Today: # Introduction to Digital Control

Lecture 2
ECE 147B
Digital Control

Reading: FPW 3.1-3.2 (pp.57-65), 4.1 (pp.73-78)
or: FV 2.2, 3.1-3.2, 6.3.1,6.3.2

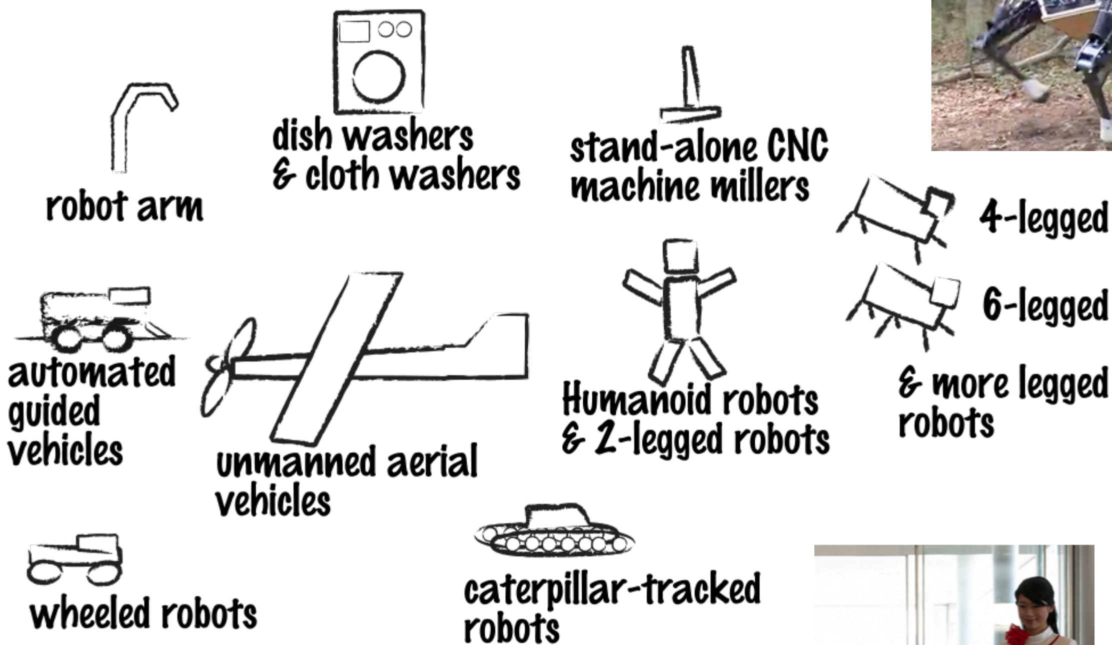
Topics:
- Wrap up CT Review (see Lecture 1 notes)
- Overview: Sampled data systems
- Difference Equations
- Sampling: Effect of Zero-Order Hold (ZOH)
- Numerical Integration: Tustin Approx.

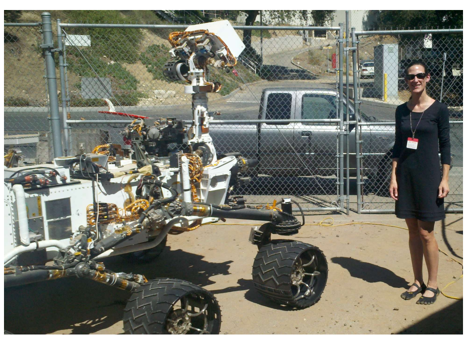
Next Class: ZOH equivalent, Z xform, DT TF, Tustin with pre-warp
- FPW: 6.3.1, 4.6.1, 4.2.1, 4.3.1, 6.1 (pp.194-195)

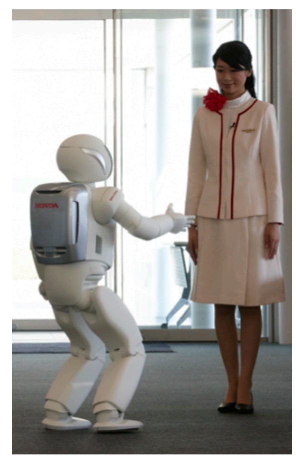
or: - FV: 2.3, 2.5, 2.8, 6.3.3

Sampled-Data Systems

- We want to use computers to control cool stuff in the real world...

