Review: Circuits

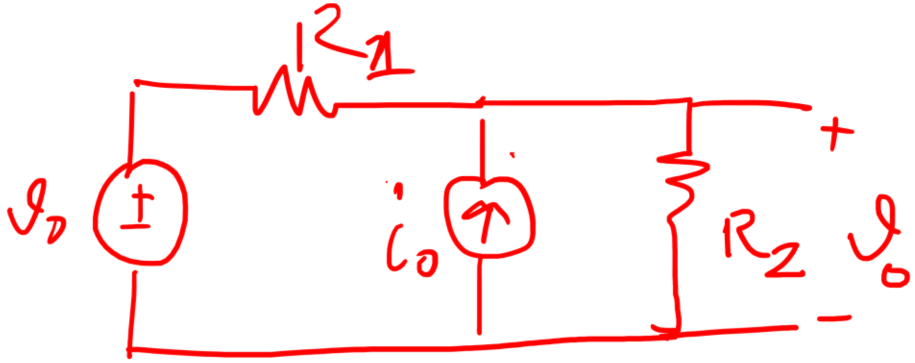
05 June 2025

Linear Circuits

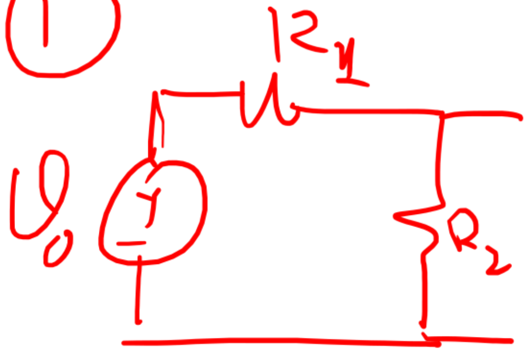
$$f(x)$$

$$f(k_1 x_1 + k_2 x_2 + k_3 x_3 \ldots)$$

$$k_1 f(x_1) + k_2 f(x_2) + k f(x_3)$$

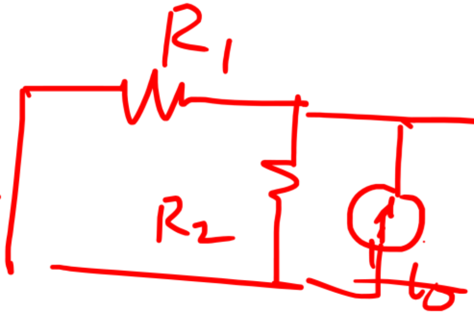


1



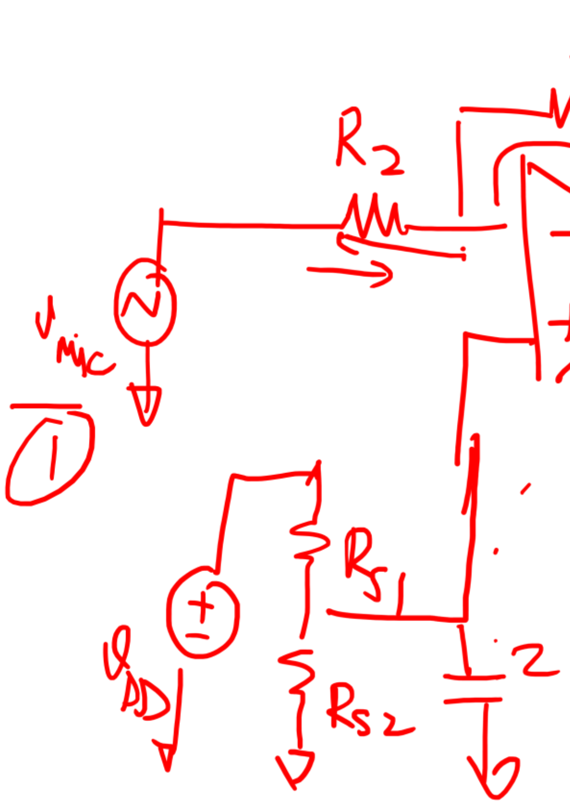
$$v_{o1} = \frac{v_o \times R_2}{R_1 + R_2}$$

2



$$v_{o2} = i_o \times \frac{R_1 R_2}{R_1 + R_2}$$

$$v_o = v_{o1} + v_{o2}$$



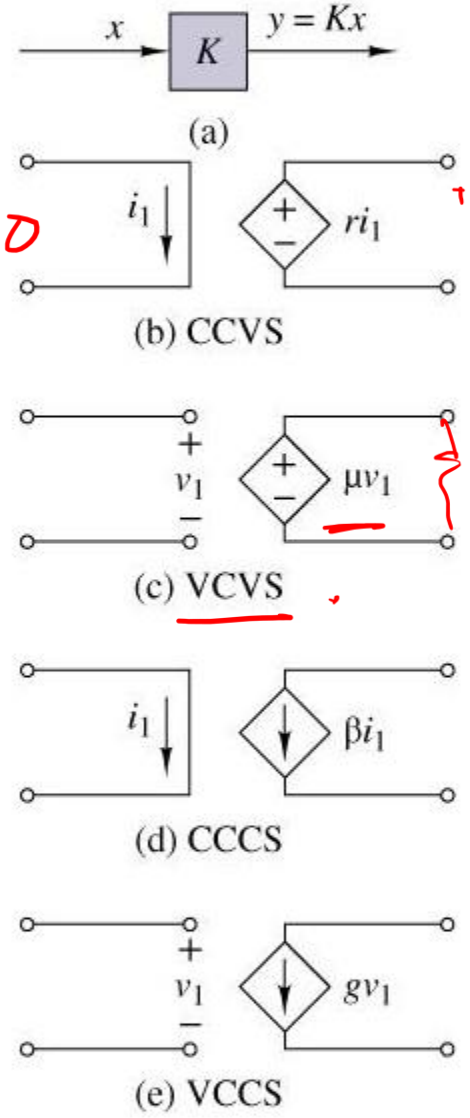
$$v_o = v_{o1} + v_{o2}$$

$$= \underbrace{-v_{mic} \cdot \frac{R_1}{R_2}}_{\text{Inverti}} + \underbrace{\frac{v_{DD}}{2}\left(1 + \frac{R_1}{R_2}\right)}_{\text{non-inverti}}$$

$R_{s1} = R_{s2}$

Active Circuits

Linear Dependent Sources



$Z_{in} = 0$

$V_o = i_1 \cdot r$

$Z_{out} = 0$

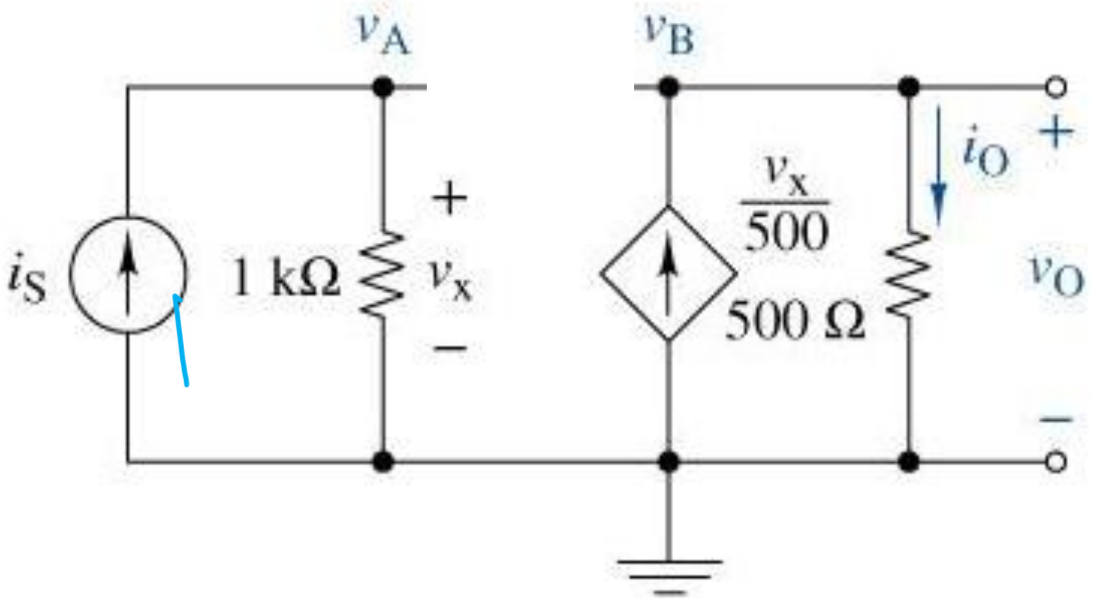
$Z_{in} = \infty$

$Z_{out} = 0$

$Z_{in} = 0$

$\beta \cdot i_1$

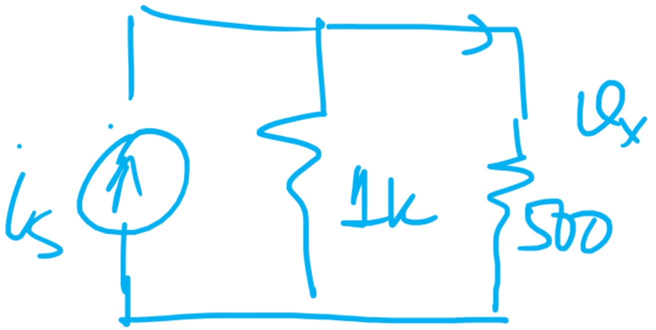
Analysis using Dependent Sources



$$v_o = i_o \times 500\,\Omega = \frac{v_x}{\cancel{500}} \times \cancel{500}\,\Omega$$

