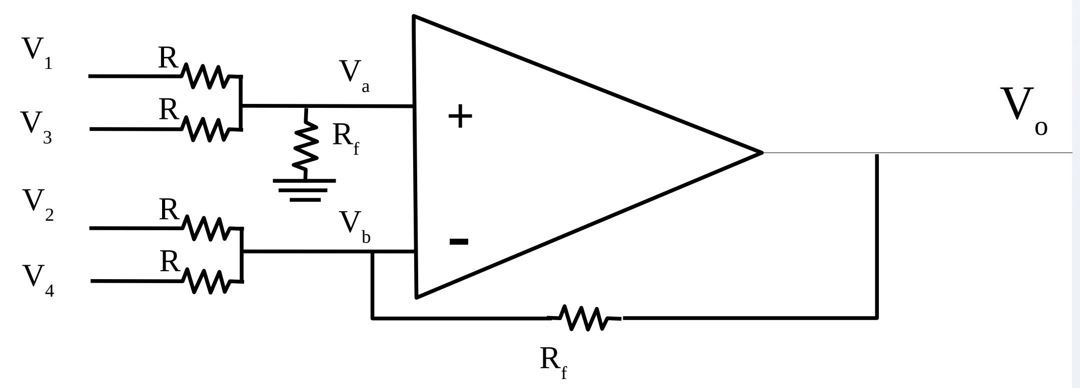
# Sample Problems

Suresh Devasahayam
Department of Bioengineering
Christian Medical College, Vellore

# Lecture - Outline

- Operational Amplifier Circuits
  - Sum and difference amplifier
  - Low-pass and high-pass filters
- Sensors with feedback compensation
  - Force sensor dynamic characteristics
  - Feedback compensation

# Problem 1: Sum and Difference Amplifier



# P1: Output of the sum-and-difference amplifier

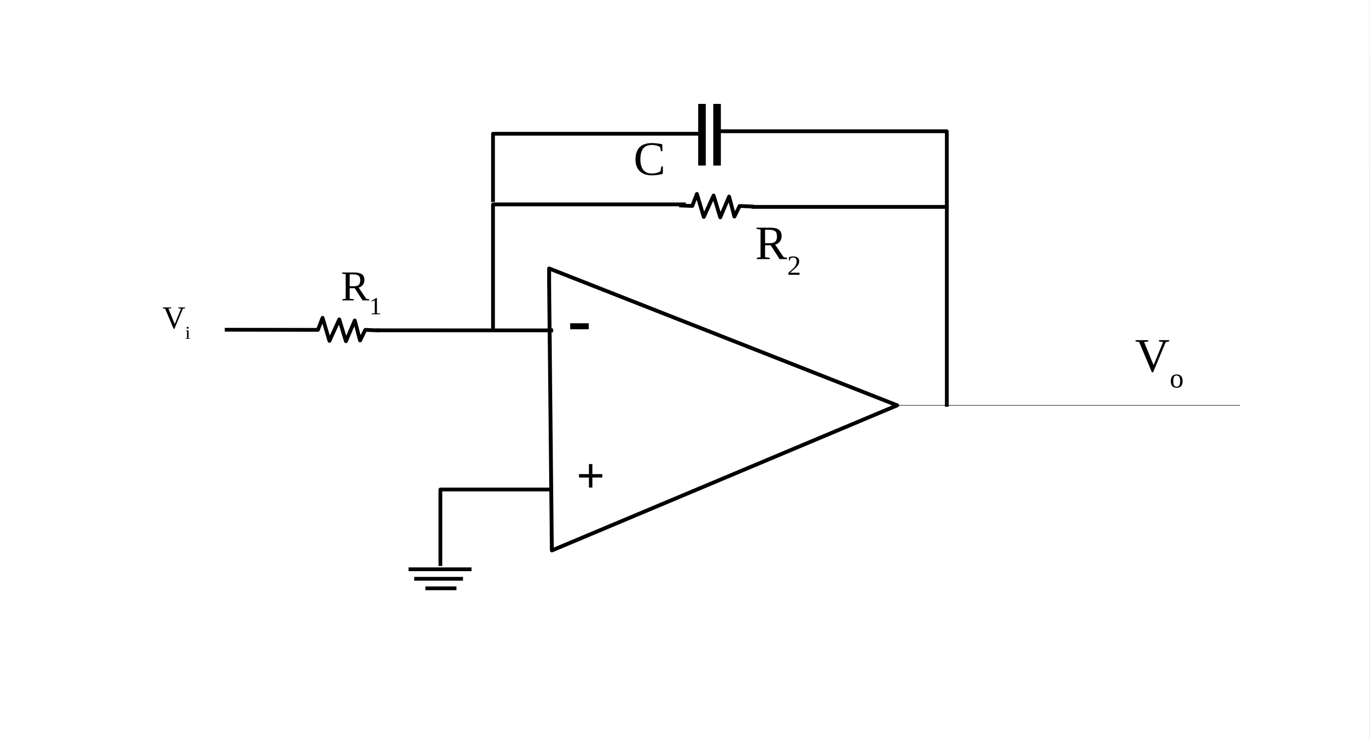
$$V_a = \left(\frac{V_1 + V_3}{R}\right)\left(\frac{R\,R_f}{2R + R_f}\right)$$

