ECEN 325
Electronics

Introduction

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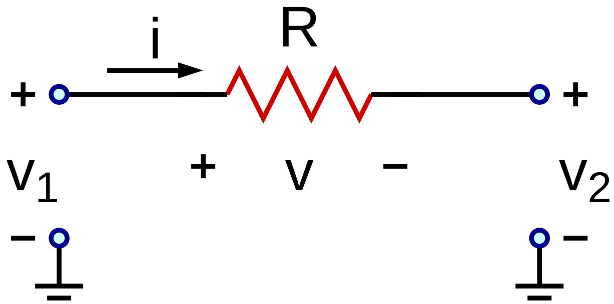
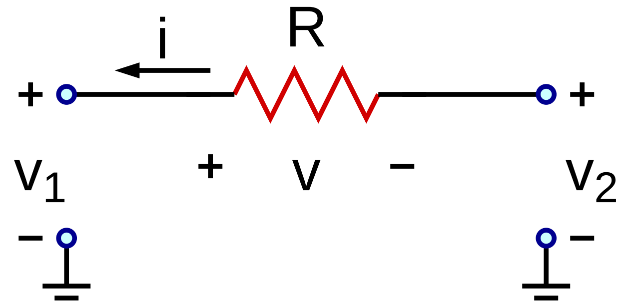
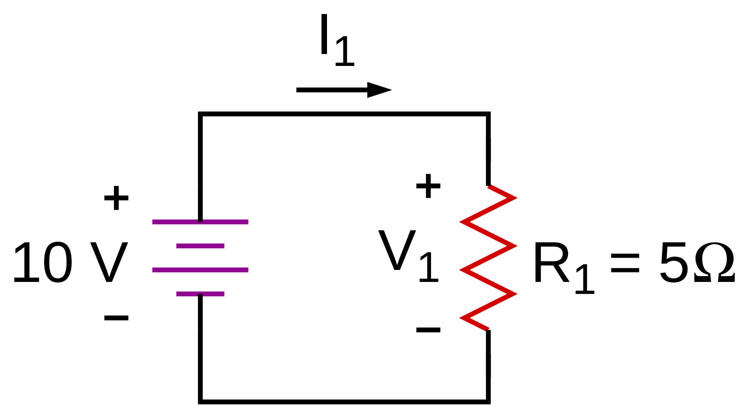
Ohm's Law

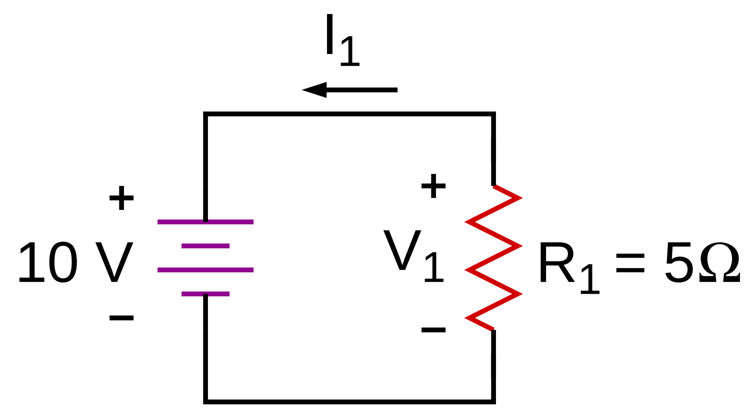




$$v = v_1 - v_2$$
$$v = iR$$
$$i = Gv$$

$$v = v_1 - v_2$$
$$v = -iR$$
$$i = -Gv$$





$\mathbf{V_1 = 10\ V}$
$\mathbf{I_1 = 2\ A}$

$\mathbf{V_1 = 10\ V}$
$\mathbf{I_1 = -2\ A}$

KVL & KCL

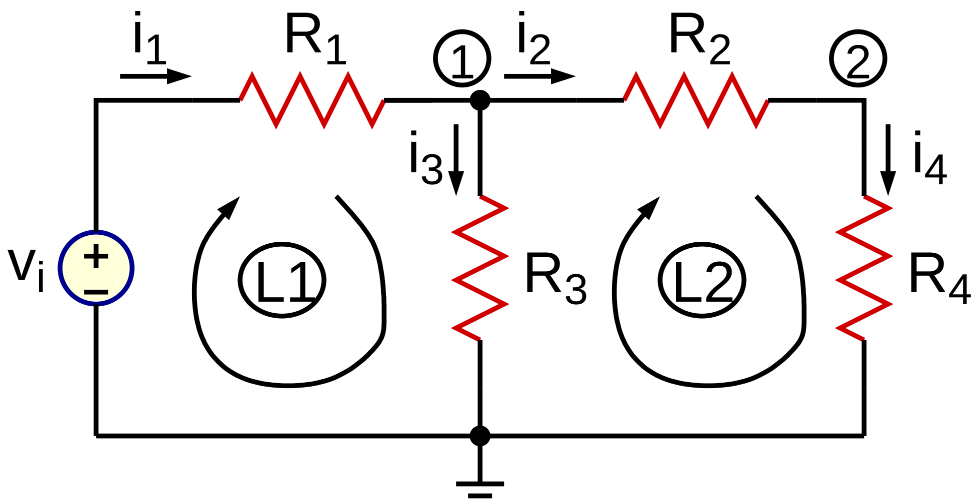
KVL: Kirchoff's Voltage Law

Sum of all node-to-node voltages around the closed loop is zero.

KCL: Kirchoff's Current Law

Sum of all currents leaving a node is zero.

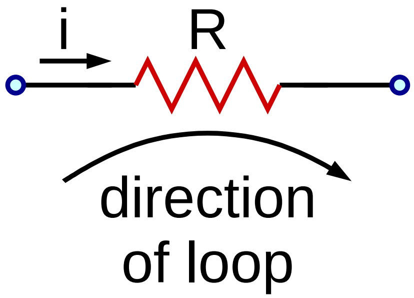
KVL



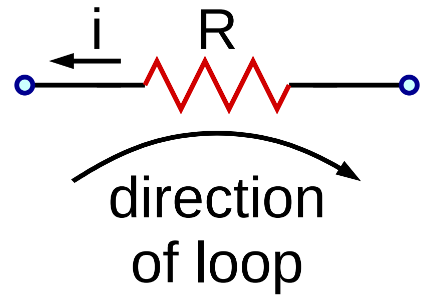
$$L_1 \quad \rightarrow \quad -v_i + i_1R_1 + i_3R_3 = 0$$