$$= i_s \times 1k\,\Omega$$

$$\frac{v_o}{i_s} = 1k\,\Omega$$



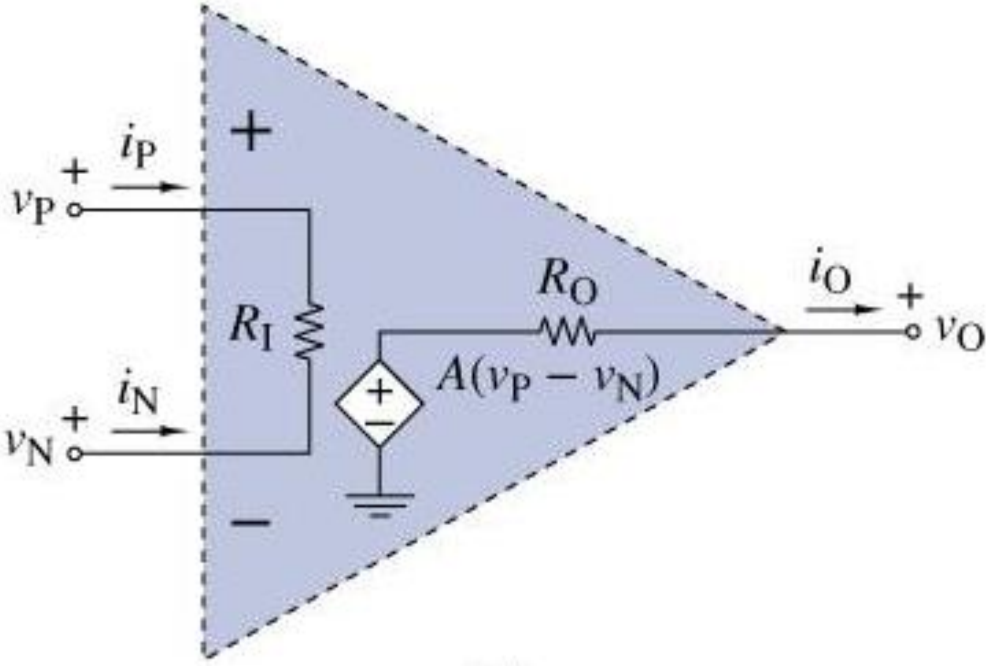
$$= i_s \times \frac{1k \times 500}{1.5k}$$

$$= i_s \times \frac{500}{1.5} = 300\, i_s$$

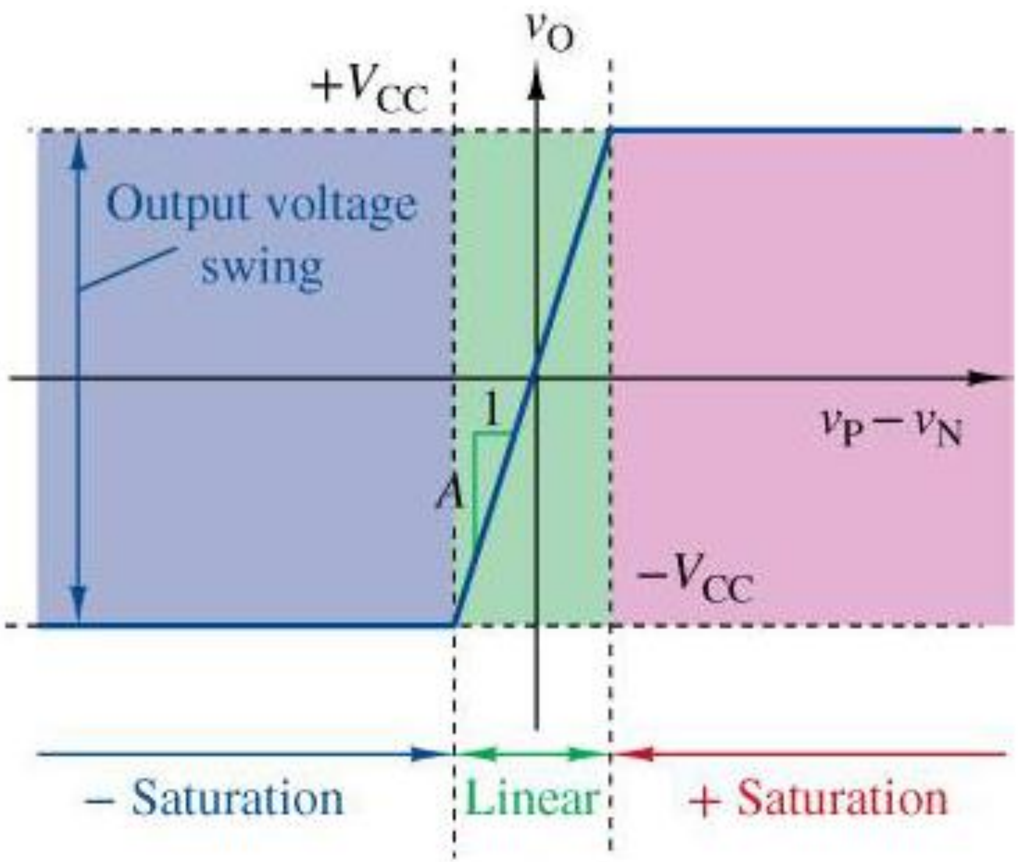
1.5

1.5

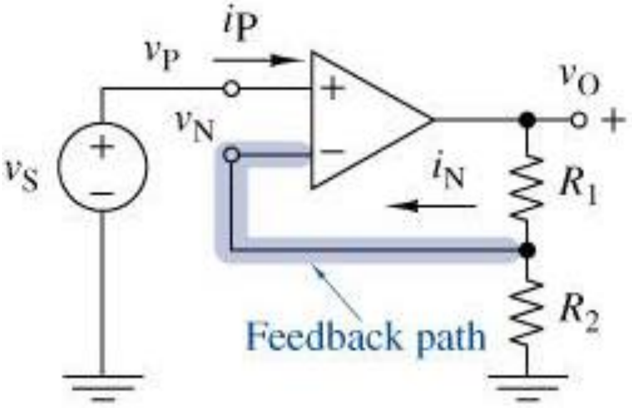
Operational Amplifier Model

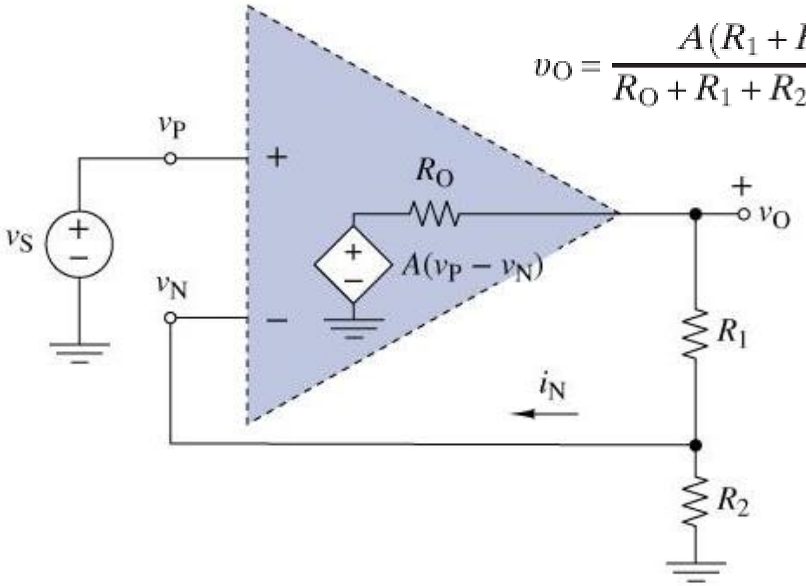


(b)



