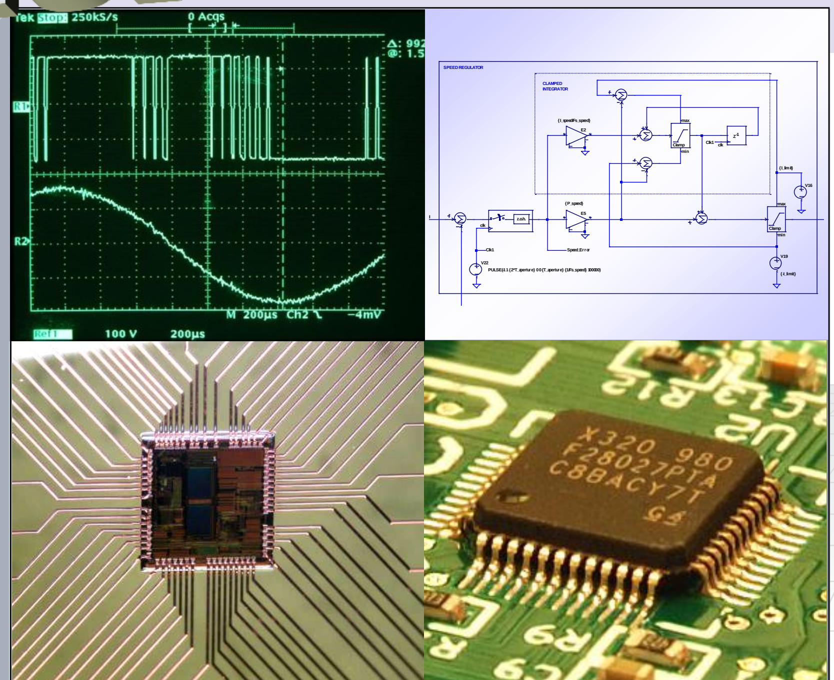
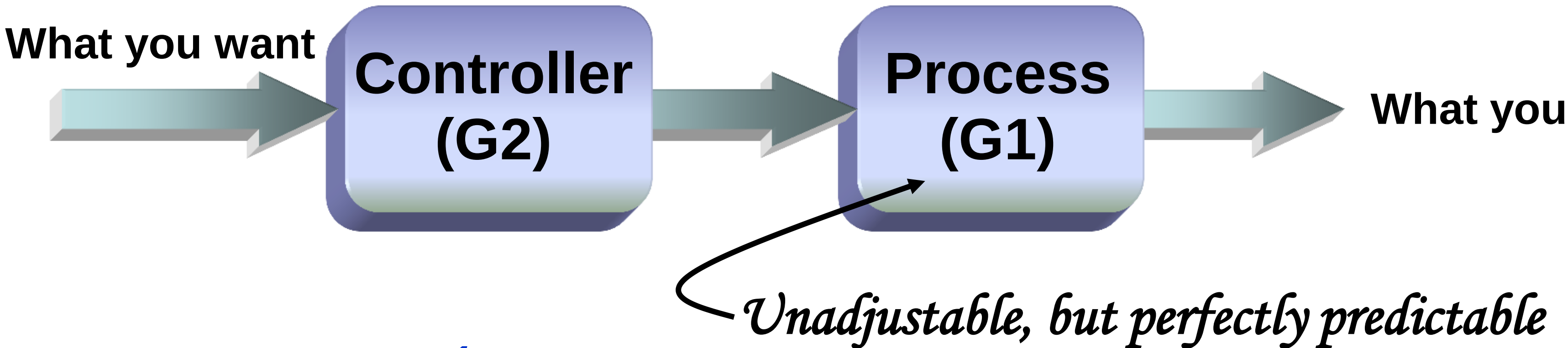
Teaching Old Motors New Tricks



Dave Wilson

Texas Instruments

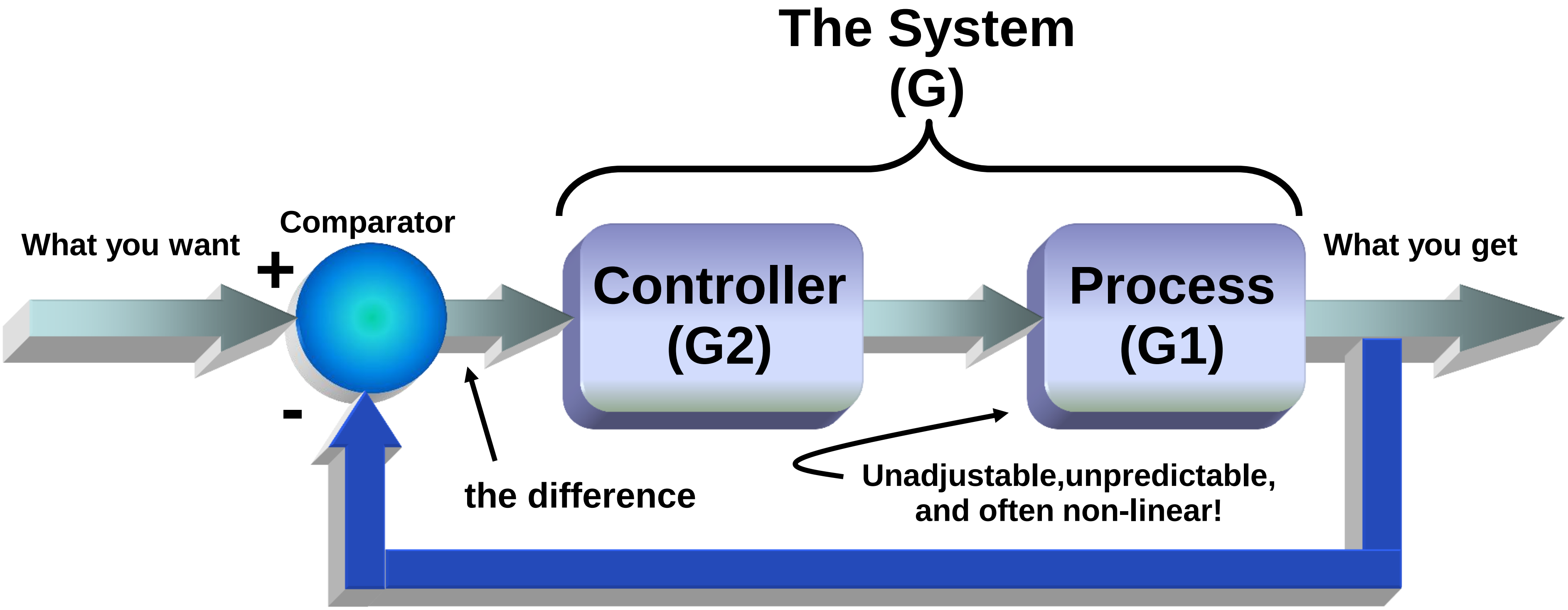
Feed-Forward Approach



$$G2 = \frac{1}{G1}$$

Everything is beautiful and linear!

Feedback Approach

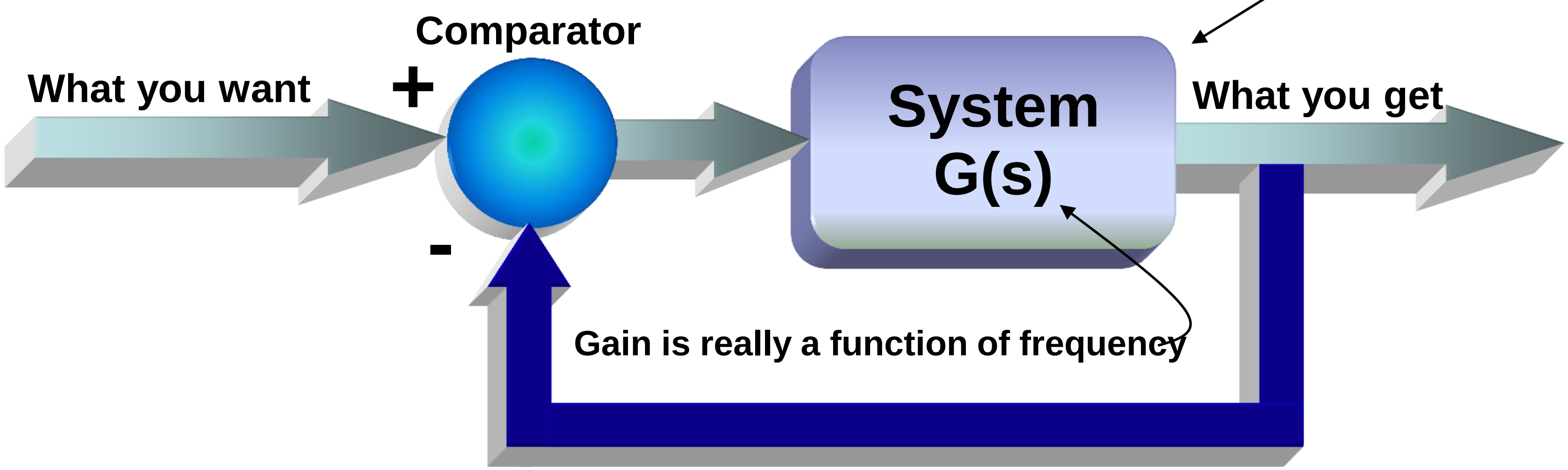


$$\text{What you get} = \left(\text{What you want}\right)\left(\frac{G}{1+G}\right)$$

What if G = 1? What about 100?