$$L_2 \quad \rightarrow \quad i_2R_2 + i_4R_4 - i_3R_3 = 0$$

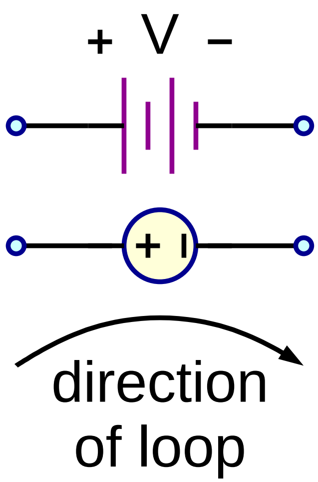
KVL



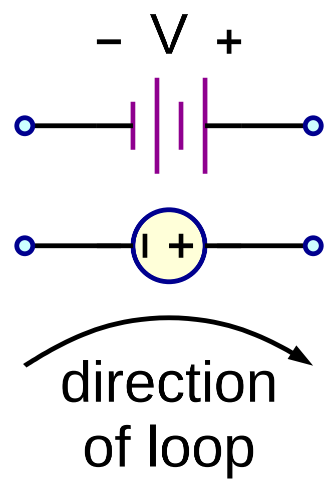
$\Rightarrow +iR$



$\Rightarrow -iR$

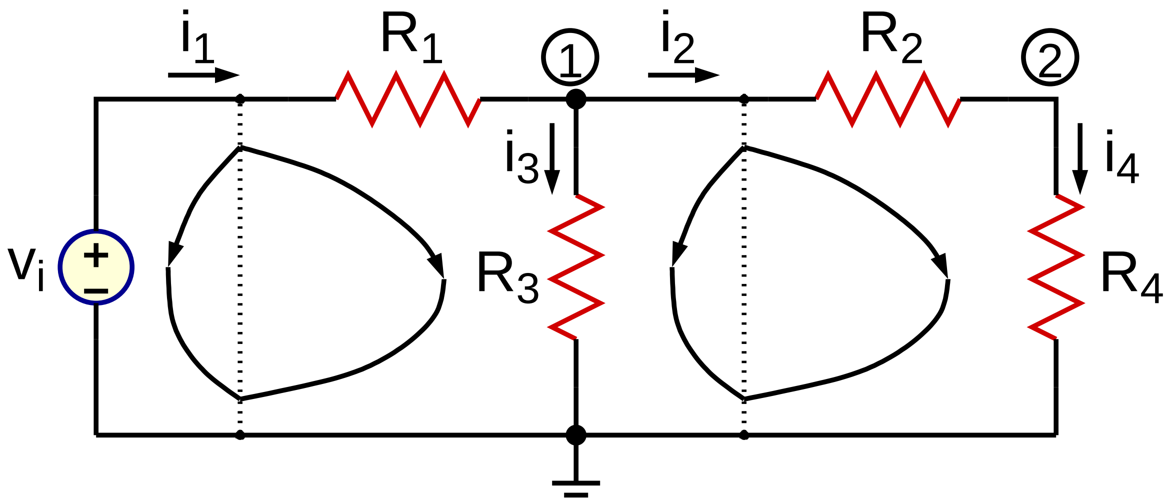


$\Rightarrow +V$



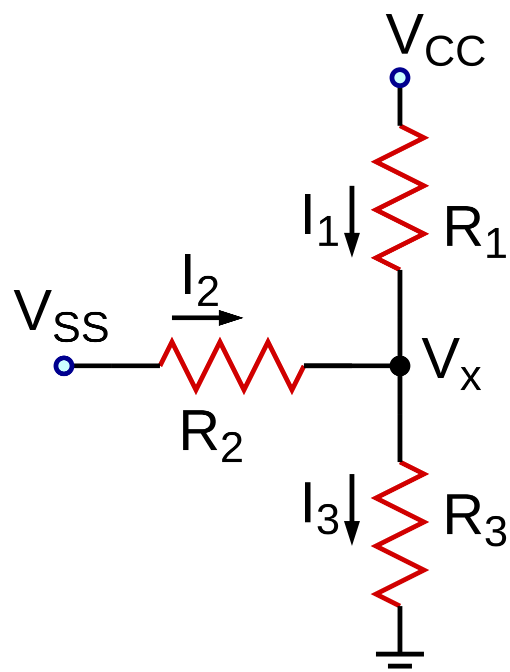
$\Rightarrow -V$

KVL



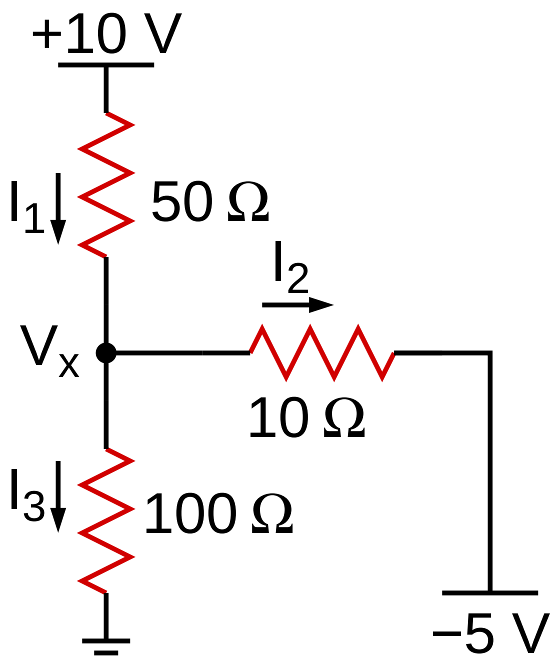
$$L_1 \;\rightarrow\; v_i = i_1R_1 + i_3R_3$$

$$L_2 \;\rightarrow\; i_3R_3 = i_2R_2 + i_4R_4$$



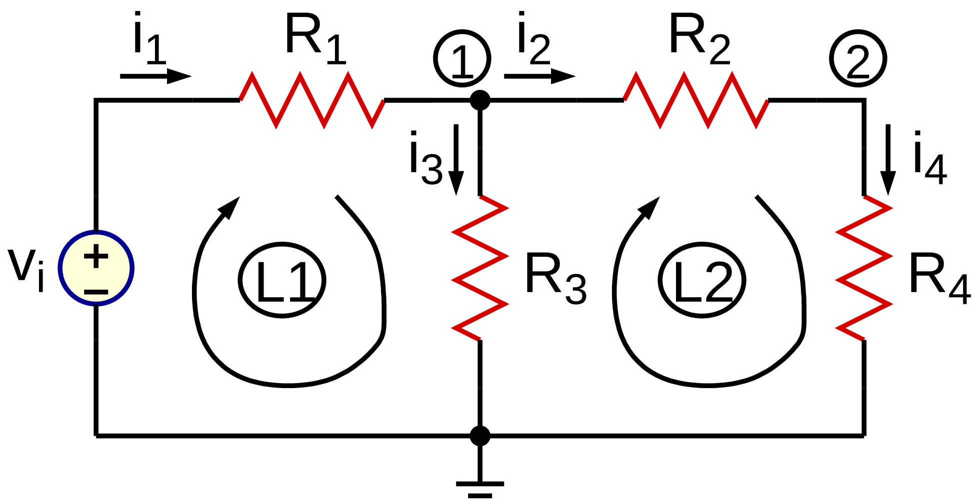
$$V_{CC} = I_1R_1 + I_3R_3$$

$$V_{SS} = I_2R_2 + I_3R_3$$



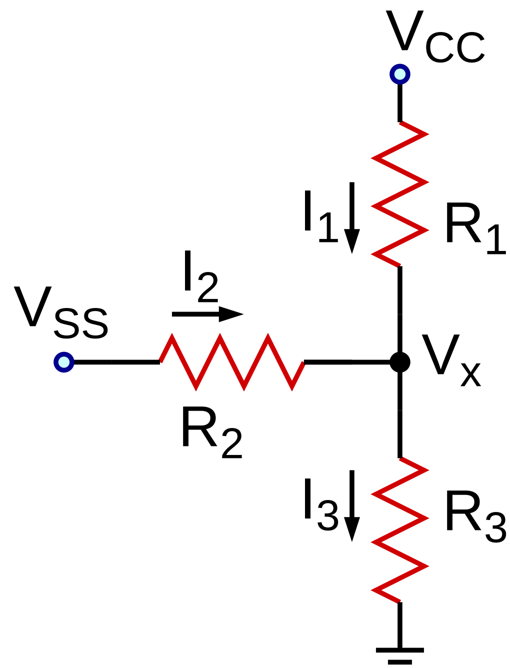
$$\begin{aligned} 10 &= 50I_1 + 100I_3 \\ -5 &= -10I_2 + 100I_3 \\ 10 &= 50I_1 + 10I_2 - 5 \end{aligned}$$

KCL

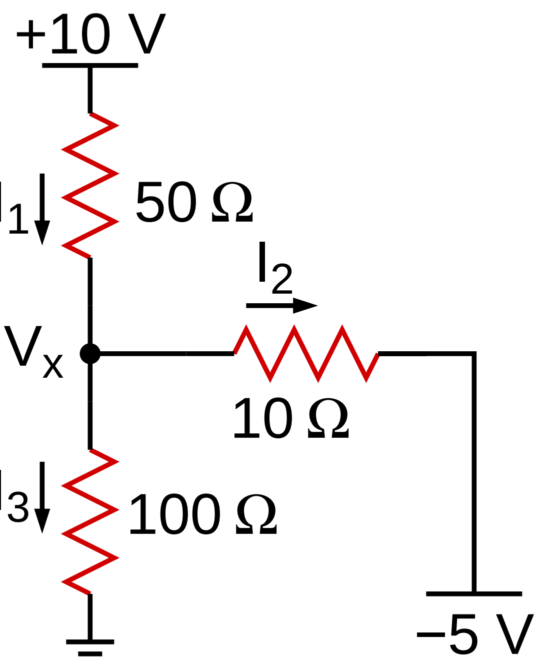


$$① \rightarrow \quad -i_1 + i_2 + i_3 = 0 \quad \rightarrow \quad \frac{v_1 - v_i}{R_1} + \frac{v_1 - v_2}{R_2} + \frac{v_1}{R_3} = 0$$

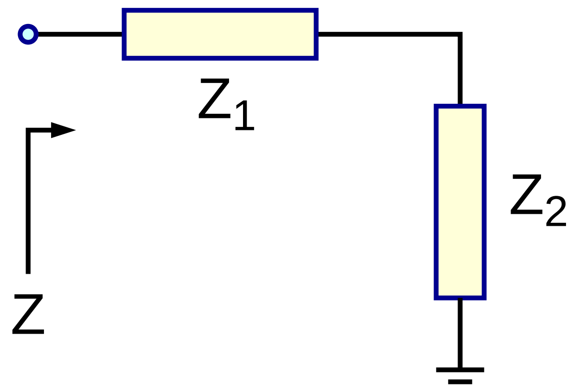
$$② \rightarrow \quad -i_2 + i_4 = 0 \quad \rightarrow \quad \frac{v_2 - v_1}{R_2} + \frac{v_2}{R_4} = 0$$