Operational Amplifier Analysis





$$v_O = \frac{A(R_1 + R_2)}{R_O + R_1 + R_2(1 + A)} v_S$$

$$\frac{v_o}{v_s} = 1 + \frac{R_1}{R_2}$$

$$v_o = A(v_p - v_n)$$

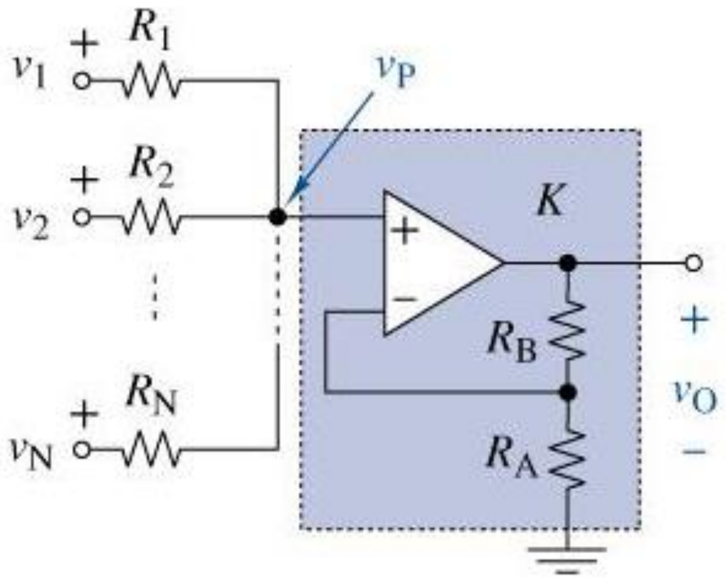
$$= A\left(v_s - \frac{v_o \times R_2}{R_1 + R_2}\right)$$

$$\frac{v_o}{A} + \frac{v_o \times R_2}{R_1 + R_2} = v_s$$

$$v_o\left(\frac{1}{A} + \frac{R_2}{R_1 + R_2}\right) = v_s$$

$$\frac{v_o}{v_s} = \frac{1}{\frac{1}{A} + \frac{R_2}{R_1 + R_2}}$$

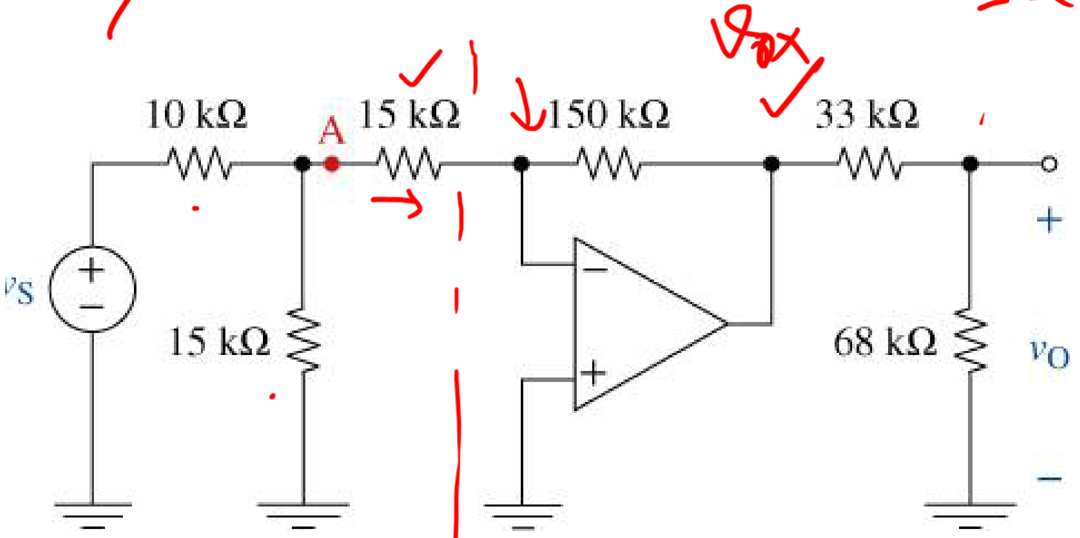
Operational Amplifier Analysis



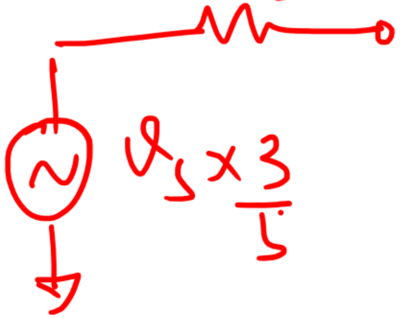
$v_{th} = v_s \times \frac{\cancel{15}\ 3}{\cancel{25}\ 5}$

$r_{th} = 15k + \frac{10\times 15}{25}$

$= 21k$

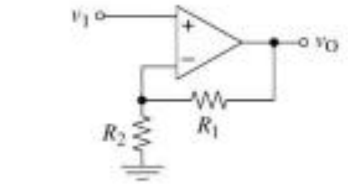
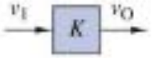
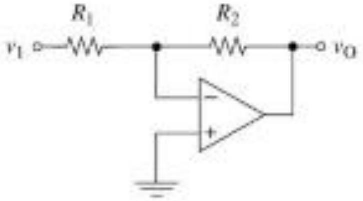
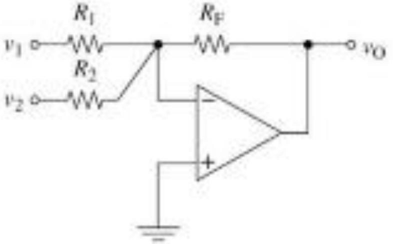
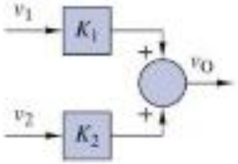
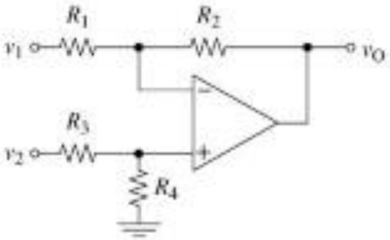
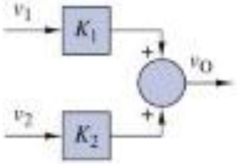
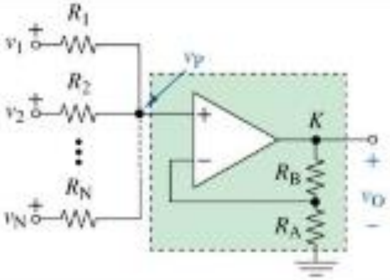
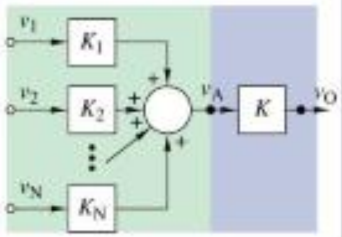
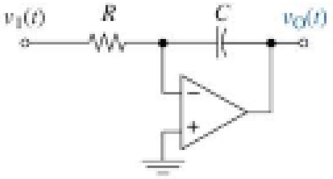
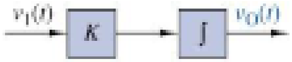
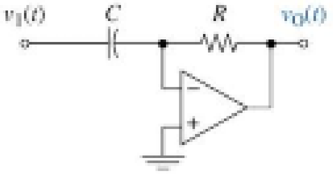
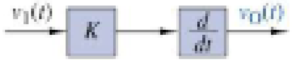


$\frac{v_o}{v_s} = ?$

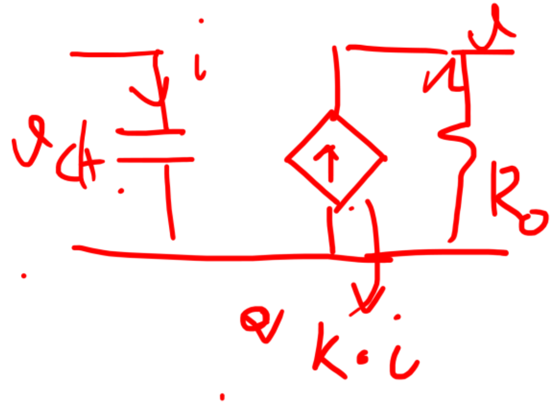


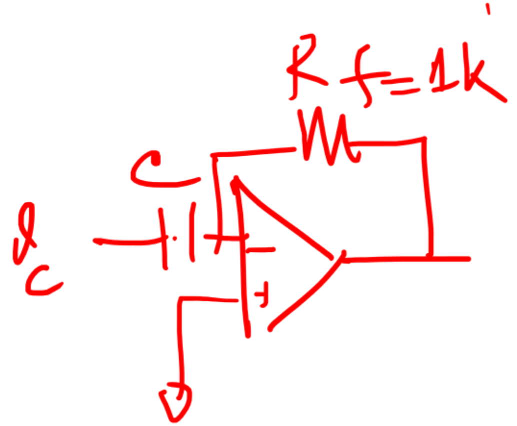
$v_{ox} = -v_s \times \frac{3}{5} \times \frac{\overset{7.5}{\cancel{150}}k}{\cancel{20}k}$