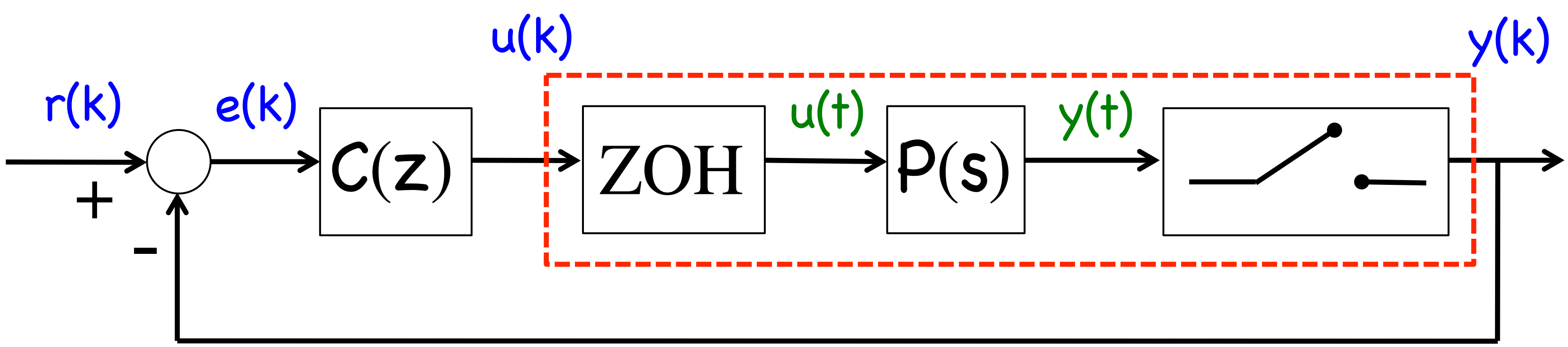






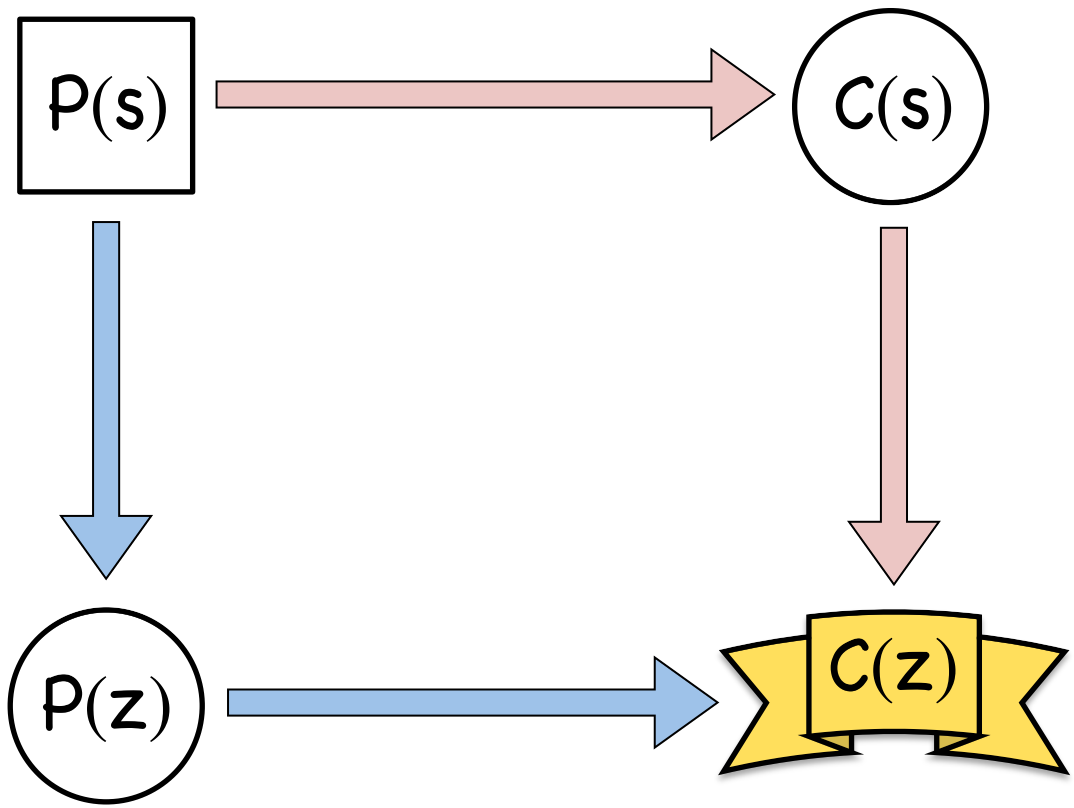
Sampled-Data Systems

- Such sampled-data systems are a combo of:
  - Discrete-time (DT) signals
  - Continuous-time dynamic system



