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Control Systems Introduction AD1

v2

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ECE 460/560

Embedded System Architectures

Slide 1

AD1 To Do:
- Currently LED-specific. Retarget to motor control?
- Redraw diagrams on pp. 10-11

Alex Dean, 2024-11-12T15:33:57.870

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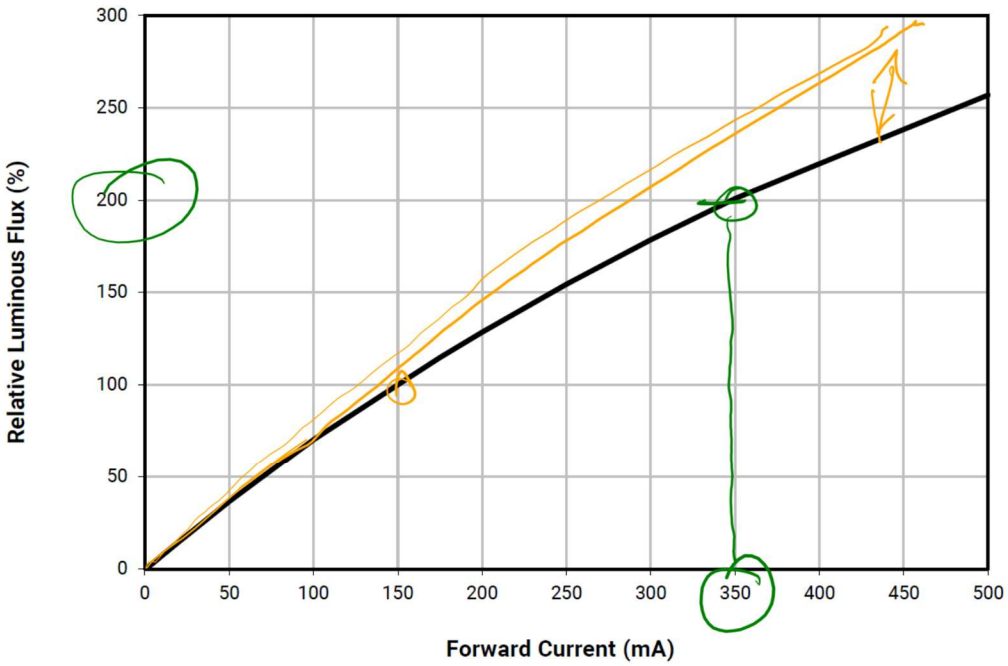
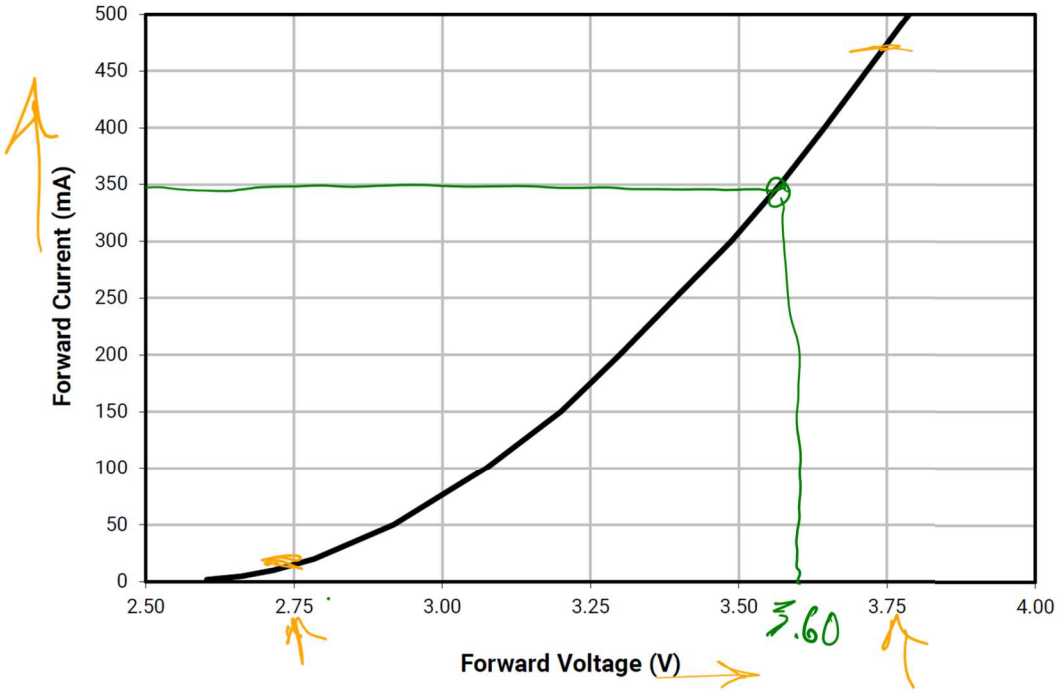
LED Basics



- Light output increases with forward current
  - Not quite linear



- Forward current increases with forward voltage V_F
  - Exponential relationship between V_F and I_F
  - White Cree XLamp MLEAWT (parallel white)

