Design IV

E232 Fall 07

Class 24

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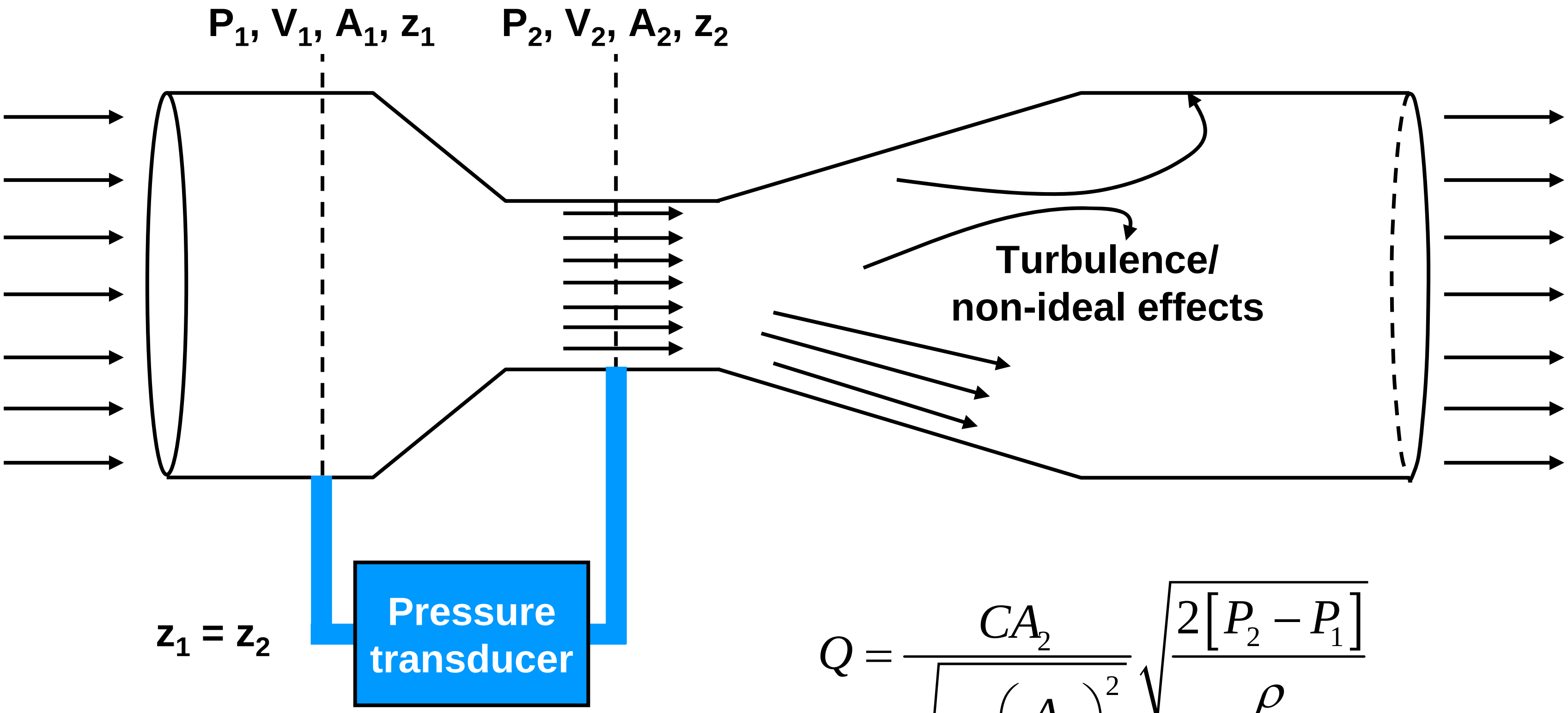
Venturi Tube



P_1, V_1, A_1, z_1

P_2, V_2, A_2, z_2

Turbulence/ non-ideal effects

Pressure transducer

$z_1 = z_2$

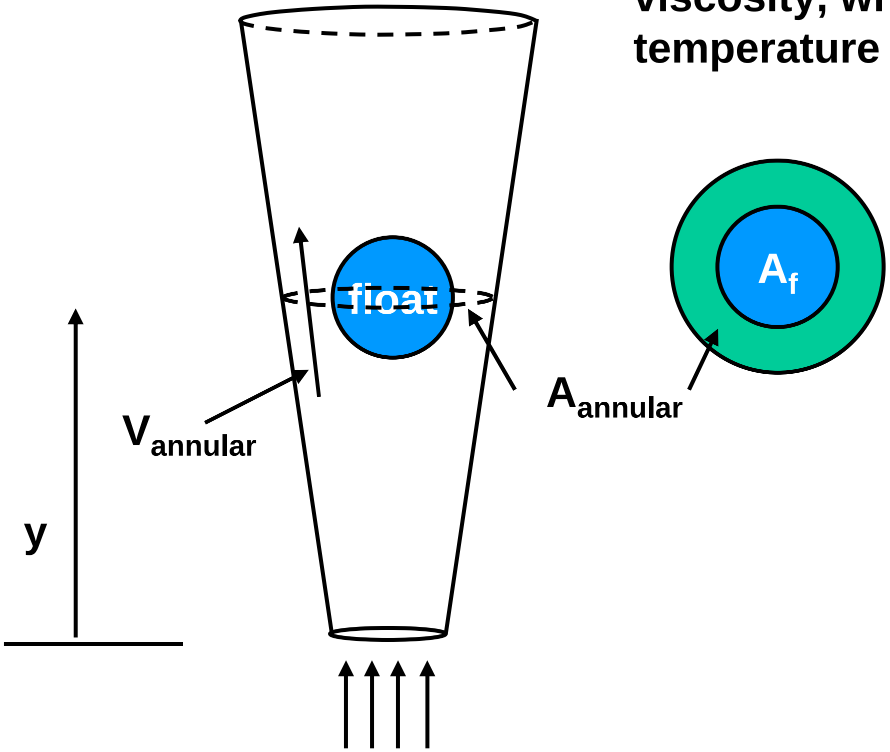
$$Q = \frac{CA_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2\left[P_2 - P_1\right]}{\rho}}$$

Variable-Area Flowmeters

- Rotameter

Issues:

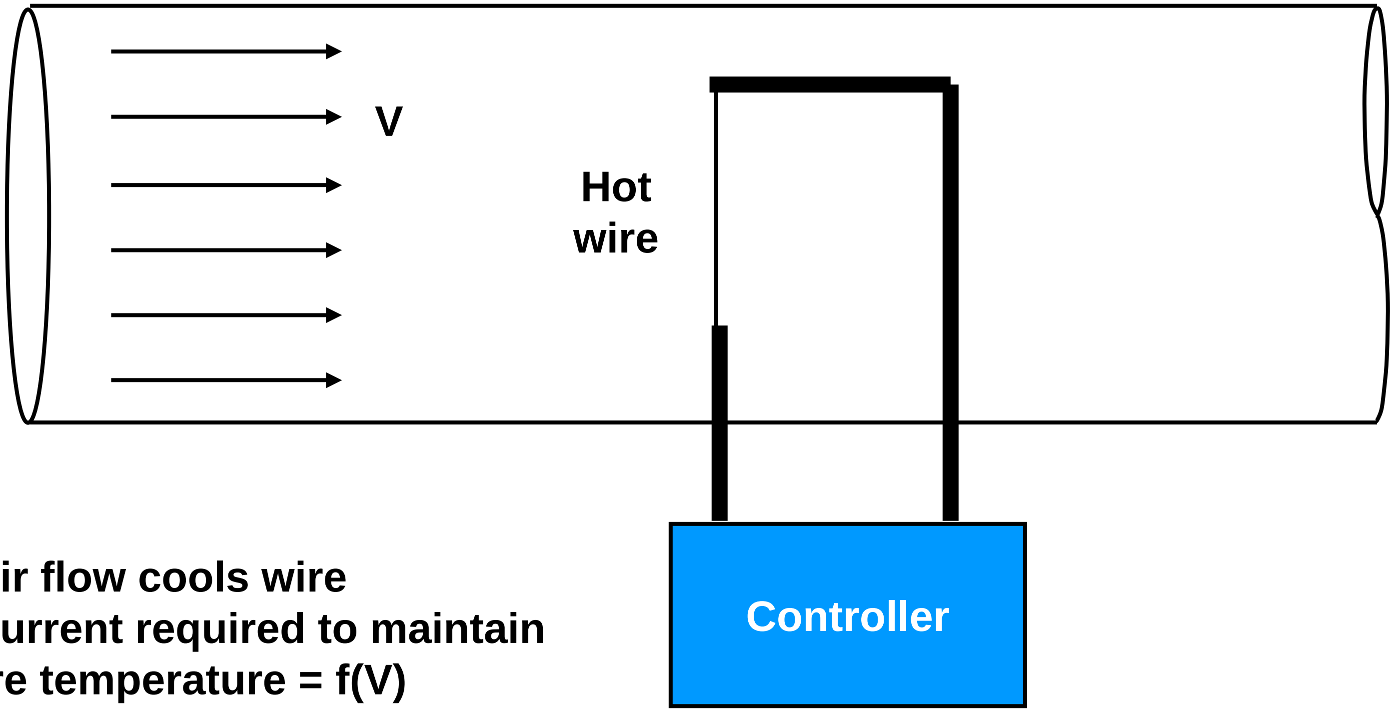
• Rotameter design is sensitive to fluid characteristics, e.g., viscosity, which changes with temperature