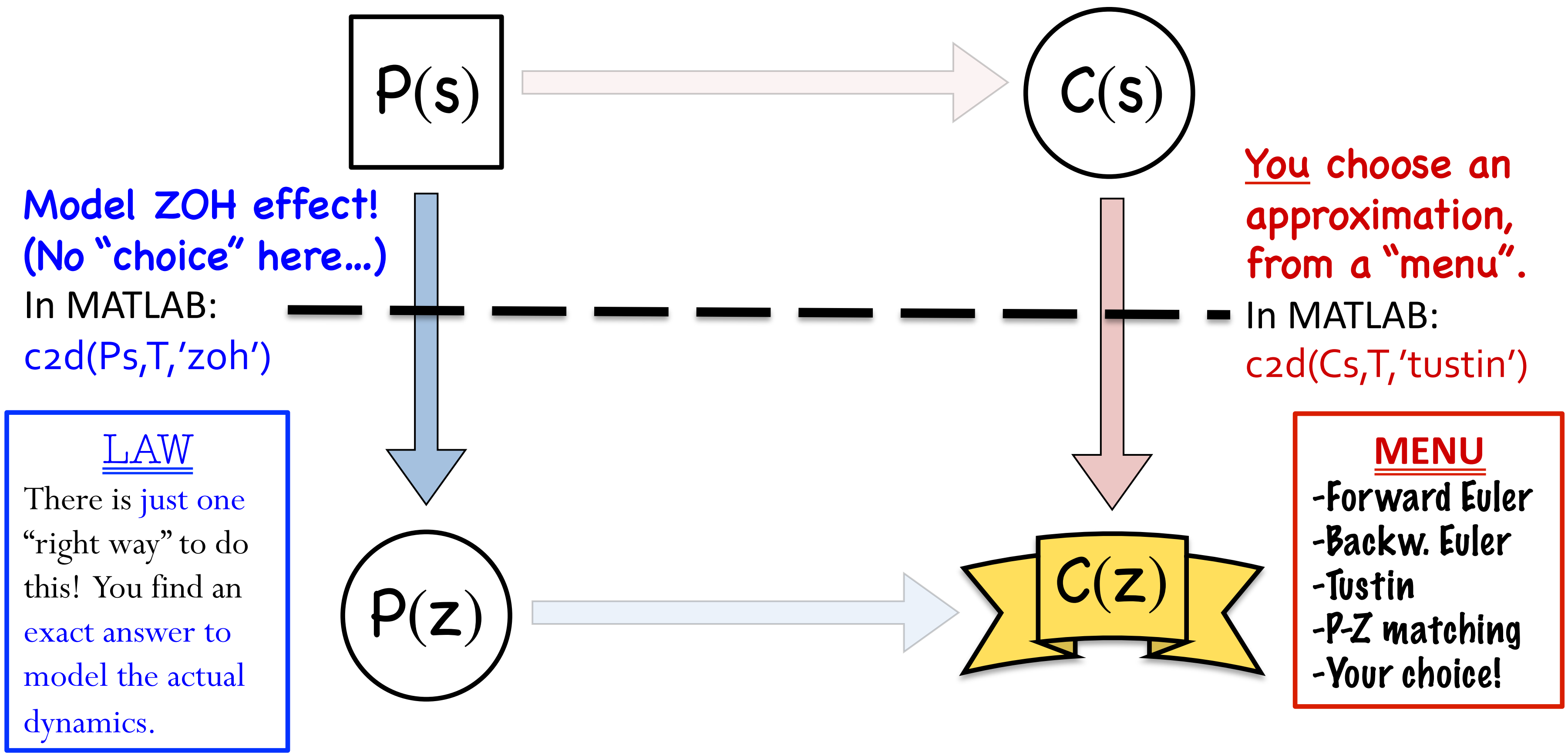
Digital Control Design Approaches

- We will look at two paths for design…



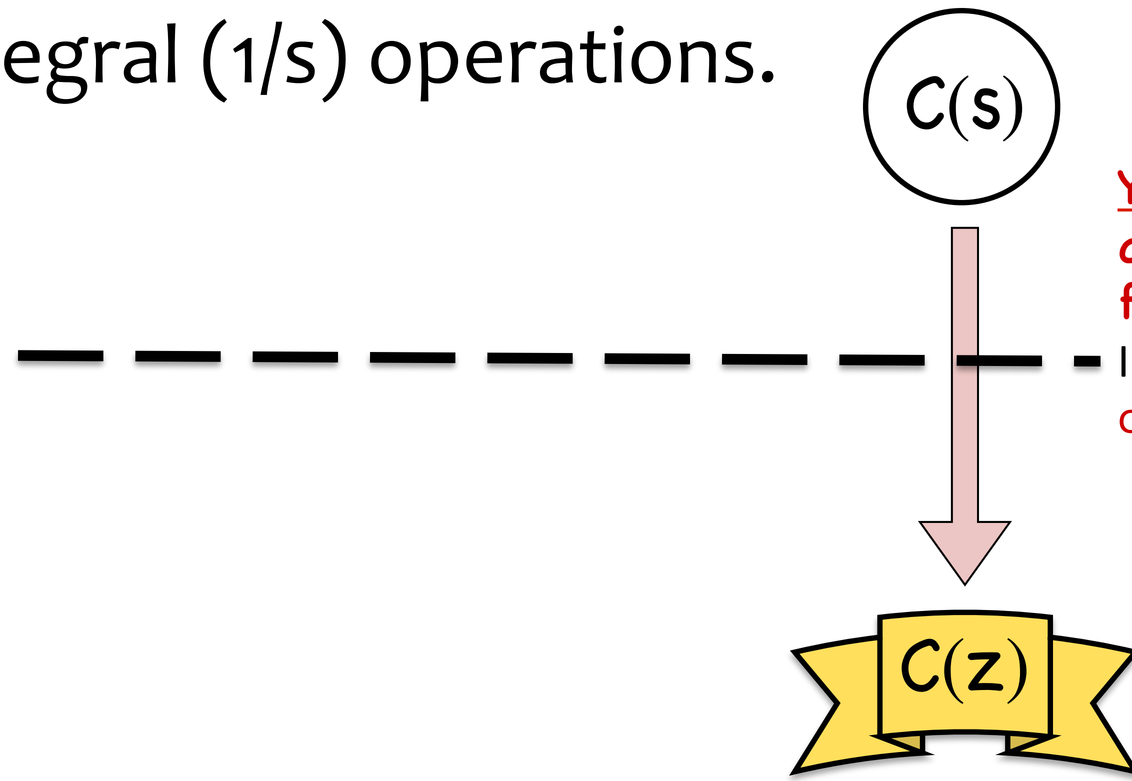
MATLAB c2d...

- There are two DIFFERENT ways we will convert a TF from CT to DT...



First, consider the "MENU"...