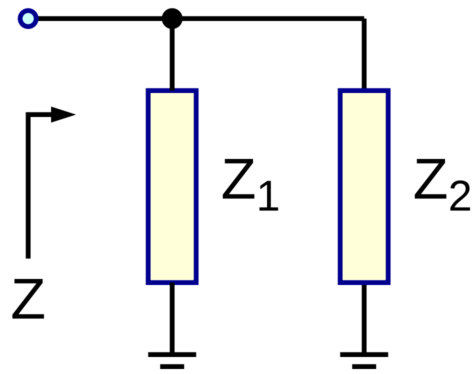
$$\frac{V_x - V_{SS}}{R_2} + \frac{V_x - V_{CC}}{R_1} + \frac{V_x}{R_3} = 0$$



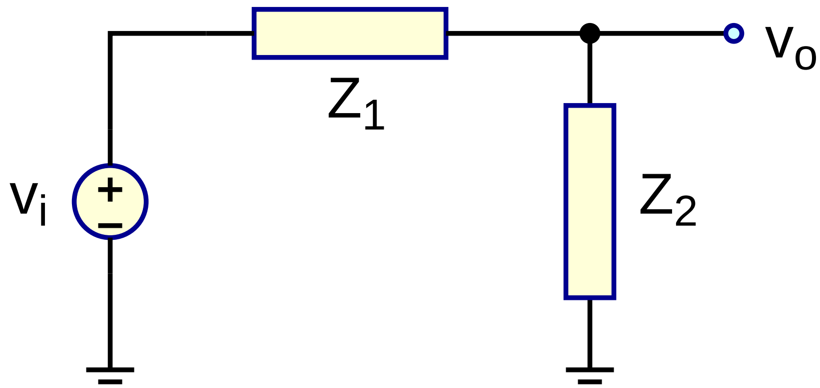
$$\frac{V_x - (-5)}{10} + \frac{V_x}{100} + \frac{V_x - 10}{50} = 0$$



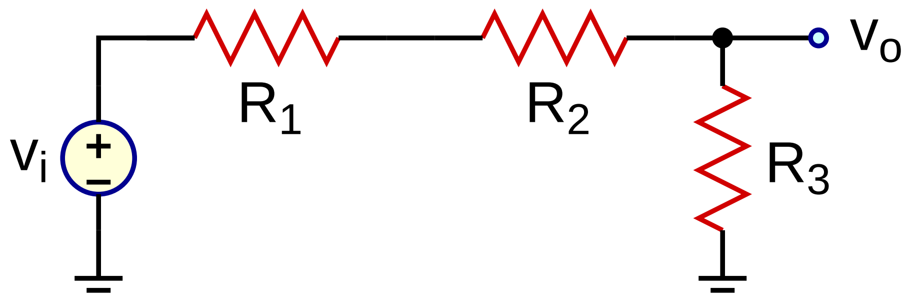
$$\mathbf{z} = \mathbf{z_1} + \mathbf{z_2}$$



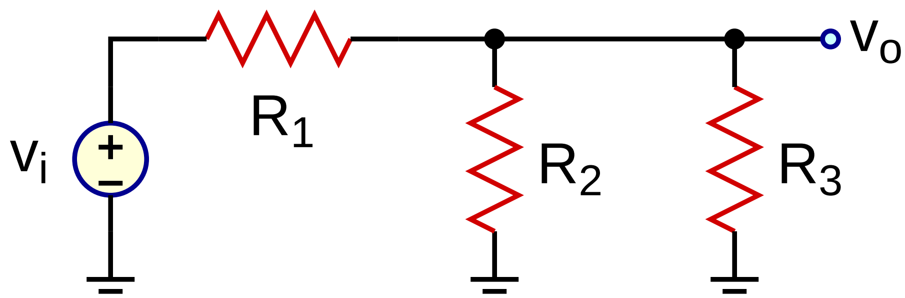
$$\mathbf{Z} = \mathbf{Z_1} \parallel \mathbf{Z_2}$$



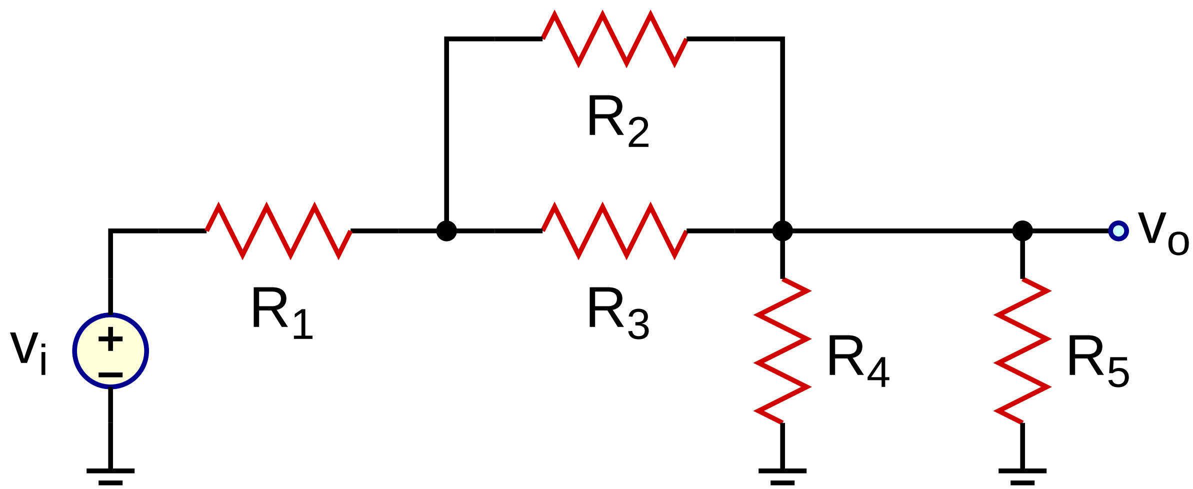
$$\frac{\mathbf{v_o}}{\mathbf{v_i}} = \frac{\mathbf{Z_2}}{\mathbf{Z_1} + \mathbf{Z_2}}$$



$$\frac{v_o}{v_i} = \frac{R_3}{R_1 + R_2 + R_3}$$

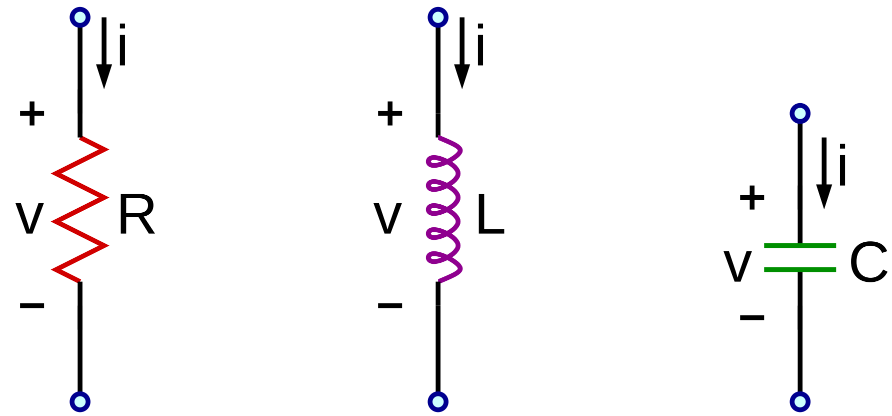


$$\frac{v_o}{v_i} = \frac{R_2 \parallel R_3}{R_1 + (R_2 \parallel R_3)}$$



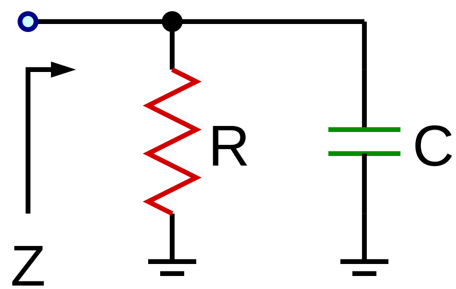
$$\frac{v_o}{v_i} = \frac{R_4 \parallel R_5}{R_1 + (R_2 \parallel R_3) + (R_4 \parallel R_5)}$$