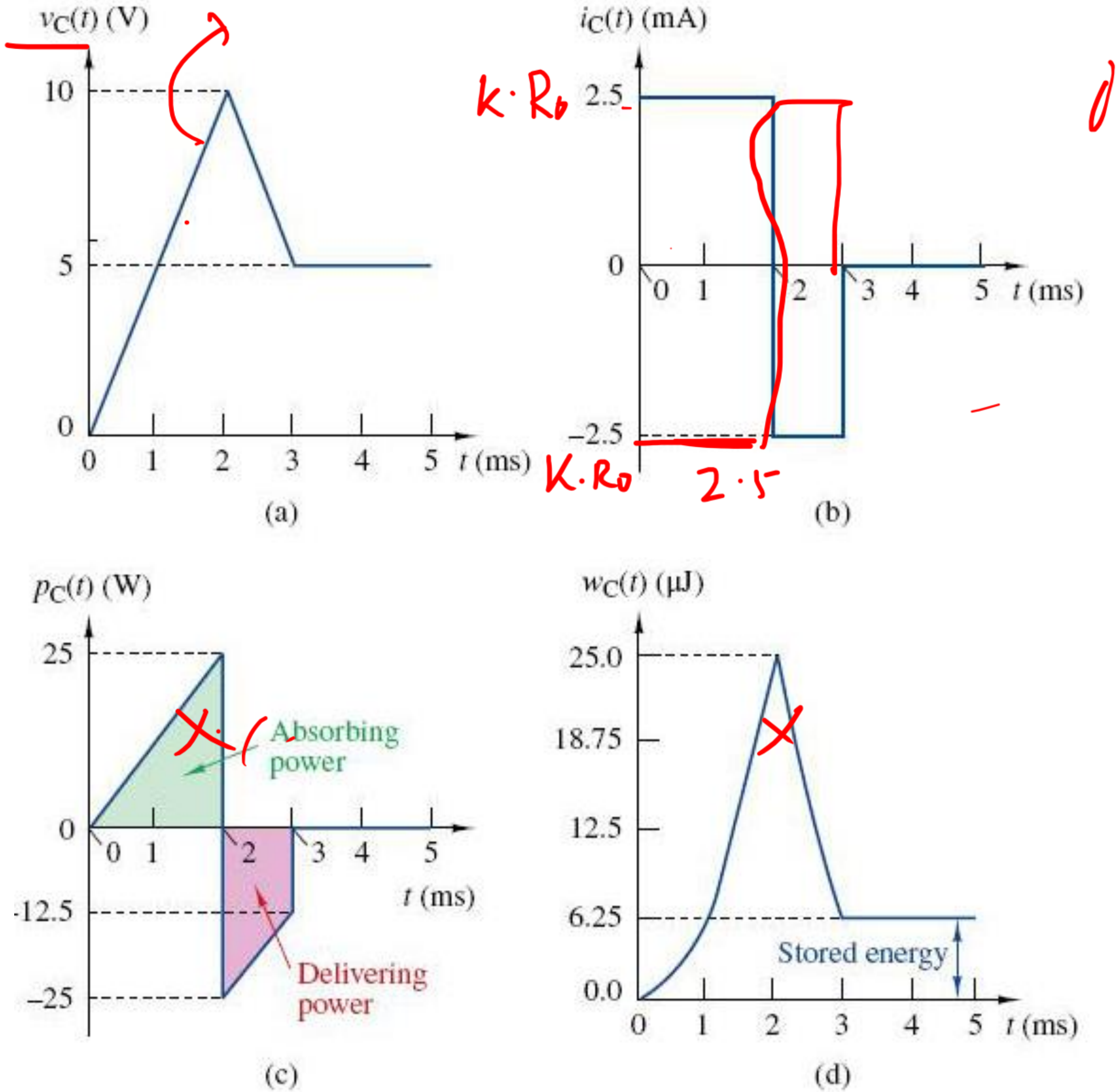
$\frac{v_{ox}}{v_s} = \cancel{v_s} \times \frac{7.5\times 3}{5} \times \frac{68}{100} = \underline{4.04}$

Circuit	Block diagram	Gains
	Non Inverting 	$K = \frac{R_1 + R_2}{R_2}$
	Inverting 	$K = -\frac{R_2}{R_1}$
	Inverting Summer 	$K_1 = -\frac{R_F}{R_1}$ $K_2 = -\frac{R_F}{R_2}$
	Subtractor 	$K_1 = -\frac{R_2}{R_1}$ $K_2 = \left(\frac{R_1 + R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)$
	Non-Inverting Summer 	$K = \frac{R_B + R_A}{R_A}$ $K_1 = \frac{(R_2 \parallel R_3 \parallel \cdots R_N)}{R_1 + (R_2 \parallel R_3 \parallel \cdots R_N)}$ $K_N = \frac{(R_1 \parallel R_2 \parallel \cdots R_{N-1})}{R_N + (R_1 \parallel R_2 \parallel \cdots R_{N-1})}$
 Integrator		$K = -\frac{1}{RC}$
 Differentiator		$K = -RC$