Frequency Response of a Feedback Loop

Every system in nature has poles in its transfer function



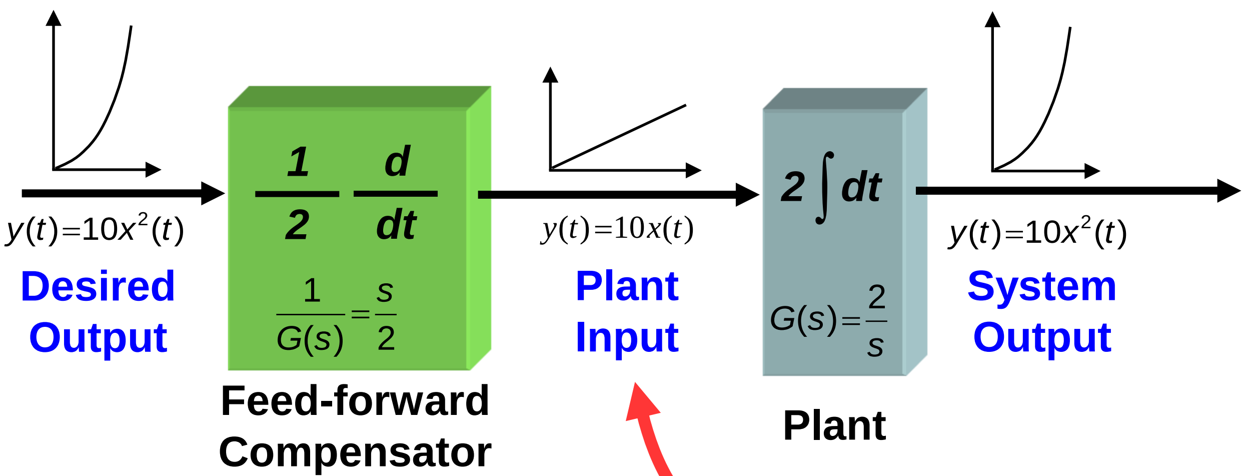
Poles negatively impact the control system in the following ways:

1. Gain is reduced at higher frequencies
2. Phase delay is introduced (90º for every real pole)

What happens if the phase delay = 180º and gain = 1 ?

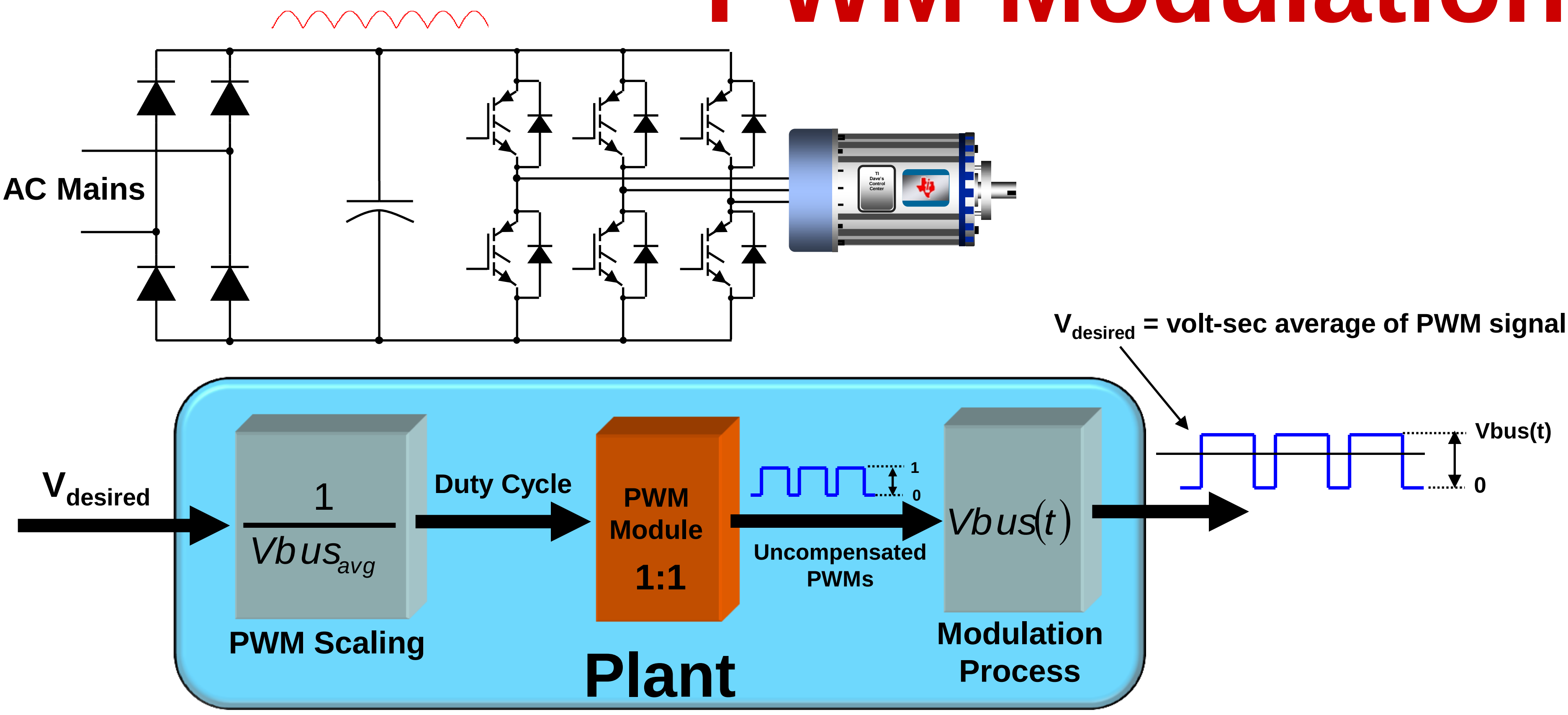
Designing a Feed-Forward Compensator

Example:



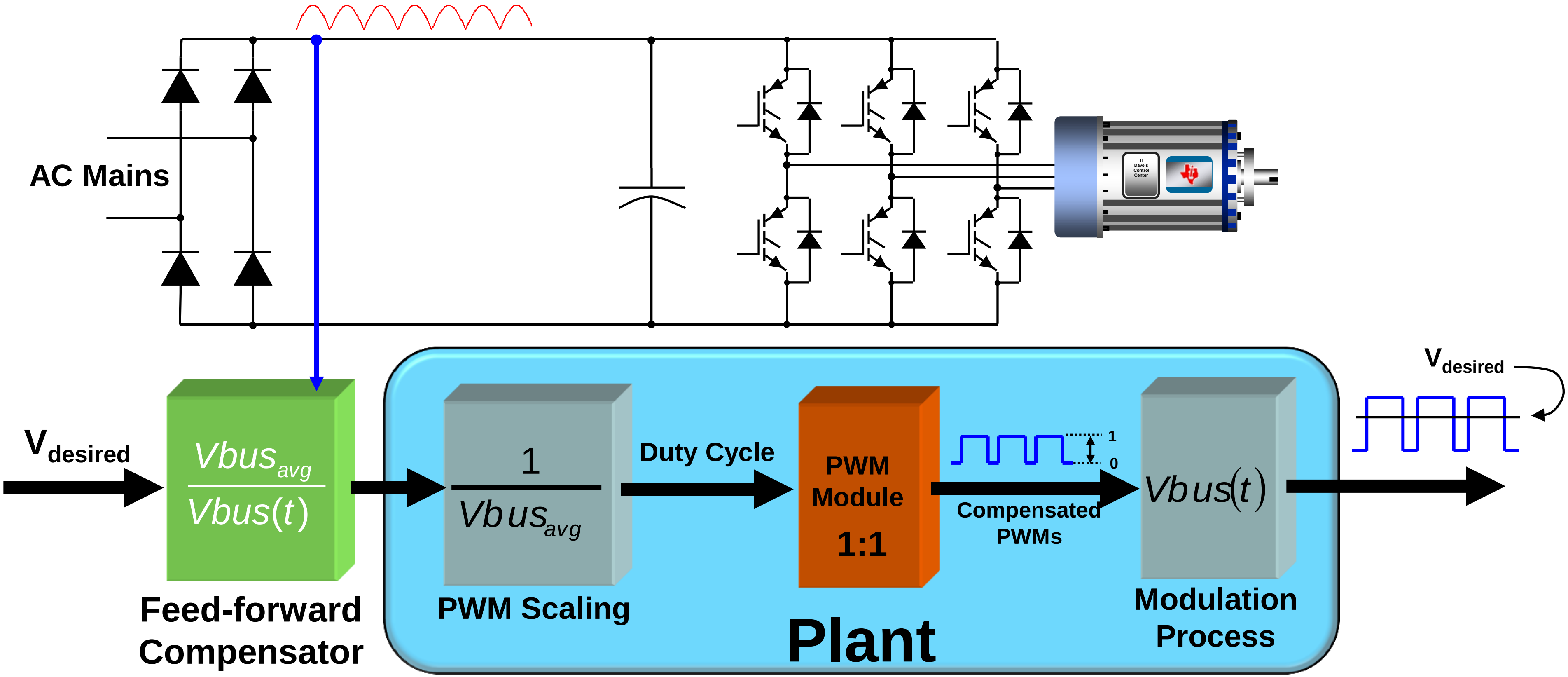
The thought process goes something like this: *"To achieve a desired output, what stimulation signal is required at the plant input to get that output? By knowing the plant transfer function in the forward direction [G(s)], I find the transfer function looking backwards through the plant [1/G(s)], and that becomes the transfer function of my feedforward filter."*