Linear Network Analysis

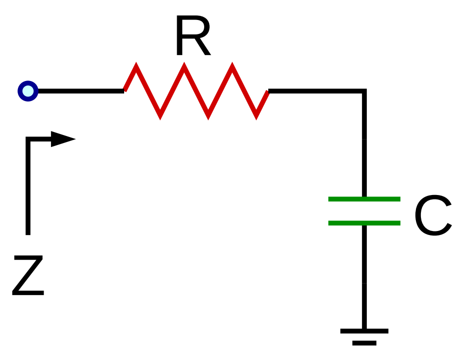


$$v = iR \qquad v = sLi \qquad v = \frac{1}{sC}i$$

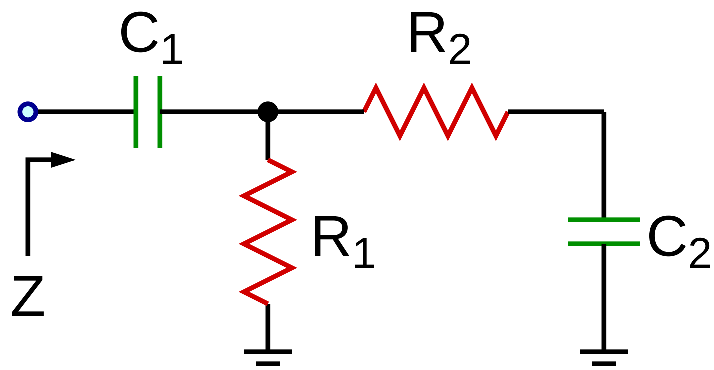
$$Z = R \qquad Z = sL \qquad Z = \frac{1}{sC}$$



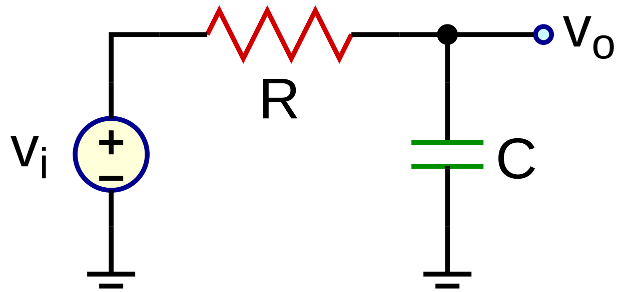
$$Z = R \parallel \frac{1}{sC}$$



$$Z = R + \frac{1}{sC}$$



$$Z = \frac{1}{sC_1} + \left(R_1 \parallel \left(R_2 + \frac{1}{sC_2} \right) \right)$$



$$\frac{v_o}{v_i} = \frac{\frac{1}{sC}}{R + \frac{1}{sC}} = \frac{1}{sRC + 1} = \frac{1}{\frac{s}{\omega_o} + 1} = T(s)$$

$$\omega_o = \frac{1}{RC}$$

$$T(s) = \frac{1}{\frac{s}{\omega_o} + 1} \Rightarrow T(j\omega) = \frac{1}{\frac{j\omega}{\omega_o} + 1}$$

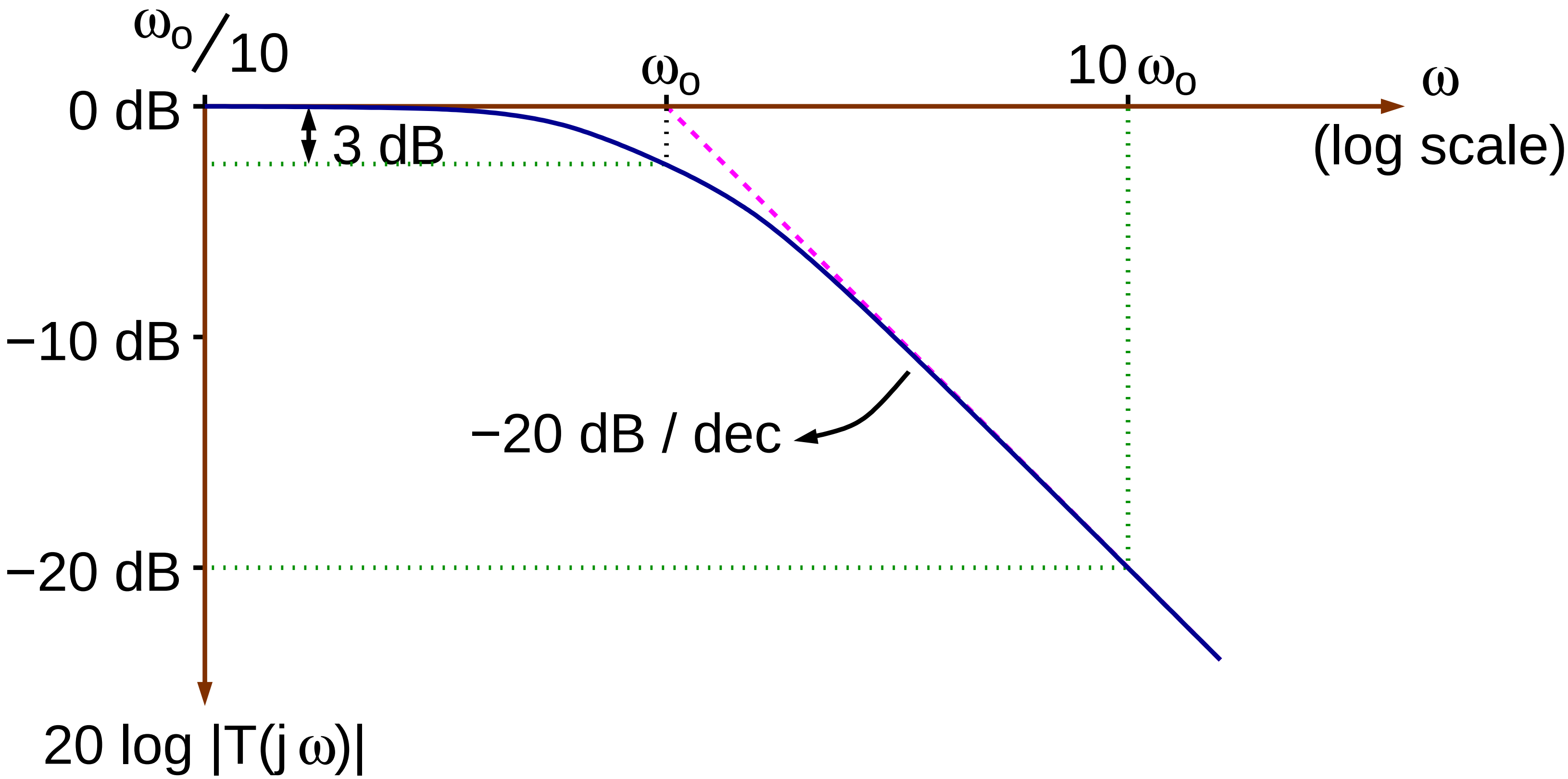
$$|T(j\omega)| = \frac{1}{\sqrt{\left(\frac{\omega}{\omega_o}\right)^2 + 1}}$$

$$20 \log |T(j\omega)| = -20 \log \sqrt{\left(\frac{\omega}{\omega_o}\right)^2 + 1}$$

$$\omega \ll \omega_o \;\Rightarrow\; 20 \log |T(j\omega)| \approx 0$$

$$\omega \gg \omega_o \;\Rightarrow\; 20 \log |T(j\omega)| \approx 20 \log \omega_o - 20 \log \omega$$

$$\omega = \omega_o \;\Rightarrow\; 20 \log |T(j\omega)| = -20 \log \sqrt{2} \approx -3 \text{ dB}$$


ωo/10
ωo
10 ωo
ω
(log scale)
0 dB
3 dB
−10 dB
−20 dB/dec
−20 dB
20 log |T(j ω)|

$$\mathbf{T(s)} = \frac{1}{\frac{\mathbf{s}}{\omega_o} + 1} \Rightarrow \mathbf{T(j\omega)} = \frac{1}{\frac{\mathbf{j}\omega}{\omega_o} + 1}$$