$$Q = V_a A_a$$

Design float so V_a is constant
Design flowmeter so A_a is linear with y

Hot-wire Air Mass Flowmeter

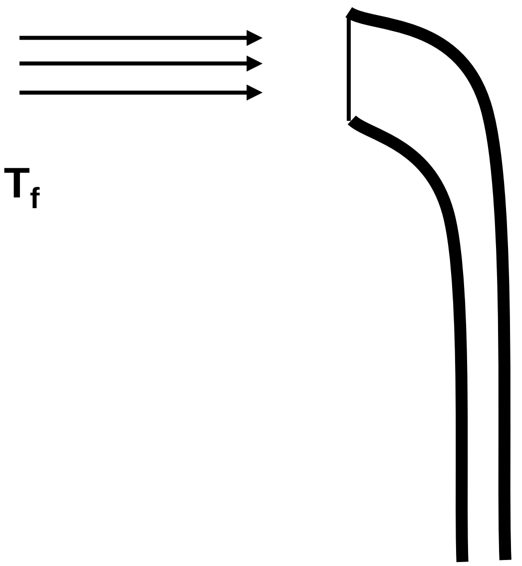


- **Air flow cools wire**
- **Current required to maintain wire temperature = f(V)**

Today’s topics

- Measurement sensors
  - **Fluid Flow Rate**
  - **Fluid Velocity**
  - **Fluid Level**

Fluid Velocity Sensor – Hot-Wire Anemometer



Fluid velocity, U

Hot wire, T_s

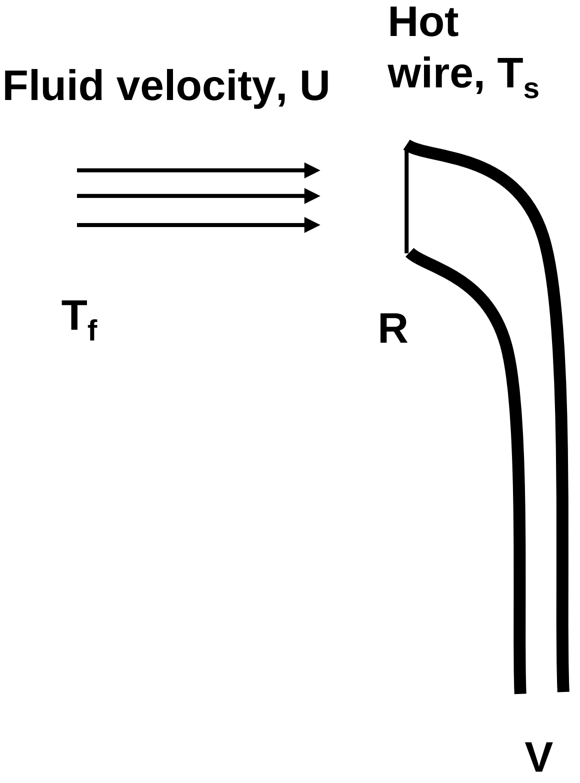
T_f

Heat loss:

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

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

Fluid Velocity Sensor – Hot-Wire Anemometer



Heat loss:

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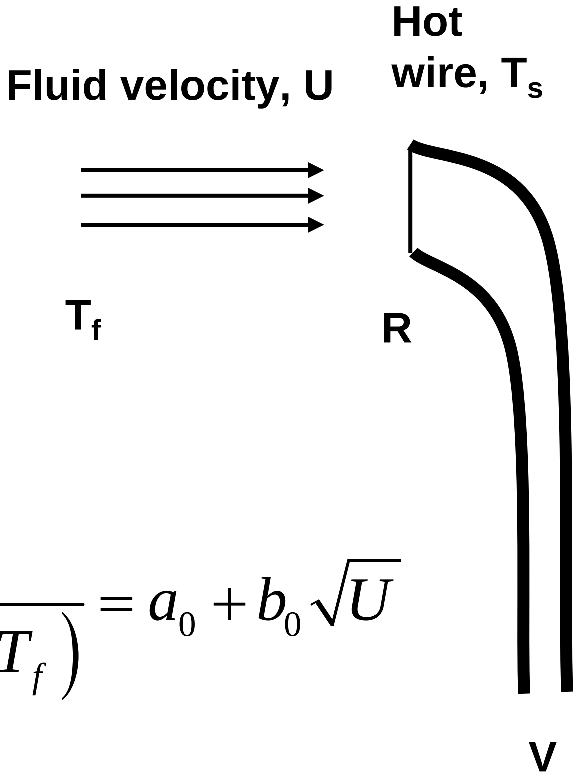
Heat gain:

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

Fluid Velocity Sensor – Hot-Wire Anemometer



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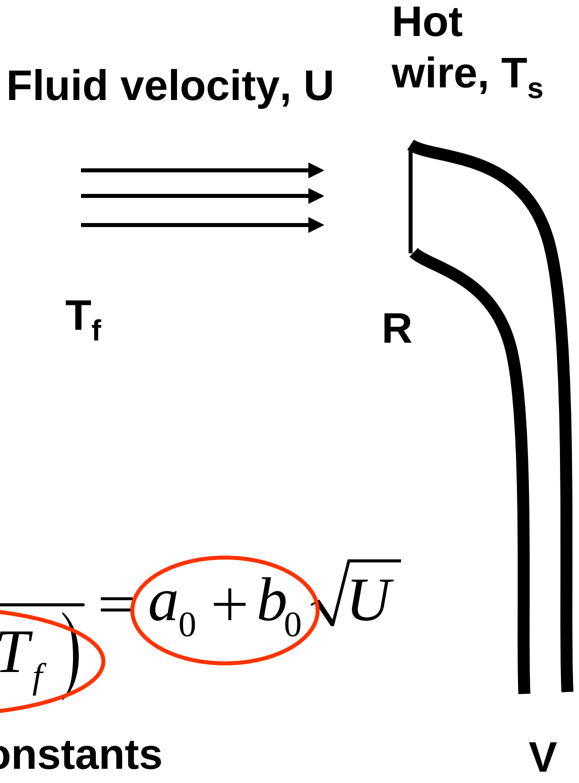
$$\mathrm{Re} = \frac{\rho U D}{\mu}$$

Heat gain:

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

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

Fluid Velocity Sensor – Hot-Wire Anemometer



Heat loss:

