Design IV

E232 Spring 07

Class 22

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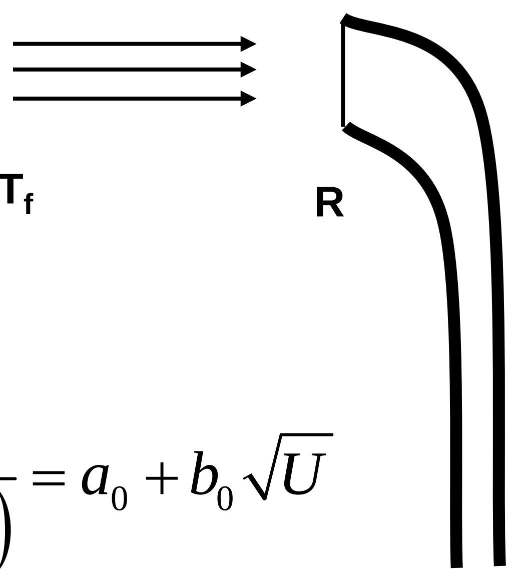
Fluid Velocity Sensor – Hot-Wire Anemometer



$$\frac{V^2}{R\left(T_s - T_f\right)} = a_0 + b_0\sqrt{U}$$

Heat loss:

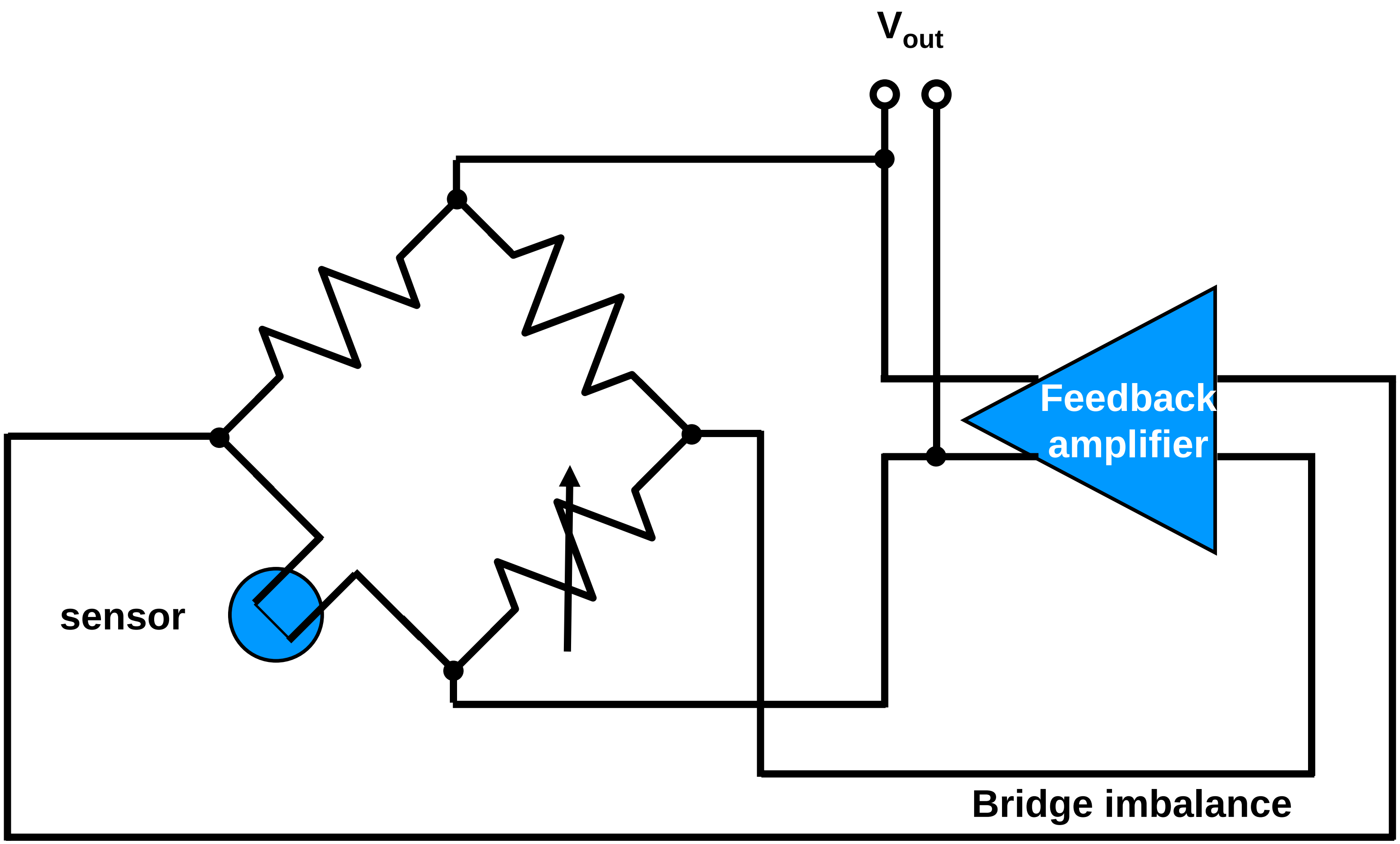
$$q = \left(T_s - T_f\right)\left(A_0 + B_0\sqrt{\mathrm{Re}}\right)$$

$$\mathrm{Re} = \frac{\rho U D}{\mu}$$

Heat gain:

$$q = \frac{V^2}{R}$$

Application of Hot-wire Anemometer



Today's topics

- Control systems
  - Examples
  - Open loop vs. closed loop control

Reference Material

- K. Ogata, “Modern Control Engineering,” Prentice-Hall, **1970**, ISBN 13-590232-0
- R. Dorf, R. Bishop, “Modern Control Engineering, 10th Ed.,” Pearson/Prentice-Hall, **2005**, ISBN 0-13-145733-0.