$$V_b = \left(\frac{V_2 + V_4}{R} + \frac{V_o}{R_f}\right)\left(\frac{R\,R_f}{2R + R_f}\right)$$

$$V_a = V_b$$

$$V_o = \left(V_1 + V_3 - V_2 - V_4\right)\left(\frac{R_f}{R}\right)$$

# Problem 2: Low-pass filter



# P2: Design the filter for a cutoff of 20Hz

$$\frac{V_o(s)}{V_i(s)} = \frac{-(R_2/R_1)}{1+R_2Cs}$$

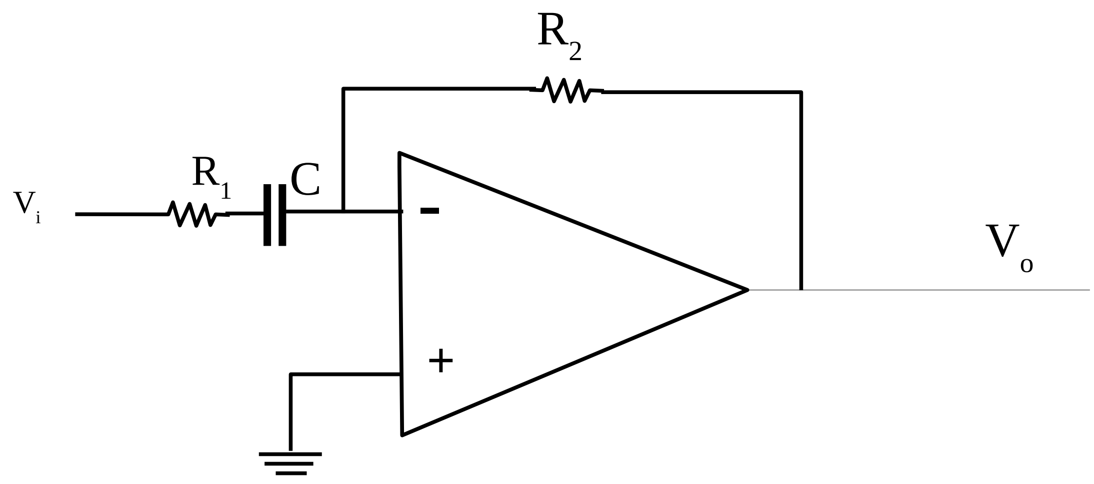
$$R_1 = R_2 = 10\,k\Omega, \quad C = 0.8\,\mu F, \quad f_c = 20\ Hz, \omega_c = 125\, r/s$$

$$\left|\frac{V_o(j\omega)}{V_i(j\omega)}\right| = \frac{1}{\sqrt{1+(RC\,\omega)^2}} = \frac{1}{\sqrt{1+(\omega/125)^2}}$$

# P2:

| f | ω | Magnitude | Magnitude (dB) | Phase |
|---|---|---|---|---|
| 0.2 | 1.25 | 1 | 0 | 0 |
| 2.0 | 12.5 | 1 | 0 | |
| 20 | 125 | 0.707 | -3 | 45 |
| 200 | 1250 | 0.1 | -20 | |
| 2000 | 12500 | 0.01 | -40 | 90 |