Capacitance







$$i = C\frac{dv}{dt}$$

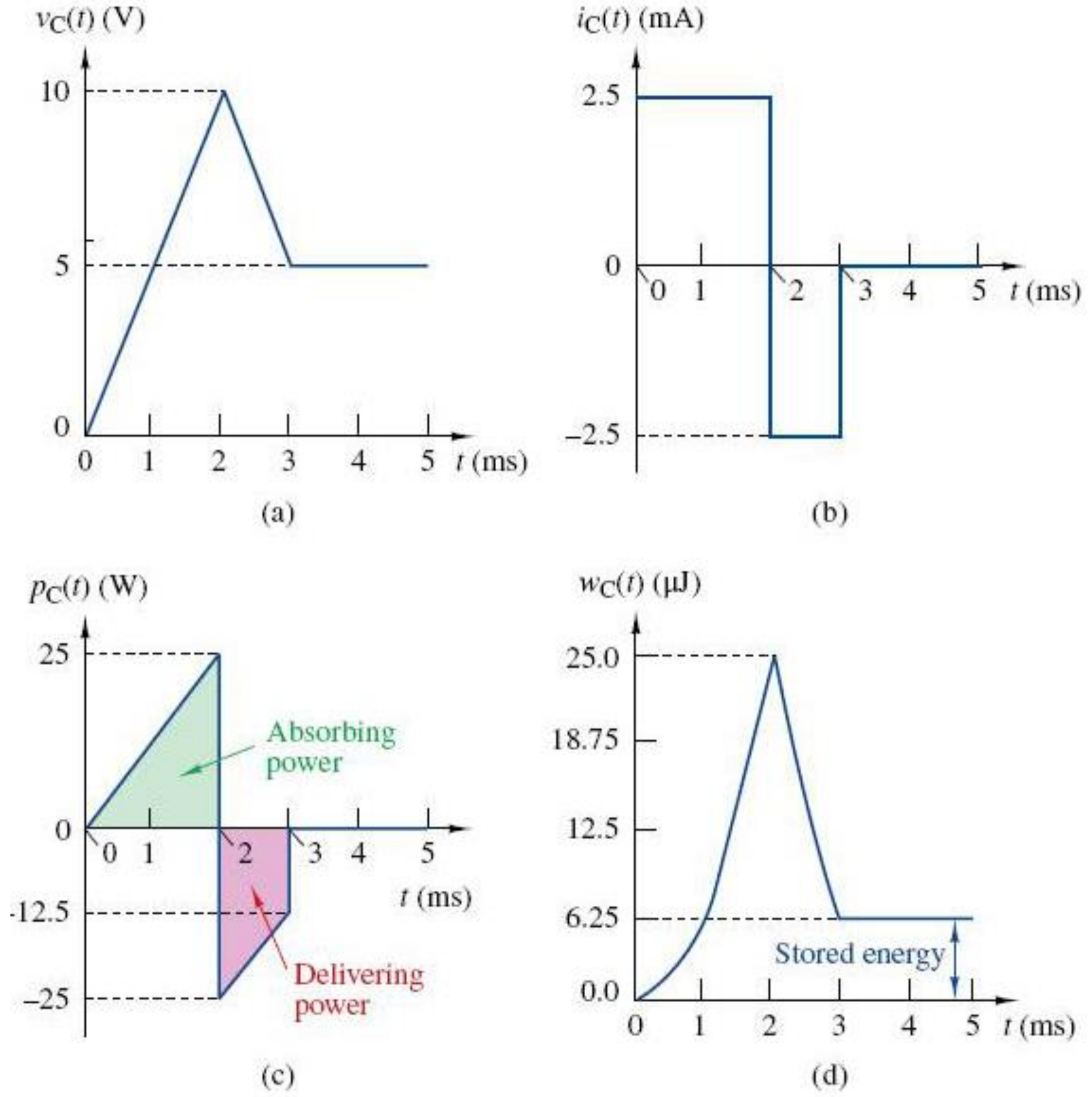
$$C = \frac{i}{\text{slop}}$$

$$= \frac{2.5\,mA}{10V/2ms}$$

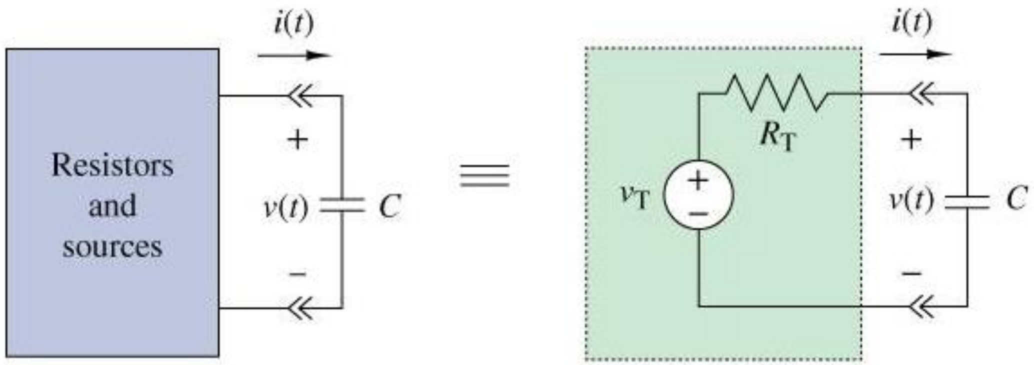
$$= \frac{2.5\,mA \cdot 2ms}{10V}$$

$$= \underline{5\,\mu F}$$

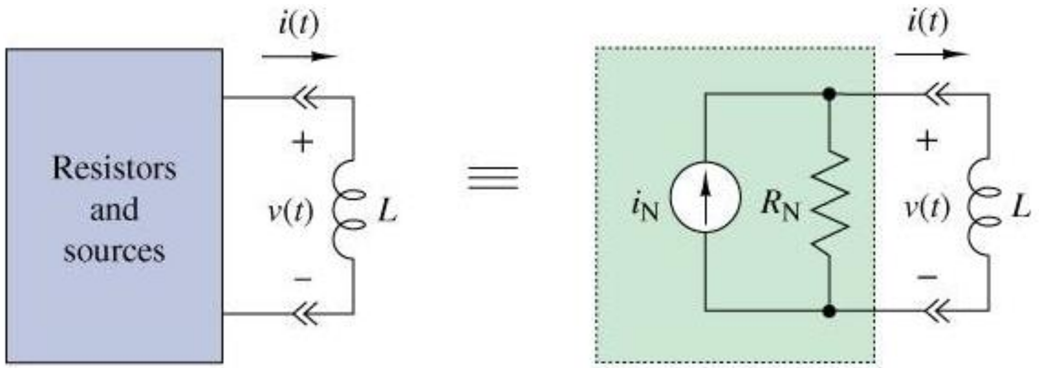
Capacitance



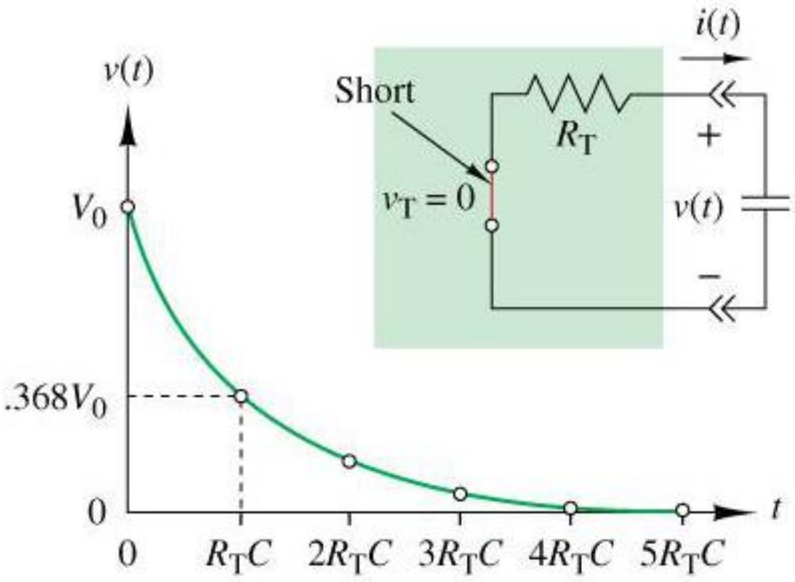
First-Order Circuits



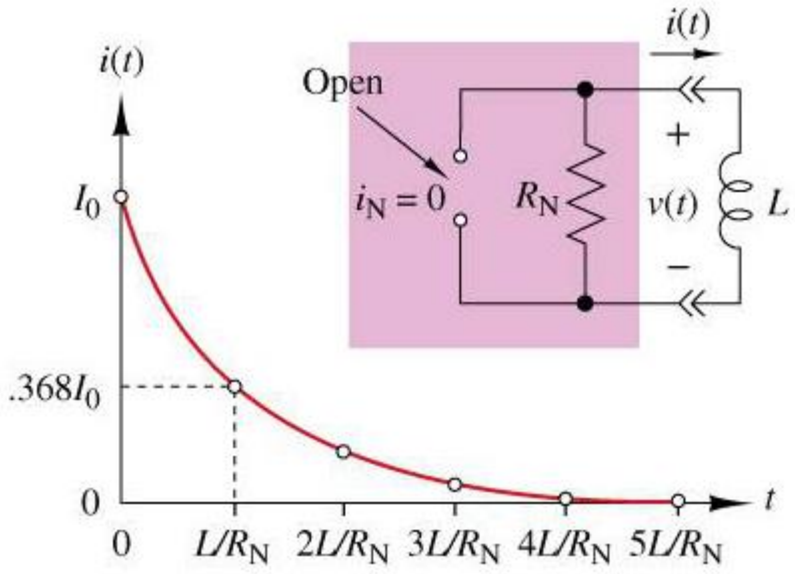
(a)



(b)