Examples of Control Systems

Hard disk read/write head positioning

CNC machining tools

Water treatment system

Car's cruise control

Aircraft auto-pilot

Body's glucose level

Highway traffic control

Car's engine controller

Employee performance appraisal process

Building heating/cooling system control

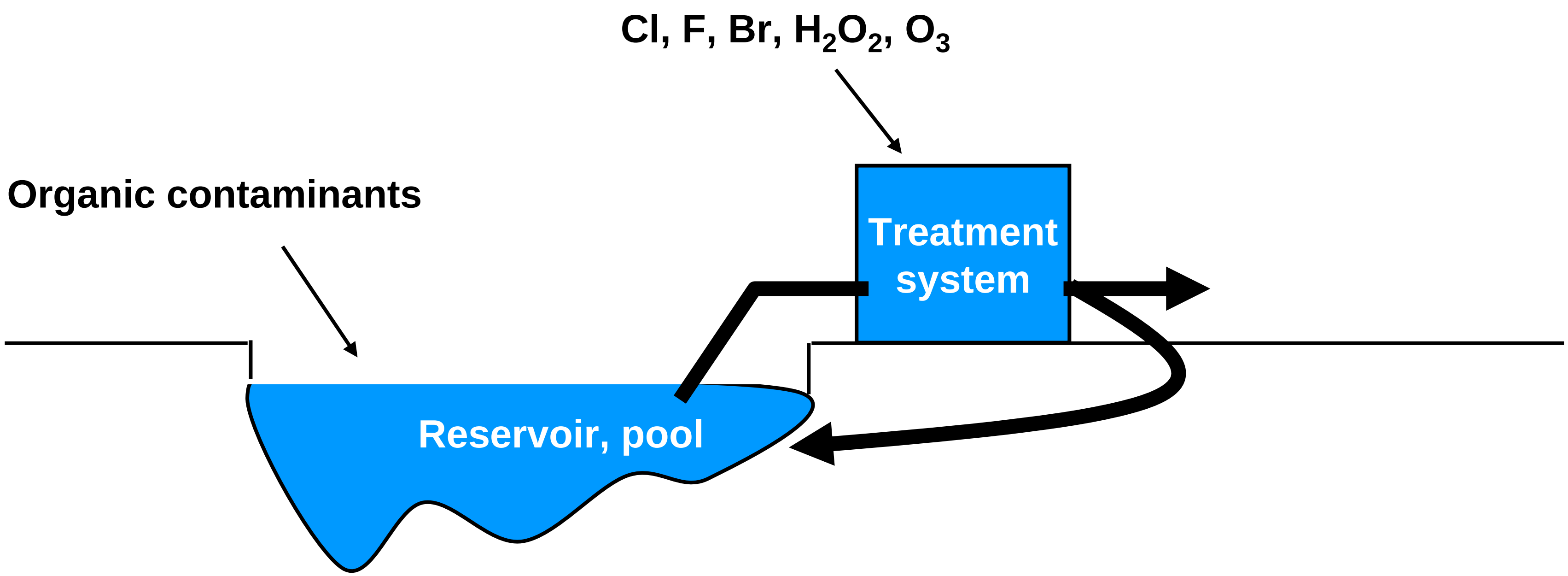
Modem's adaptive equalizer

Corporate budgets

Body's heart-rate pacemaker

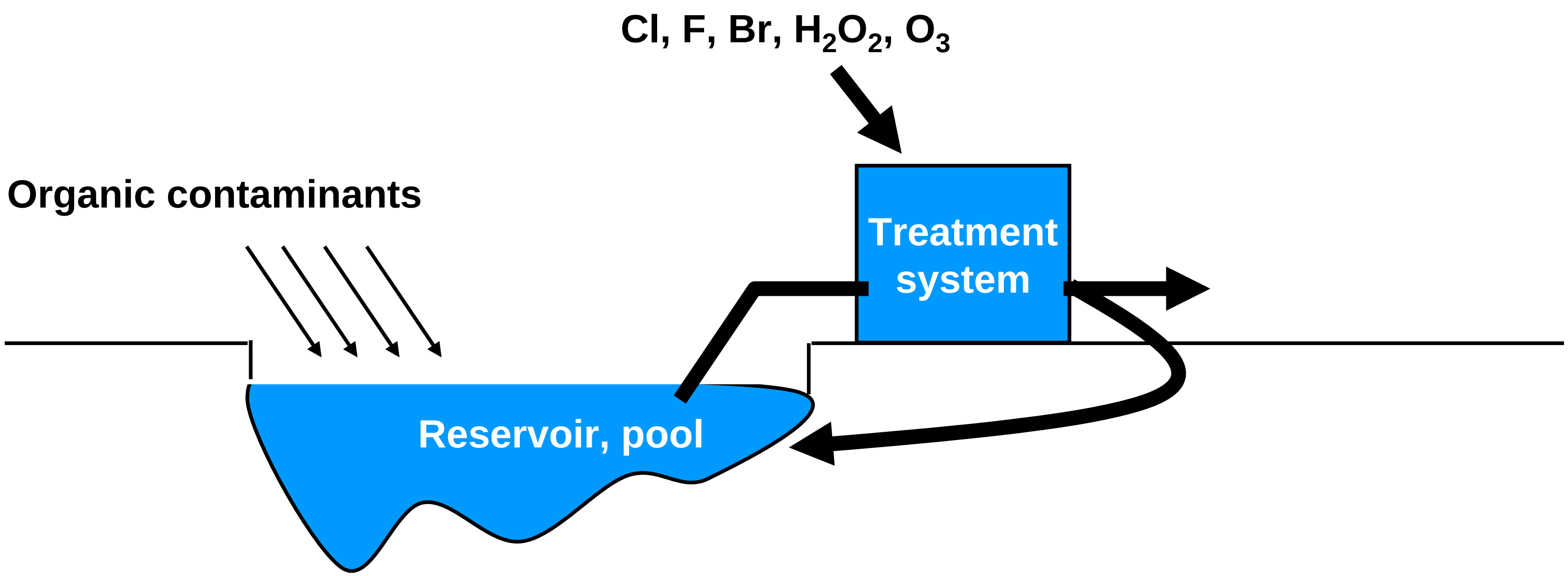
Consider a Water Treatment System

- Chlorine, etc., are added to water to kill bacteria, deal with other organic contaminants



Consider a Water Treatment System

- Chlorine, etc., are added to water to kill bacteria, deal with other organic contaminants
- Rain, runoff, usage may add additional contaminants, so we increase level of treatment



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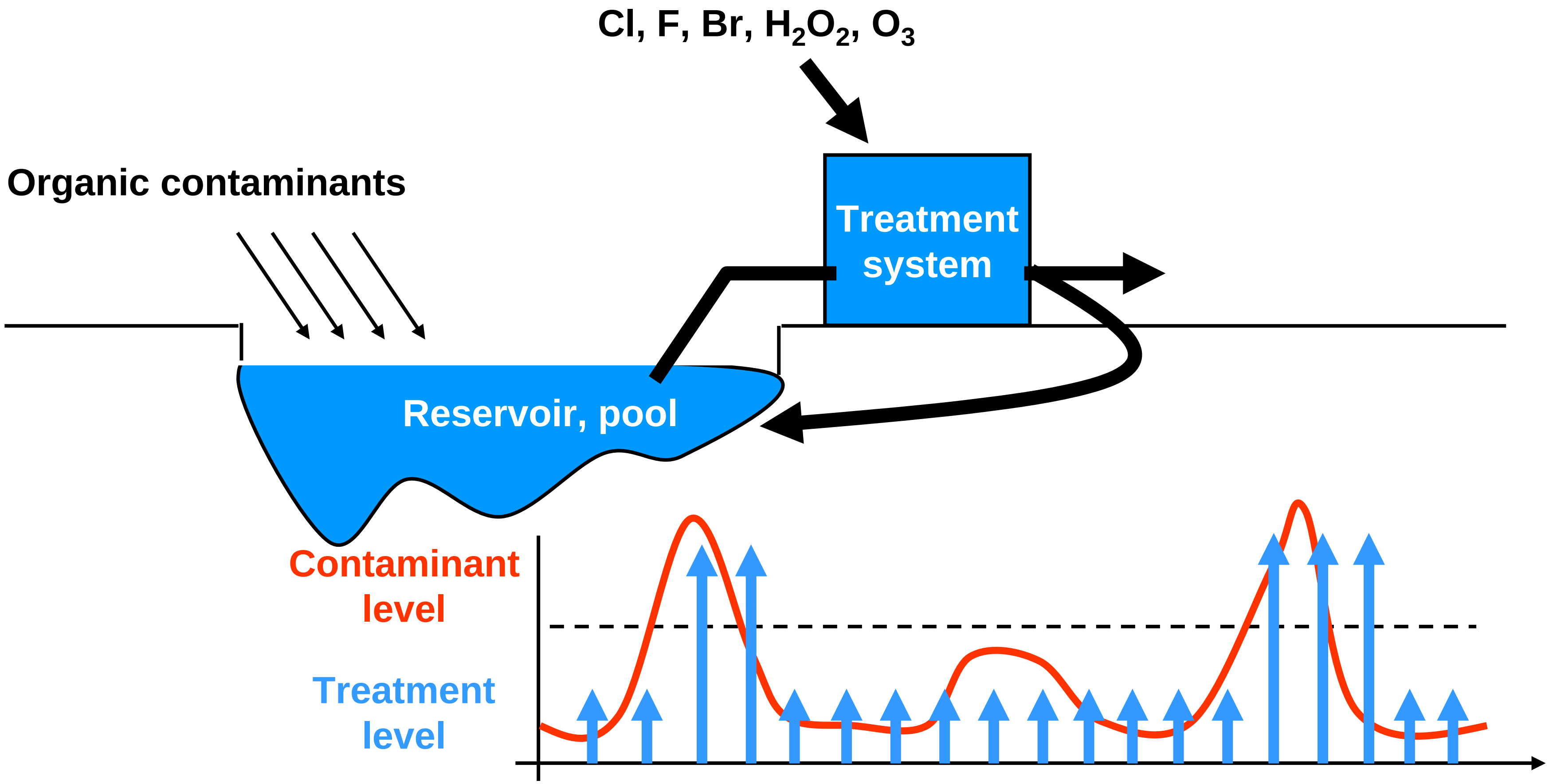