# Problem 3: High-pass filter



# P3: Design the HPF with cutoff freq of 20Hz

$$\frac{V_o(s)}{V_i(s)} = \frac{-R_2 Cs}{1+R_1 Cs}$$

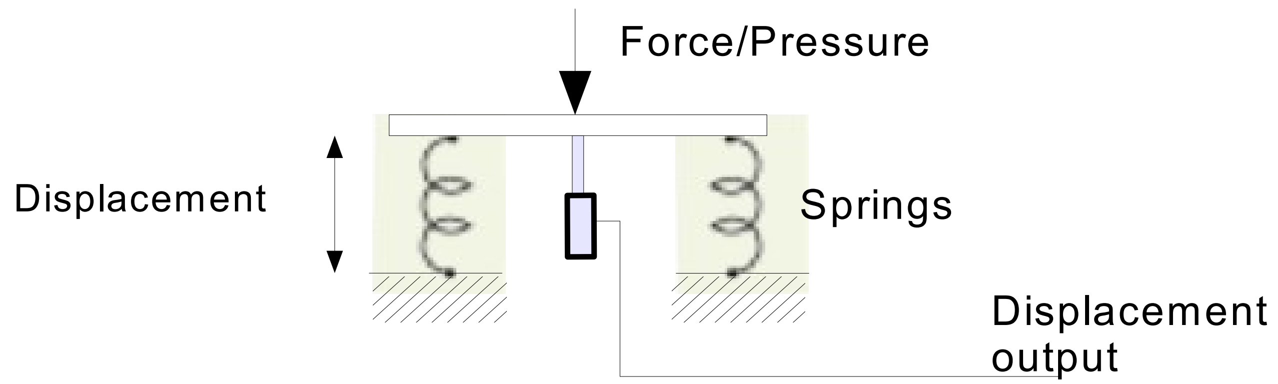
$$R_1 = R_2 = 10\,k\Omega, \quad C = 0.8\,\mu F, \quad f_c = 20\ Hz, \omega_c = 125\,r/s$$

$$\left|\frac{V_o(j\omega)}{V_i(j\omega)}\right| = \frac{RC\omega}{\sqrt{1+(RC\omega)^2}} = \frac{\omega/125}{\sqrt{1+(\omega/125)^2}}$$

# P3:

| f | ω | Magnitude | Magnitude (dB) | Phase |
|---|---|---|---|---|
| 0.2 | 1.25 | 0.01 | -40 | |
| 2.0 | 12.5 | 0.1 | -20 | |
| 20 | 125 | 0.707 | -3 | |
| 200 | 1250 | 1 | 0 | |
| 2000 | 12500 | 1 | 0 | |