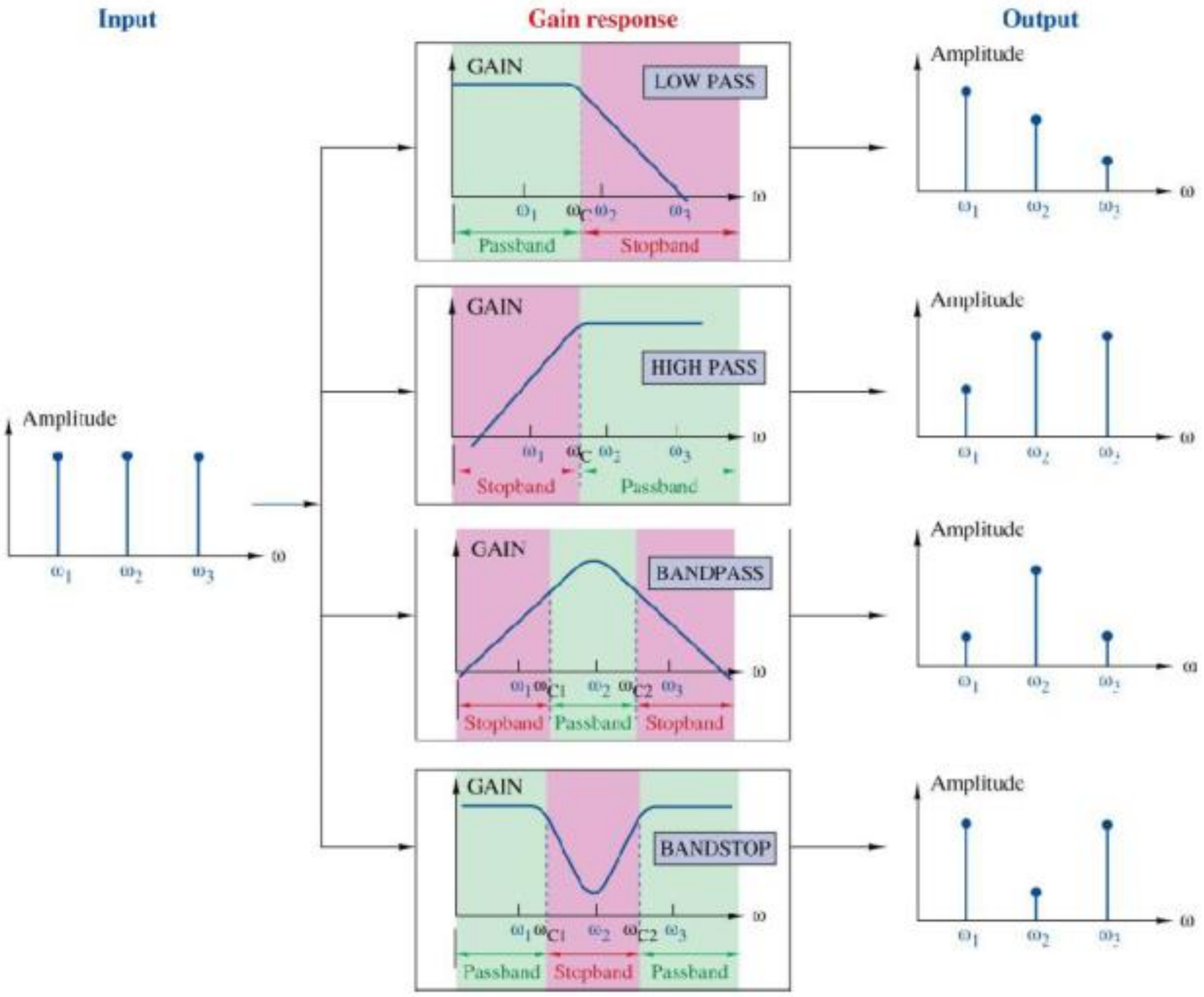


(a)



(b)

Frequency Response (Four Basic Gain Responses)



▸ First-Order Low-Pass Response

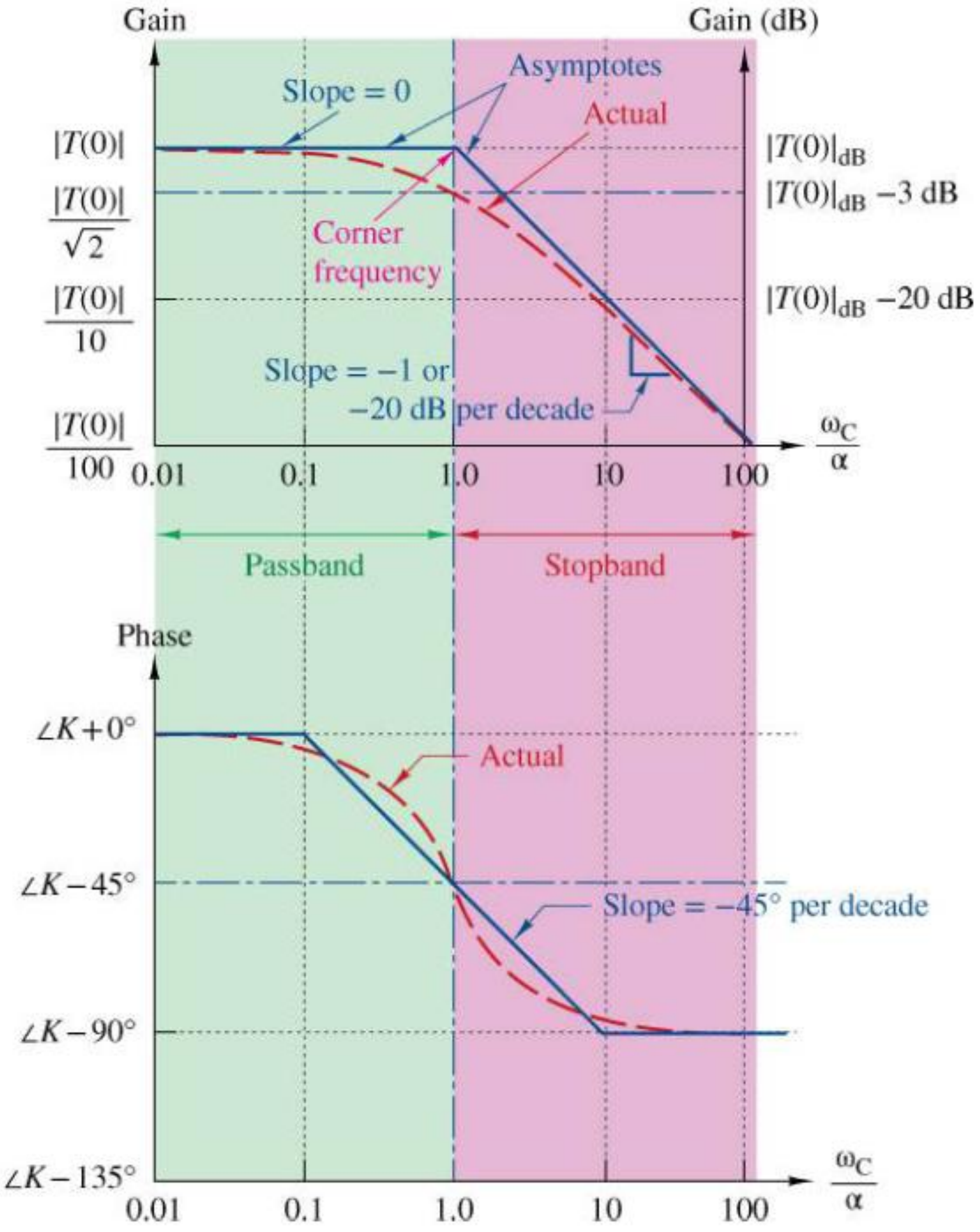
$$T(s) = \frac{K}{s+\alpha}$$

$$T(j\omega) = \frac{K}{j\omega+\alpha}$$

$$|T(j\omega)| = \frac{|K|}{\sqrt{\omega^2+\alpha^2}}$$

$$\theta(\omega) = angle(K) - \tan^{-1}(\omega/\alpha)$$

$\lvert T(j\omega)\rvert$	$\lvert T(j\omega)\rvert_{dB}$
10^3	60
10^2	40
10	20
2	6
$\sqrt{2}$	3
1	0
$1/\sqrt{2}$	−3
0.5	−6
10^{-1}	−20
10^{-2}	−40
10^{-3}	−60