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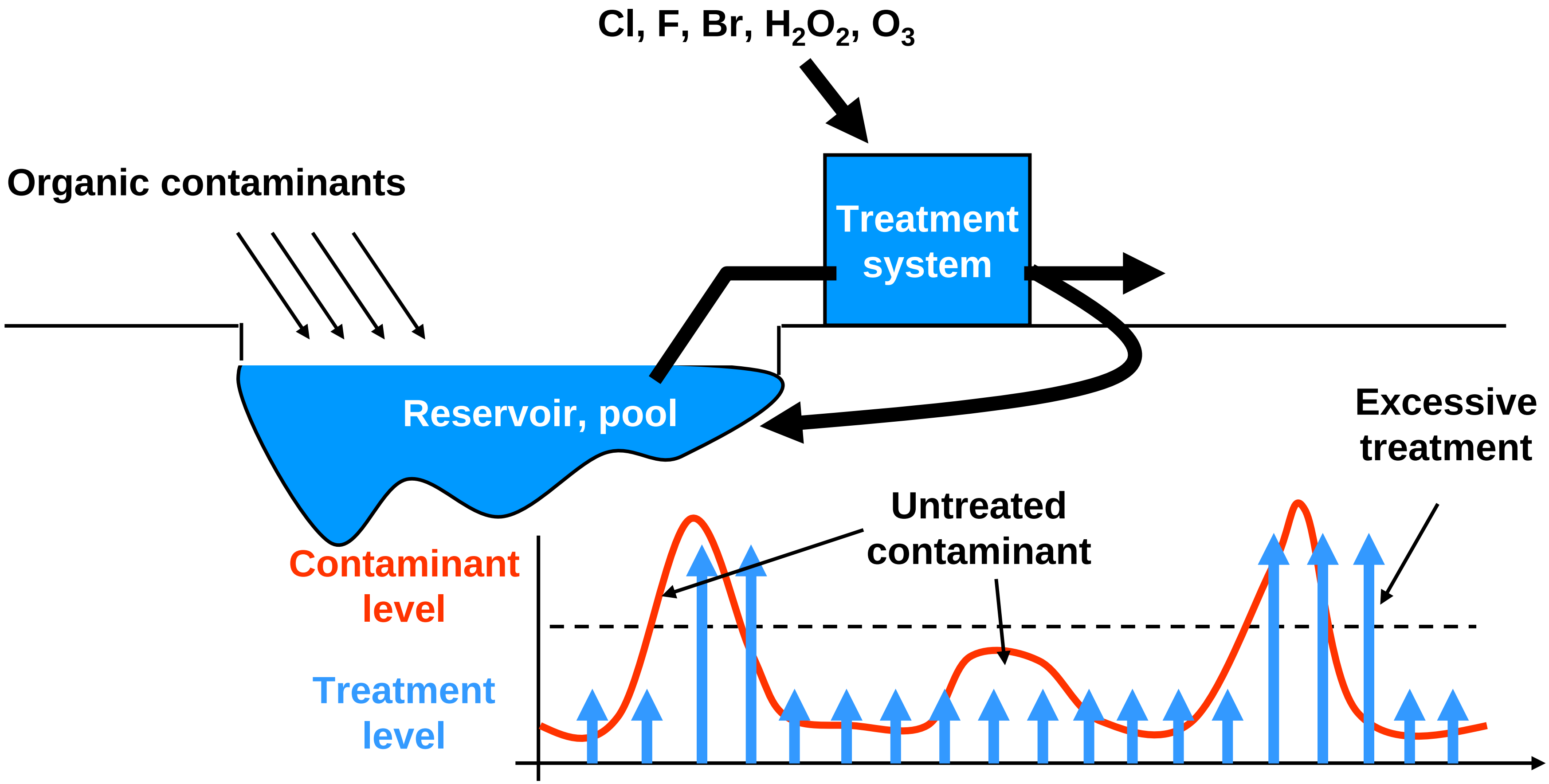
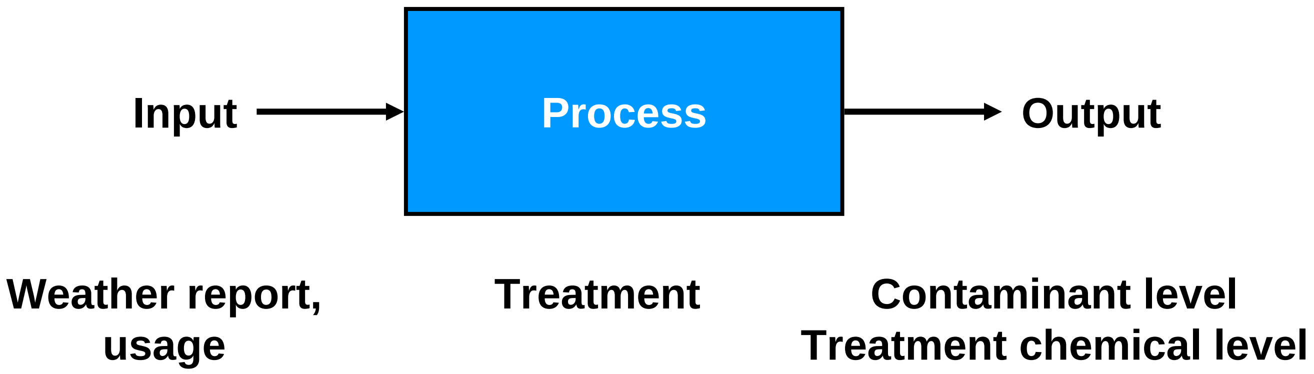