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

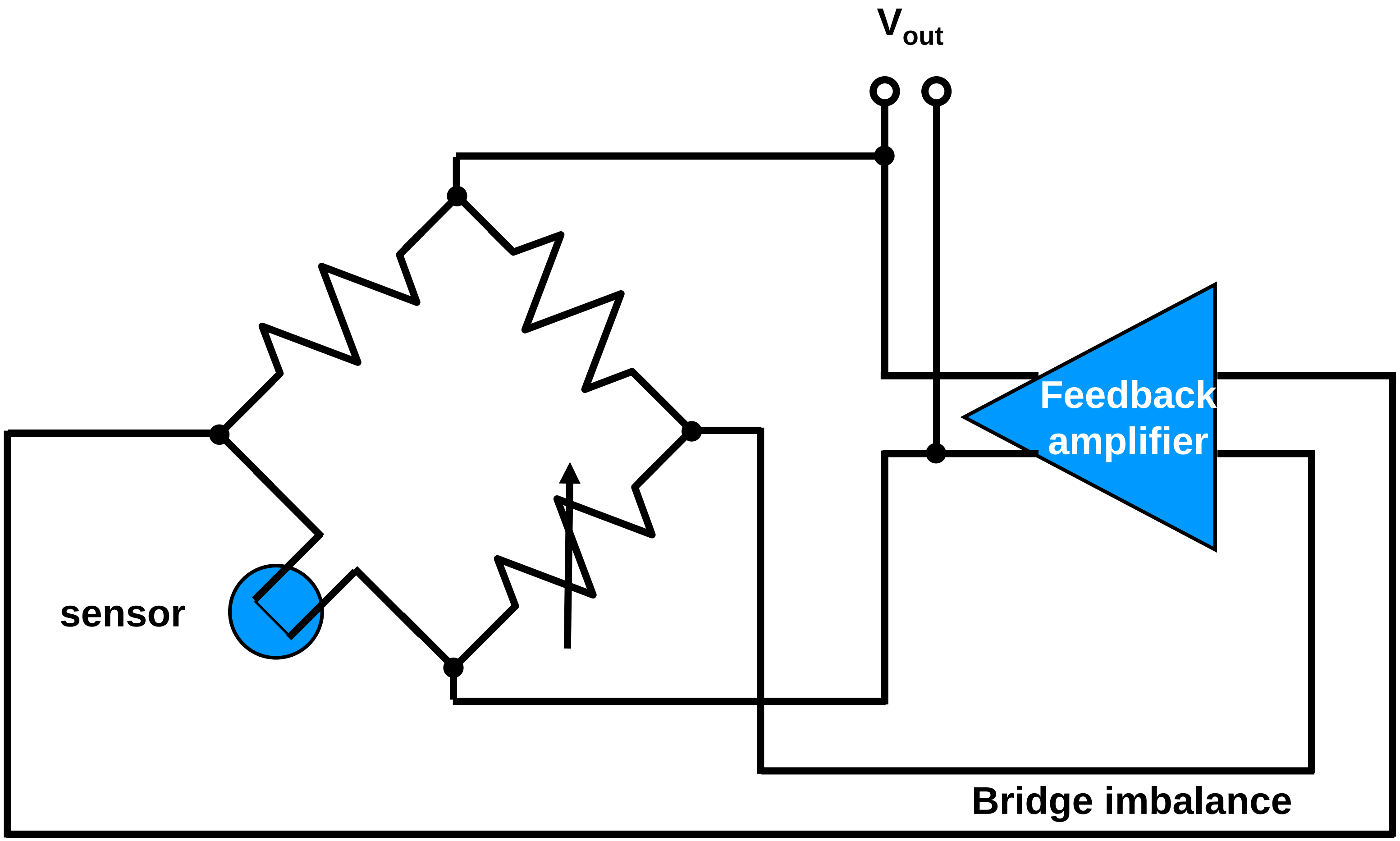
Heat gain:

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

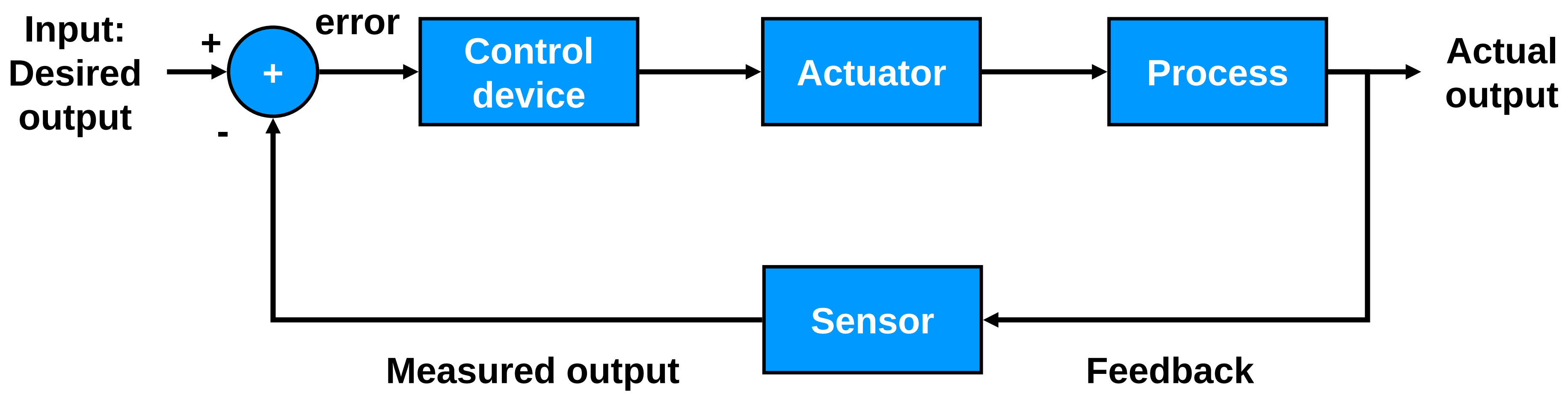
$$\frac{V^2}{\boxed{R(T_s - T_f)}} = \boxed{a_0 + b_0}\sqrt{U}$$