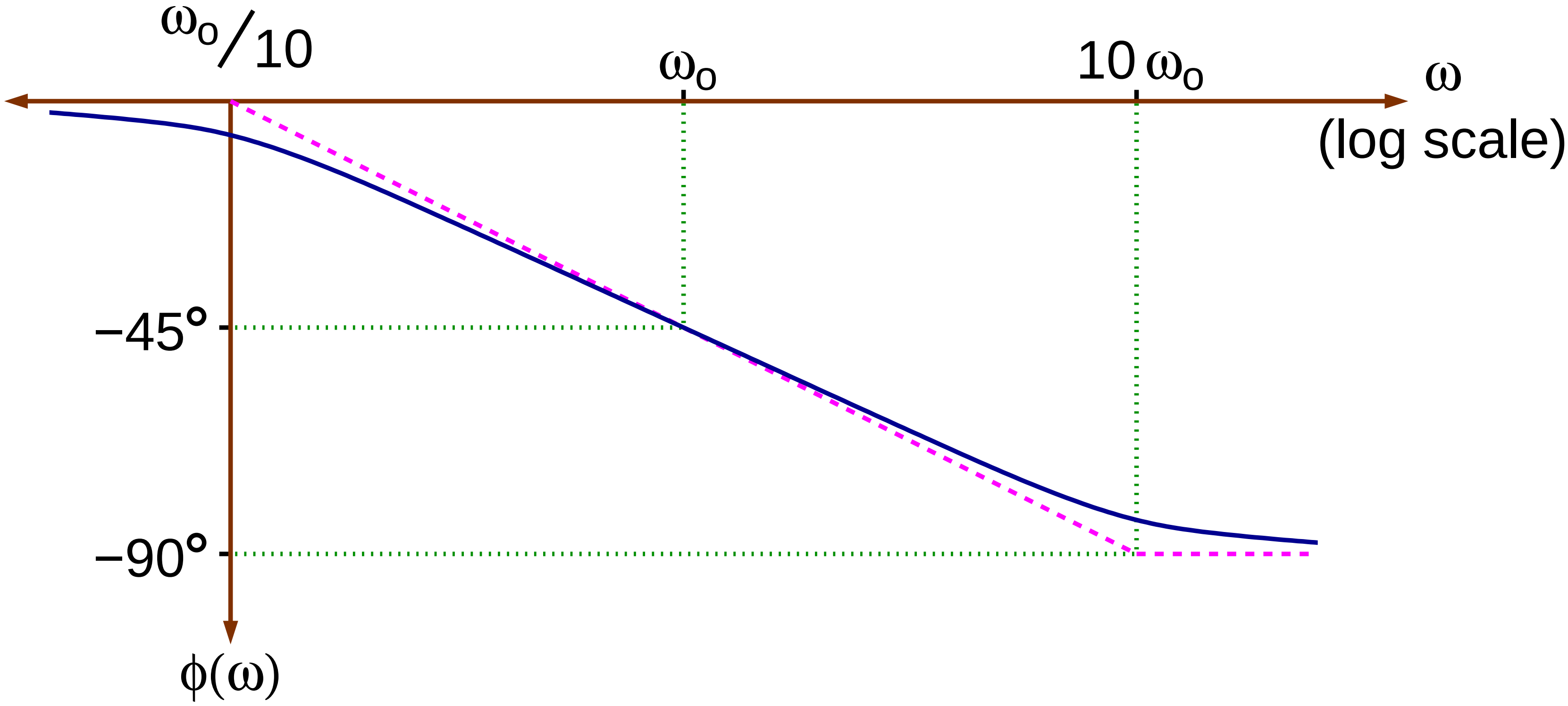
$$\angle \mathbf{T(j\omega)} = -\tan^{-1}\left(\frac{\omega}{\omega_o}\right)$$

$$\omega \ll \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} \approx 0^\circ$$

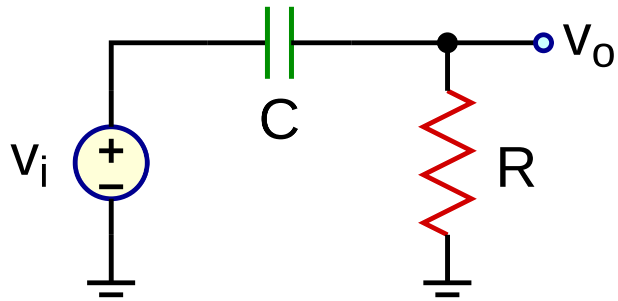
$$\omega \gg \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} \approx -90^\circ$$

$$\omega = \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} = -45^\circ$$

Low-pass Network



High-pass Network



$$\frac{v_o}{v_i} = \frac{R}{\frac{1}{sC} + R} = \frac{s}{s + \frac{1}{RC}} = \frac{s}{s + \omega_o} = T(s)$$

$$\omega_o = \frac{1}{RC}$$

$$T(s) = \frac{s}{s + \omega_o} \Rightarrow T(j\omega) = \frac{j\omega}{j\omega + \omega_o} = \frac{1}{1 - \dfrac{j\omega_o}{\omega}}$$

$$|T(j\omega)| = \frac{1}{\sqrt{1 + \left(\dfrac{\omega_o}{\omega}\right)^2}}$$

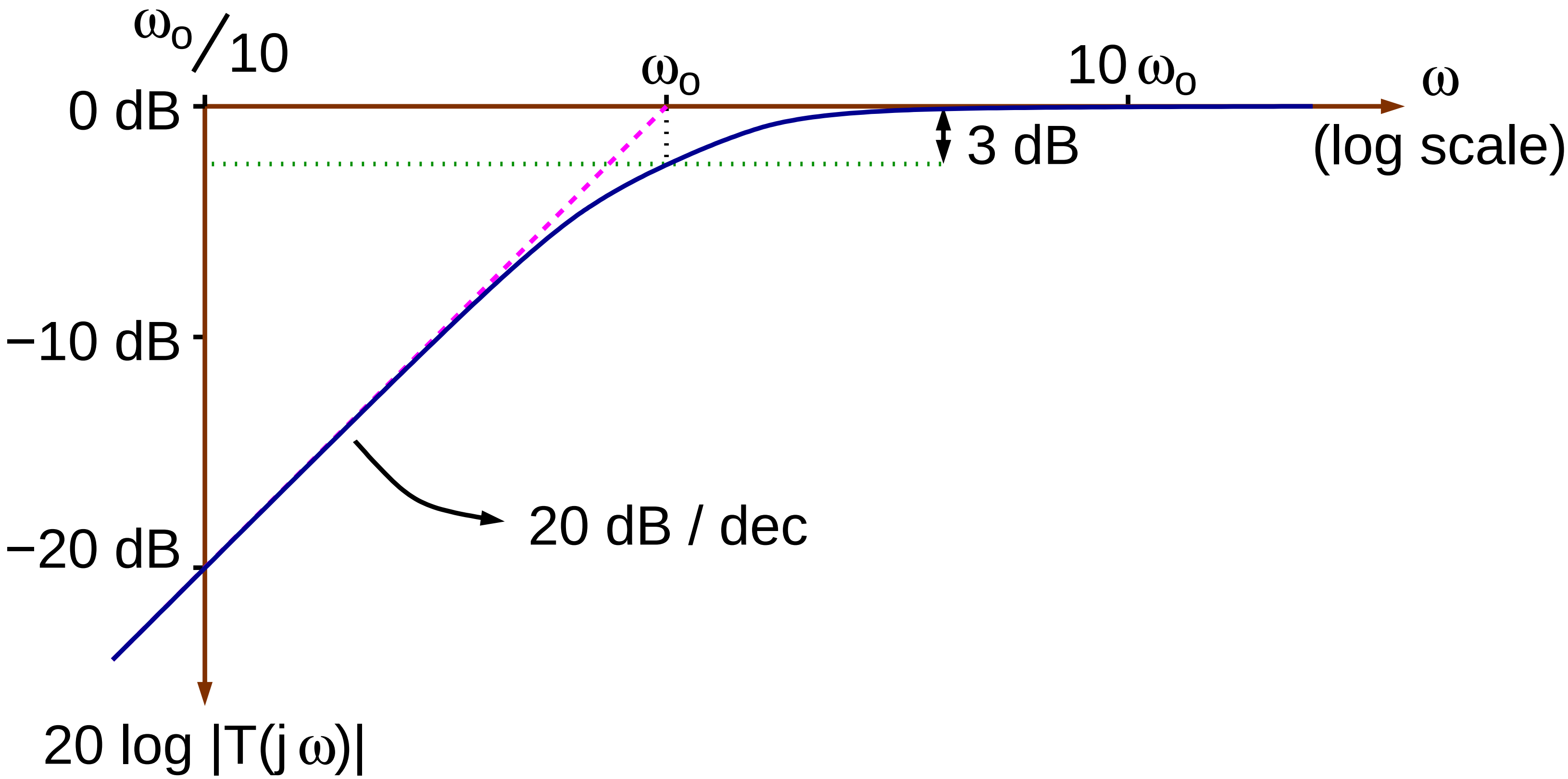
$$20 \log |T(j\omega)| = -20 \log \sqrt{1 + \left(\frac{\omega_o}{\omega}\right)^2}$$

$$\omega \ll \omega_o \Rightarrow 20 \log |T(j\omega)| \approx 20 \log \omega - 20 \log \omega_o$$

$$\omega \gg \omega_o \Rightarrow 20 \log |T(j\omega)| \approx 0$$

$$\omega = \omega_o \Rightarrow 20 \log |T(j\omega)| = -20 \log \sqrt{2} \approx -3 \text{ dB}$$