- To convert C(s) to C(z), you use a numerical approximation to estimate any derivative (s) or integral (1/s) operations.



You choose an approximation, from a "menu".

In MATLAB:

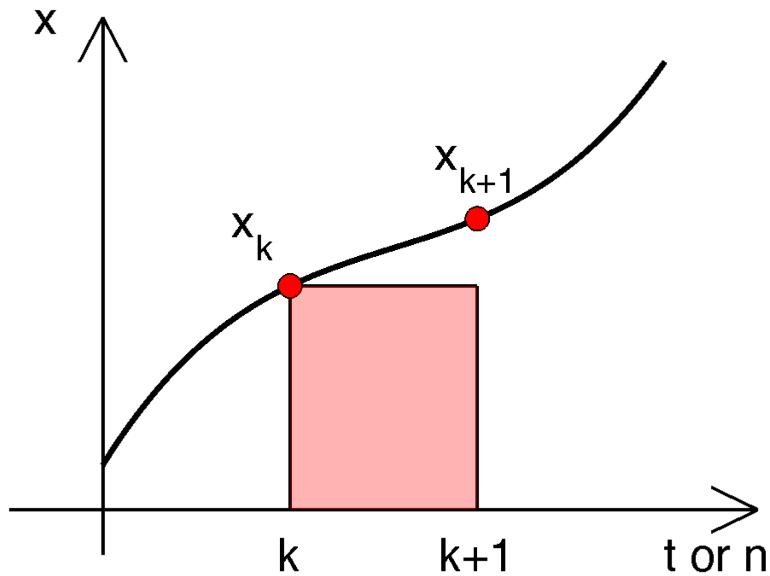
c2d(Cs,T,'tustin')

MENU

- Forward Euler
- Backw. Euler
- Tustin
- P-Z matching
- Your choice!