constants

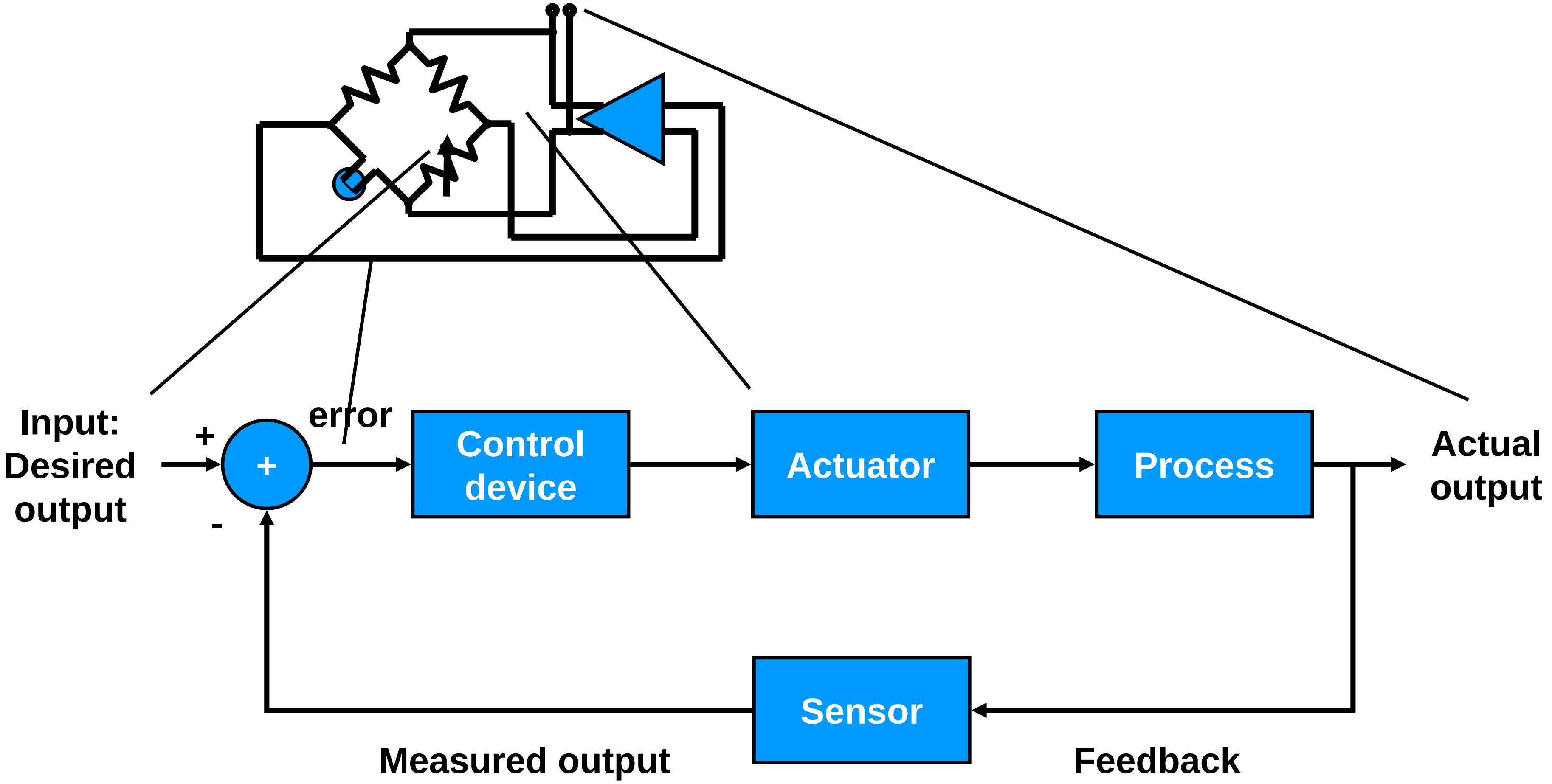
Application of Hot-wire Anemometer



Negative Feedback Control System

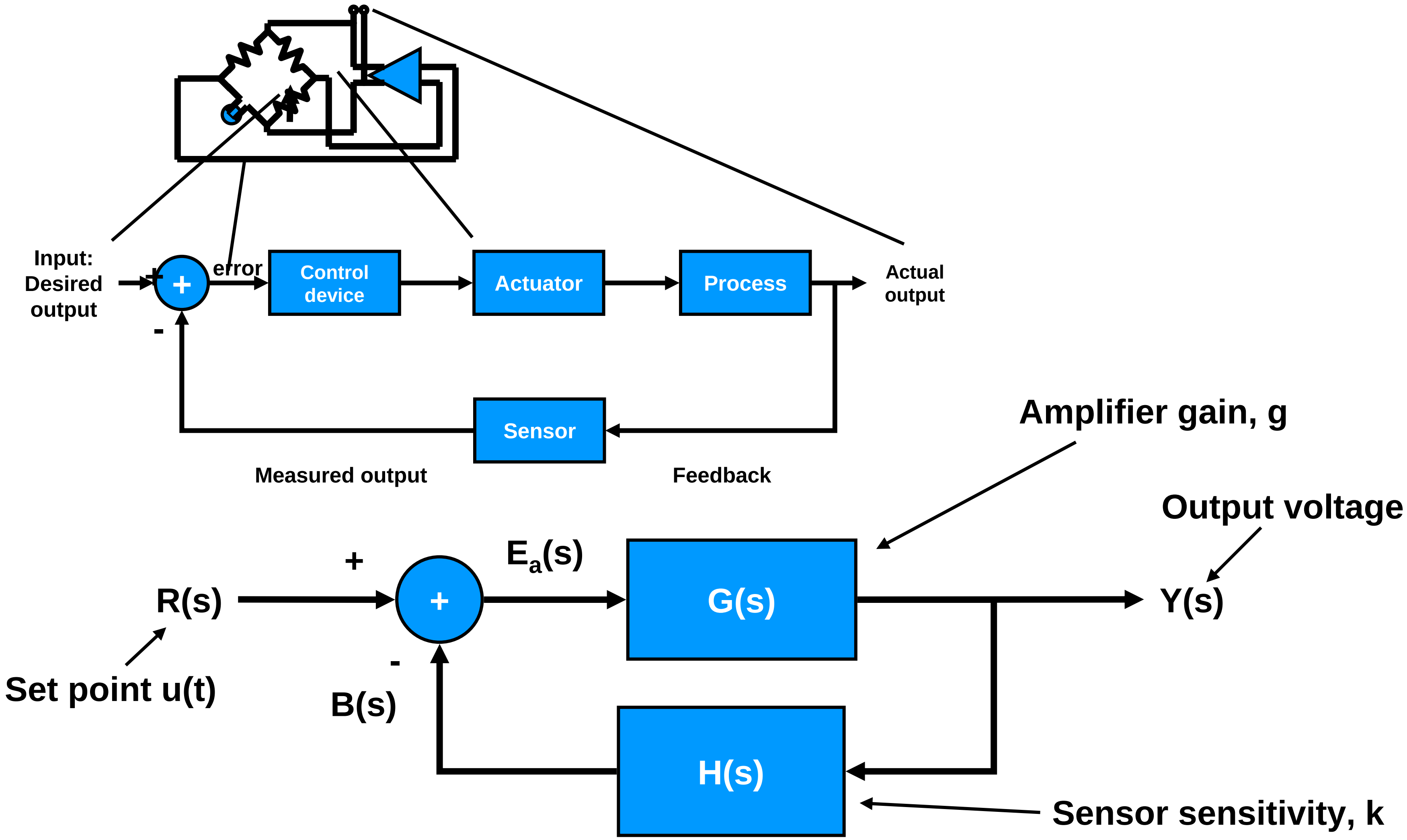


Hot-wire Anemometer Feedback Control System



Steady State Response

- Consider the hot-wire anemometer as a feedback control system



Input: Desired output

+

-

error

Control device

Actuator

Process

Actual output

Sensor

Measured output

Feedback

Amplifier gain, g

Output voltage

+

$E_a(s)$

R(s)

+

G(s)

Y(s)

Set point u(t)

-

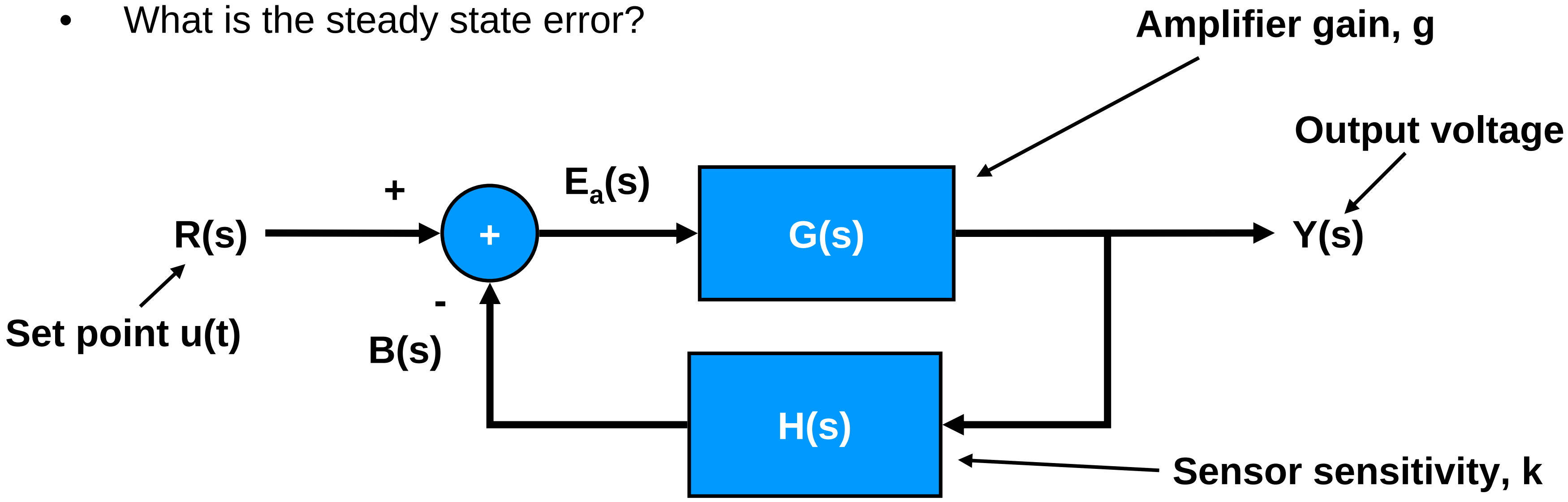
B(s)

