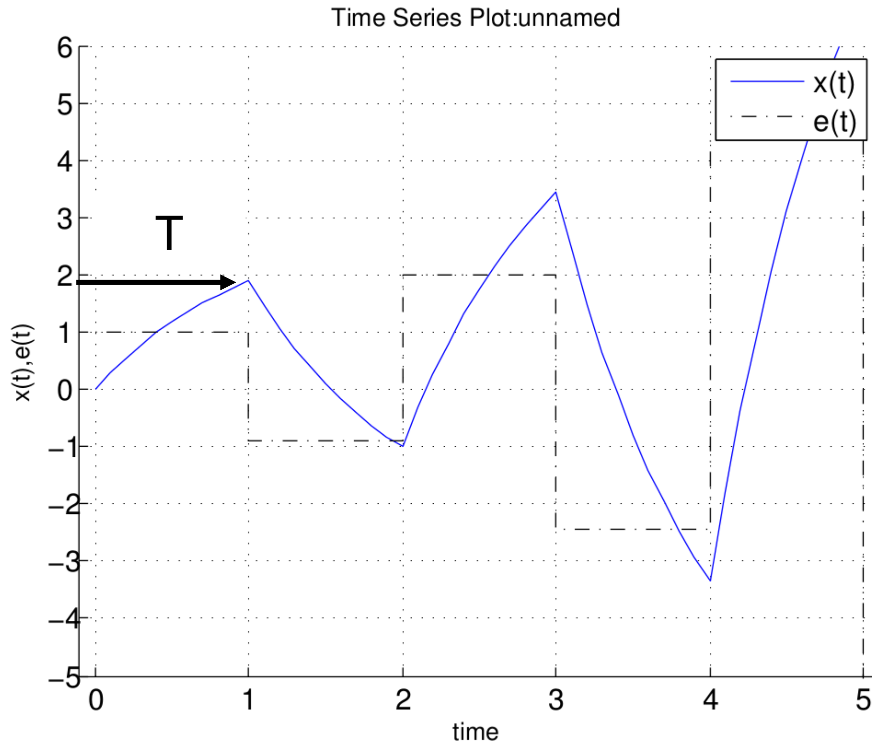
Example control- discrete time

First order CT system $\dot{x} = -x + u$

Let x = car velocity
Reference r=1 m/s unit step, k=3
e(t) = r(t) – x(t)
Let control input u[n]=3(r[n]-x[n]) = 3e[n],

Watch out for delay!
Watch out for excess gain!

t (sec)	x(t)	e(t) = r(t) - x(t)	u(t)
0^-	0	0	0
0	0	1	3
1	2	-1	-3
2	-1	2	6
3	3.5	-2.5	-7.5
4	-3.5	4.5	13.5



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NATCAR Notes

Cones +2 second
Finish line:The start/finish line will be marked with two 4-inch-long segments of 1-inch-wide white tape that are parallel to the track with 1-inch spacing, as shown in the figure below.

The car must automatically stop within 6 feet of the finish line after finishing the race.

A penalty of 4 seconds will be added to the lap time for any car that does not automatically stop within the required region.