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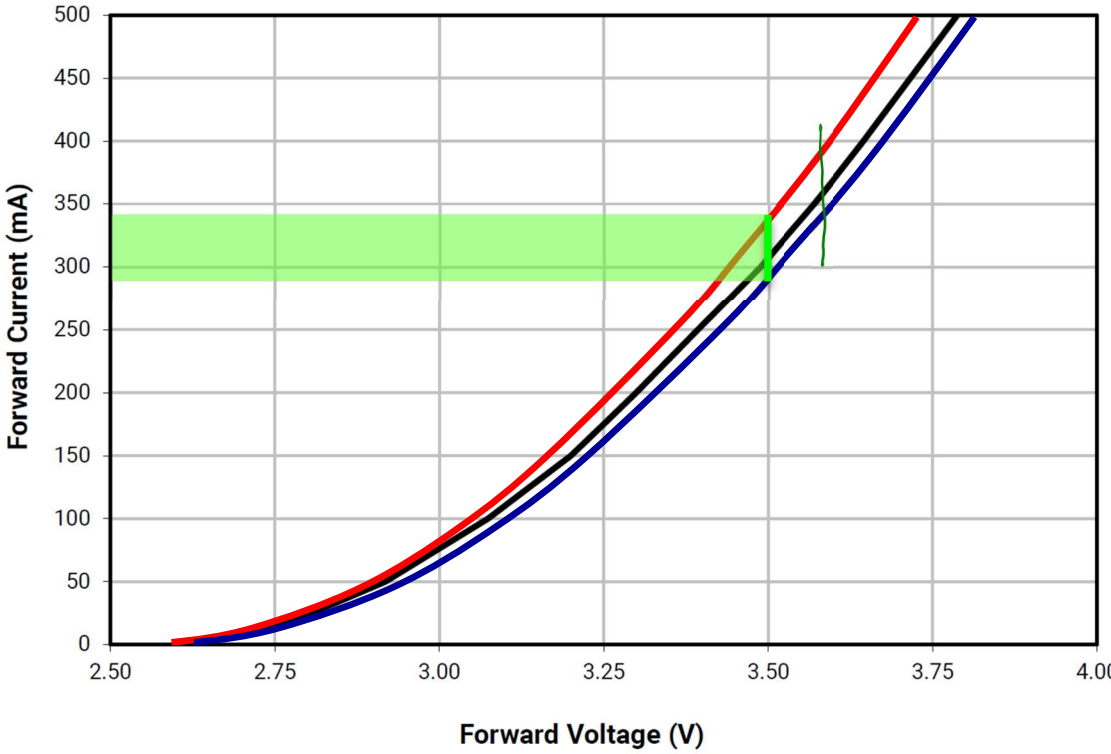
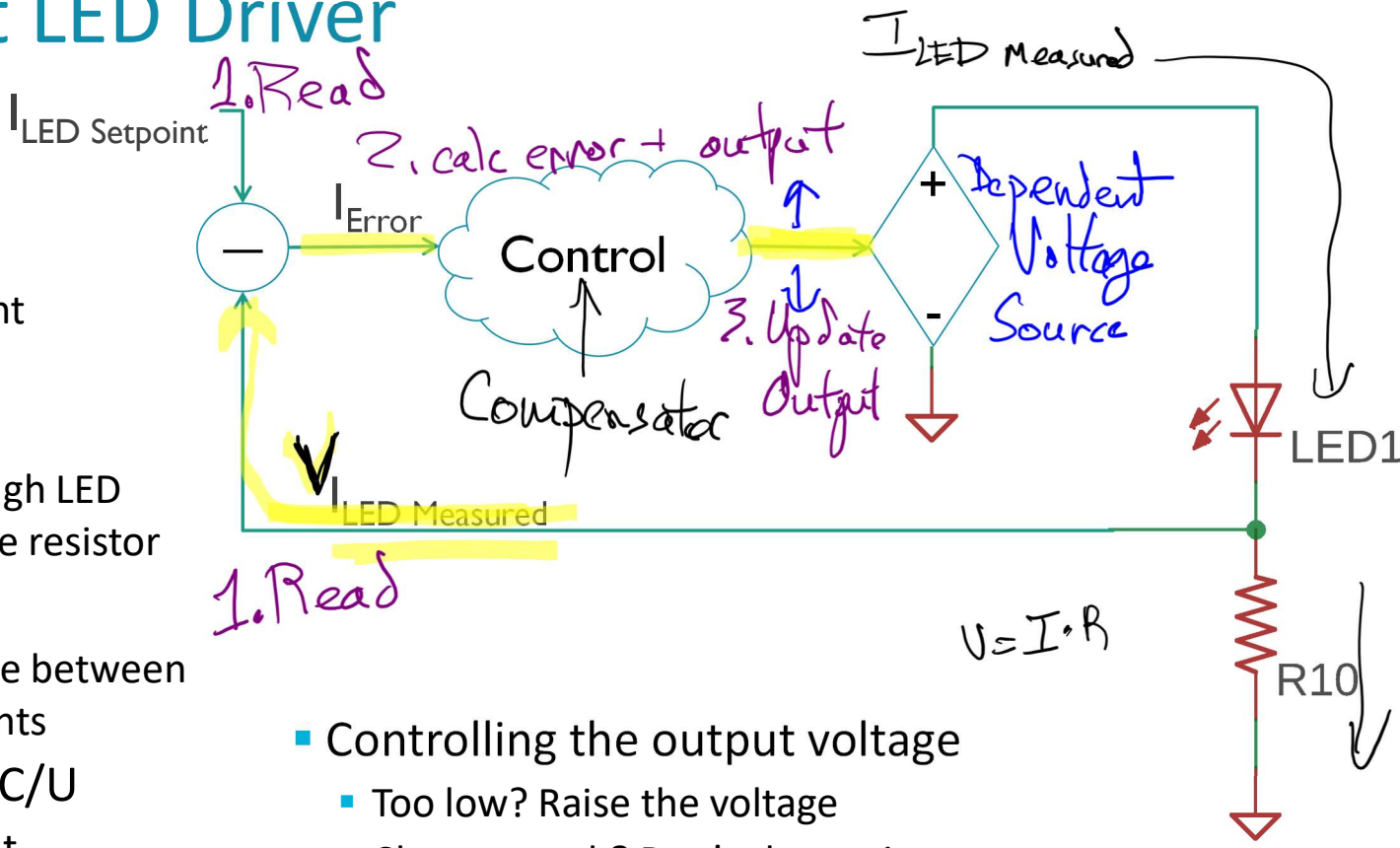
LED and Variations