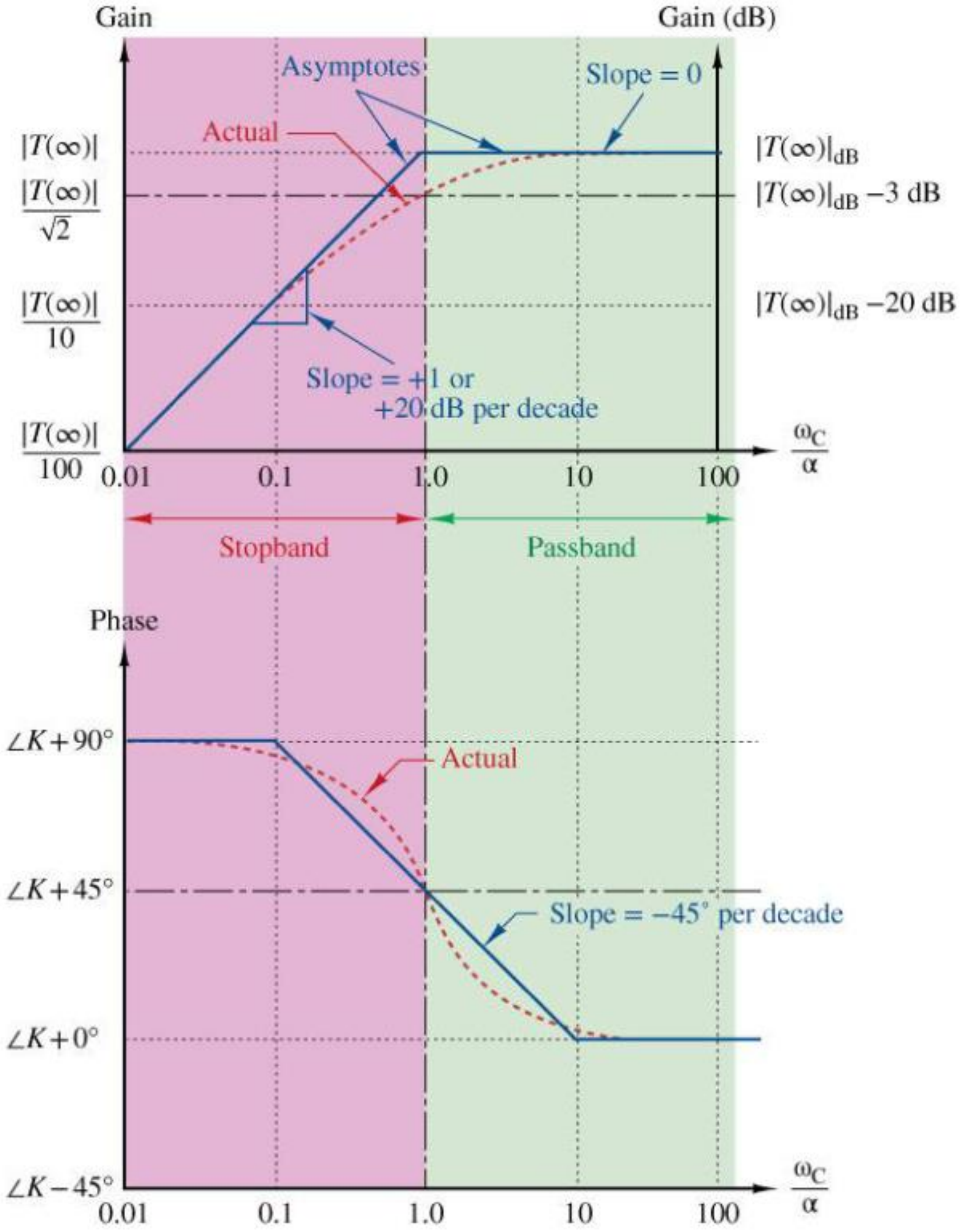
First-Order High-Pass Response

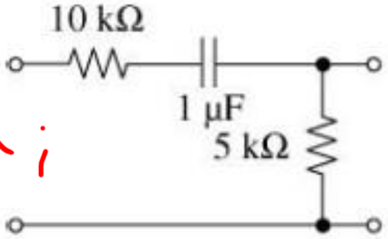
$$T(s) = \frac{Ks}{s+\alpha}$$

$$T(j\omega) = \frac{j\omega K}{j\omega + \alpha}$$

$$|T(j\omega)| = \frac{|K|\omega}{\sqrt{\omega^2 + \alpha^2}}$$

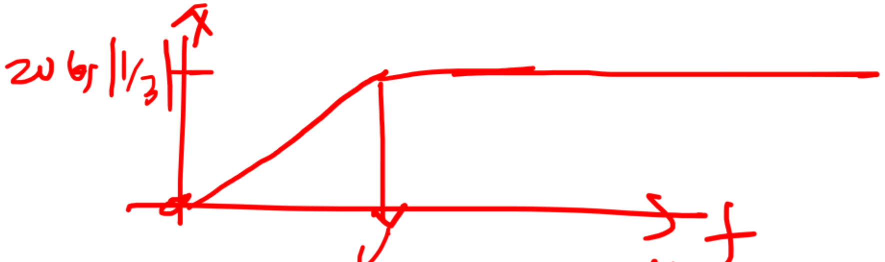
$$\theta(\omega) = angle(K) + 90^\circ - \tan^{-1}(\omega/\alpha)$$



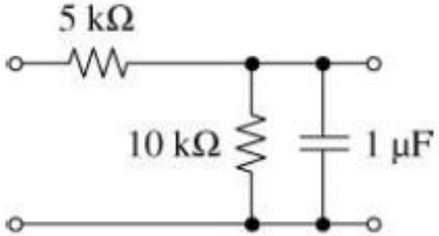
① U_i 

U_o

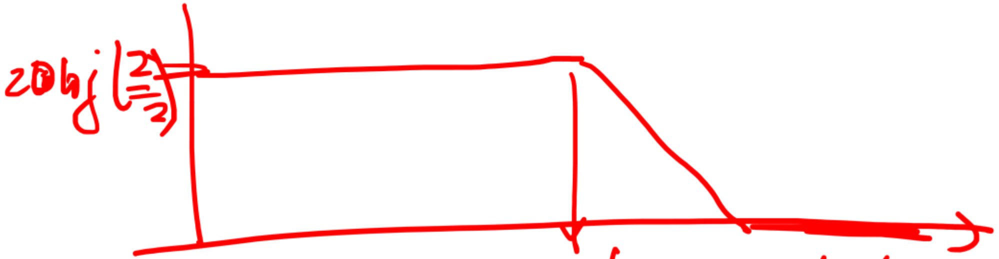
(a)



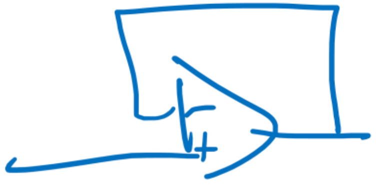
$f_{3dB} = 1/2\pi \; 15k \cdot 1\mu F$

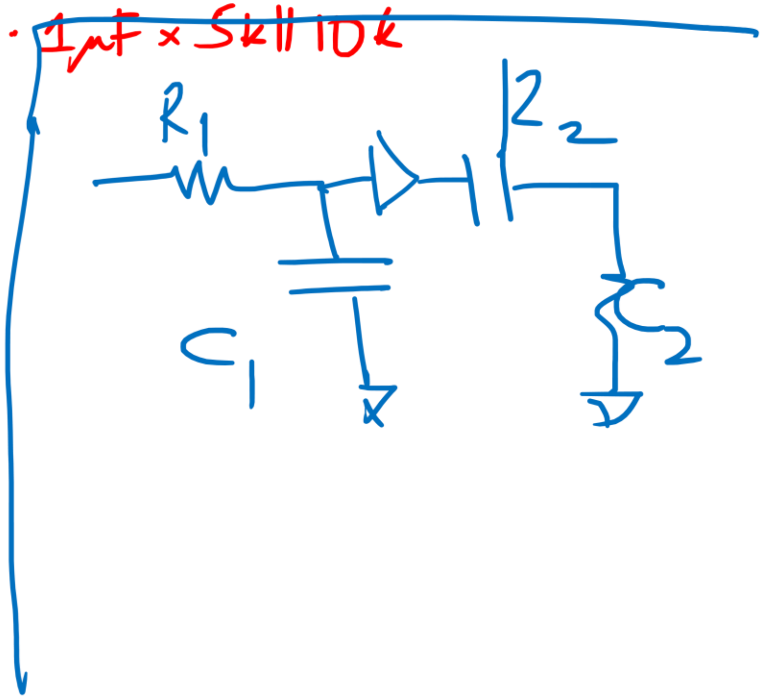
② 

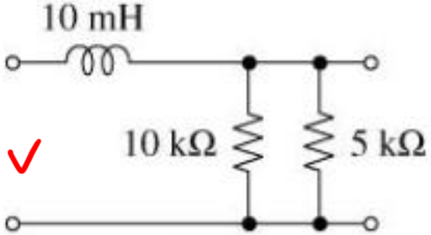
(b)



$f_{3dB} = 1/2\pi \cdot 1\mu F \times 5k \| 10k$

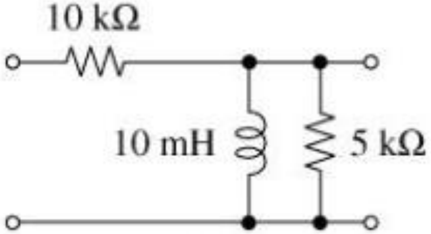




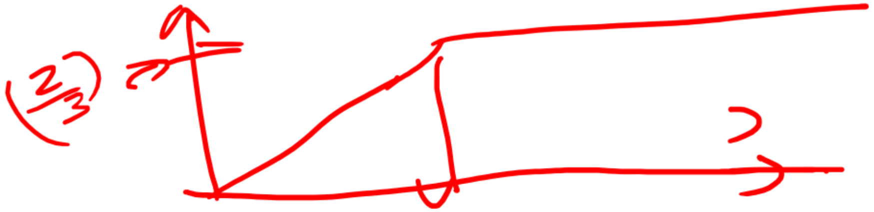
③ ✓ 

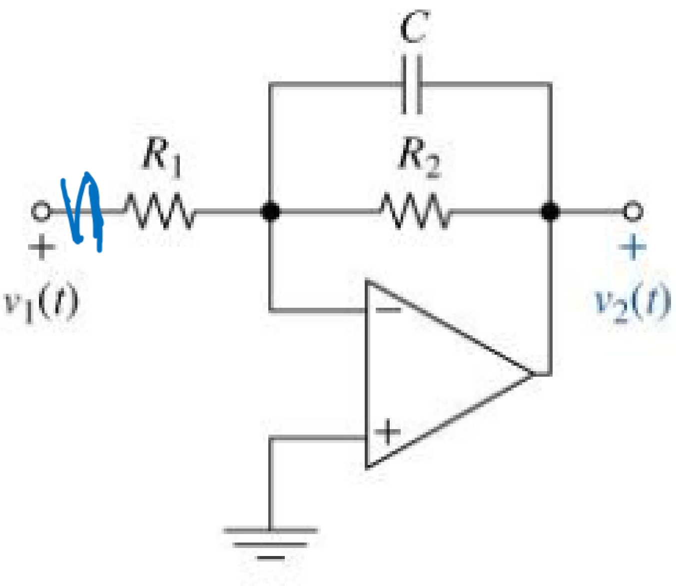
(c)