# P4: Force sensor




Mass: m=100g,

spring constant: K=25.6 N/m

viscous damping B=0.8 N.s/m

# P4:

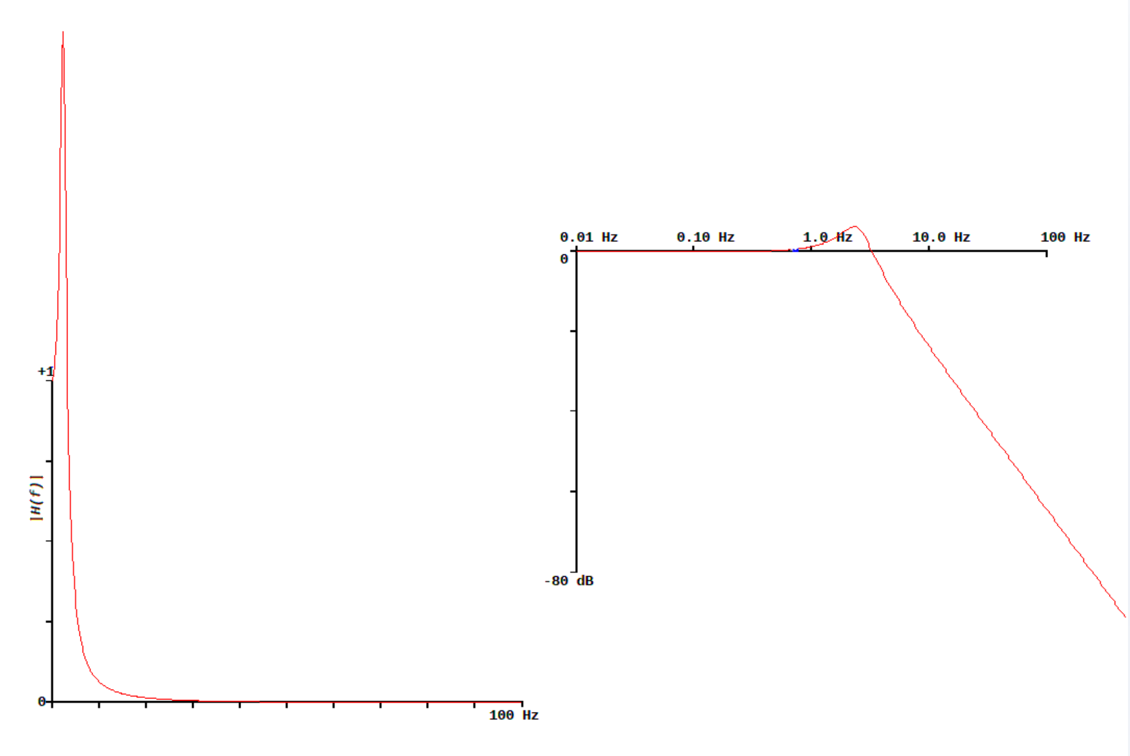
$$F(t)=m\frac{d^2x(t)}{dt}+B\frac{dx}{dt}+Kx$$

$$V_o(t)=g_a x(t)$$

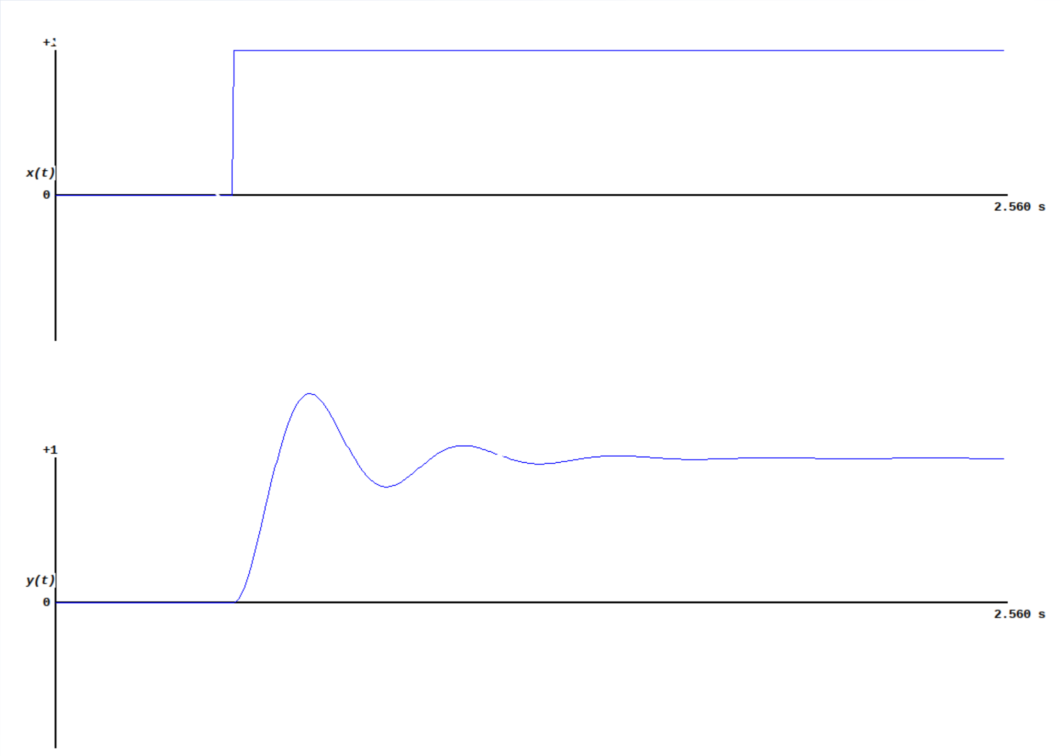
$$\frac{V_o(s)}{F_1(s)}=\frac{g_a}{ms^2+Bs+K}=\frac{g_a/K}{(m/K)s^2+(B/K)s+1}$$

$$\frac{V_o(s)}{F_1(s)}=\frac{A}{\frac{s^2}{\omega_n^2}+2\frac{\zeta}{\omega_n}s+1},\qquad \omega_n=16\,r/s,\quad \zeta=0.25$$