- Current varies, depends on…
  - LED junction temperature. Hot vs. cold
  - Specifics of LED fabrication: dopant levels, impurities, defects, etc.
- What is the LED current if V_F = 3.50V?
  - Could range from 290 to 340 mA
- How to create specific amount of light?
  - Drive LED at a specific **current** (not **voltage**)



Constant-Current LED Driver

- Input:
  - Desired current $I_{LED\ Setpoint}$
- Output:
  - Adjustable voltage (dependent voltage source) to drive LED
- Feedback:
  - Measure actual current through LED $I_{LED\ Measured}$ using current-sense resistor
- Error:
  - Current error I_{Error} is difference between setpoint and measured currents
- Basic control operation: R/C/U
  1. Read feedback and setpoint
  2. Calculate error and new output
  3. Update output



- Controlling the output voltage
  - Too low? Raise the voltage
  - Close enough? Don't change it
  - Too high? Lower the voltage

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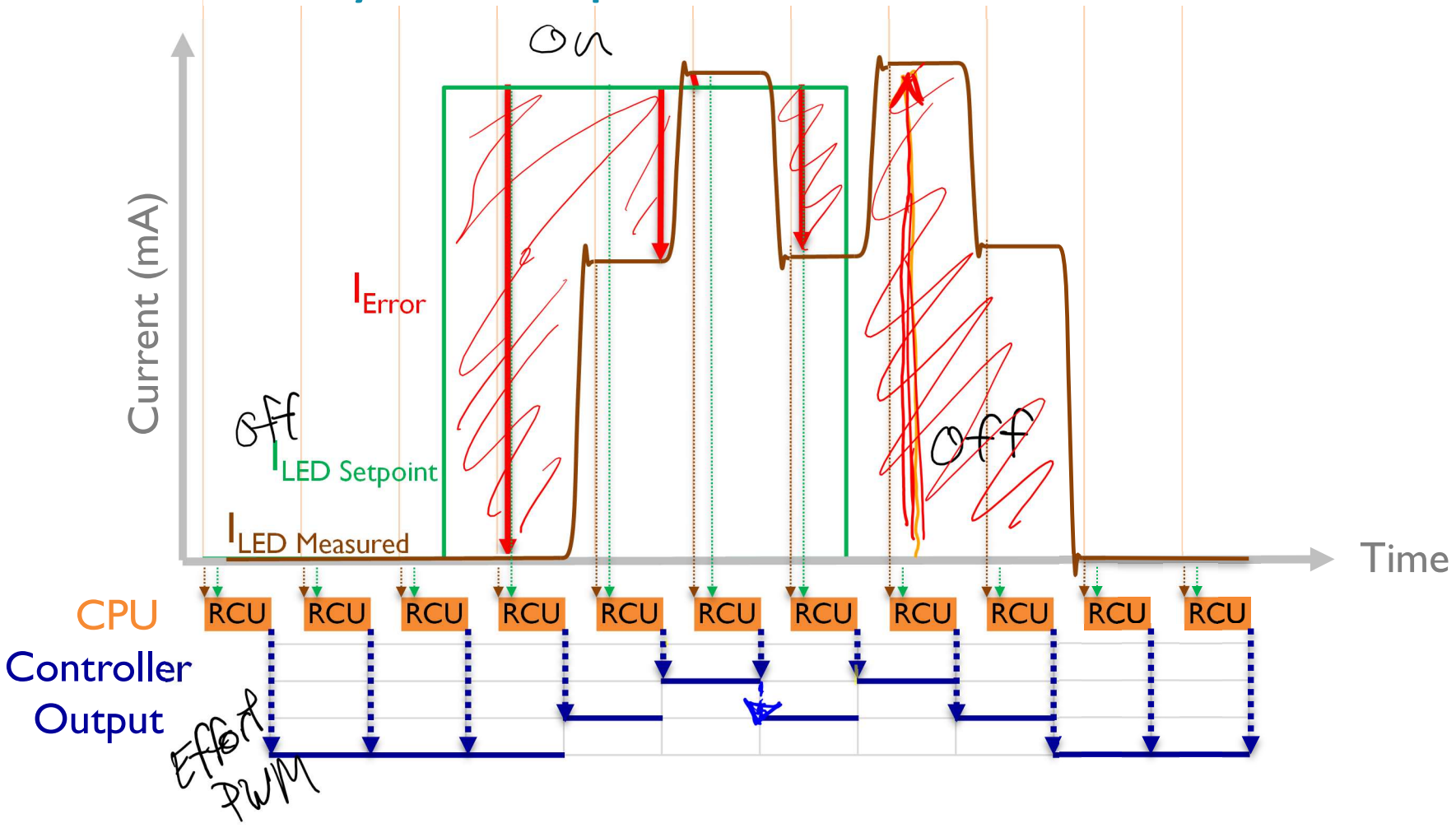
Basic Control System Operation