Real Feed-Forward Example: PWM Modulation

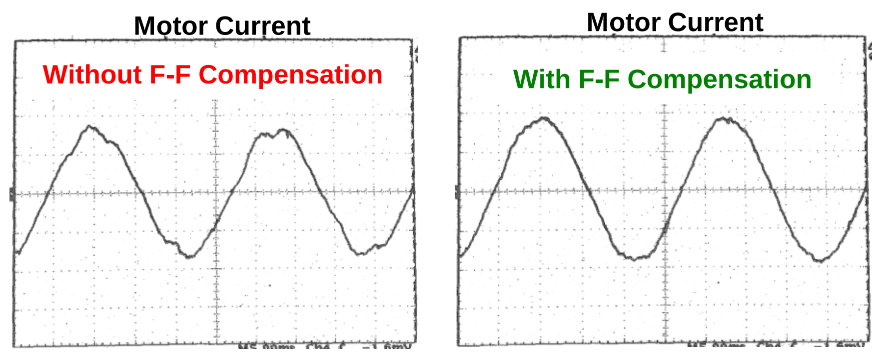


When Vbus(t) is equal to $Vbus_{avg}$, then “what you want” and “what you get” are equal. However, when they are NOT equal, the output deviates from the desired input.

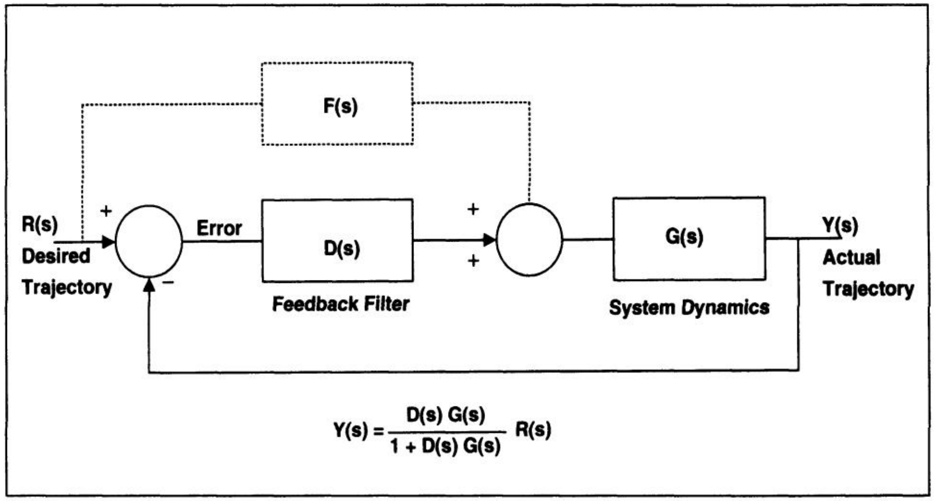
Solution: Feed-forward Compensation



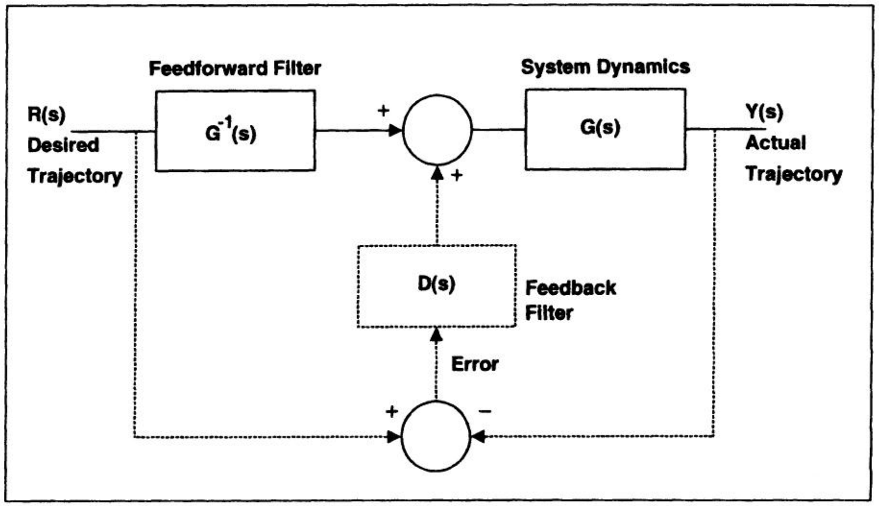
When you multiply through the gain blocks, you will see that the composite gain = 1, which again implies that "what you get" equals "what you want".



Feedback or Feedforward… Which is Best?



Feedback Philosophy.



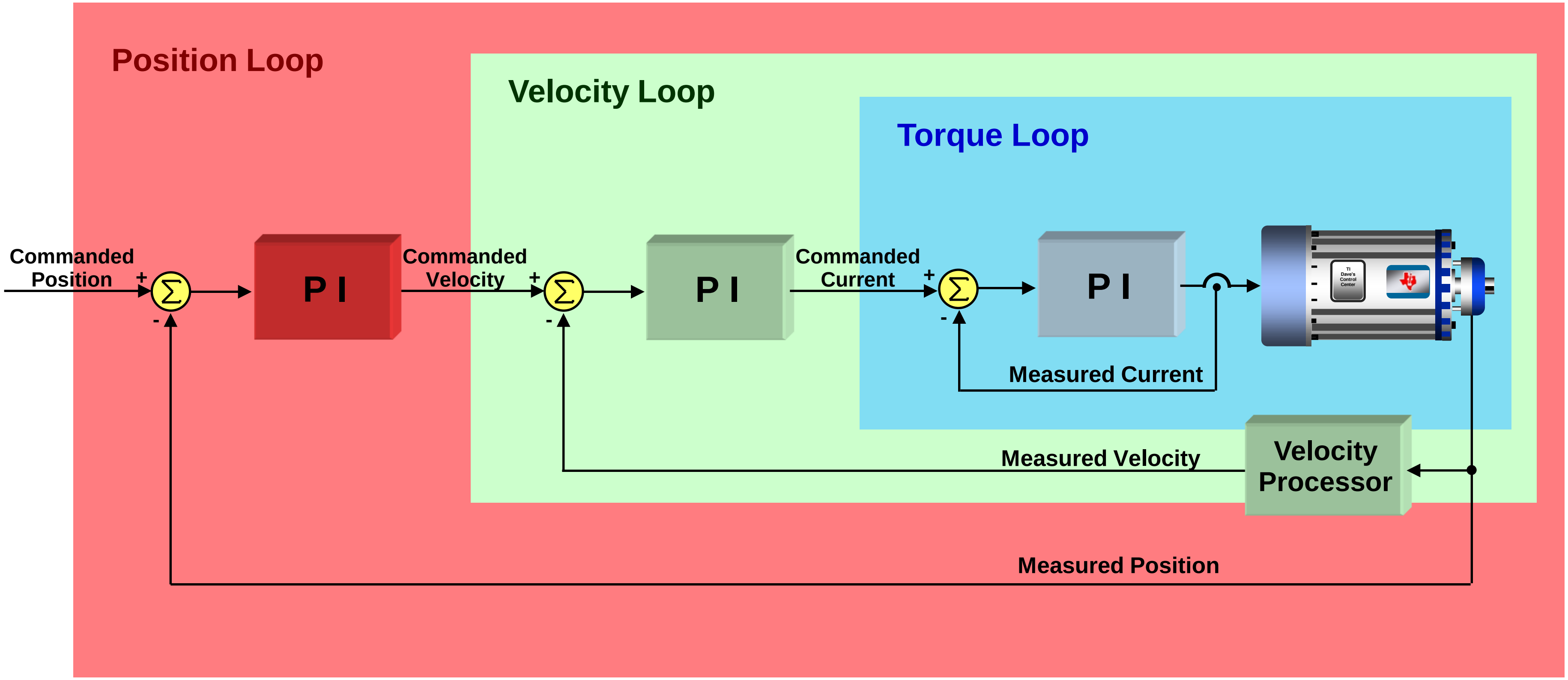
Feedforward Philosophy.