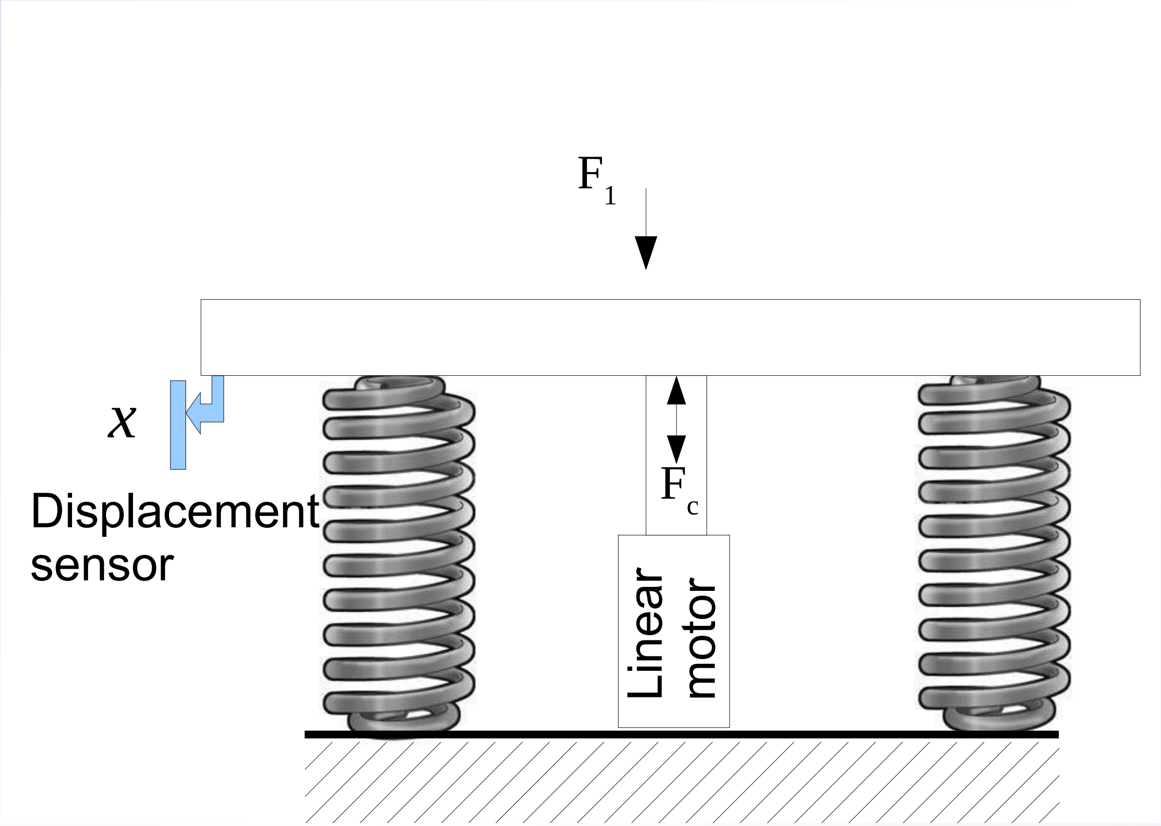
# P4: Sensor Frequency response



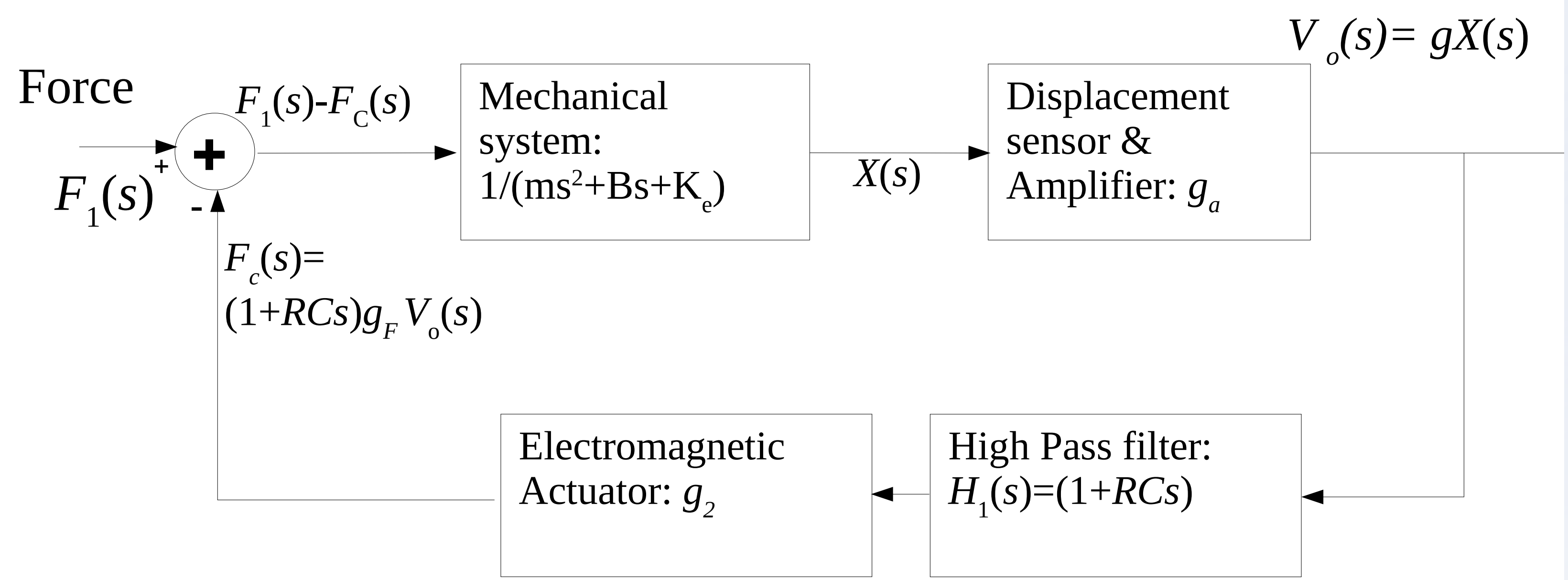
# P4: Sensor Step response



# P4: Sensor with feedback compensation



# P4: Feedback compensation



# P4: Transfer function of sensor with feedback compensation

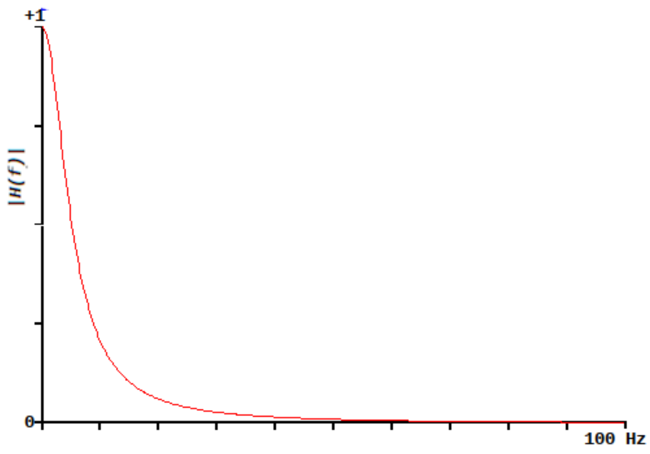
$$\frac{V_o(s)}{F_1(s)}=\frac{g_a}{ms^2+(B+g_a g_2 RC)s+(K+g_a g_2)}$$