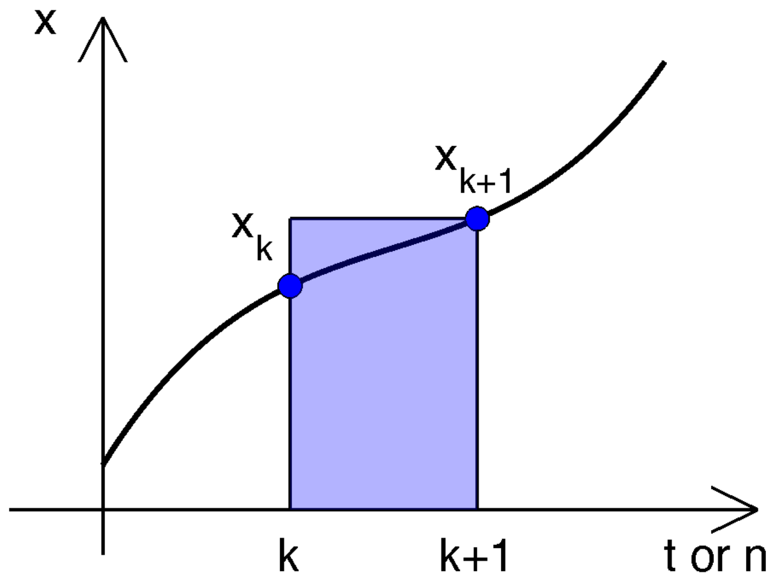
Forward Euler Approximation

- To approximate integration of x(t), draw a box going "forward" from x(k), as shown:



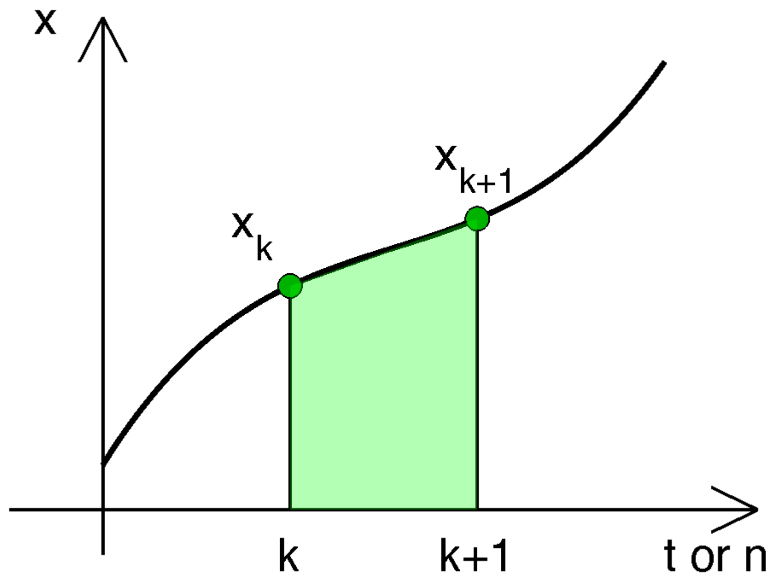
Backward Euler Approximation

- To approximate integration of x(t), draw a box going “backward” from x(k), as shown:



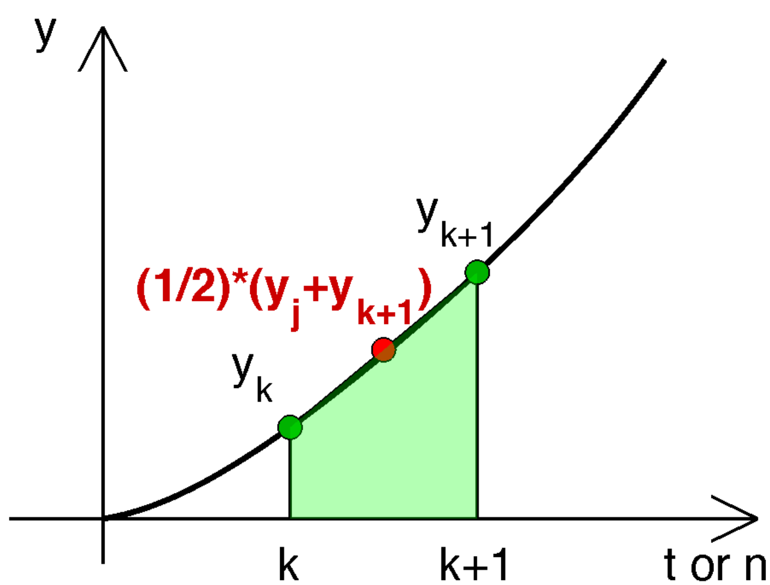
Tustin (aka bilinear [aka "Trapezoid Rule"])

- To approximate integration of x(t), draw a box using a trapezoid, as shown:



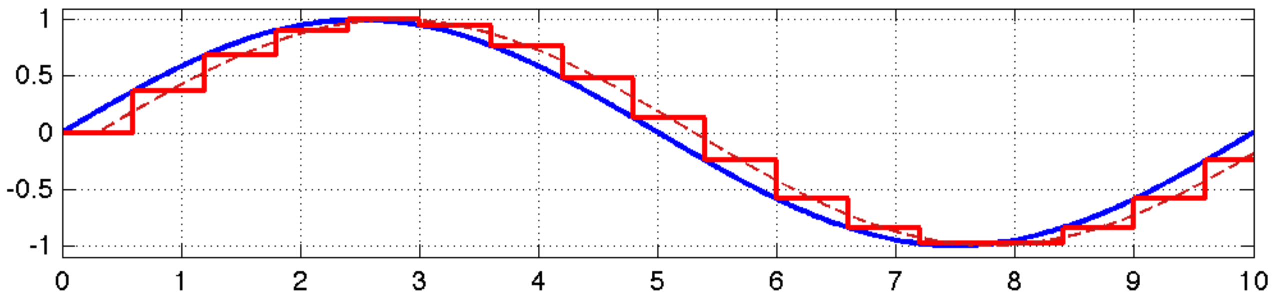
Another viewpoint: Approx. Differentiation

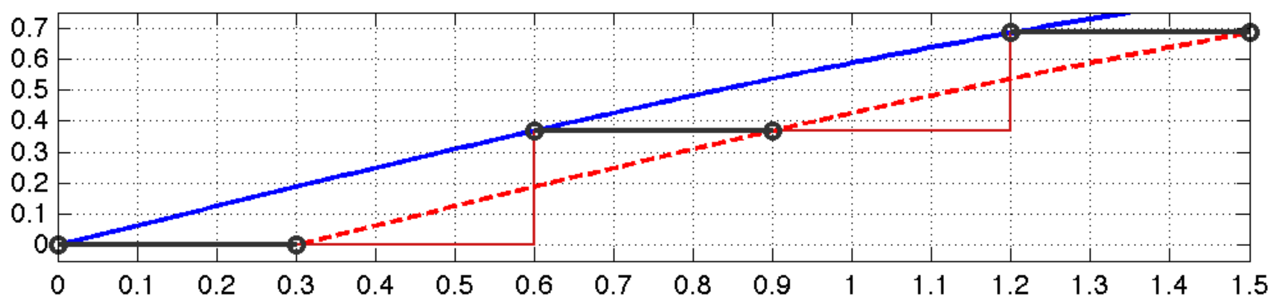
- To approximate differentiation of y(t), slope applies to midpoint between y(k) and y(k+1):



Sampling: Zero-Order Hold (ZOH)