More traditional approach
Best for disturbance rejection

Better stability
Best for trajectory tracking
Requires System Dynamics Knowledge

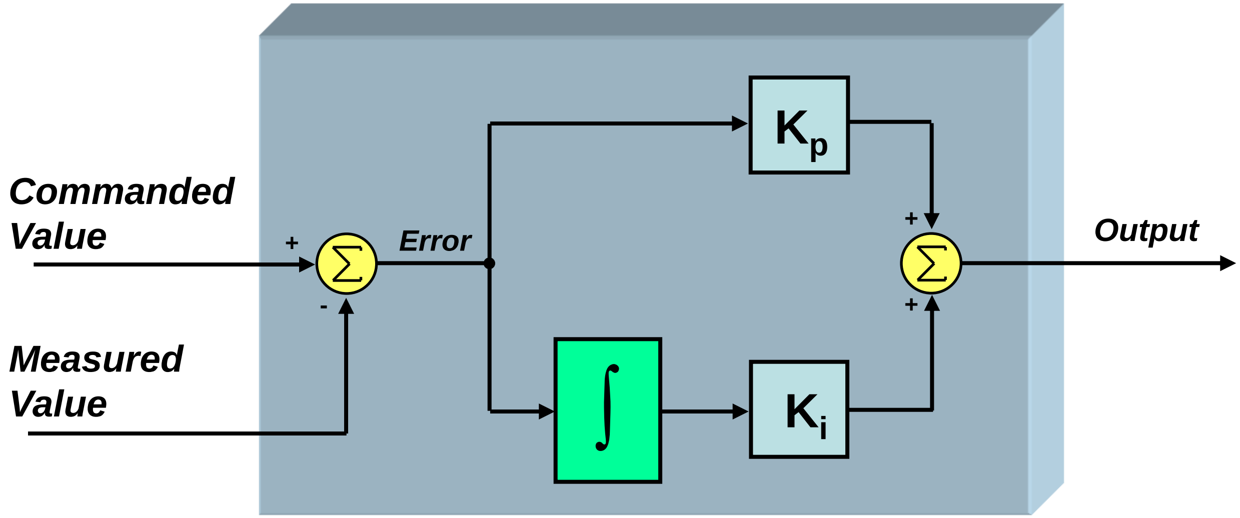
Source: Myths and Realities of Feedforward for Motion Control Systems, Curtis Wilson, Delta Tau Data Systems, PCIM – August, 1994

Cascaded Control Structures



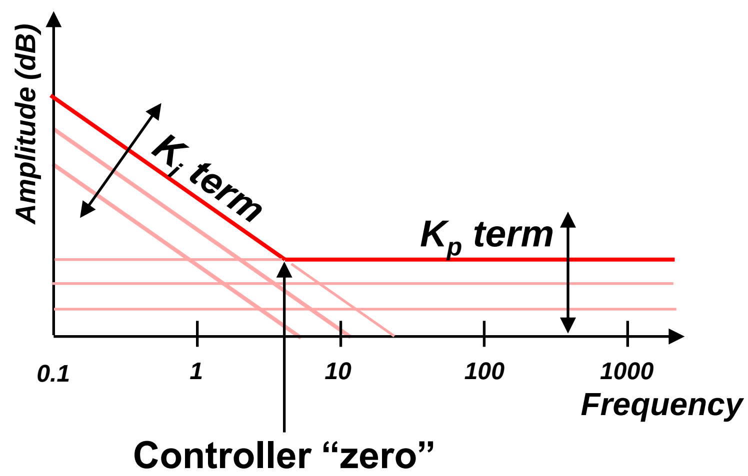
What do you think the bandwidth requirements are for each cascaded loop?

Parallel PI Controller

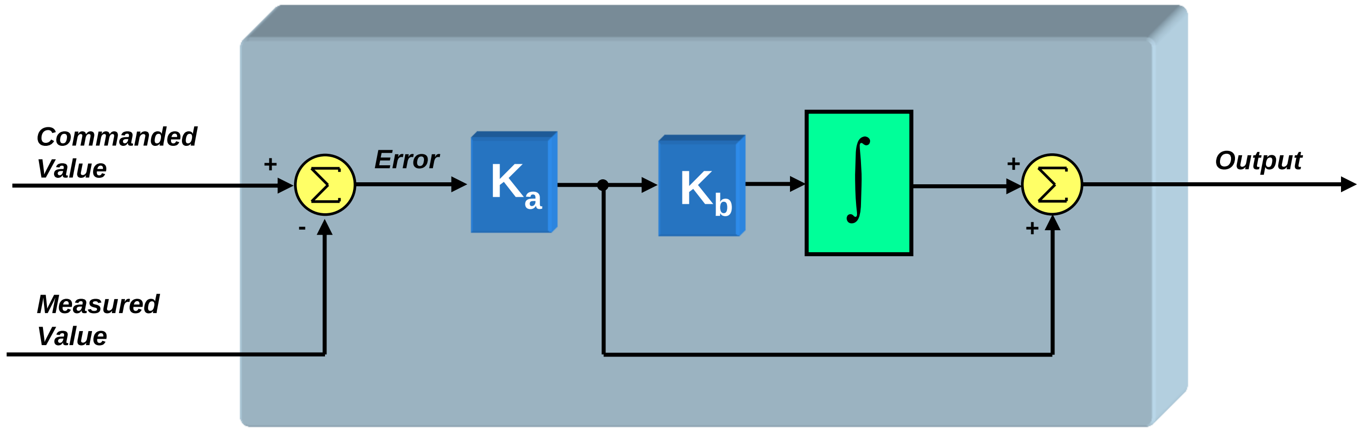


K_p term specifies the gain at higher frequencies

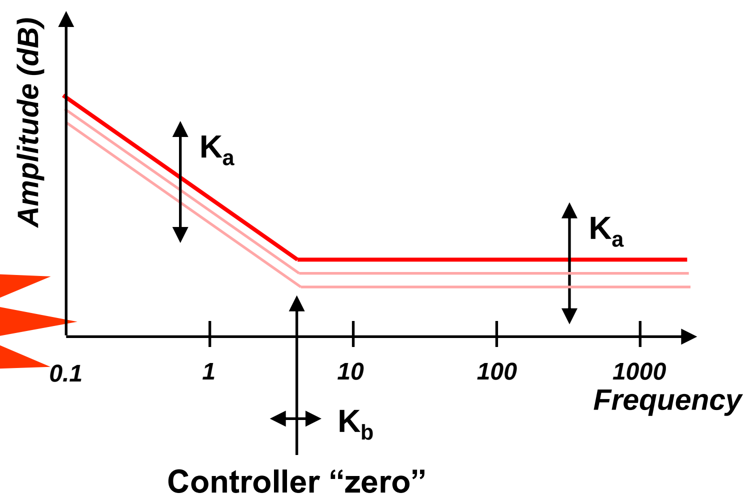
K_i term specifies the gain at lower frequencies



Series PI Controller



K_a is simply a gain term for all frequencies
K_b is equal to the controller's "zero" in rad/sec