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Improving Quality of Control

- Stabilize input sampling and output update timing **enough**
  - Compensator was designed for specific timing conditions
- Control (measure and update output) more often
  - Raise control loop frequency $f_{control}$
- Provide finer grain control of output
  - Raise output resolution
- Improve control approach
  - Calculate based on known system dynamics
- (Choose one or more)

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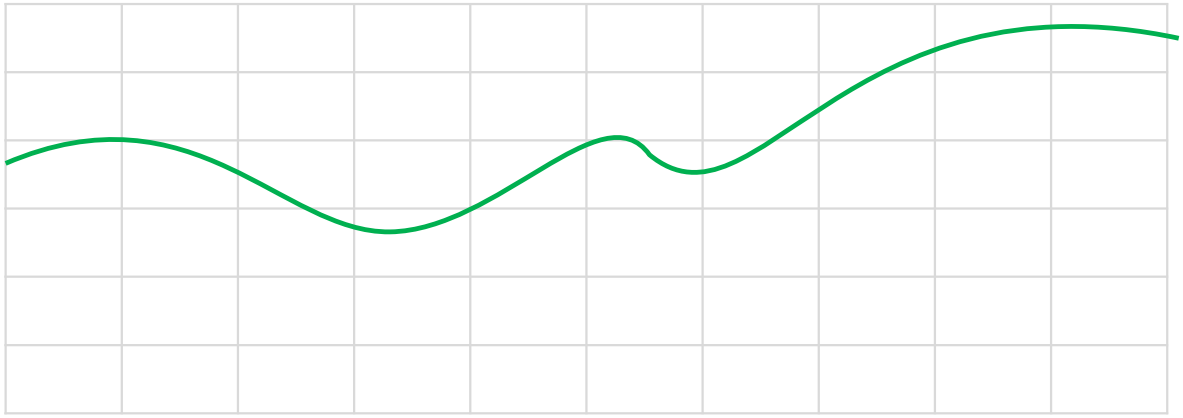
Timing Requirements on Input and Output



- How tight do the windows need to be for acceptable performance?
  - Not covered in this class, but interesting
  - *What is the maximum acceptable timing jitter for input sampling or output update?*
  - Different for inputs and outputs?
  - Doesn't PWM output introduce timing jitter?
- Example:
  - Effect of sampling jitter and control jitter on positioning error in motion control systems, Kristofer Smeds, Xiaodong Lu ∗ doi:10.1016/j.precisioneng.2011.09.002

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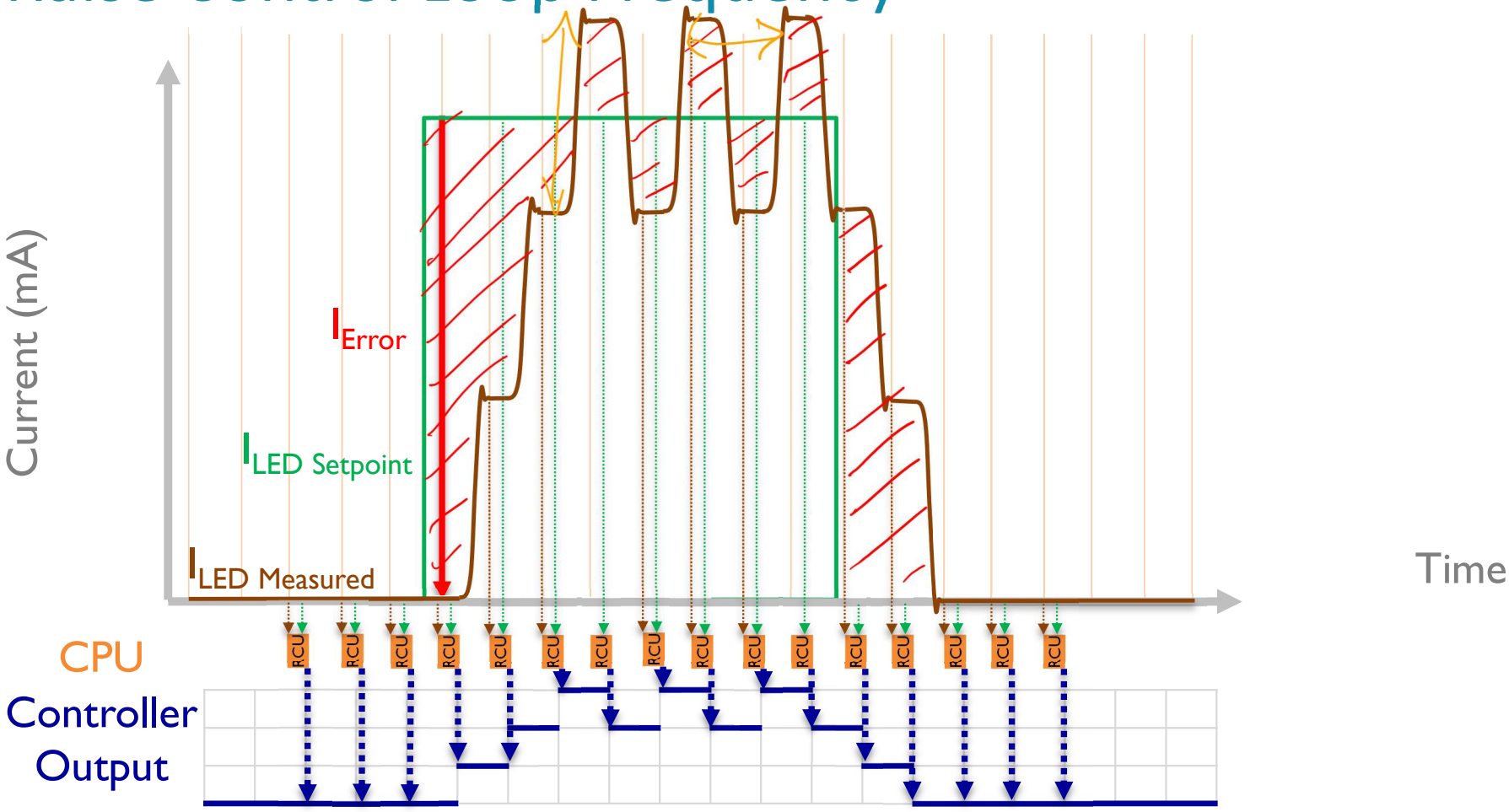
Raise Control Loop Frequency