H(s)

Sensor sensitivity, k

Steady State Response

- Consider the hot-wire anemometer as a feedback control system
- What is the steady state error?



$$\frac{Y(s)}{R(s)} = \frac{G(s)}{1+G(s)H(s)}$$

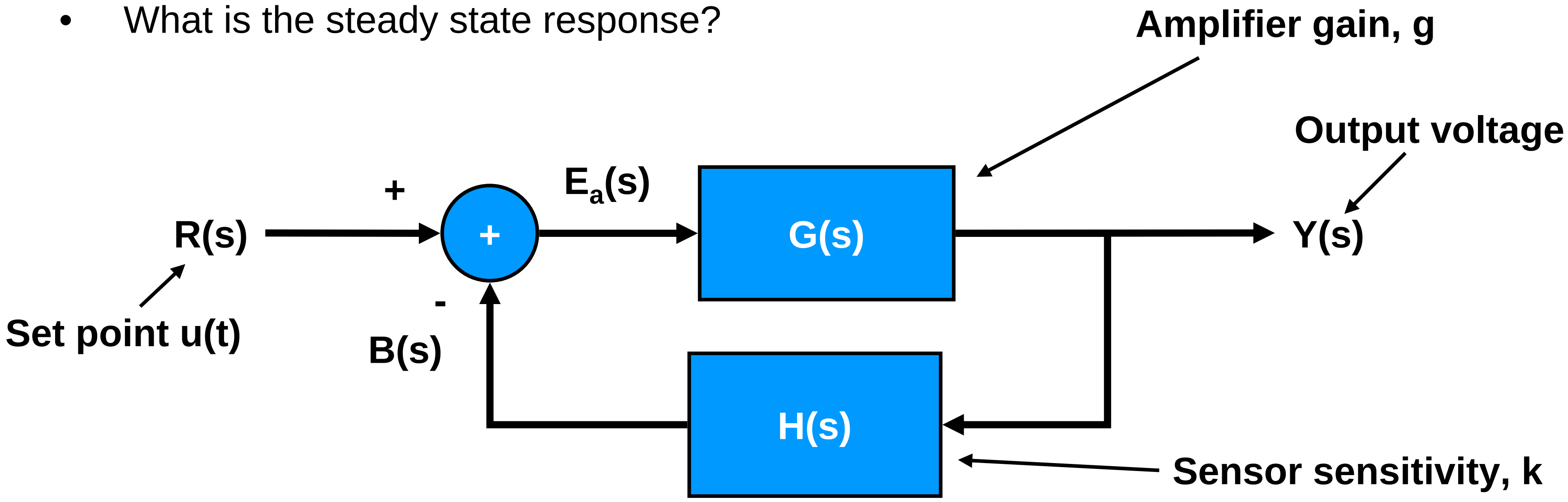
$$Y(s) = \frac{G(s)}{1+G(s)H(s)}R(s)$$

$$Y(s) = \frac{g}{1+gk}\frac{1}{s}$$

$$E_a(s) = \frac{g}{1+gk}\frac{1}{s}\frac{1}{g}$$

Steady State Response

- Consider the hot-wire anemometer as a feedback control system
- What is the steady state response?

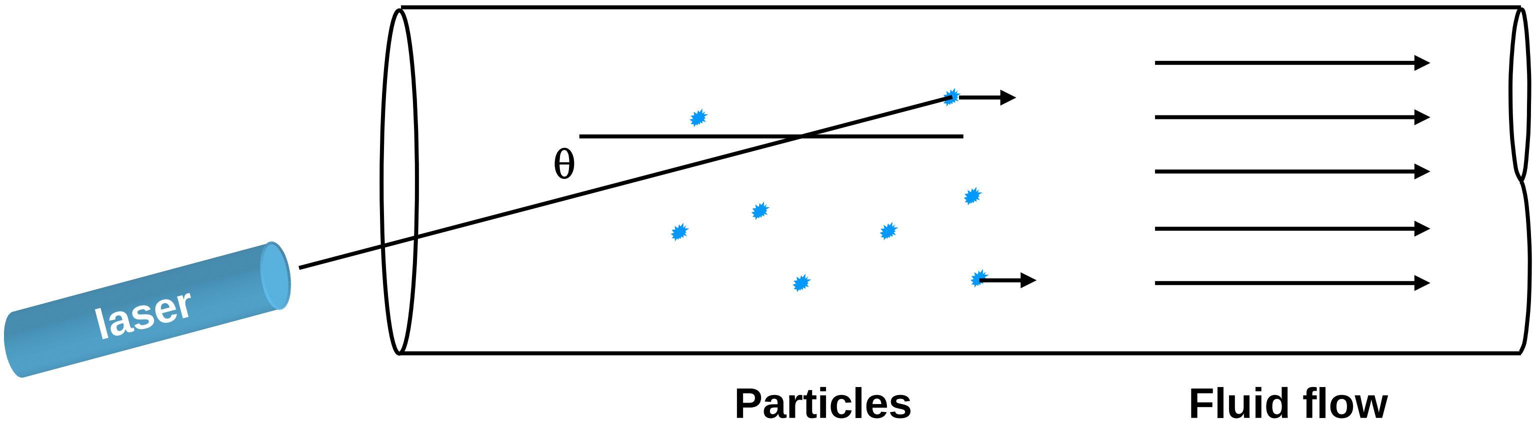


$$E_a(s) = \frac{1}{s\left(1+gk\right)}$$

From the final value theorem:

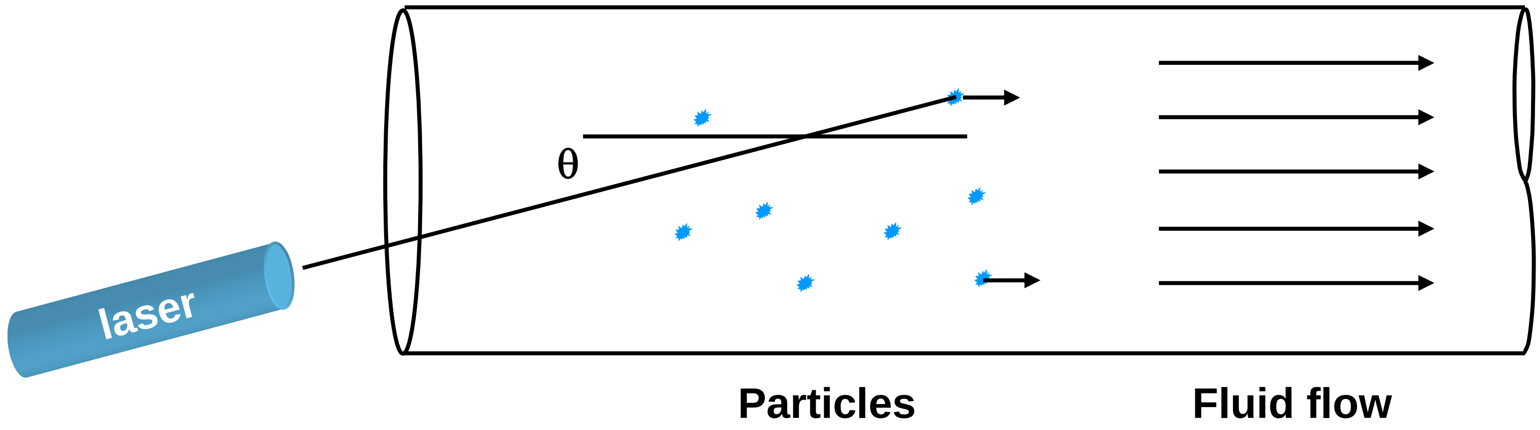
$$\lim_{t\to\infty} z(t) = \lim_{s\to 0} sZ(s) \qquad \lim_{t\to\infty} e_a(t) = \lim_{s\to 0} s\frac{1}{s\left(1+gk\right)}$$