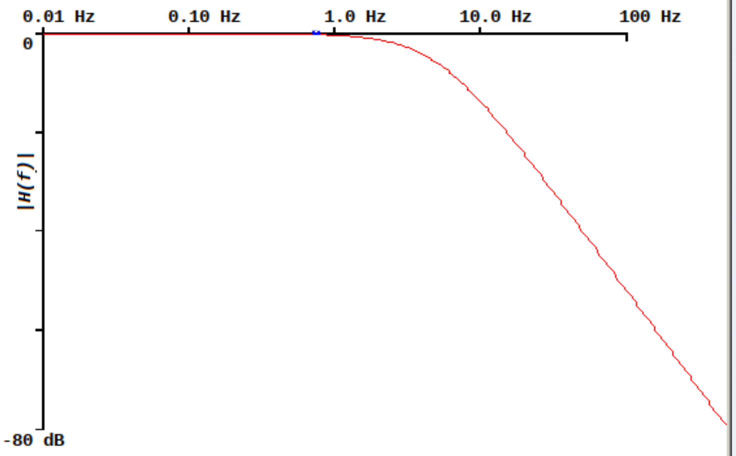
$$\frac{V_o(s)}{F_1(s)}=\frac{A}{\frac{s^2}{\omega_c^2}+2\frac{\zeta}{\omega_c}s+1}$$

$$A=\frac{g_a}{K+g_a g_2} \qquad \omega_c=\sqrt{\frac{K+g_a g_2}{m}} \qquad \zeta=\frac{B+g_a g_2 RC}{\sqrt{4m(K+g_a g_2)}}$$

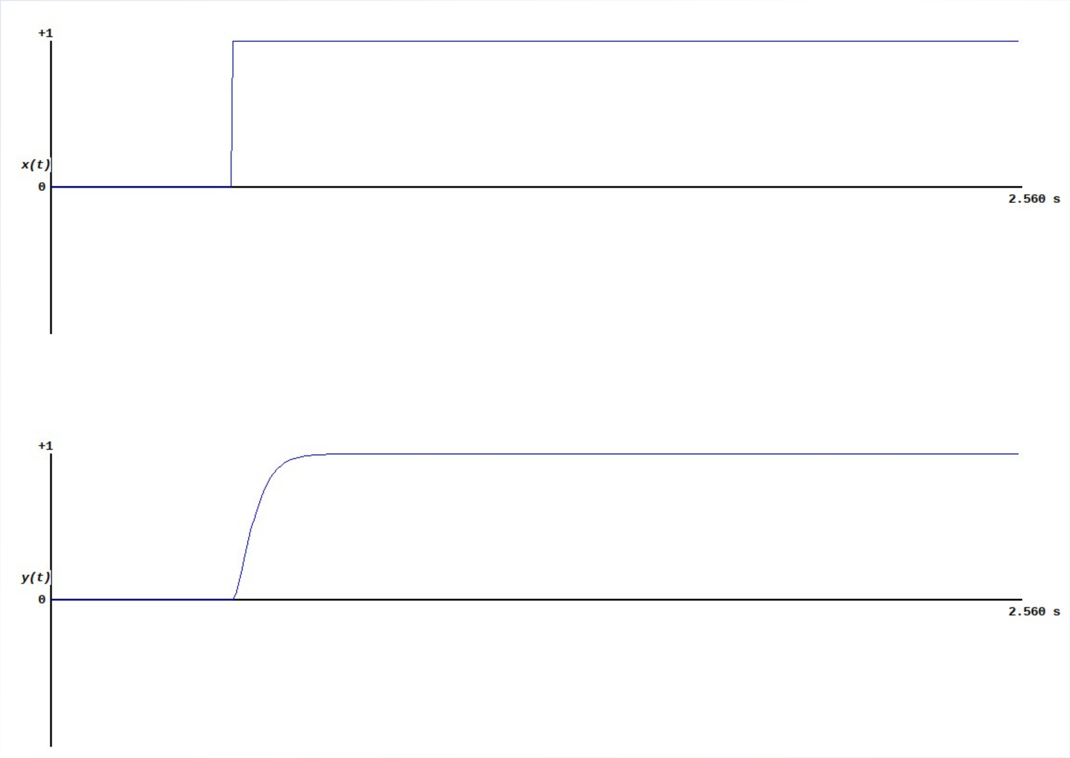
$$g_a g_2=76.8\,, \quad RC=0.073\,, \qquad \omega_n=32\, r/s=5.08\, Hz\,, \zeta=1.0$$

# P4: Compensated Sensor Freq Response



# P4: Compensated Sensor Step Response



End of Lecture