Process Control

- Generic process control

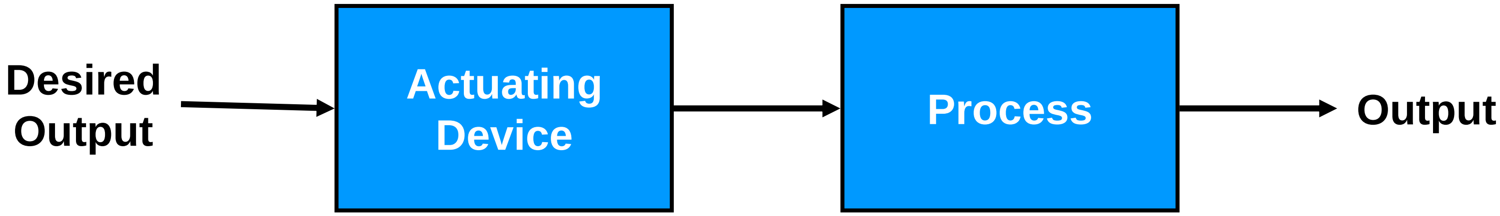
Process Control

- Water treatment



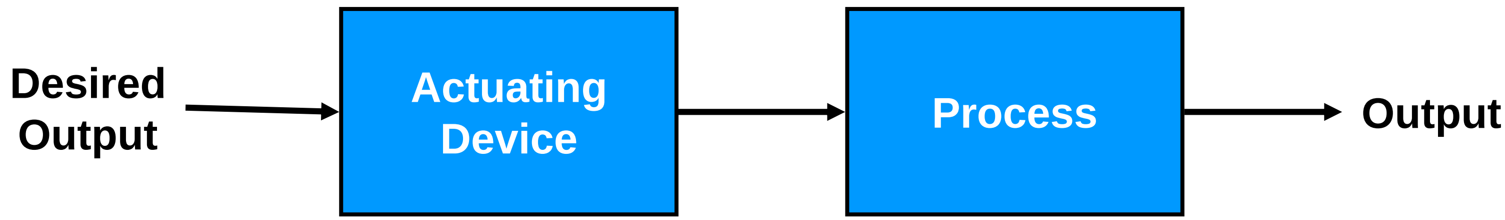
Open Loop Process Control

- Generic process



Open Loop Process Control

- Water treatment



Zero contaminant level

Minimal treatment chemical level

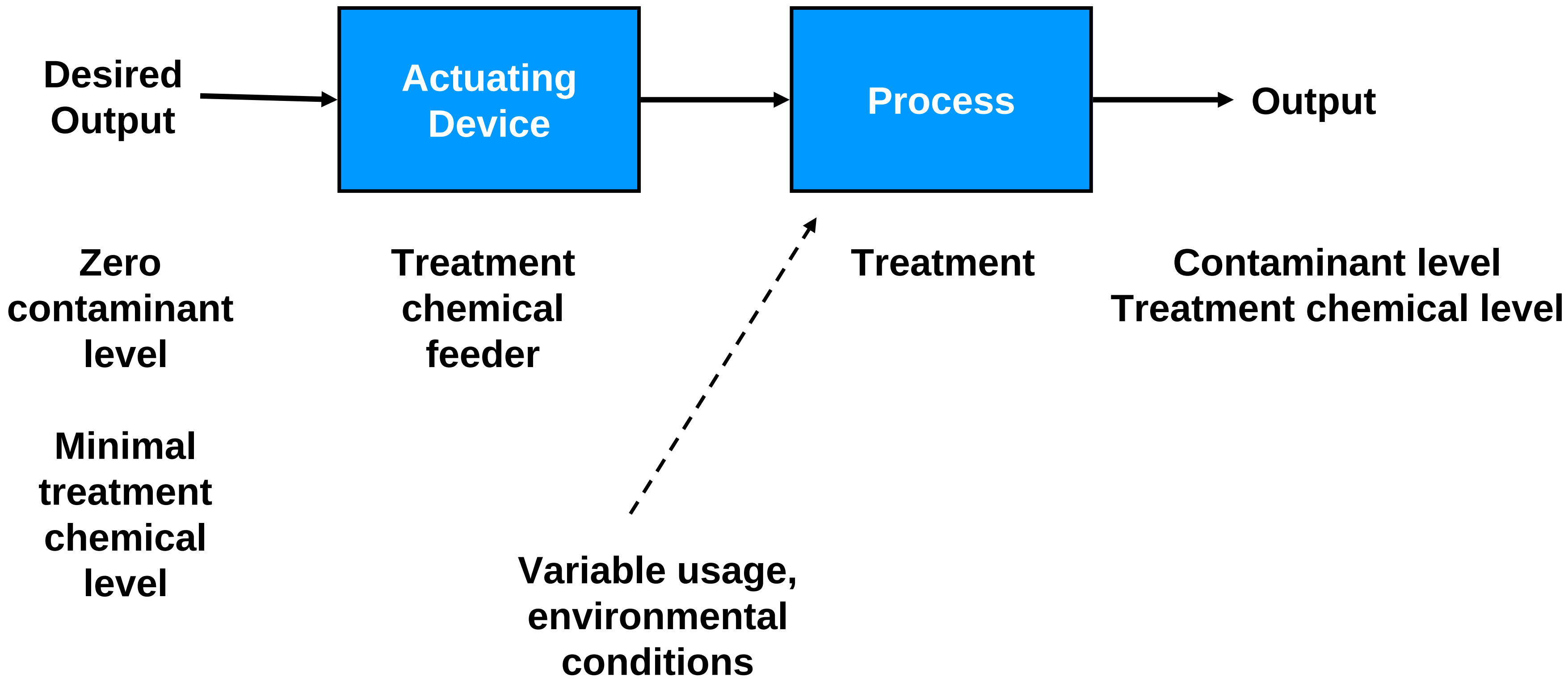
Treatment chemical feeder

Treatment

Contaminant level
Treatment chemical level

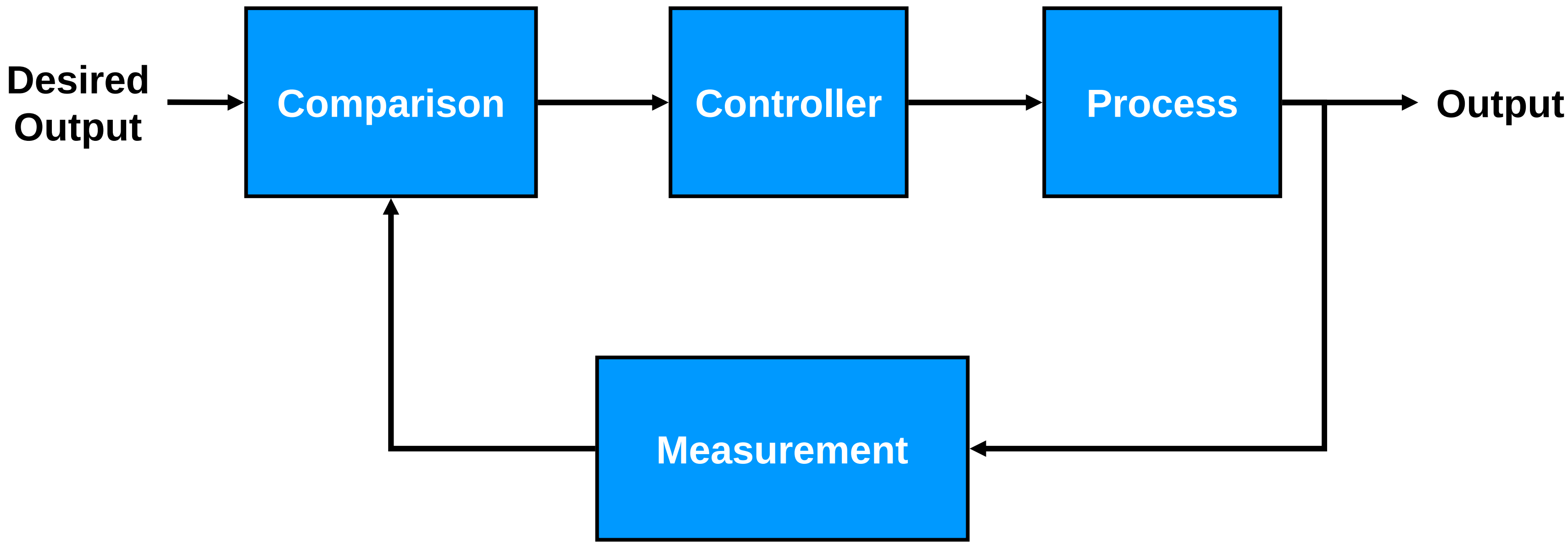
Open Loop Process Control

- Water treatment



Closed Loop Process Control

- Generic process



Closed Loop Process Control

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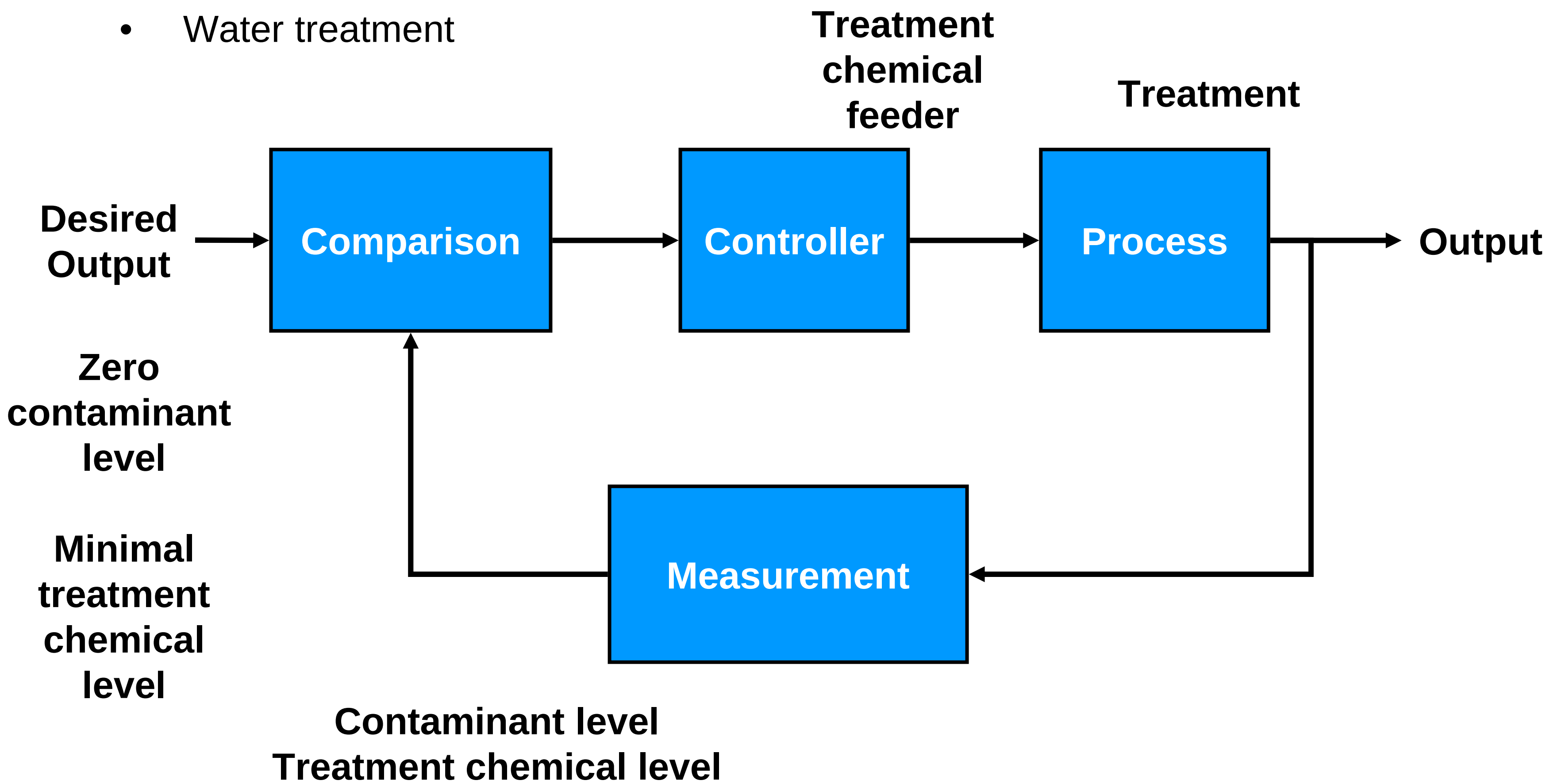

Closed Loop Process Control

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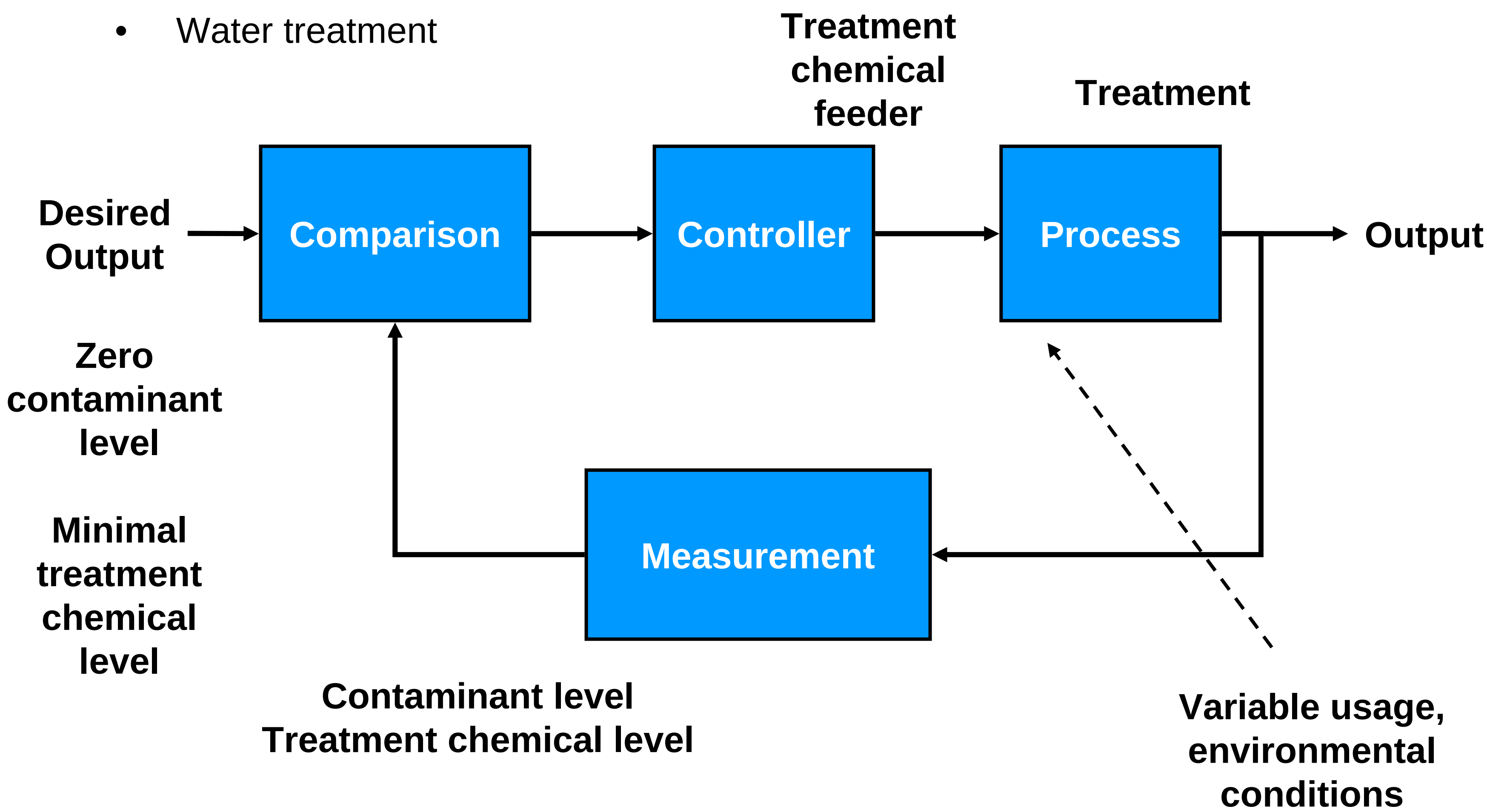