Fluid Velocity Sensor – Laser Doppler



$$f_D = \frac{2V\cos(\theta)}{\lambda} = \frac{2V\cos(\theta)}{c} f_0$$

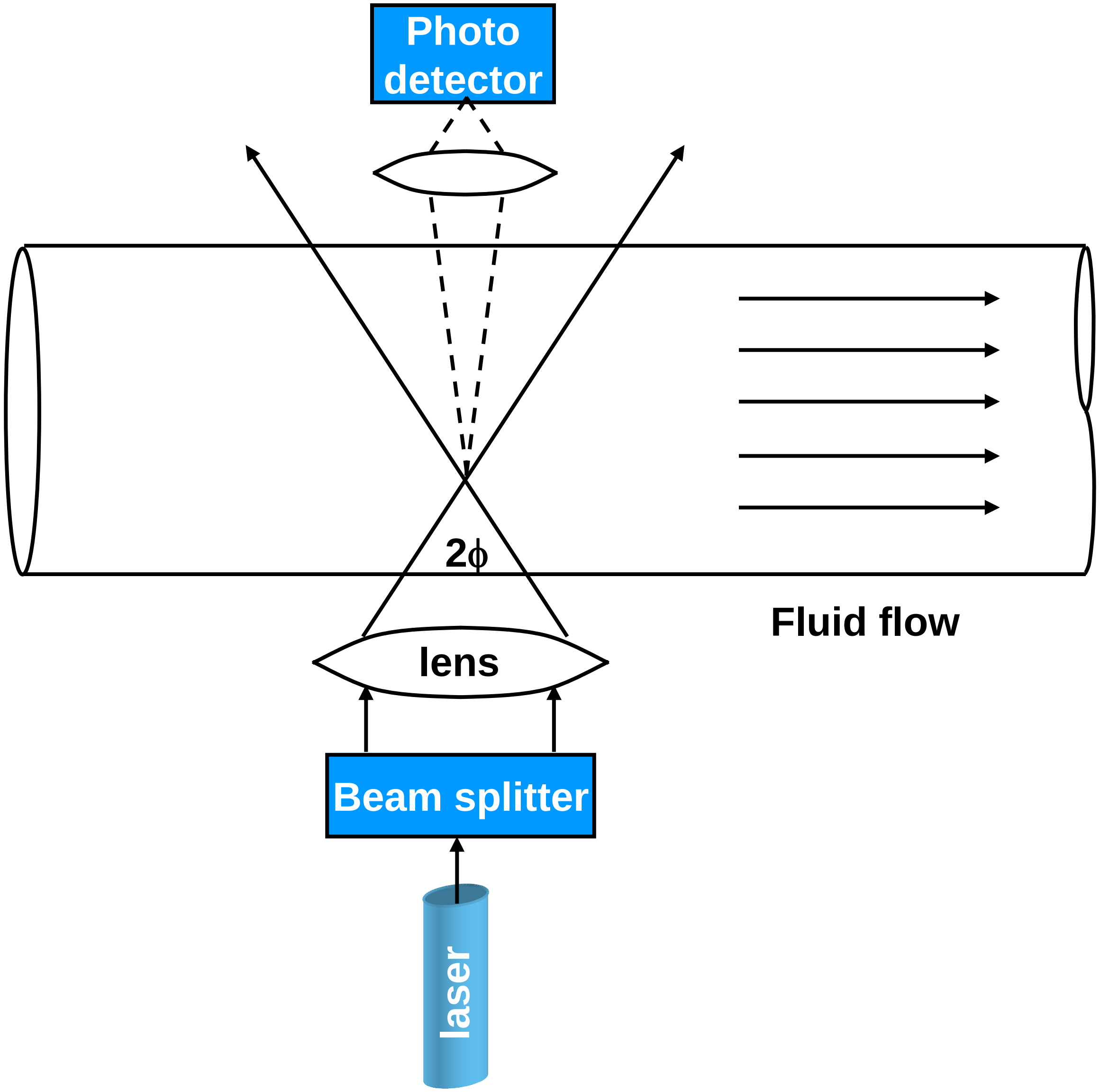
Fluid Velocity Sensor – Laser Doppler



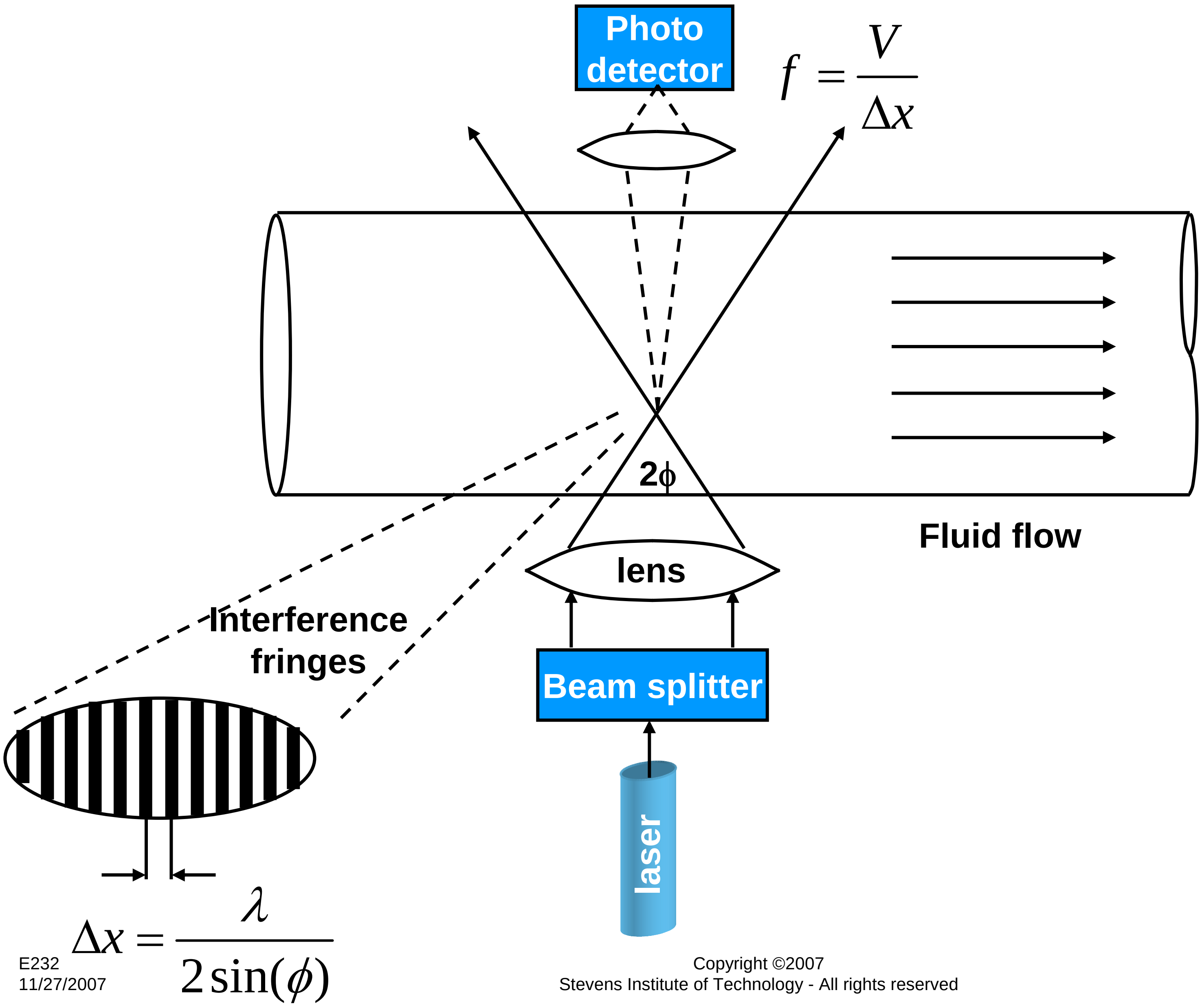
$$f_D = \frac{2V\cos(\theta)}{\lambda} = \frac{2V\cos(\theta)}{c}\, f_0$$