High-pass Network



$$\mathbf{T(s)} = \frac{\mathbf{s}}{\mathbf{s} + \omega_o} \;\Rightarrow\; \mathbf{T(j\omega)} = \frac{\mathbf{j\omega}}{\mathbf{j\omega} + \omega_o} = \frac{1}{1 - \dfrac{\mathbf{j}\omega_o}{\omega}}$$

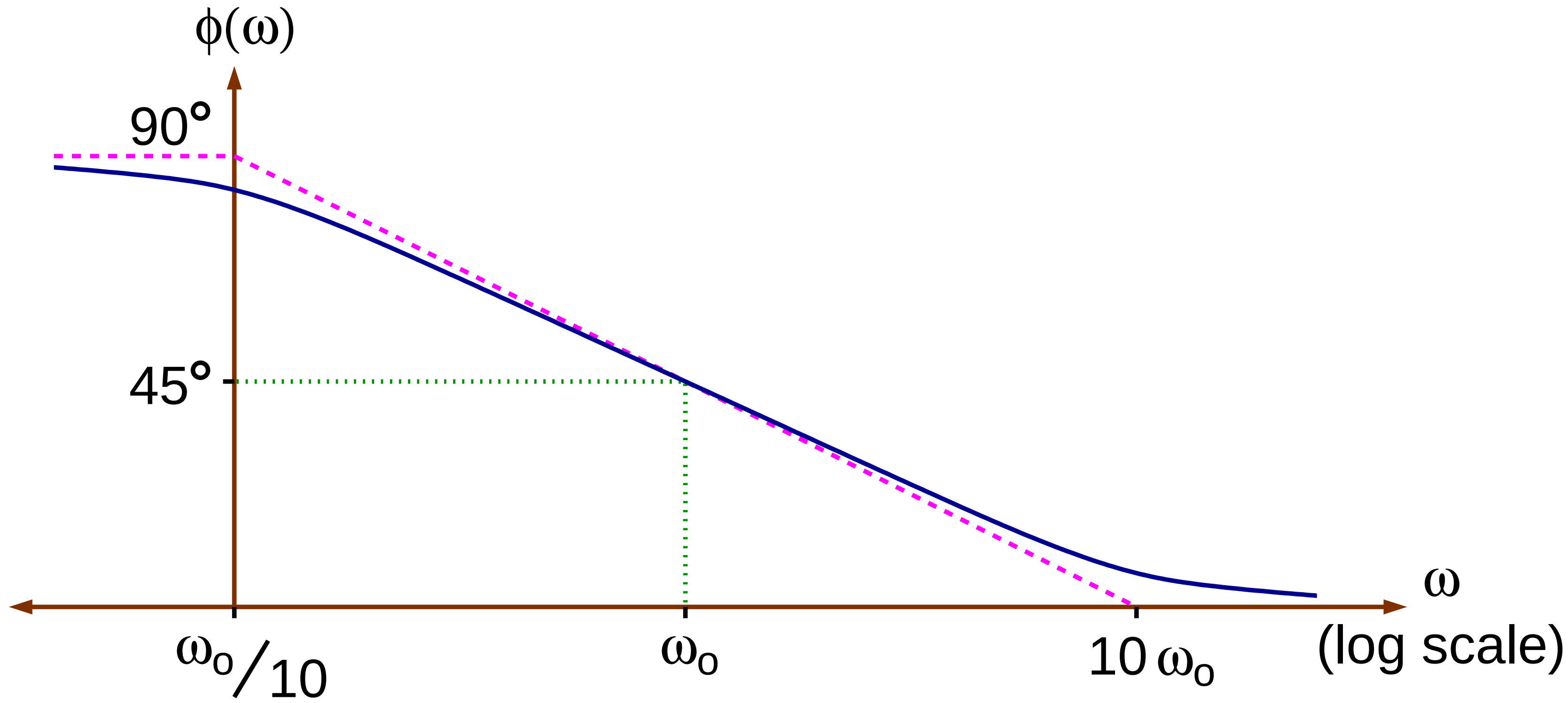
$$\angle \mathbf{T(j\omega)} = \tan^{-1}\left(\frac{\omega_o}{\omega}\right)$$

$$\omega \ll \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} \approx 90^\circ$$

$$\omega \gg \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} \approx 0^\circ$$

$$\omega = \omega_o \;\Rightarrow\; \angle \mathbf{T(j\omega)} = 45^\circ$$

High-pass Network



Generalized first order low-pass:

$$T(s) = \frac{K}{\frac{s}{\omega_o} + 1}$$

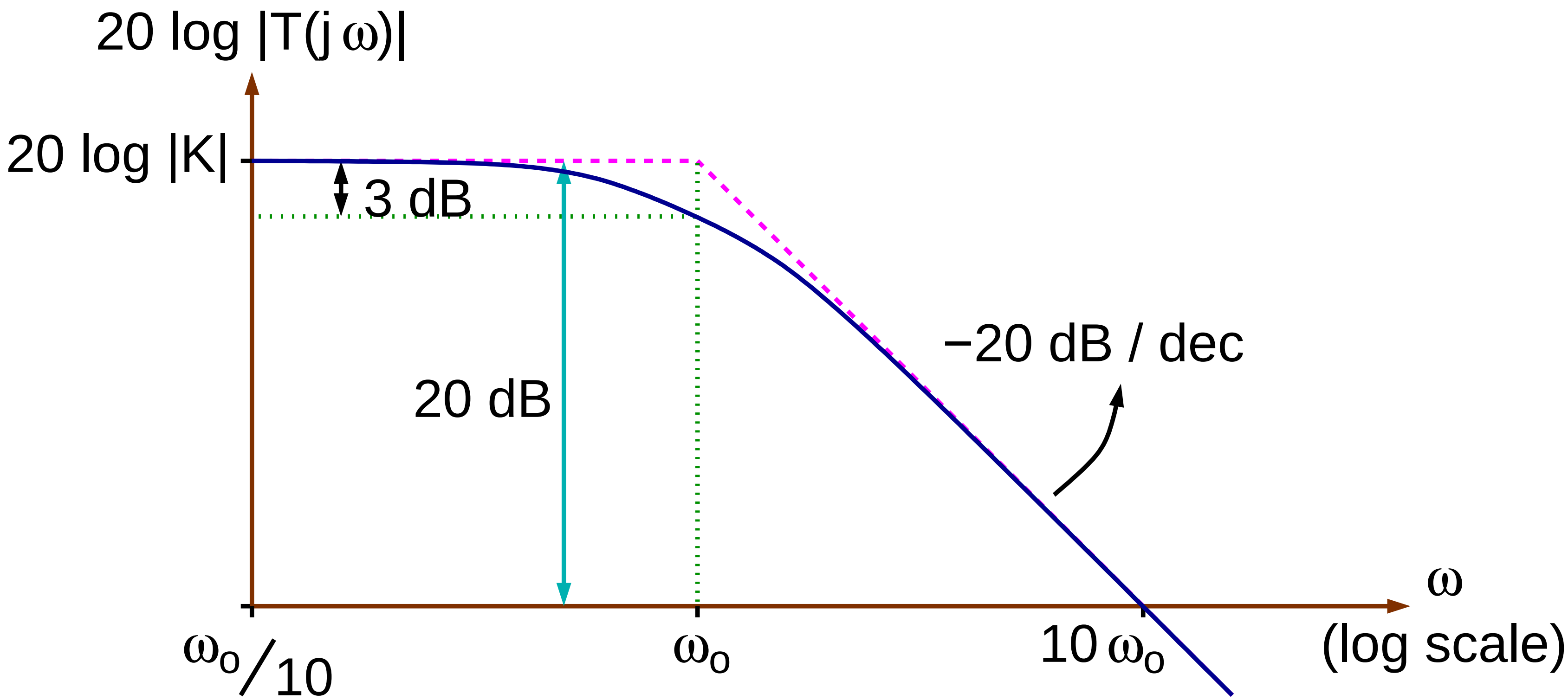
$$20 \log |T(j\omega)| = 20 \log K - 20 \log \sqrt{\left(\frac{\omega}{\omega_o}\right)^2 + 1}$$