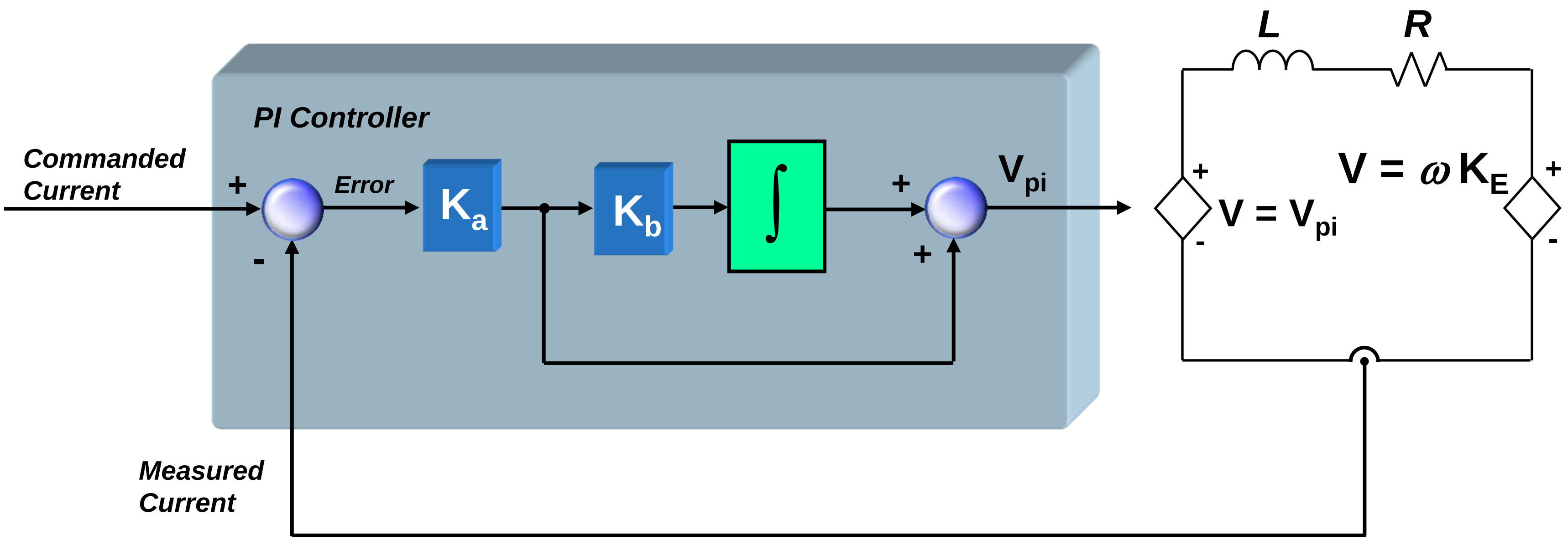


Popular with Current Contollers

$$K_a = K_p$$

$$K_b = \frac{K_i}{K_p}$$

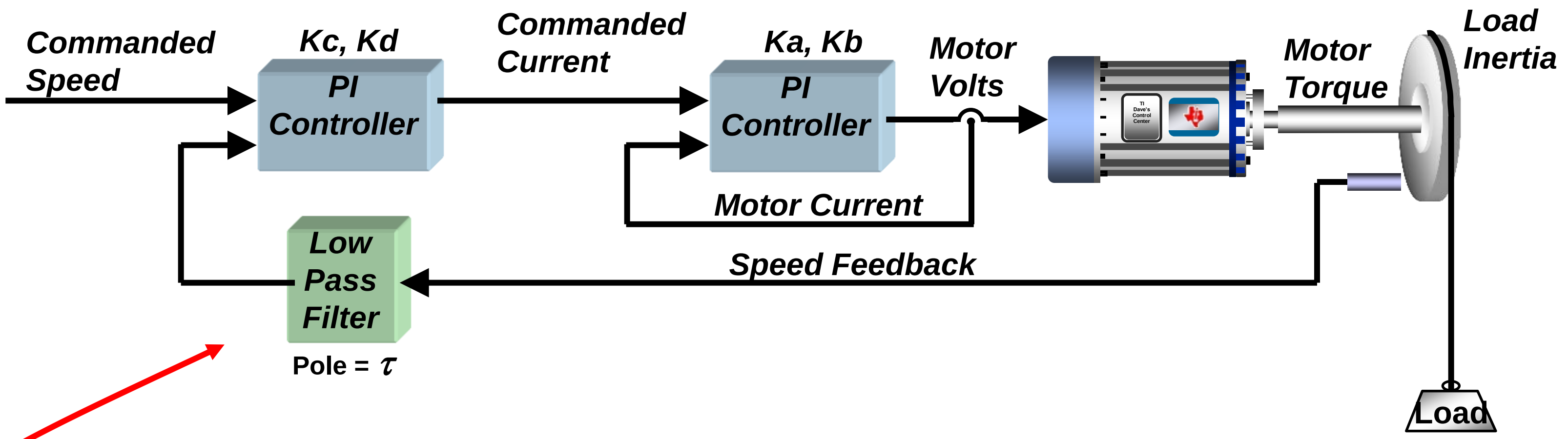
Current PI Controller Coefficients



$$K_a = L \cdot Current\ Bandwidth\ (rad/\sec),\quad K_b = \frac{R}{L}$$

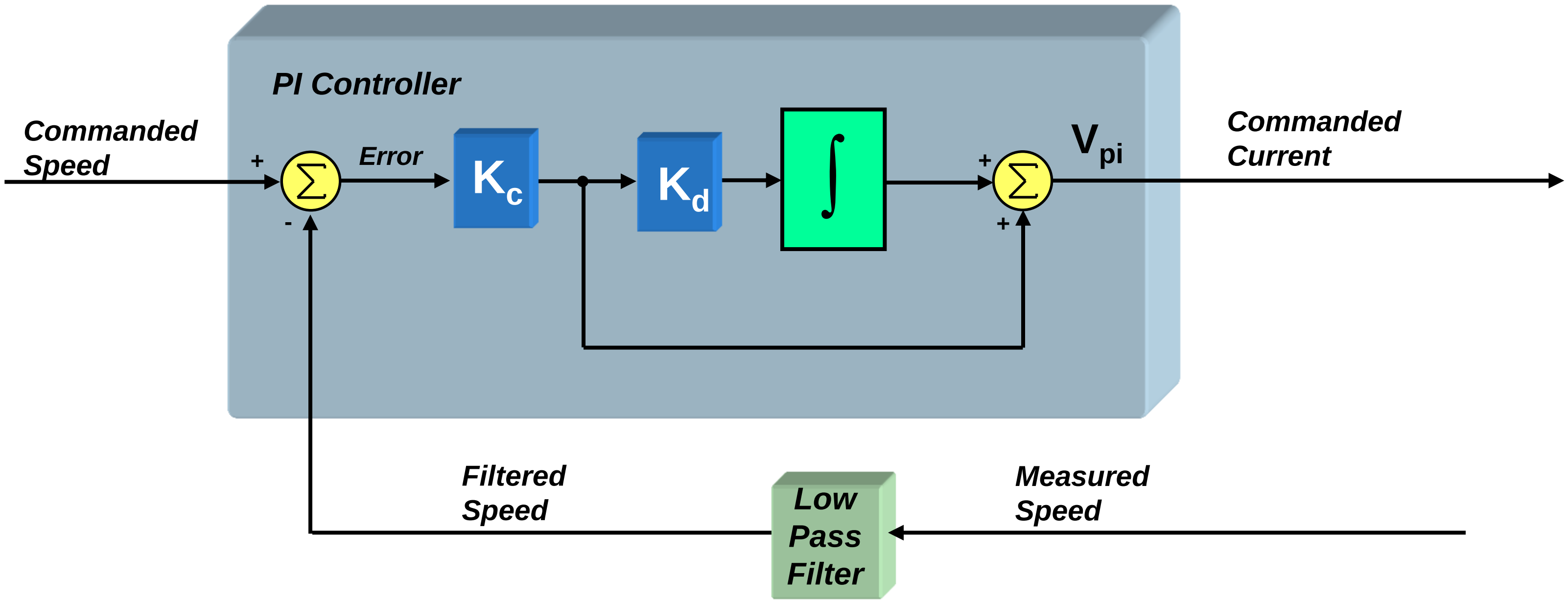
Motor	Rd	Rq	Ld	Lq
PMSM	*Rs*	*Rs*	*Ls*	*Ls*
ACIM	*Rs*	*Rs+Rr*	$L_s\left(1-\frac{L_m{}^2}{L_r L_s}\right)$	$L_s\left(1-\frac{L_m{}^2}{L_r L_s}\right)$
IPM	*Rs*	*Rs*	*Ls_d*	*Ls_q*

Cascaded Velocity Controller



Due to the techniques used for velocity feedback synthesis, the velocity signal must be filtered in most cases.