Closed Loop Process Control

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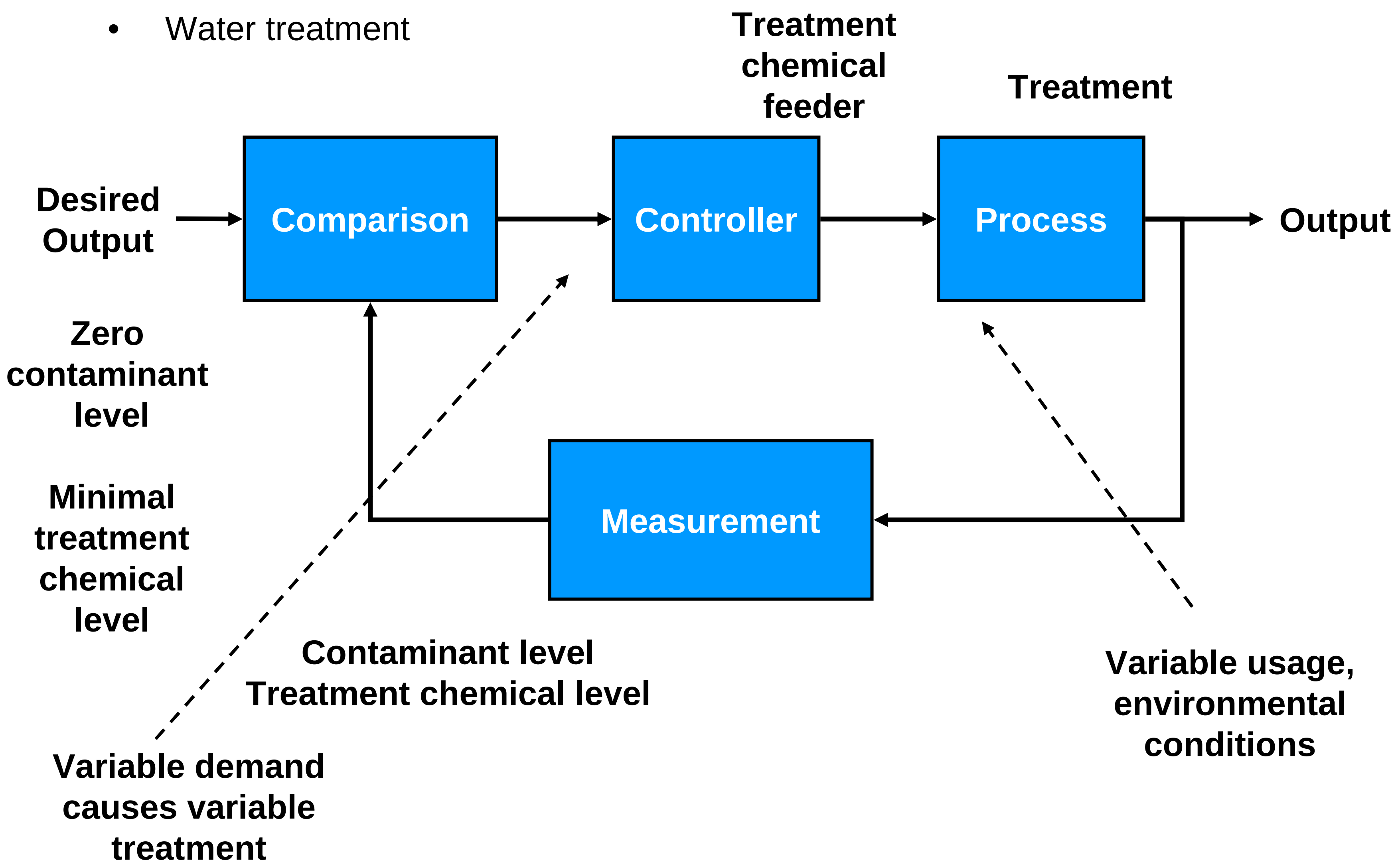
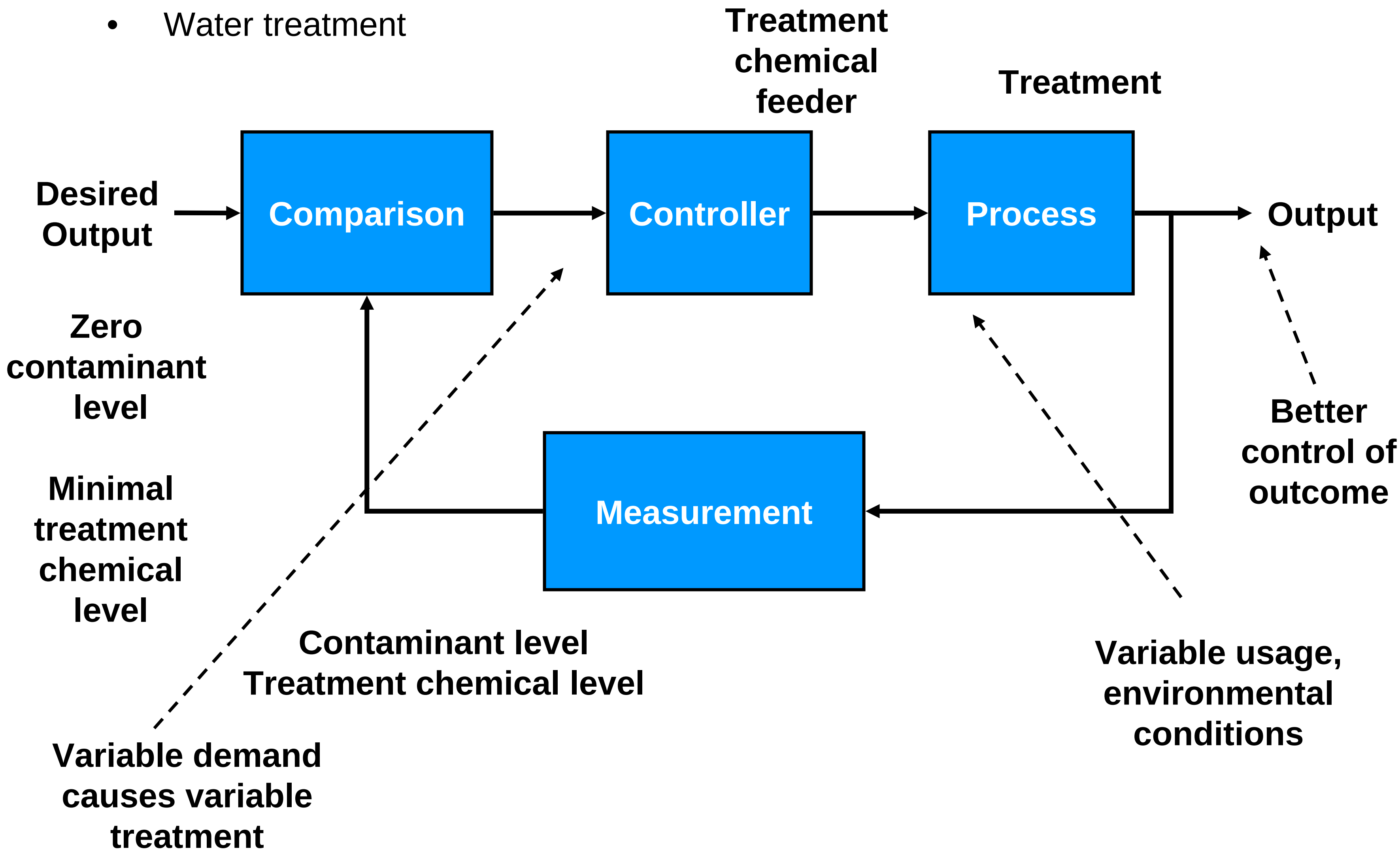