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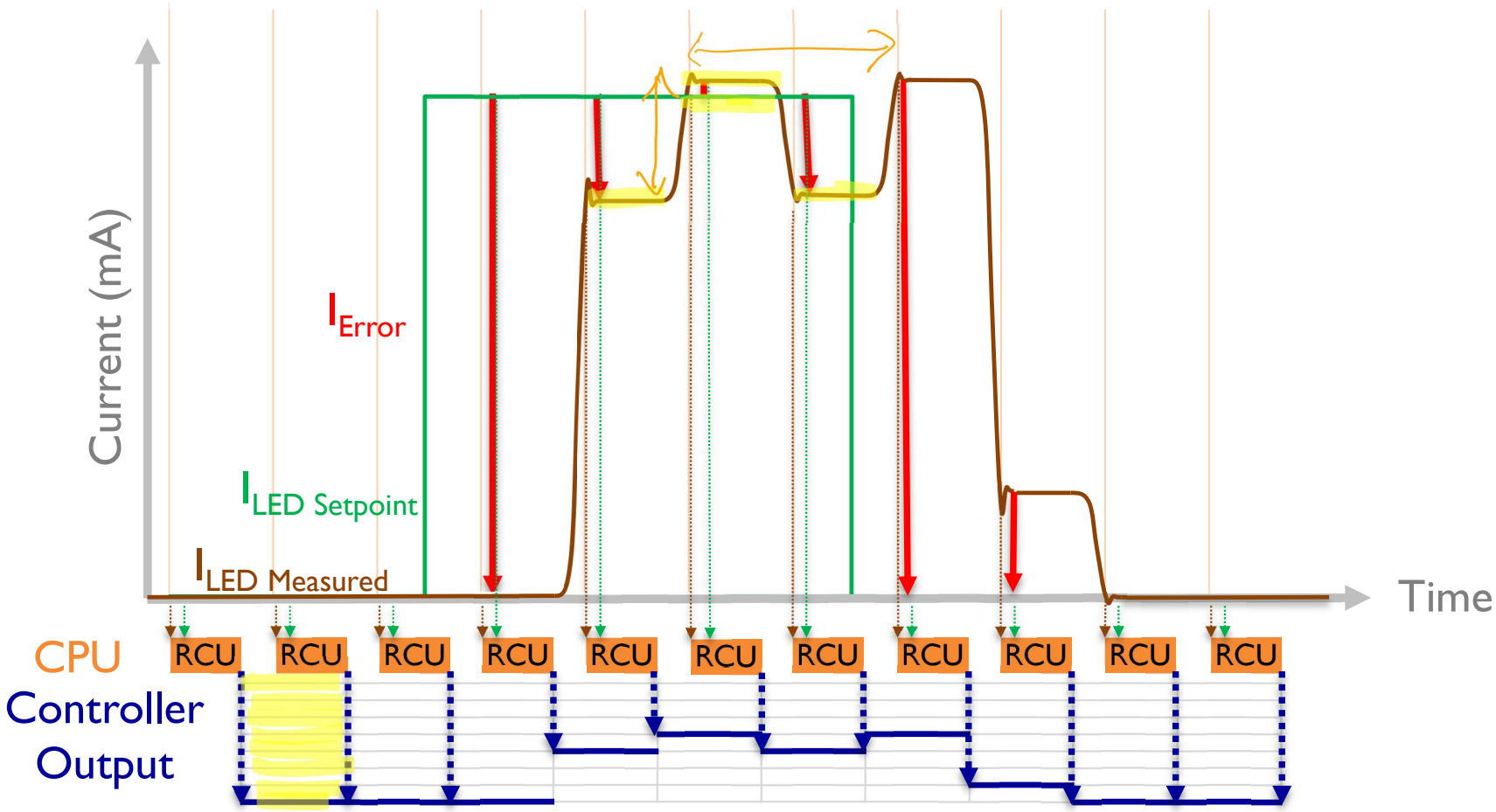
Raise Controller Output Resolution