For λ = 800 μm,
V = 100 m/sec
f_0 = 4 x 10^{11} Hz
f_D = 250 kHz

Fluid Velocity Sensor – Dual-Beam Laser Velocimeter



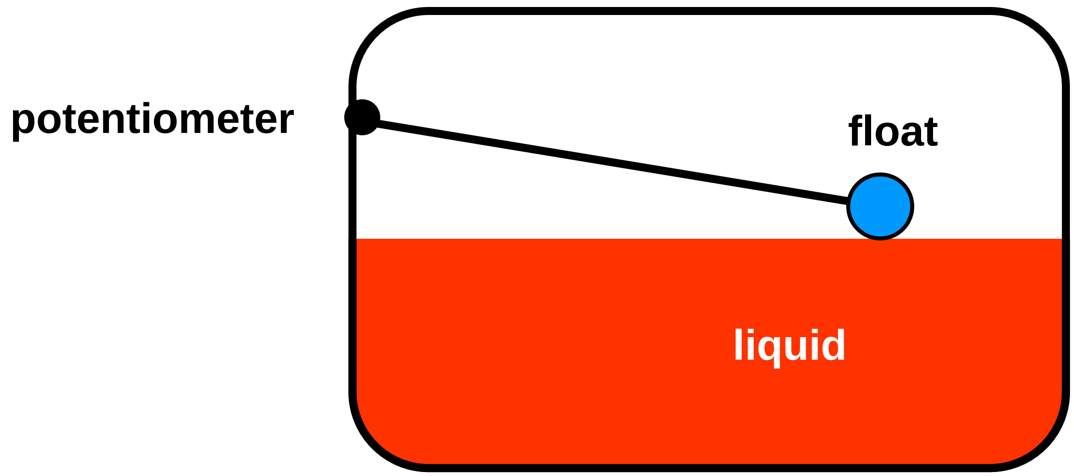
Fluid Velocity Sensor – Dual-Beam Laser Velocimeter