Closed Loop Process Control

- Water treatment



History of Automatic Control

- **250 BC: Greek's use float regulator to control level of oil in lamps**
- **1600's – 1700's: temperature, pressure regulators for steam boilers**
- **1769: Watt's flyball speed governor for steam engine**
- **1868: Maxwell's mathematical analysis of steam engine governor**

Empirical design

Early 1900s: Telephone network

Mid 1900s: gun control

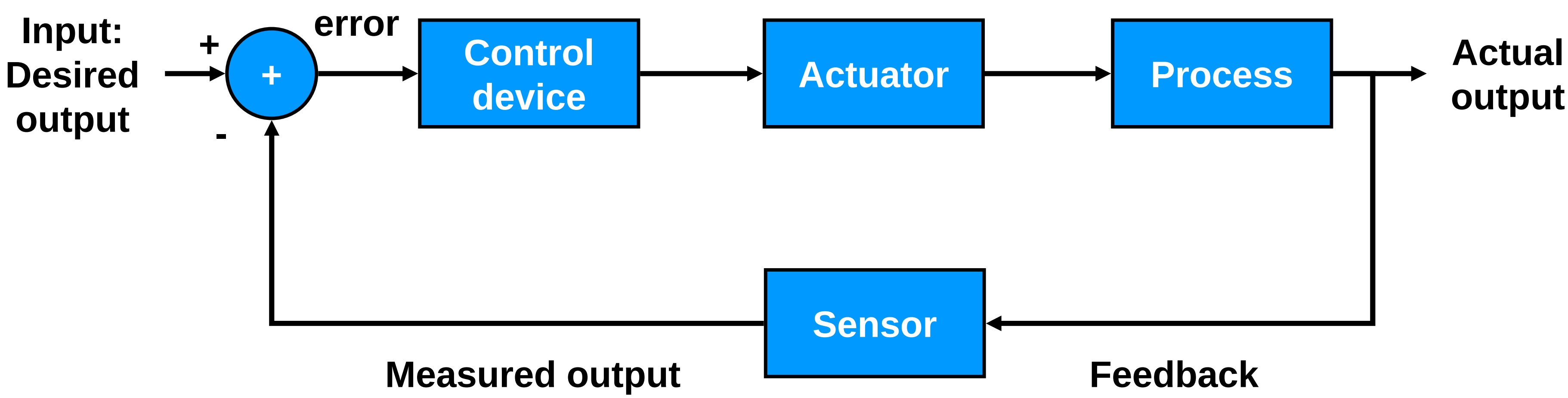
US: Frequency domain techniques (Laplace Transform)

Mid 1900s: flight control, radar

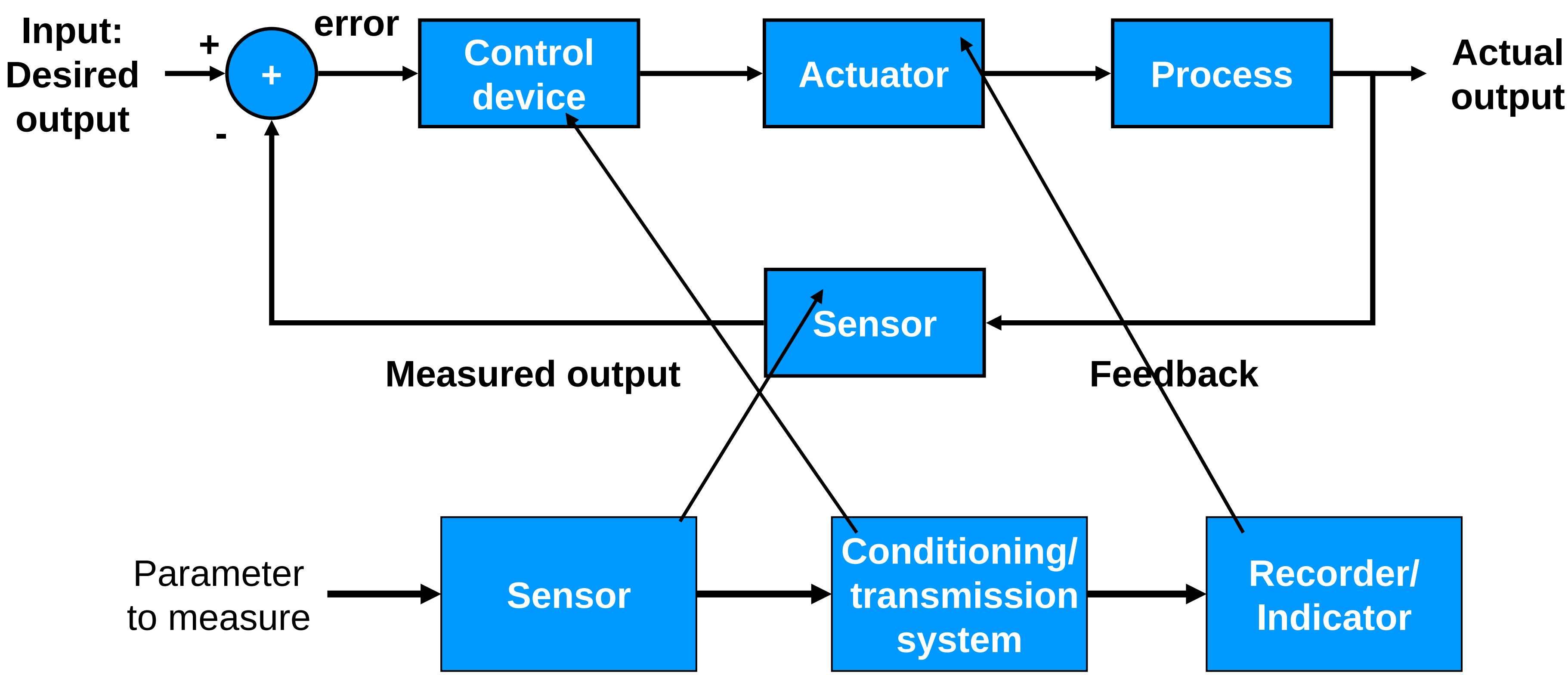
Russia: Time domain techniques (differential equations)