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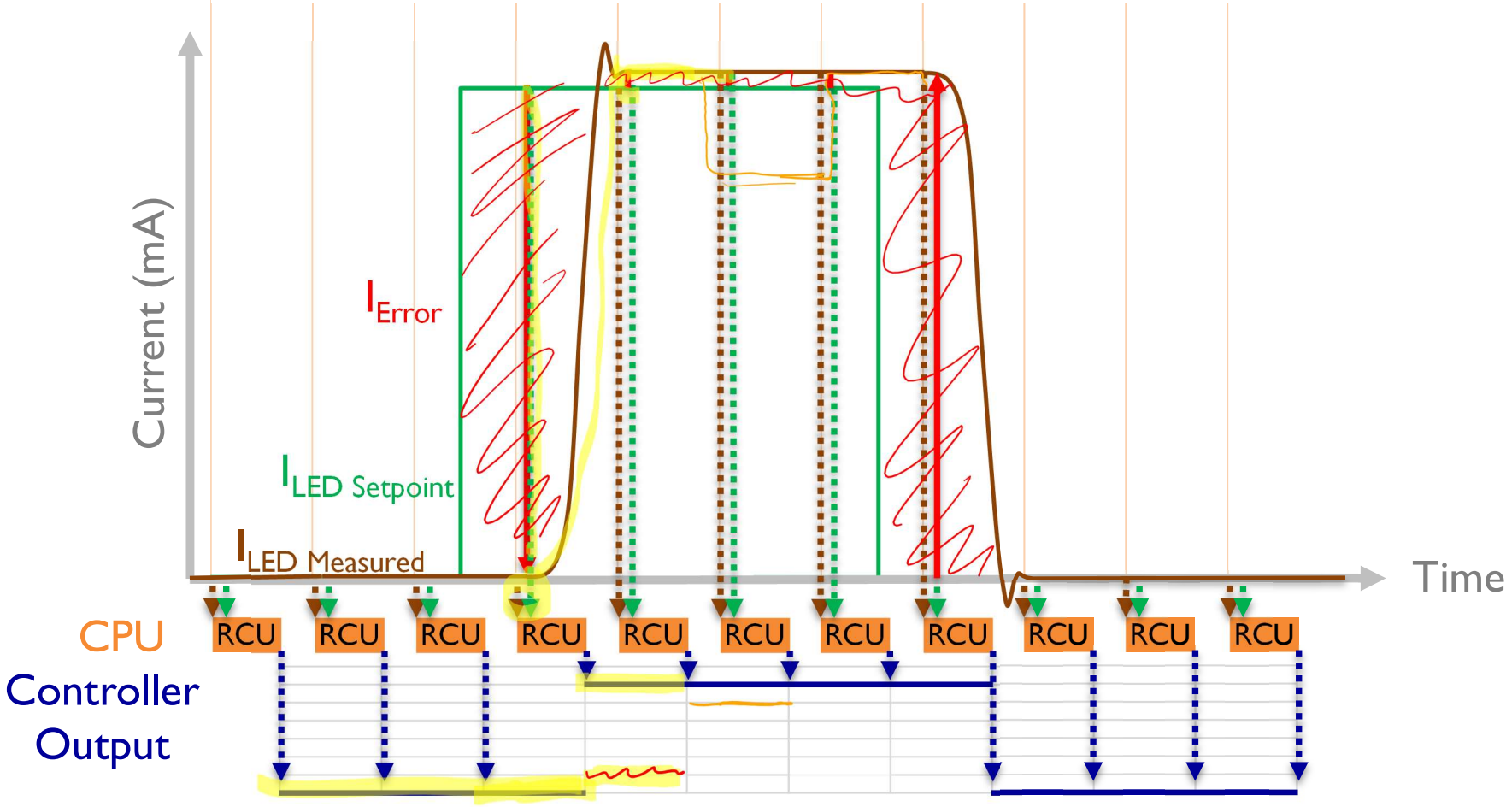
Use Smarter Controller (& Better Output Resolution)