Velocity PI Controller Coefficients



Pole = τ

$$K_c = \frac{1}{\delta K \tau}, \quad K_d = \frac{1}{\delta^2 \tau}$$

$$K = \frac{3PK_e}{4J}$$ ***for permanent magnet motors***

$$K = \frac{3}{4} P \frac{Lm^2}{J\,Lr} I_d$$ ***for AC Induction motors***

K_e = Back-EMF constant

P = Number of motor poles

J = System Inertia (as seen by the motor)

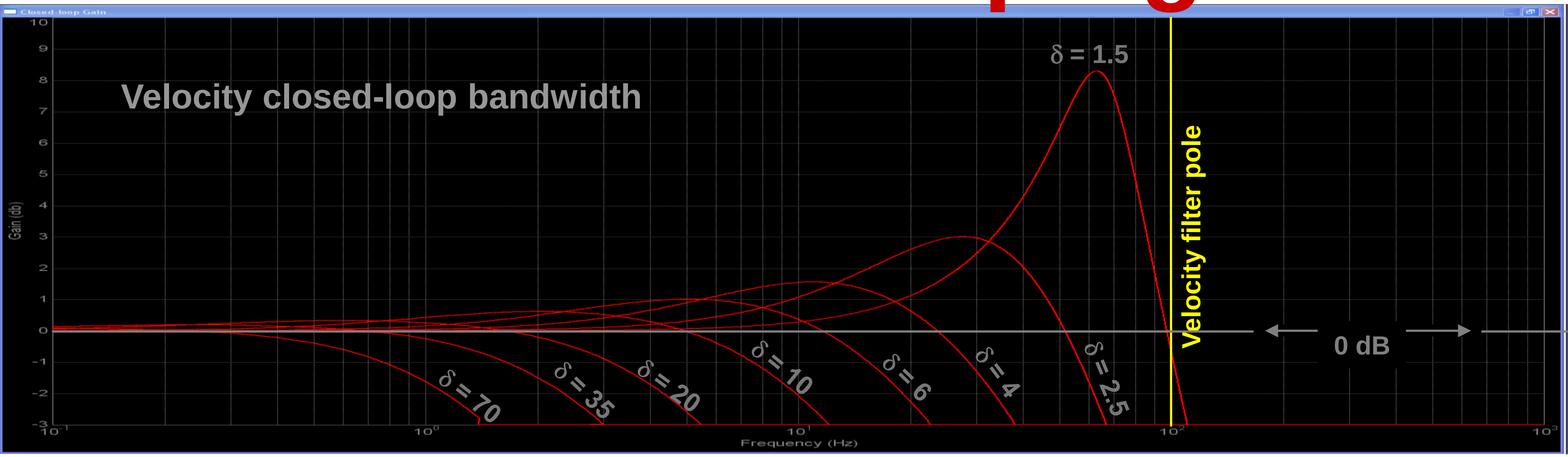
τ = LPF Pole

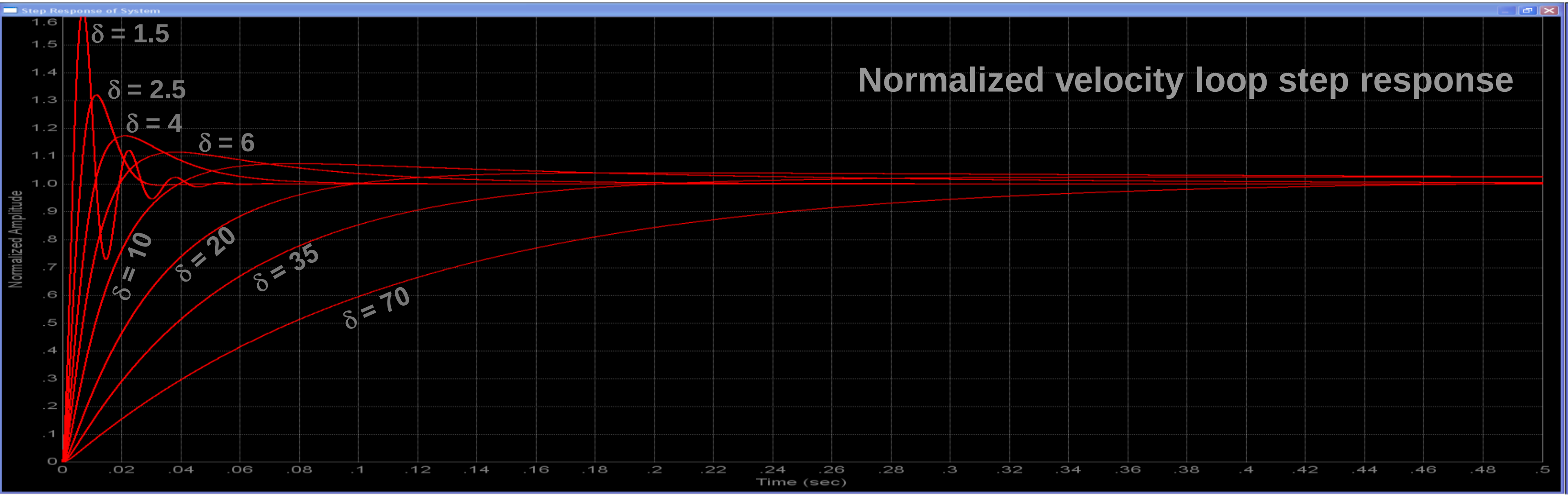
δ = the Damping Factor

Single tuning adjustment!

(Equations assume that the Current Controller closed-loop bandwidth is greater than 3τ)