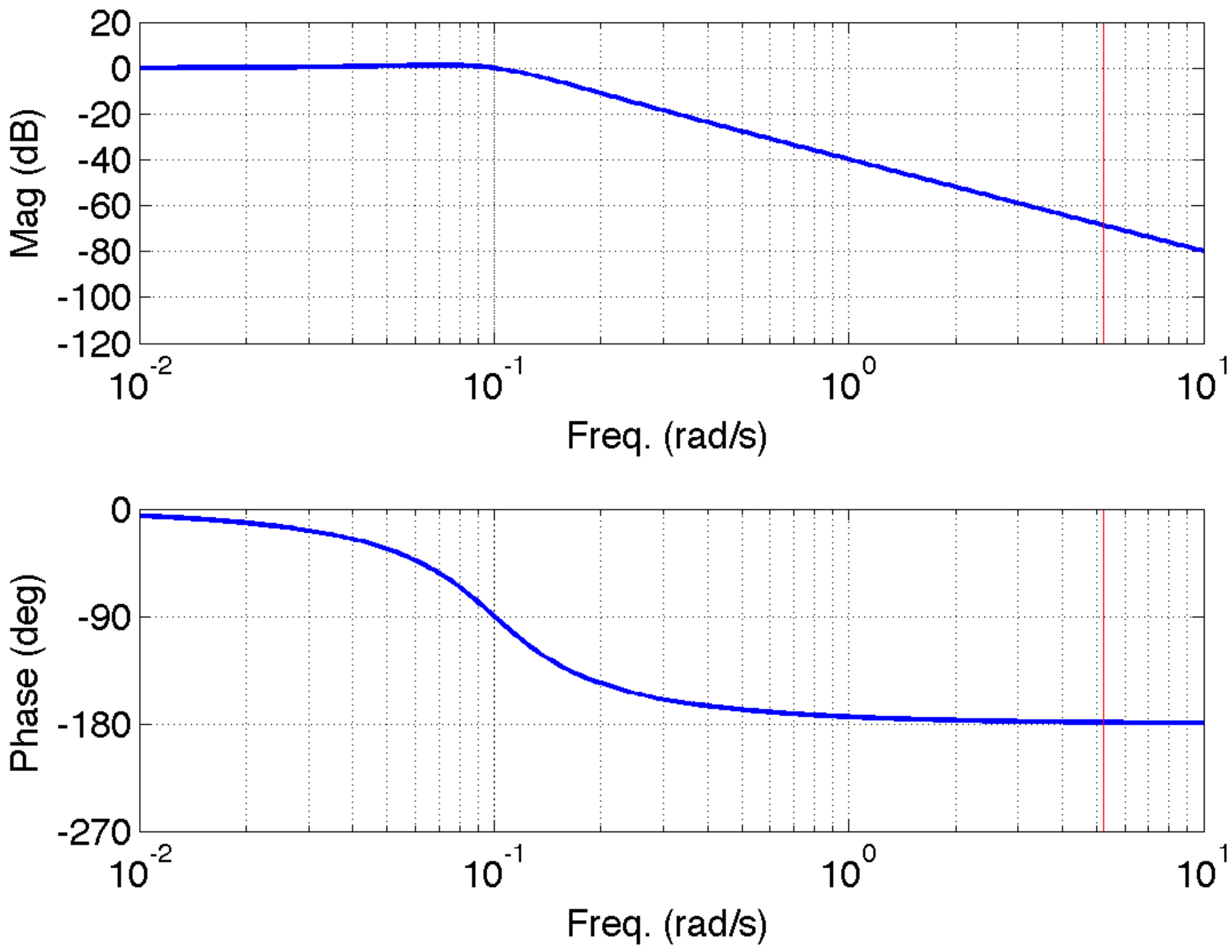
1. Fourier: CT signal can be broken into sinusoids.
2. After ZOH, the CT waveform of a sinusoid has the original (primary) freq plus higher freqs, too.
3. The primary freq sinusoid is now <u>shifted in time</u>…