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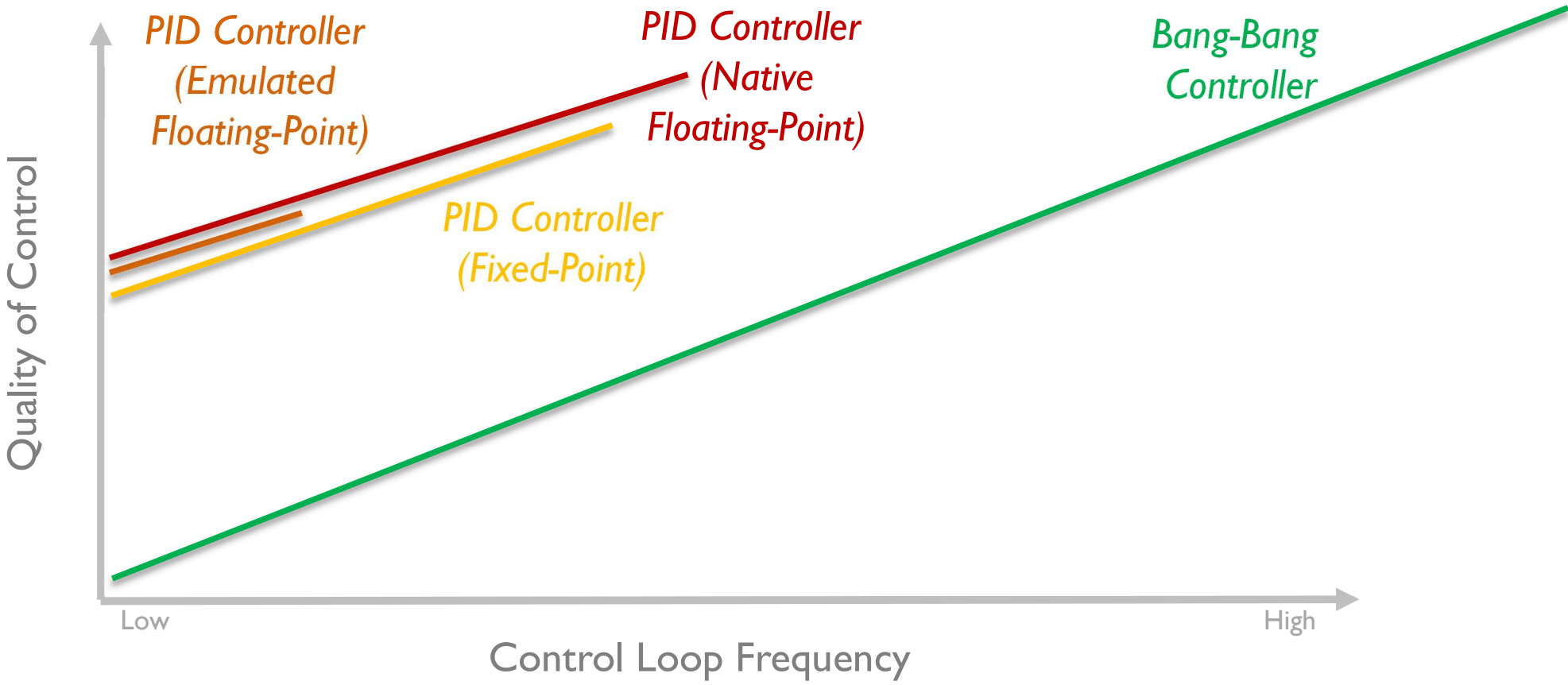
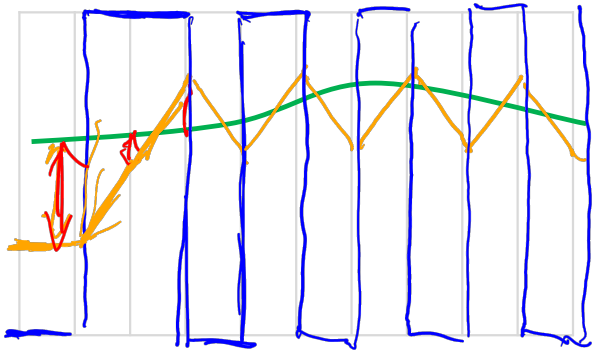
Quality of Control vs. Control Loop Frequency



Compensator Changes Controller Effort based on Error

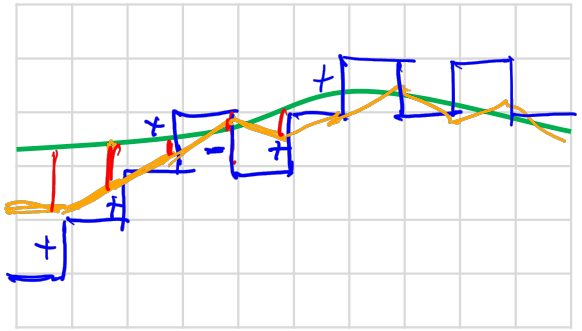
- Bang-Bang

```
if (error > 0)
  d = 100;
else
  d = 0;
```



- Incremental

```
if (error > 0)
  d += step;
else
  d -= step;
d = CLIP(0, d, 100);
```



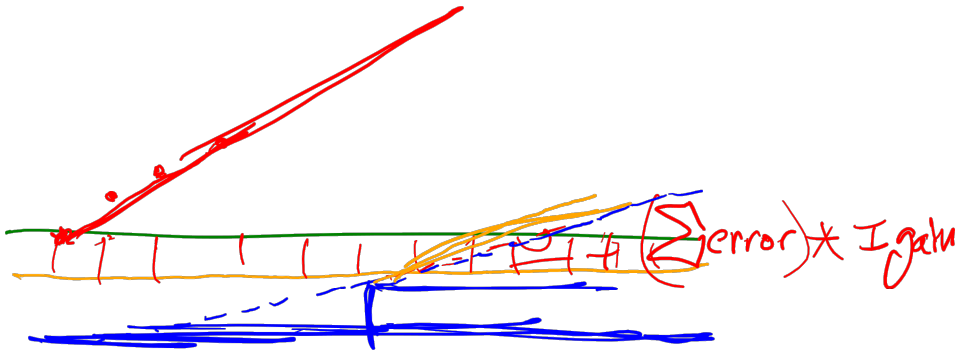
Compensator Changes Controller Effort based on Error