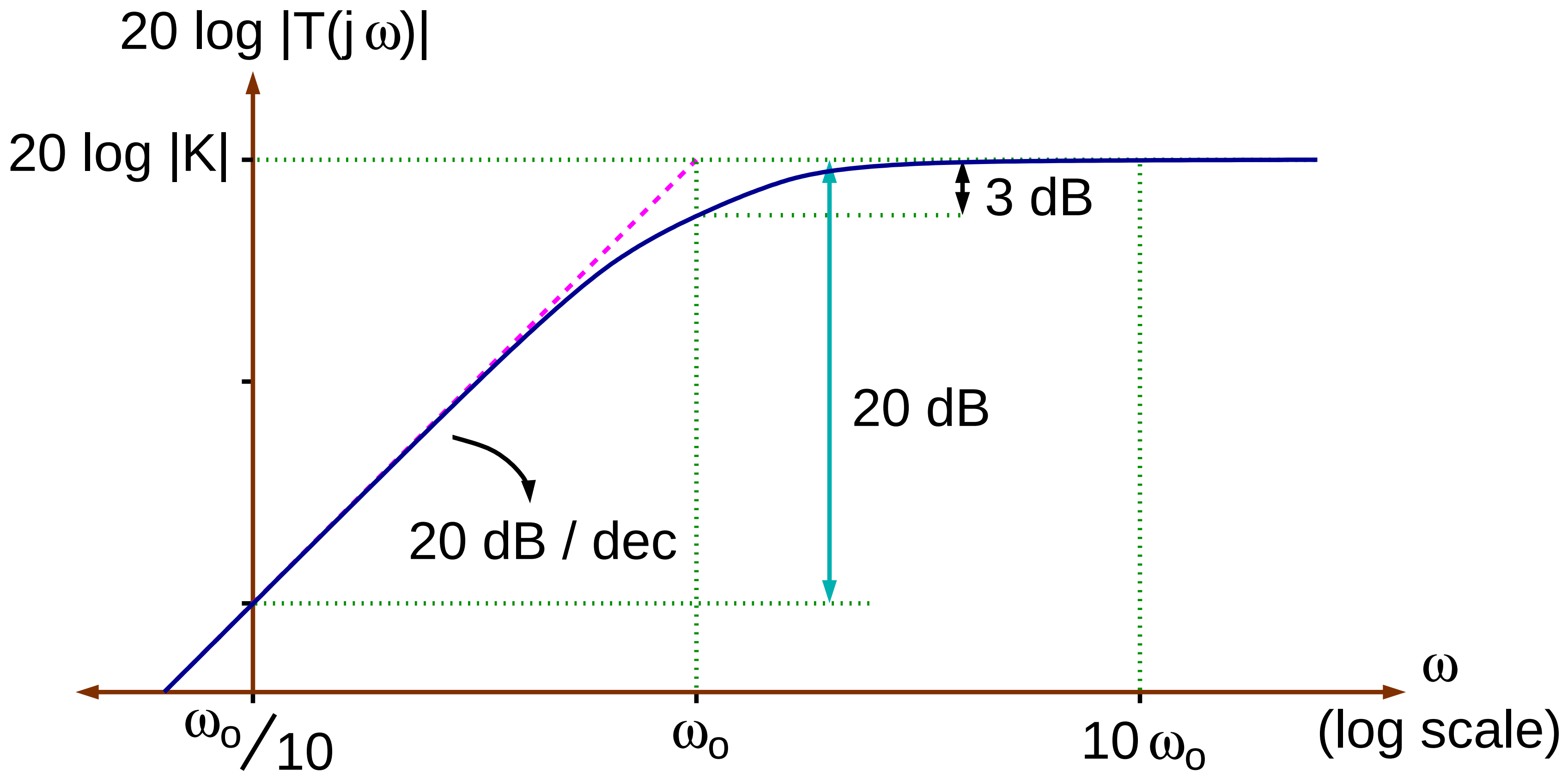
Generalized first order high-pass:

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

$$20 \log |T(j\omega)| = 20 \log K - 20 \log \sqrt{1 + \left(\frac{\omega_o}{\omega}\right)^2}$$

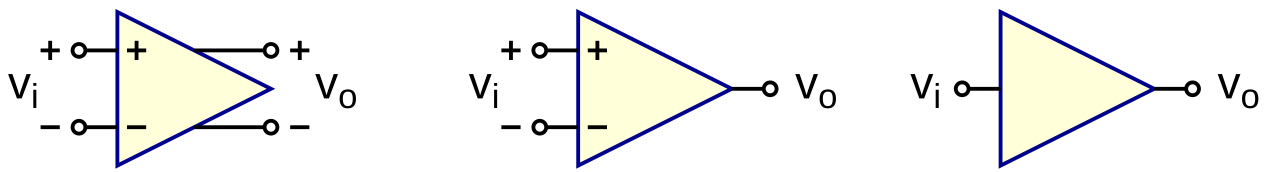
Generalized Low-pass





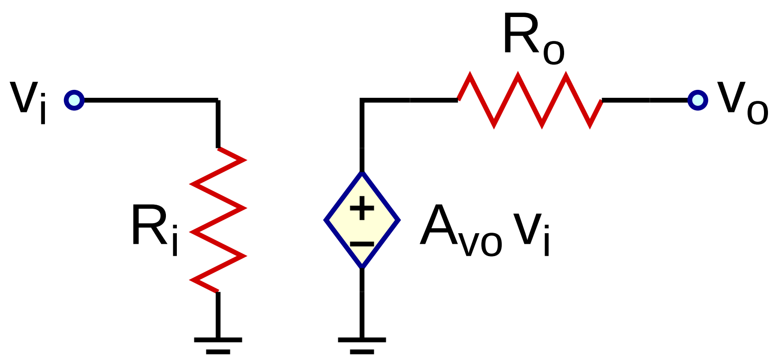
20 log |T(j ω)|
20 log |K|
3 dB
20 dB
20 dB / dec
ω
(log scale)
ωo/10
ωo
10 ωo

Amplifiers



In:	Differential	Differential	Single-ended
Out:	Differential	Single-ended	Single-ended