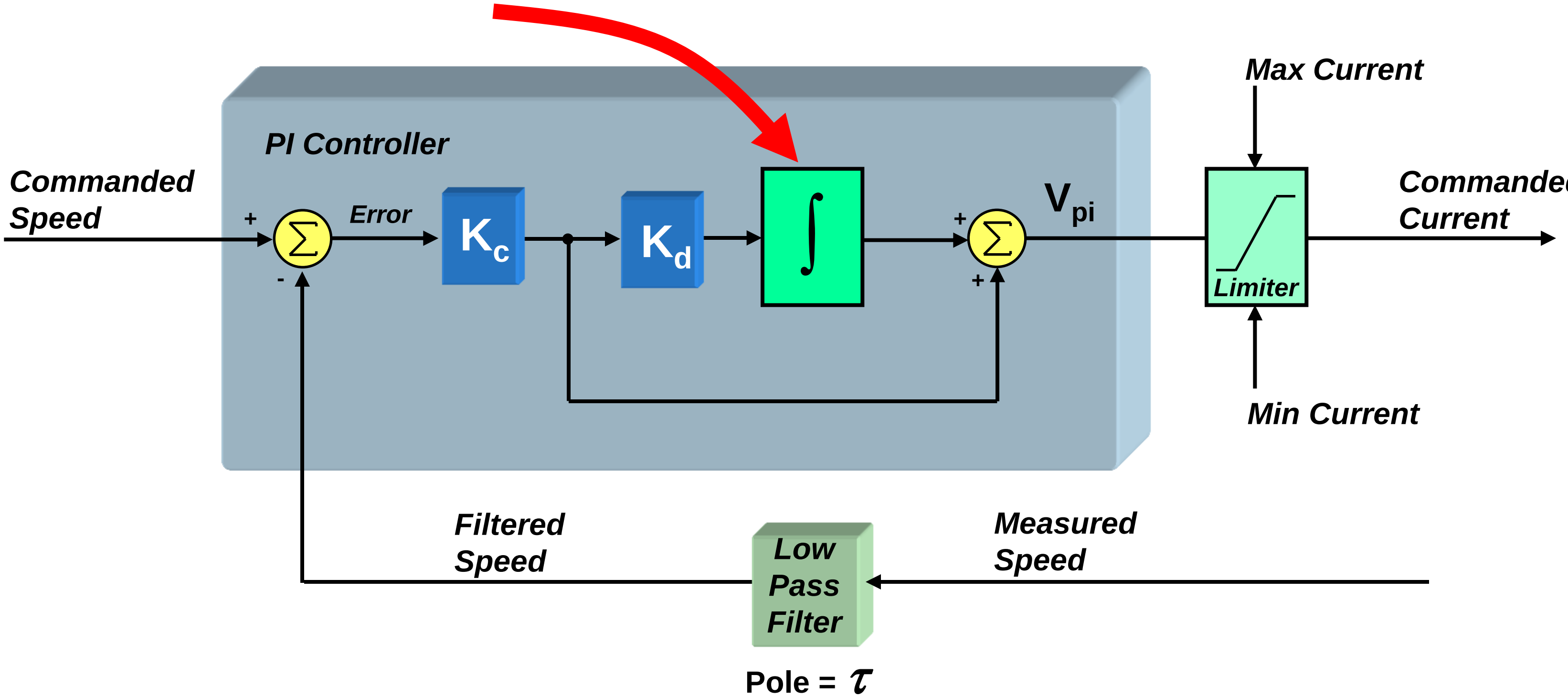
Damping Factor



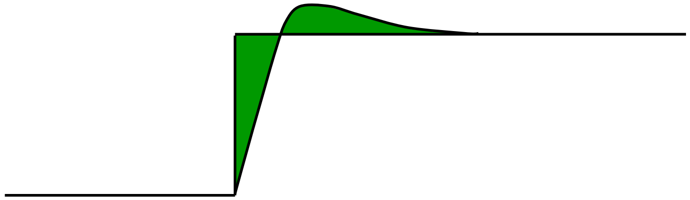


For more information on PI tuning, read my blog series at www.ti.com/motorblog

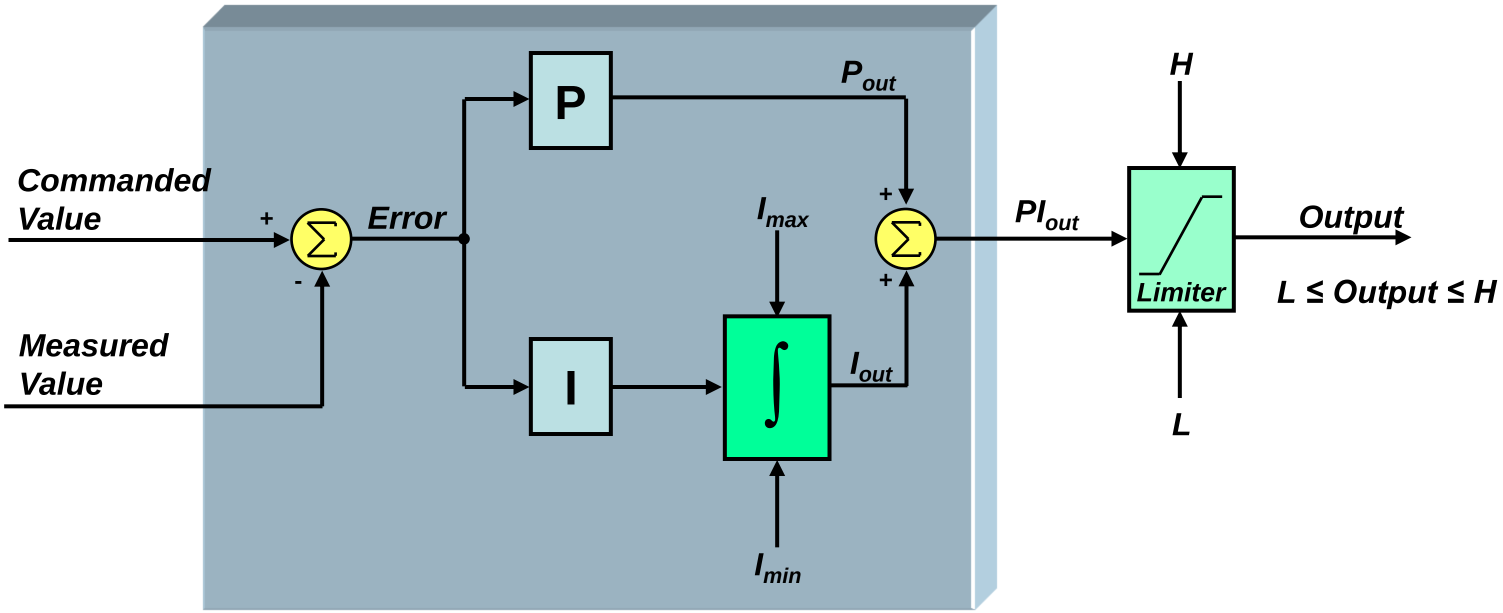
Integrator Windup



Unfortunately, the Integrator exhibits "windup" under sudden transient conditions.