- Proportional

```
d += error*gain;
d = CLIP(0, d, 100);
```

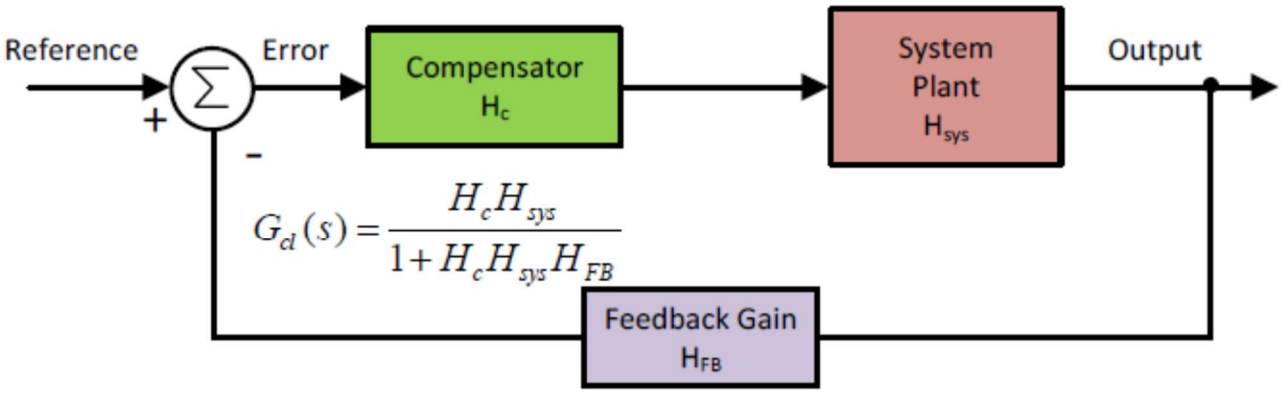
- PID: adds integral and derivative terms to proportional

```
d += error*p_gain +
     integrate(error)*i_gain +
     derivative(error)*d_gain;
d = CLIP(0, d, 100);
```



- Many others derived from system transfer function analysis

Controller Basics



Reference: This is the desired set-point we want the Output to follow

Error: Calculation of (Reference – Feedback), this is the value the compensator acts upon

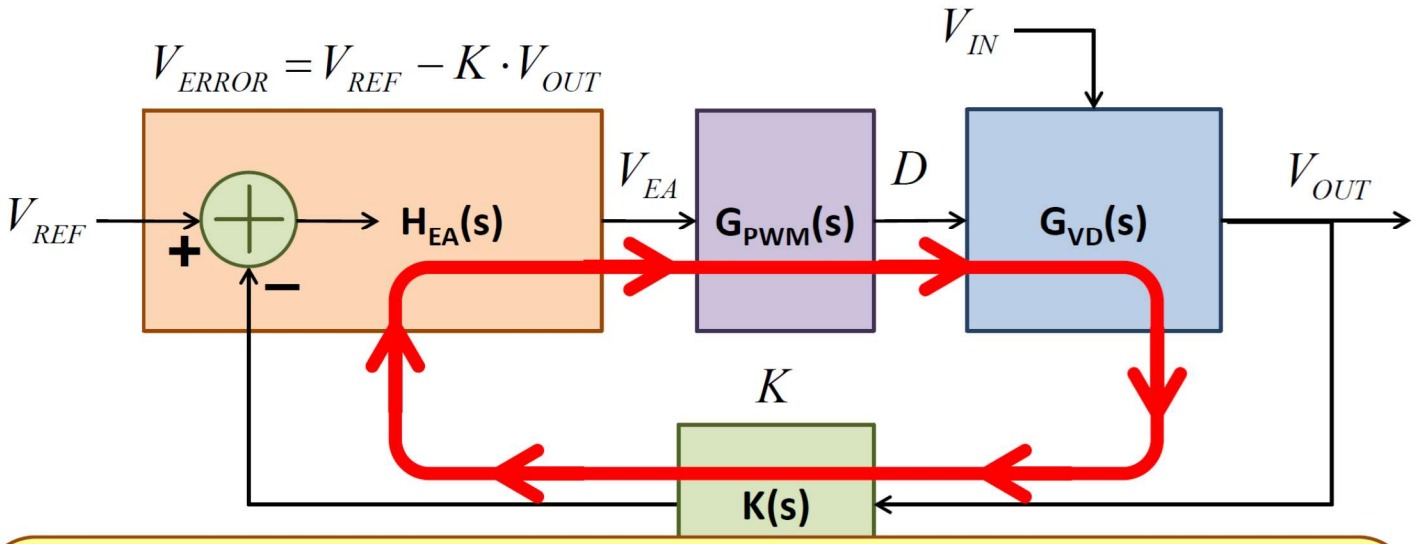
Compensator: Digital compensator (PID, 2P2Z, 3P3Z, or 4th order, etc.)

System: This is the System/Plant/Power stage being controlled (SMPS, Motor, Actuator, etc)

Output: For our purposes this will be Voltage or Current

Feedback: The measurement of the output signal level

Loop Gain T(s)



Loop Gain

$$T(s) = K(s) \cdot H_{EA}(s) \cdot G_{PWM}(s) \cdot G_{VD}(s)$$

- System performance depends on system's loop gain
- Design compensator $H_{EA}(s)$ to make **overall** system behave as desired
- To design compensator effectively and quickly, need to understand theory
- Can determine $G_{VD}(s)$ with modeling or measurement

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Compensator Details

- Many types of compensators
  - Analog vs. digital implementations
  - Bang-Bang, incremental, PID, 2P2Z, 3P3Z, etc.
  - Custom compensator based on analysis of system transfer functions

- System performance concerns
  - Tracking: How well does the output track the commanded value?
  - Disturbance Rejection: How well does the output return to the commanded value if there is a change in the input voltage, output load, or noise?
  - Stability: Will the output never run away?