Analytical design

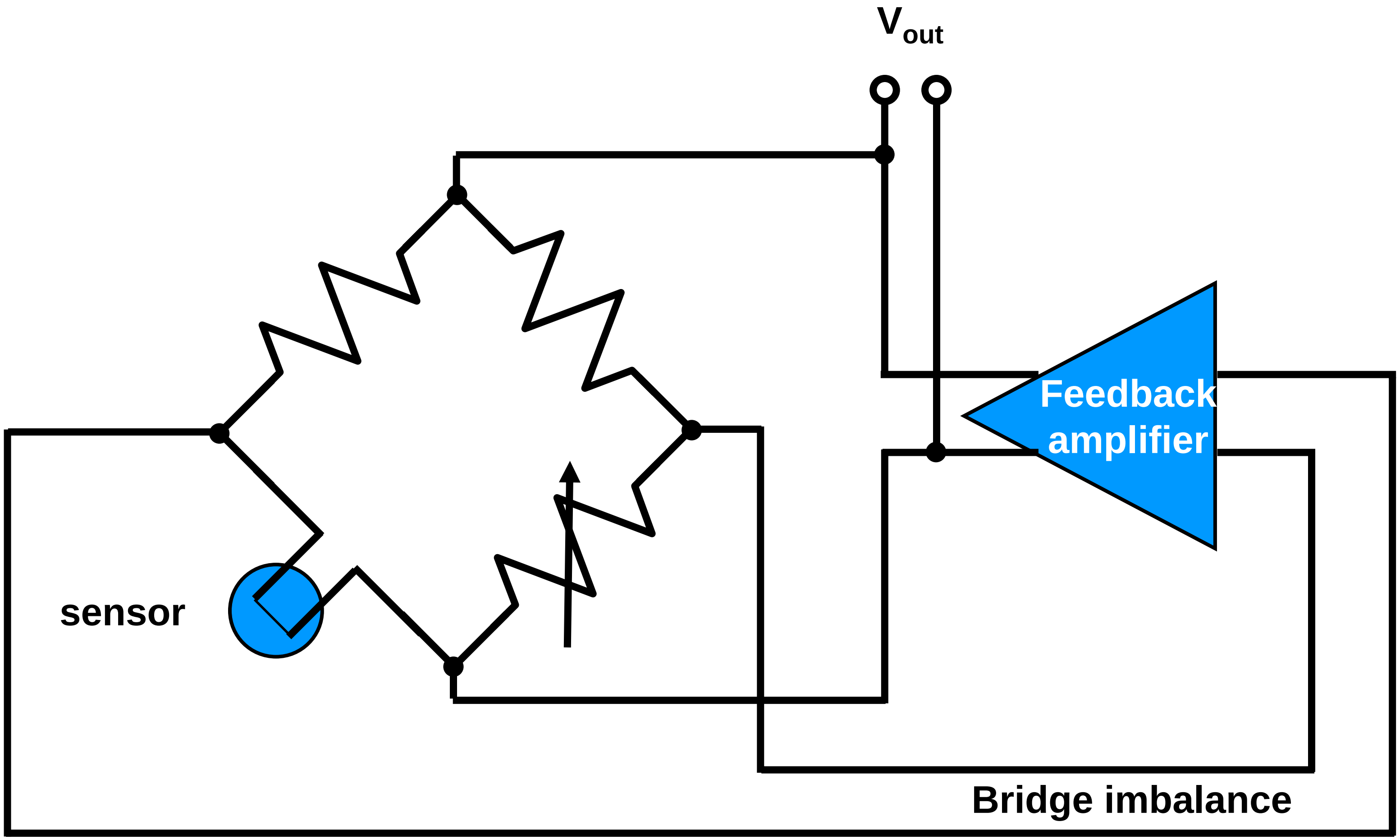
Negative Feedback Control System



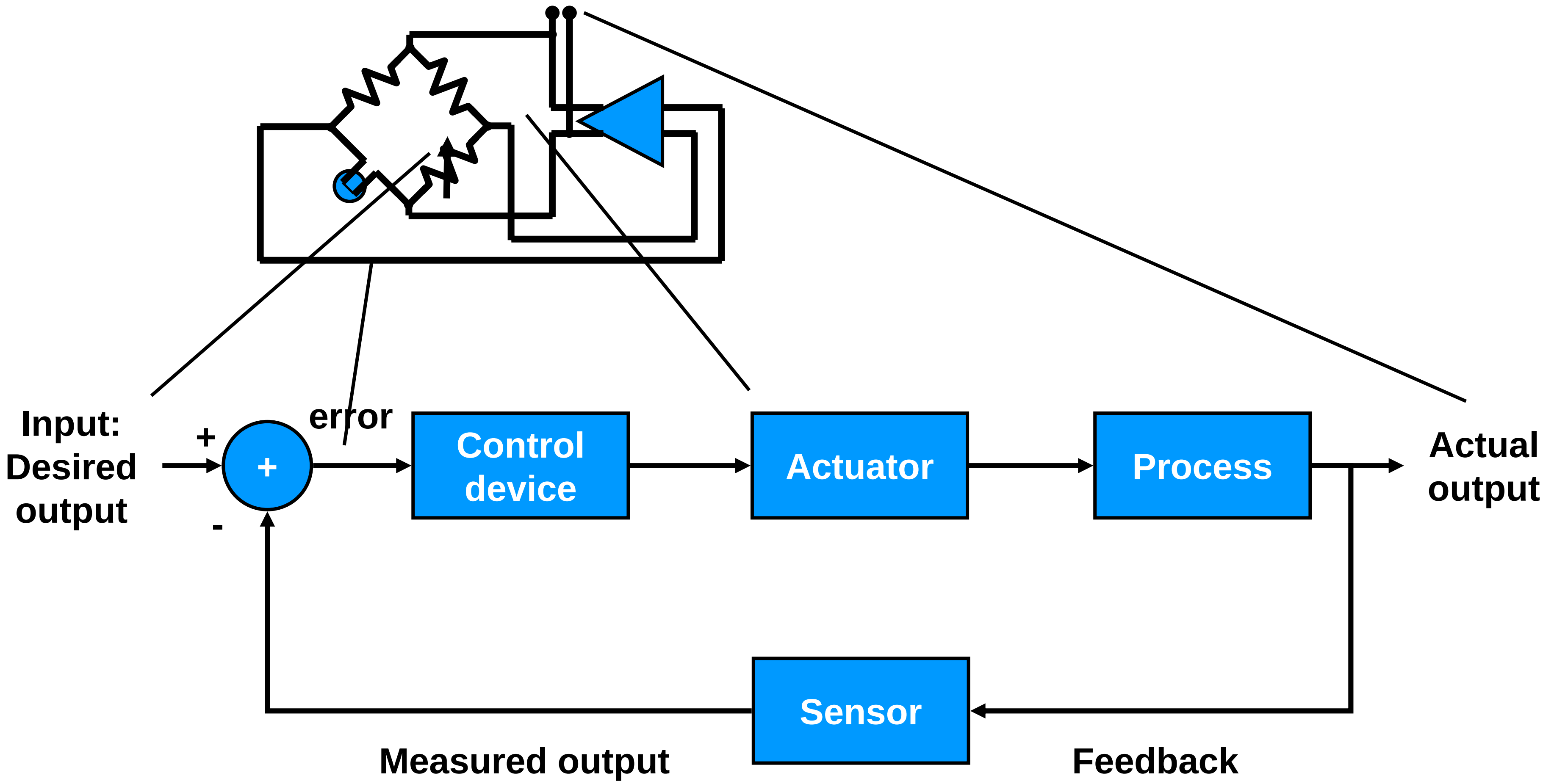
Negative Feedback Control System



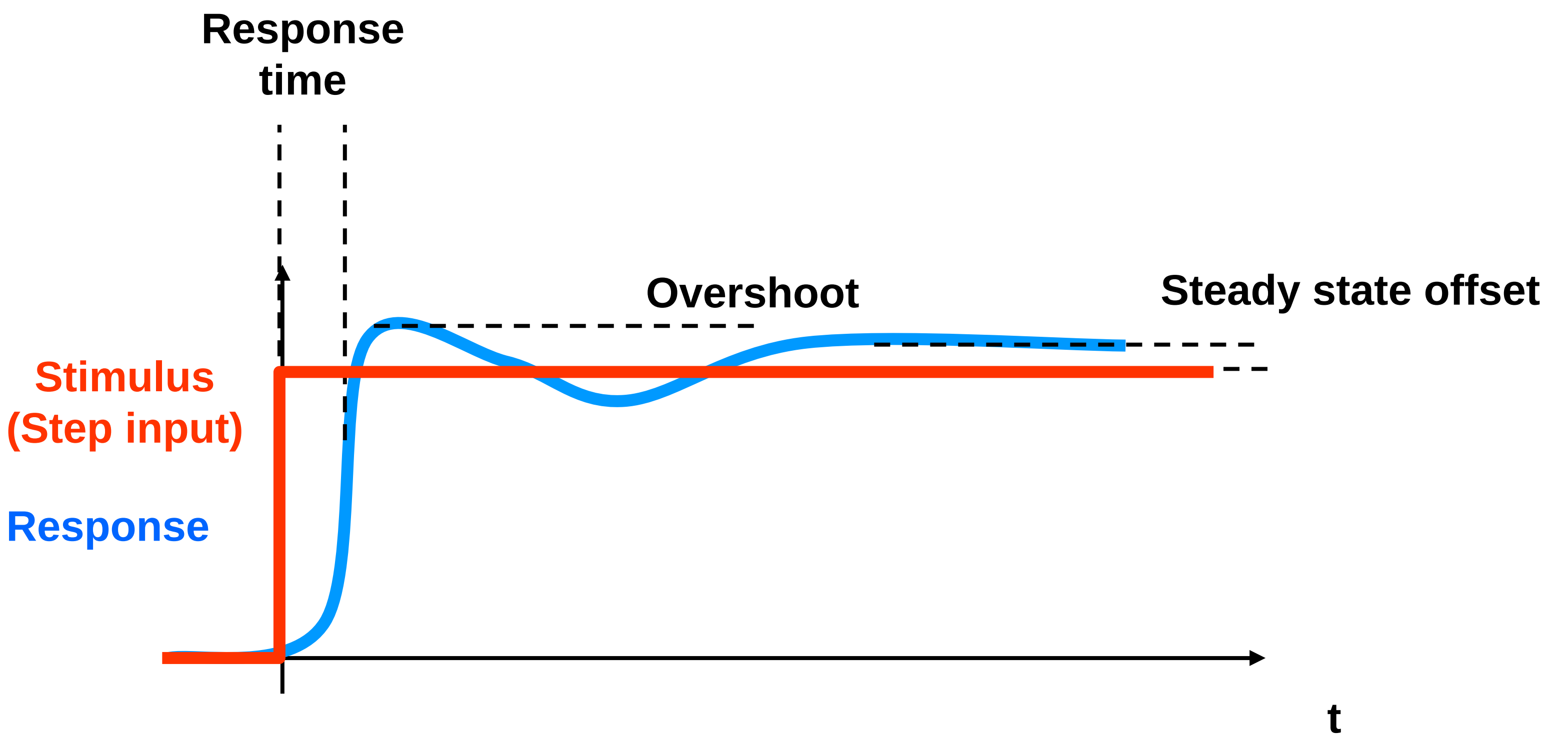
Application of Hot-wire Anemometer



Hot-wire Anemometer Feedback Control System



Issues in Control Systems



Generalizing The Fourier Series

- Start with the complex Fourier Series

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{j\frac{2\pi nt}{T}}$$

$$c_k = \frac{1}{T}\int_{-T/2}^{T/2} f(t)e^{-j\frac{2\pi kt}{T}}dt$$

Generalizing The Fourier Series

- Change variables

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{j\frac{2\pi nt}{T}} \qquad f(t) = \sum_{n=-\infty}^{\infty} c_n e^{jn\omega_0 t}$$