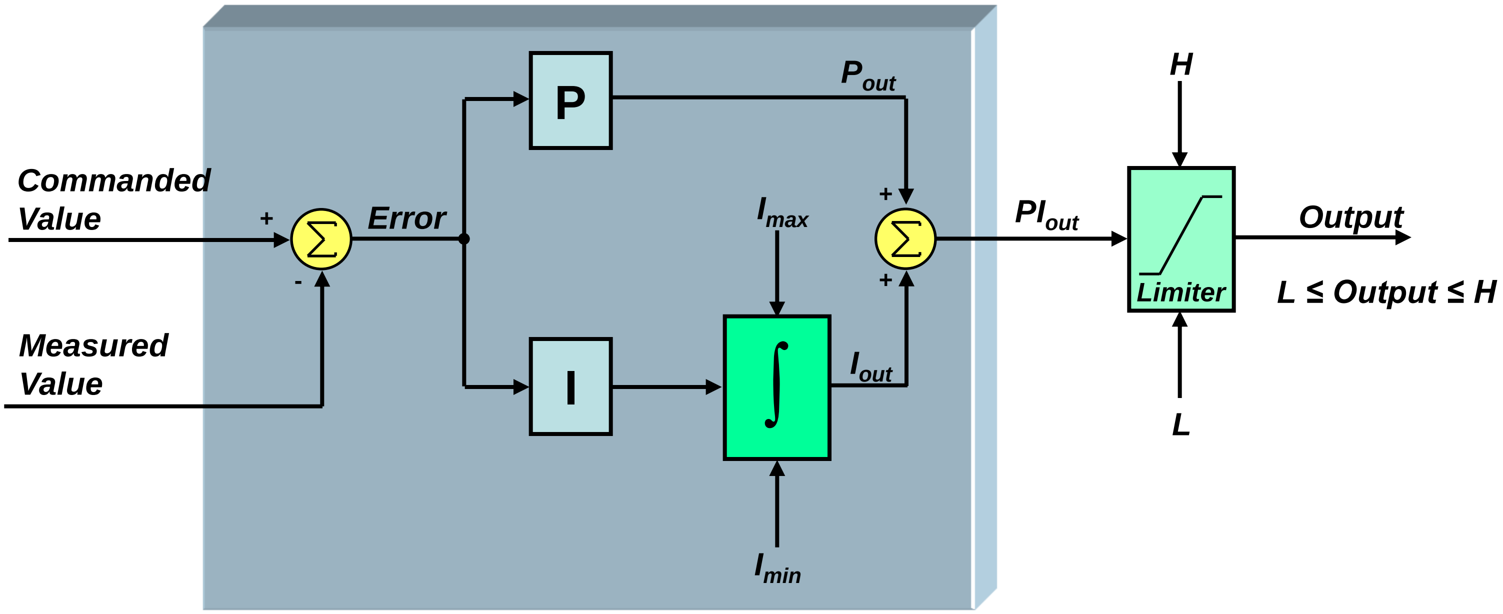


Simple Static Integrator Clamping



$$I_{min} = L, I_{max} = H$$

Dynamic Integrator Clamping

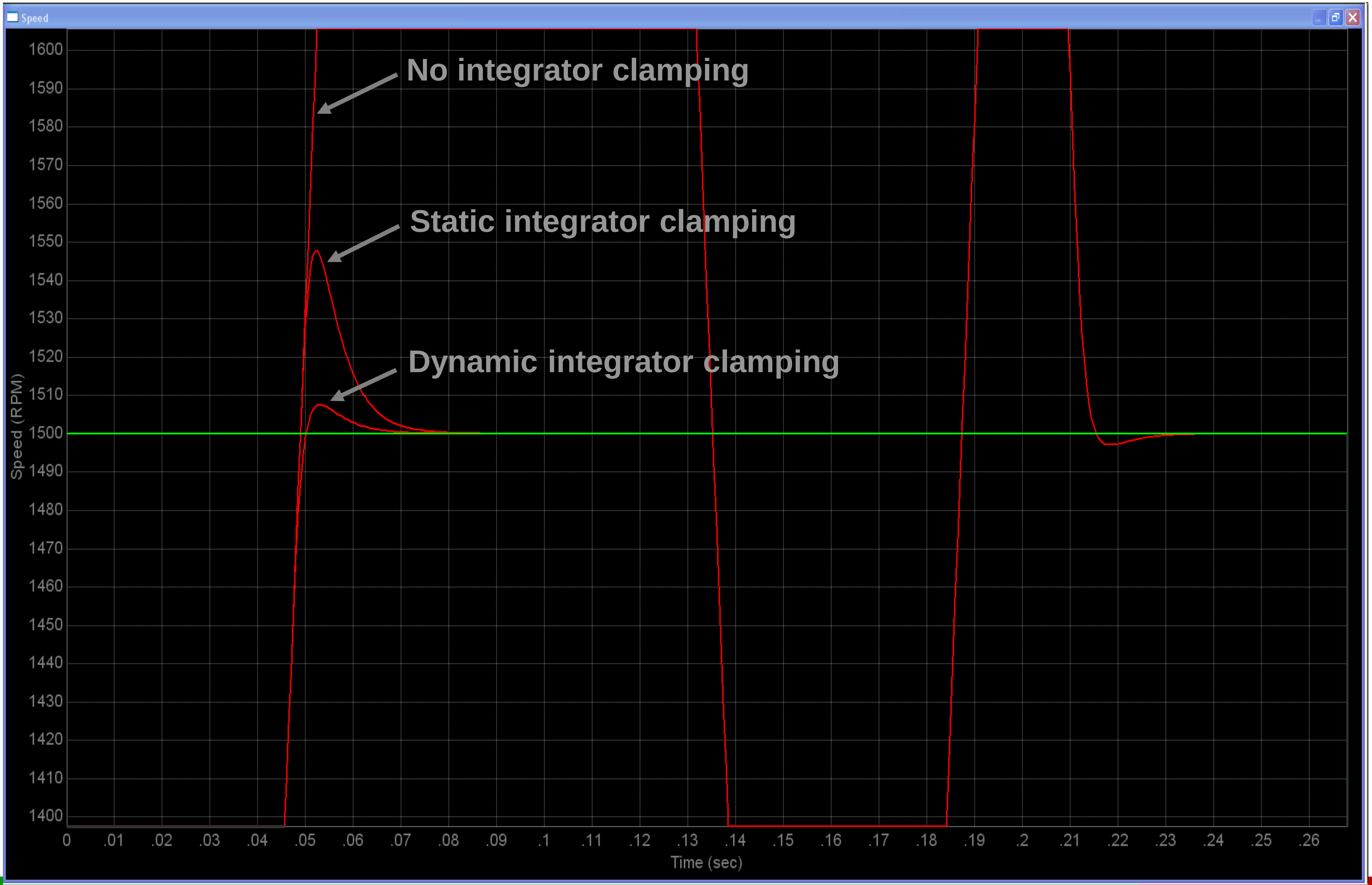


$$L \le P_{out} + I_{out} \le H$$

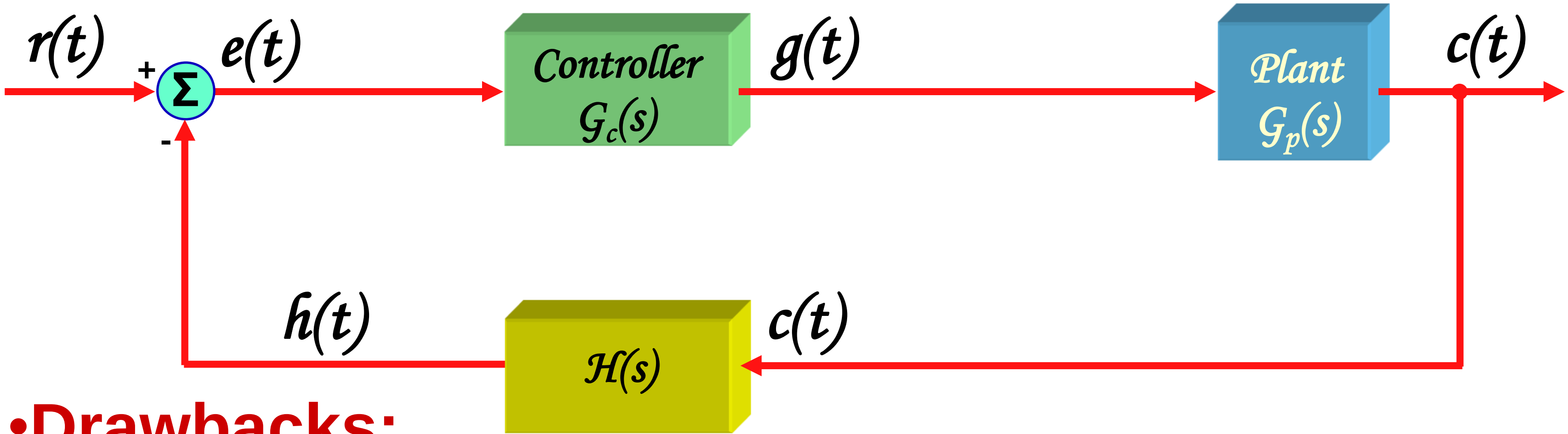
for minimum condition: $L = P_{out} + I_{min} \rightarrow I_{min} = Min(L - P_{out}, 0)$

for maximum condition: $H = P_{out} + I_{max} \rightarrow I_{max} = Max(H - P_{out}, 0)$

Comparison of Clamping Techniques



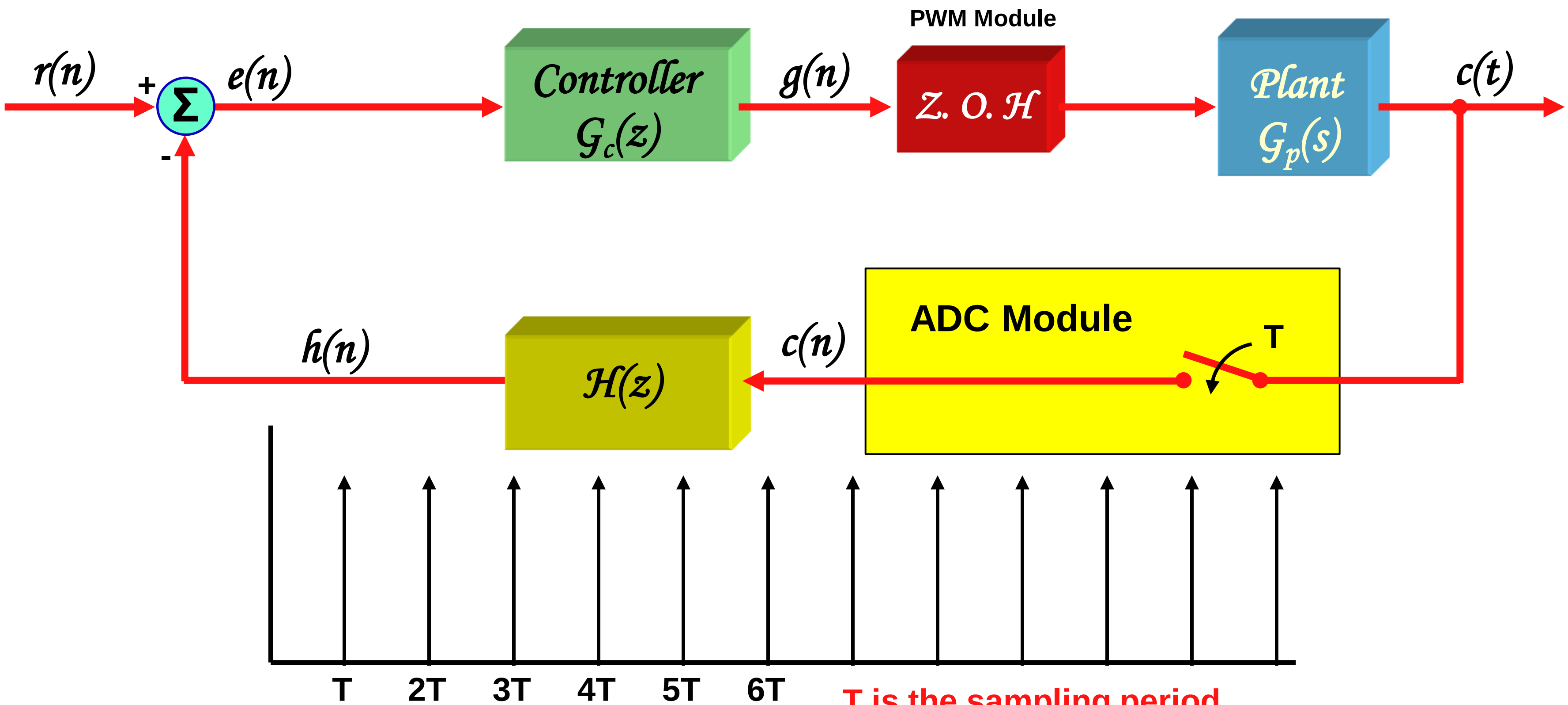
Typical Analog Control System



•Drawbacks:

- Low noise immunity
- Filter characteristics change with temperature
- Little flexibility
- Component aging
- Power supply variation
- Lot-to-lot manufacturing
- Requires adjustments
- Critical component specification, especially for high order filters

Typical Digital Control System



T is the sampling period
(Inverse of sampling frequency)

In most digital controllers, the control block ($G_c(z)$) is implemented as an IIR filter to minimize phase delay.

The 10 Commandments of Digital Control

There are 10 facts of life about digital control systems that your mother never told you!

If you can handle the truth, read about them on my blog site: www.ti.com/motorblog