$\frac{5k \| 10k}{2\pi 10 m\Omega}$

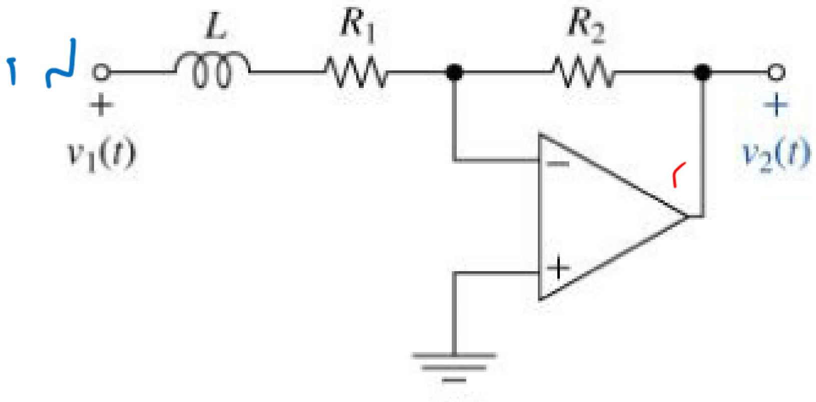
④ 

(d)

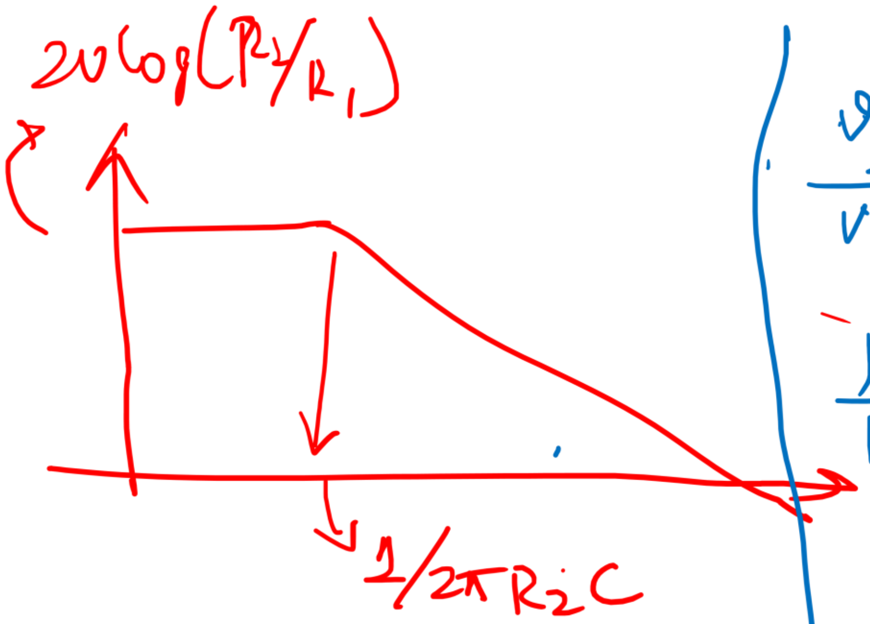




(a)



(b)



$$\frac{v_2}{v_1}(s) = \frac{K}{s+\alpha} \rightarrow \frac{R_1}{L}$$

$$\frac{K}{R_1/L} = -\frac{R_2}{R_1}$$

$$K = -R_2/L$$

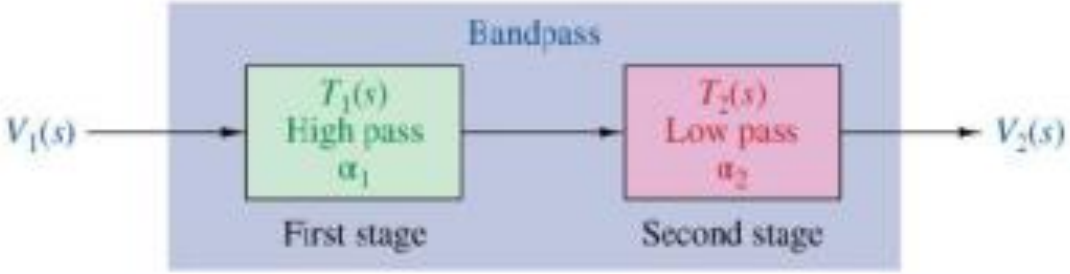
$$H(s) = \frac{-R_2/L}{s + R_1/L}$$

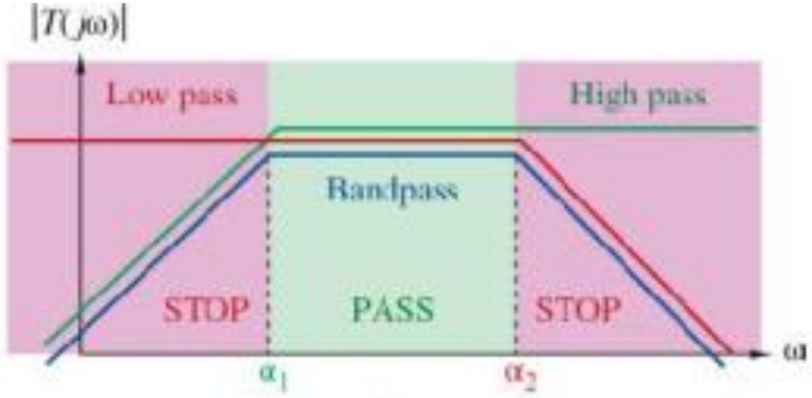
$$\frac{K}{\cancel{s+0}\ 1/R_2C} = \frac{-R_2}{R_1}$$

$$K = \frac{-1}{R_1 C}$$

$$\frac{-1/R_1C}{s + 1/R_2C}$$

First-Order Band-Pass Response





$s = j\omega \quad \omega >> \alpha_1$

$$T(s) = T_1(s) \times T_2(s) = \underbrace{\left(\frac{K_1 s}{s+\alpha_1}\right)}_{\text{high pass}} \underbrace{\left(\frac{K_2}{s+\alpha_2}\right)}_{\text{low pass}}$$

$s = j\omega \quad \omega << \alpha_2$

$$|T(j\omega)| = \underbrace{\left(\frac{|K_1|\omega}{\sqrt{\omega^2+\alpha_1^2}}\right)}_{\text{high pass}} \underbrace{\left(\frac{|K_2|}{\sqrt{\omega^2+\alpha_2^2}}\right)}_{\text{low pass}}$$

$$\frac{K_1}{1+\cancel{\alpha_1}} \times \frac{K_2}{\alpha_2} = \frac{K_1 K_2}{\alpha_2} =$$

Low frequency $(\omega \ll \alpha_1 \ll \alpha_2)$: $|T(j\omega)| \to \underbrace{\left(\frac{|K_1|\omega}{\alpha_1}\right)}_{\text{high pass}} \underbrace{\left(\frac{|K_2|}{\alpha_2}\right)}_{\text{low pass}} = \frac{|K_1||K_2|\omega}{\alpha_1 \alpha_2}$

High frequency $(\alpha_1 \ll \alpha_2 \ll \omega)$: $|T(j\omega)| \to \underbrace{\left(\frac{|K_1|\omega}{\omega}\right)}_{\text{high pass}} \underbrace{\left(\frac{|K_2|}{\omega}\right)}_{\text{low pass}} = \frac{|K_1||K_2|}{\omega}$

Mid-frequency $(\alpha_1 \ll \omega \ll \alpha_2)$: $|T(j\omega)| \to \underbrace{\left(\frac{|K_1|\omega}{\omega}\right)}_{\text{high pass}} \underbrace{\left(\frac{|K_2|}{\alpha_2}\right)}_{\text{low pass}} = \frac{|K_1||K_2|}{\alpha_2}$