Replace 2π/T with ω_0

$$c_k = \frac{1}{T}\int_{-T/2}^{T/2} f(t) e^{-j\frac{2\pi kt}{T}} dt \qquad c_k = \frac{1}{T}\int_{-T/2}^{T/2} f(t) e^{-jk\omega_0 t} dt$$

Generalizing The Fourier Series: The Fourier Transform

- Consider what happens when the analysis period is allowed to increase

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{j\frac{2\pi nt}{T}}$$

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{jn\omega_0 t}$$

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)e^{j\omega t}d\omega$$

Replace 2π/T with ω_0

Let ω_0 go to 0
T becomes infinite

$$c_k = \frac{1}{T}\int_{-T/2}^{T/2} f(t)e^{-j\frac{2\pi kt}{T}}dt$$

$$c_k = \frac{1}{T}\int_{-T/2}^{T/2} f(t)e^{-jk\omega_0 t}dt$$

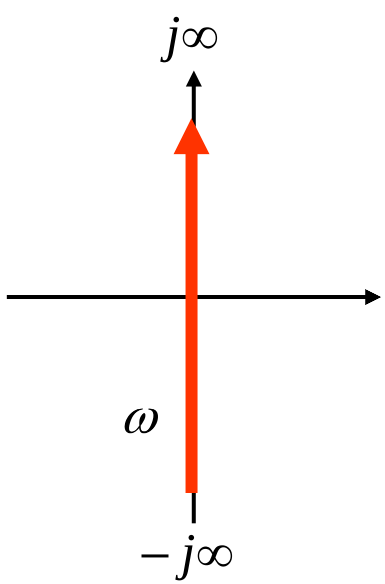
$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$$

Generalizing The Fourier Transform

- The Fourier Transform works well with sinusoidal and oscillatory signals
- The Fourier Integral inherently assumes the signal lies somewhere on the $j\omega$ axis

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{j\omega t} d\omega$$

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt$$



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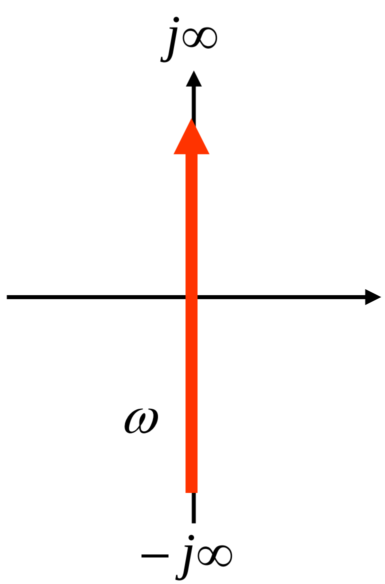
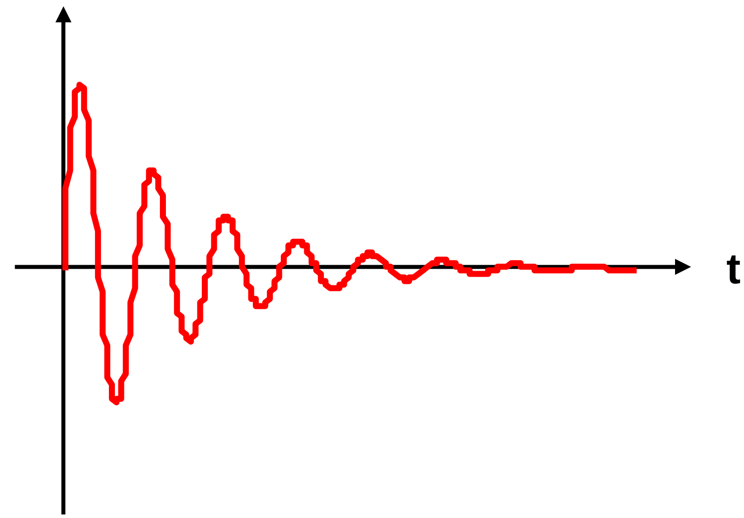


- But signals in control systems generally exhibit damped or decaying behavior, which the Fourier Transform cannot readily represent

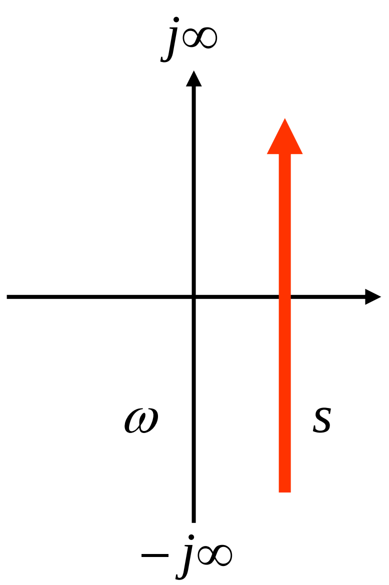


Generalizing The Fourier Transform: The Laplace Transform

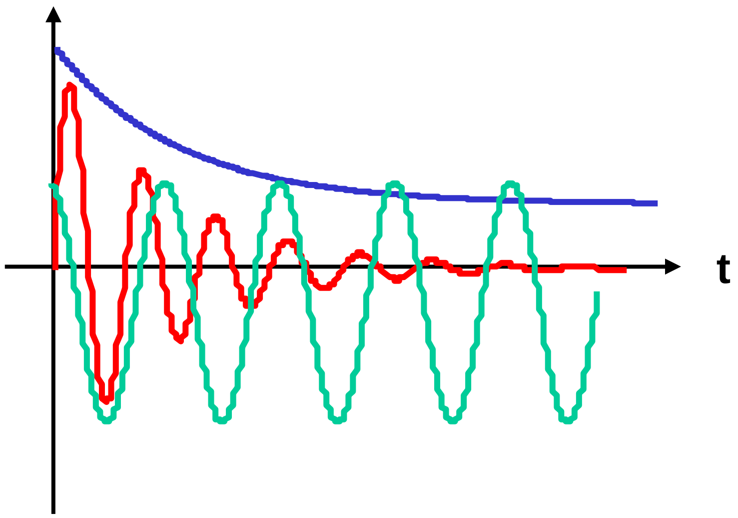
- The Laplace Transform is a generalization of the Fourier Transform with a transform operator that represents oscillatory as well as decaying oscillations

$$f(t) = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} F(s)e^{st}\,ds$$

$$F(s) = \int_{0-}^{\infty} f(t)e^{-st}\,dt$$



- The Laplace Transform can deal with a wider variety of signals than the Fourier Transform can.



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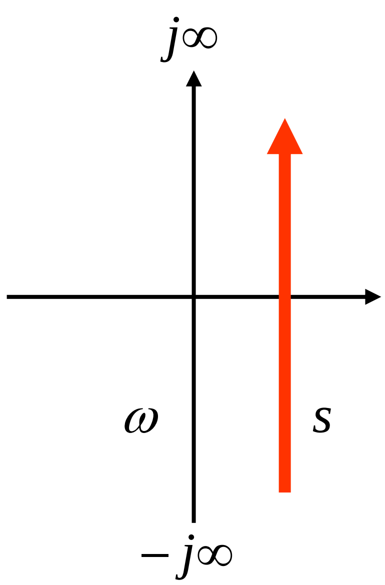

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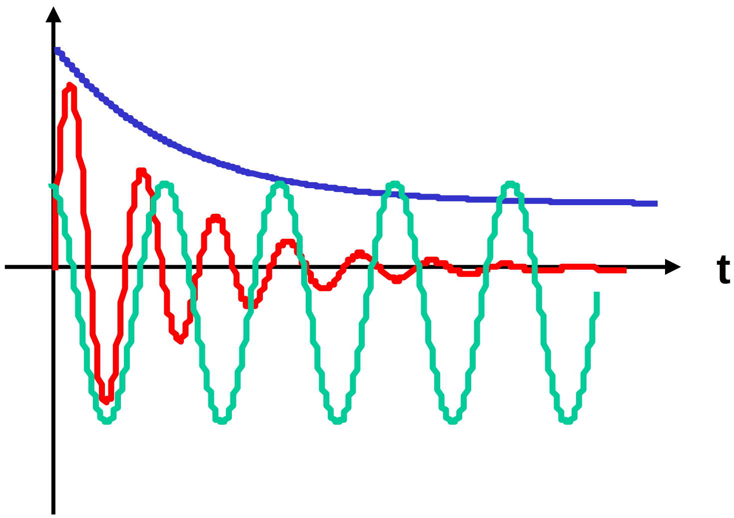

- The Laplace Transform provides a straightforward way to transform differential equations into algebraic equations, which can be more easily solved.

Next time

- Mathematical analysis of control systems

Homework

- Will be assigned on Wednesday/Thursday