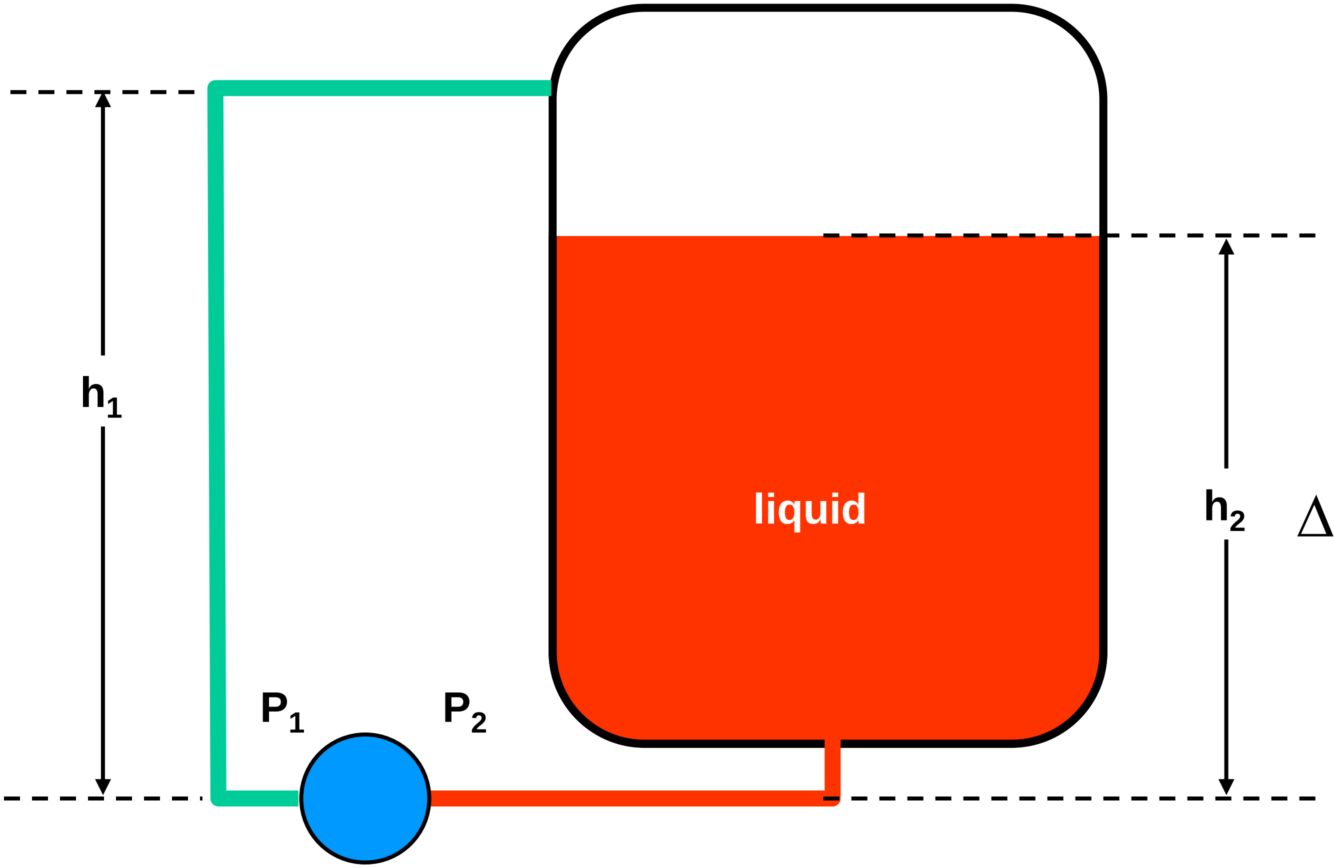
$$f = \frac{V}{\Delta x}$$

$$\Delta x = \frac{\lambda}{2\sin(\phi)}$$

Fluid Level Measurement – Buoyancy Sensors

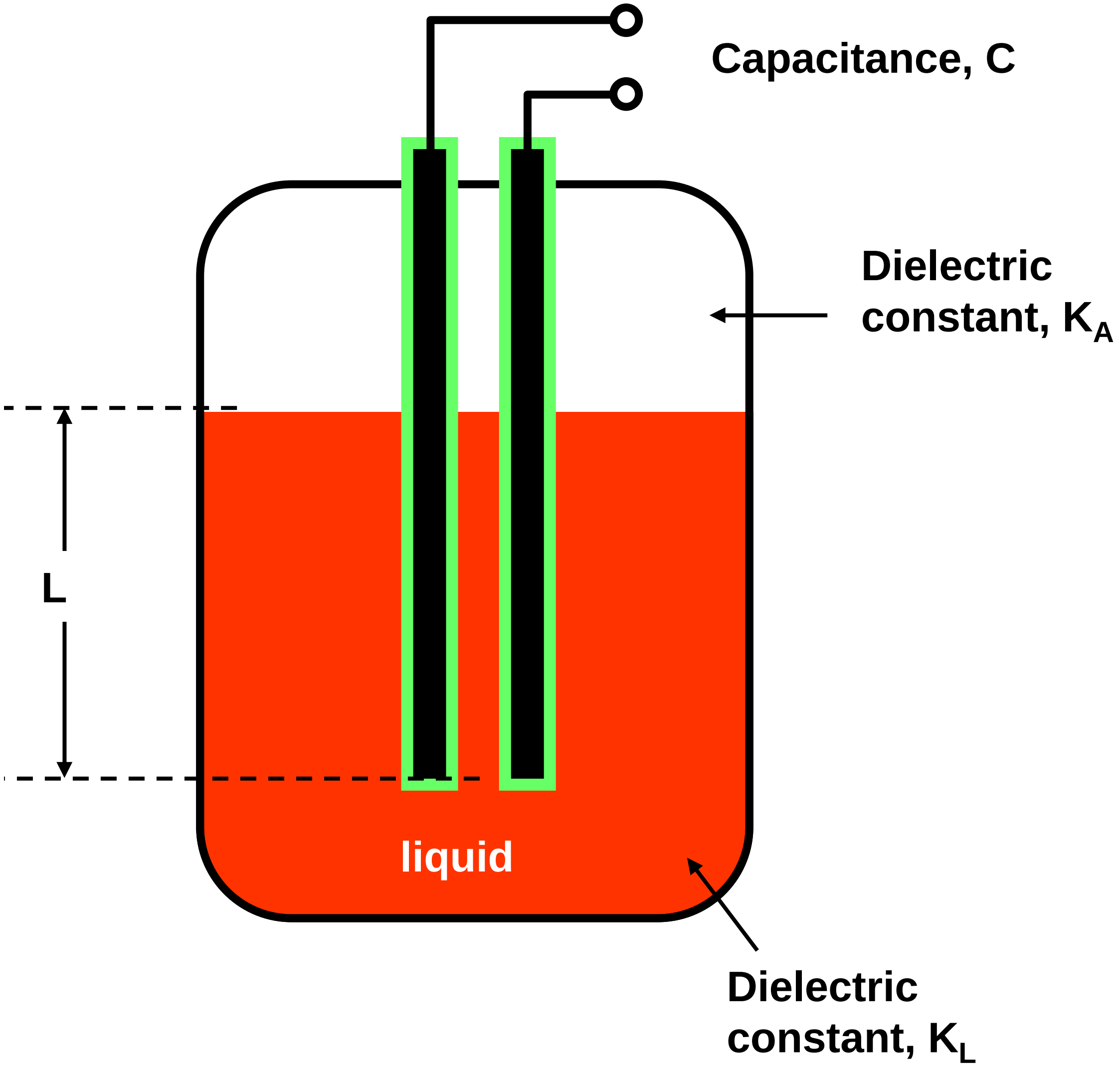


Fluid Level Measurement – Differential Pressure

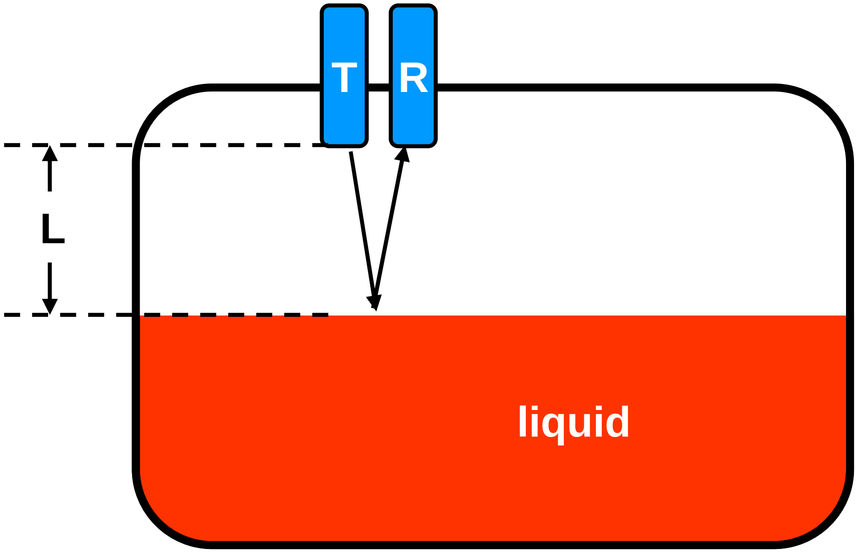


$$\Delta P = \rho g h$$

Fluid Level Measurement – Capacitance Sensors



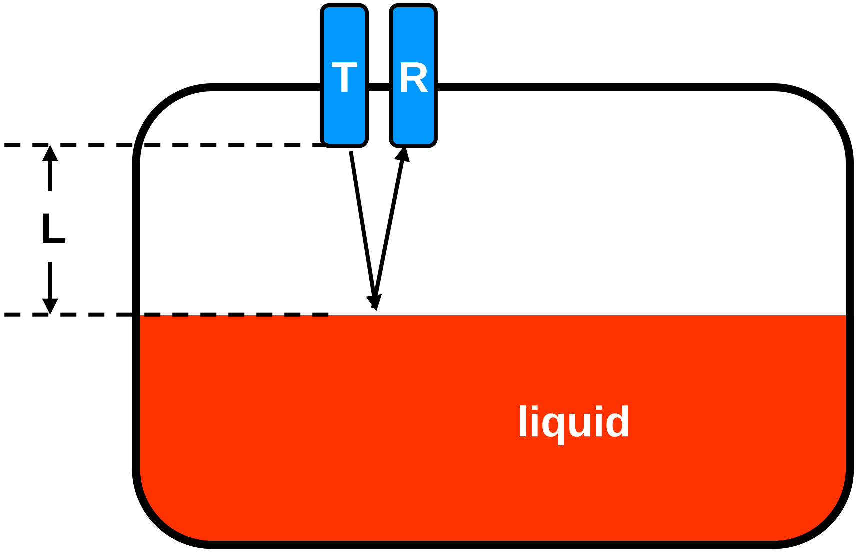
Fluid Level Measurement – Ultrasonic Devices



$$L = \frac{ct}{2}$$

Fluid Level Measurement – Ultrasonic Devices

- Ultrasonic pulse roundtrip time measurement



$$L = \frac{ct}{2}$$

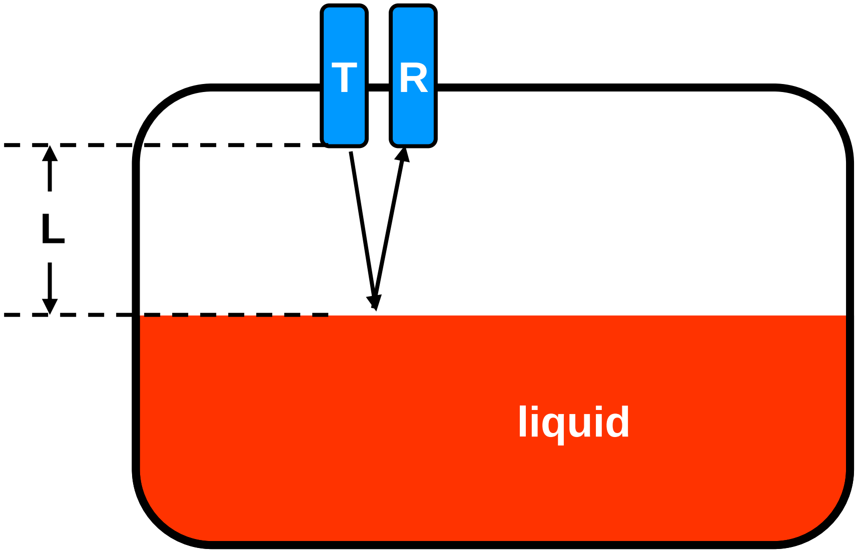
But c=f(T, liquid)

In air, c=1 ft/ms

Fluid Level Measurement – Ultrasonic Devices

- Ultrasonic chirp pulse

$$f(t) = \sin\left(2\pi\left(f_0 + \left(\frac{\Delta f}{\Delta\tau}\right)t\right)t\right)$$



$$f_D = \left(\frac{\Delta f}{\Delta\tau}\right)\left(\frac{2L}{c}\right)$$

Homework10

- Problems 9.1, 9.16
- Problems 10.25, 10.31, 10.39