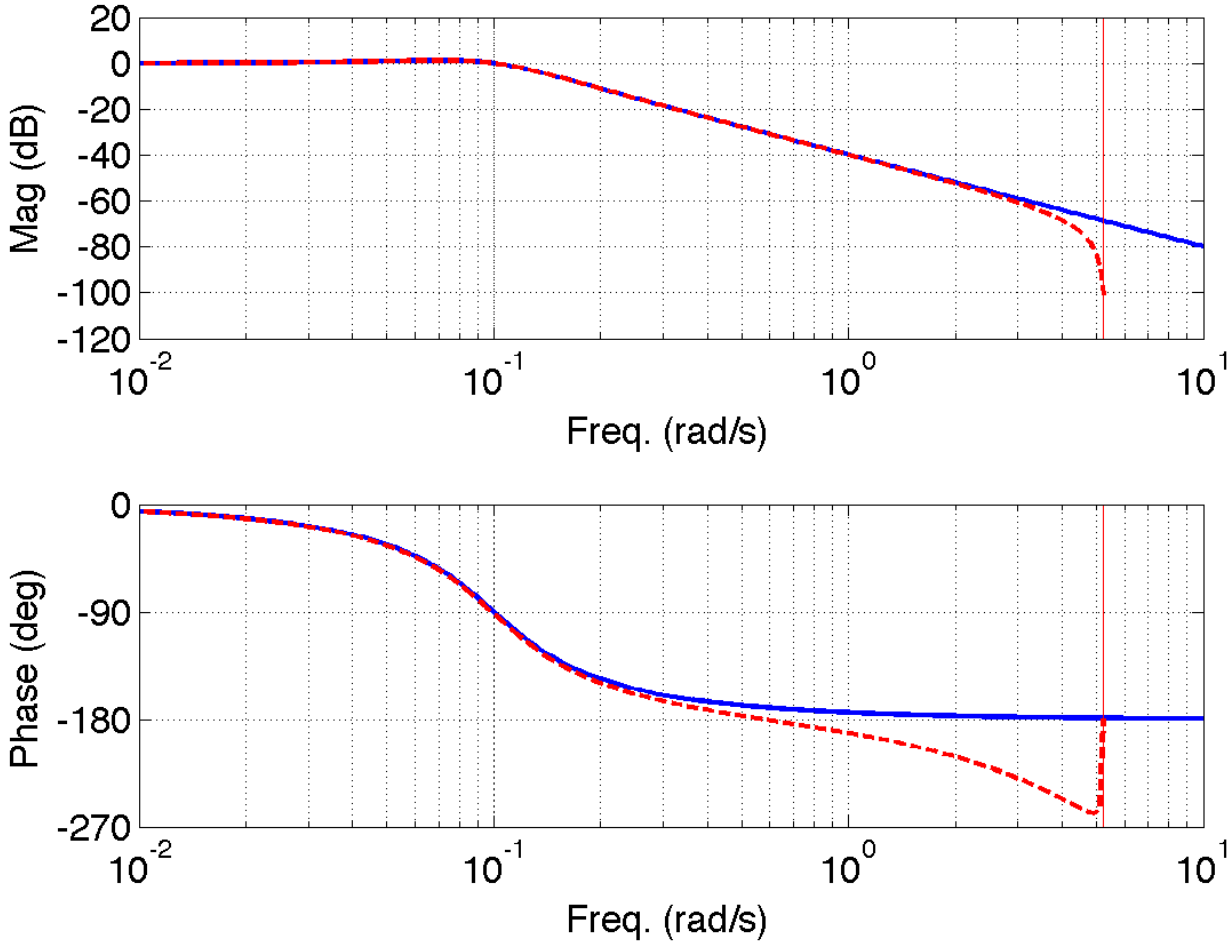
ZOH Consequences in FREQUENCY DOMAIN

- The PHASE LOSS due to half-sample delay may DESTABILIZE the closed-loop system!



ZOH Consequences in FREQUENCY DOMAIN

- But wait, G(z) at z=-1 (Nyquist) must be REAL-VALUED! i.e., phase of 0 or +/-180 deg.

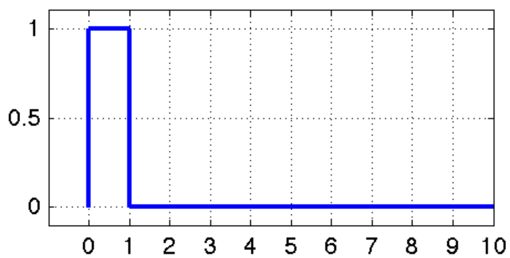


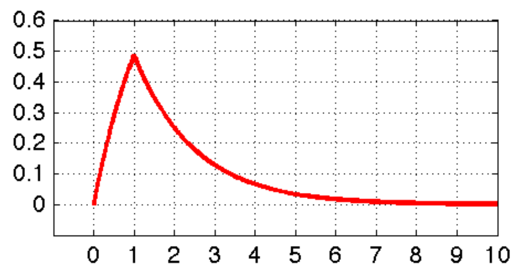
ZOH Equivalent, P(z)

$$P_{ZOH}(z) = (1 - z^{-1}) \cdot Z\left\{\frac{P(s)}{s}\right\}$$

Zero-Order Hold Equivalent:

- u(k) gives a "pulse", to be integrated over "T".





- ZOH into P(s), then sampled (rate T) EQUAL P(z).