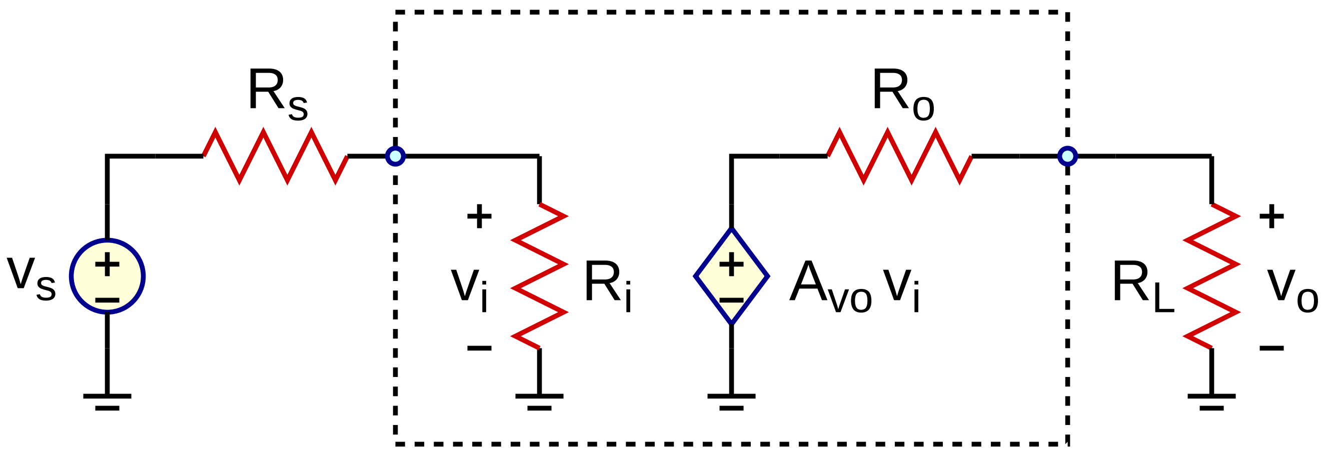
Voltage Amplifier



$\mathbf{R_i}$: Input resistance

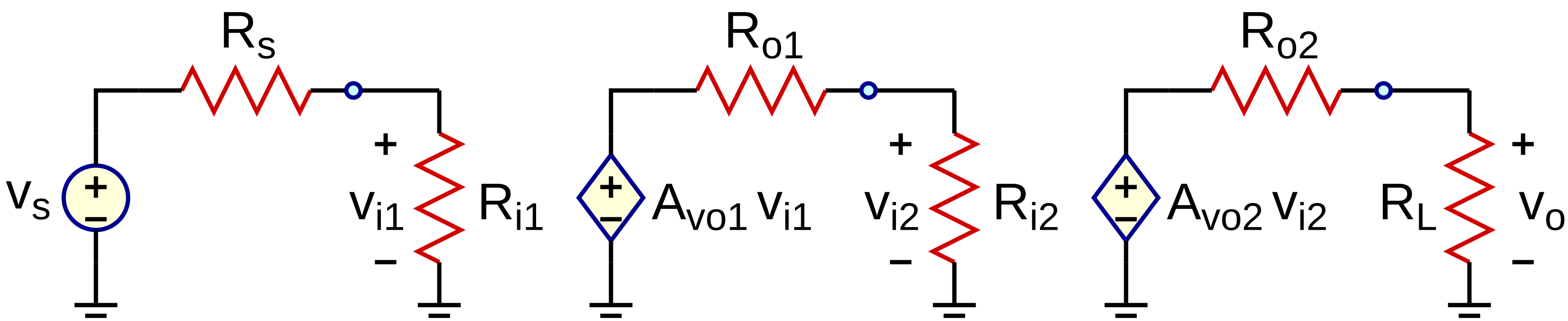
$\mathbf{R_o}$: Output resistance

$\mathbf{A_{vo}}$: Open-loop voltage gain



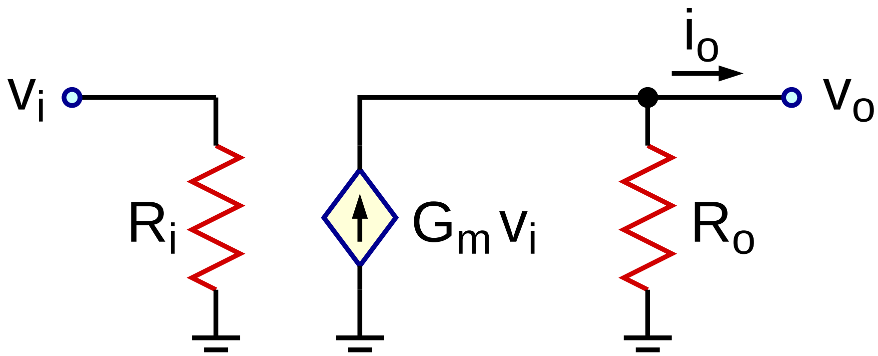
$$\frac{v_o}{v_s} = \frac{R_i}{R_s + R_i}\, A_{vo}\, \frac{R_L}{R_o + R_L}$$

Voltage Amplifier



$$\frac{v_o}{v_s} = \frac{R_{i1}}{R_s + R_{i1}} A_{vo1} \frac{R_{i2}}{R_{o1} + R_{i2}} A_{vo2} \frac{R_L}{R_{o2} + R_L}$$

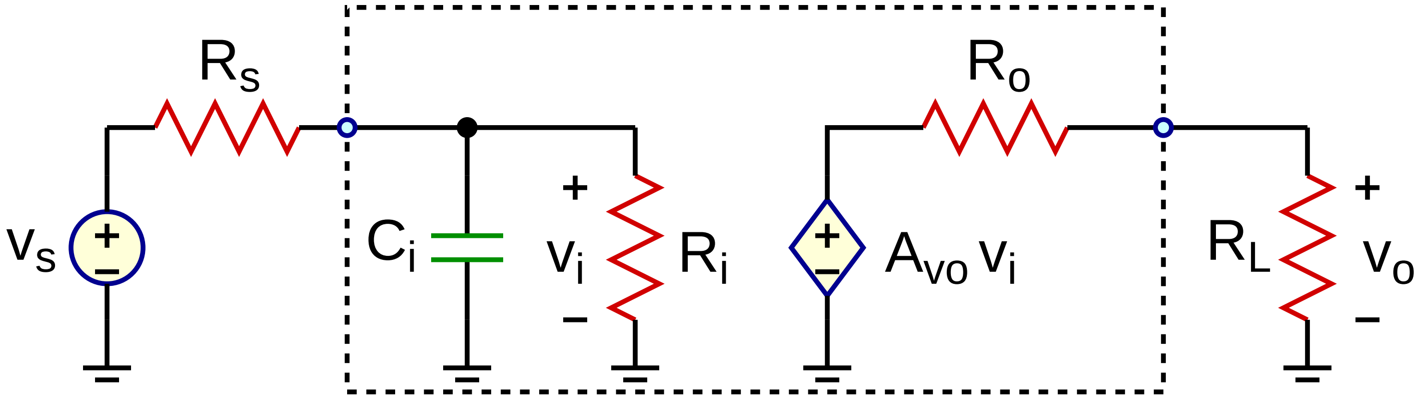
Transconductance amplifier



$\mathbf{R_i}$: Input resistance

$\mathbf{R_o}$: Output resistance

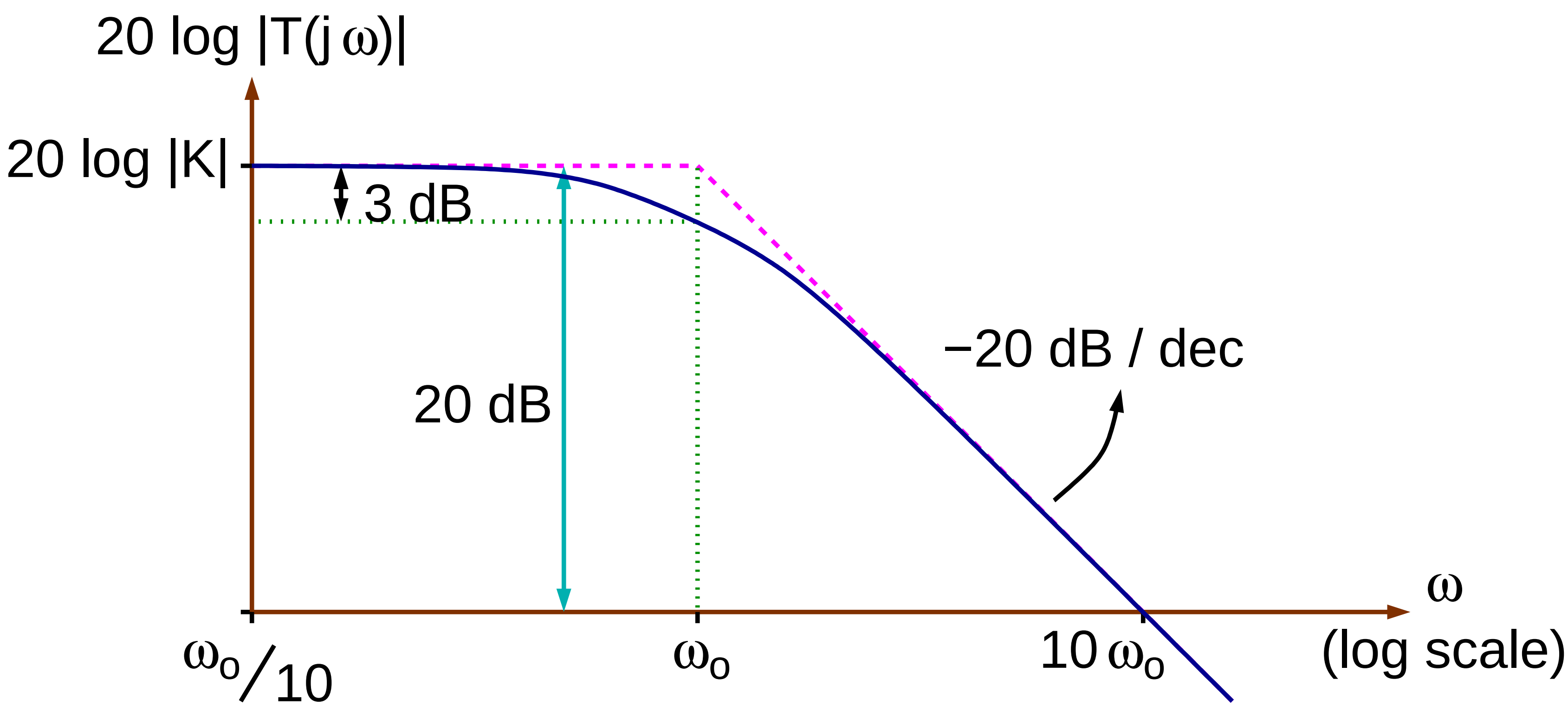
$\mathbf{G_m}$: Short-circuit transconductance gain



$$\frac{v_o}{v_s} = \frac{R_i \parallel \frac{1}{sC_i}}{R_s + \left(R_i \parallel \frac{1}{sC_i}\right)}\, A_{vo}\, \frac{R_L}{R_o + R_L} = T(s)$$

$$T(s) = \frac{K}{\frac{s}{\omega_o} + 1}$$

$$K = \frac{R_i}{R_s + R_i}\, A_{vo}\, \frac{R_L}{R_o + R_L}\,, \quad \omega_o = \frac{1}{(R_i \parallel R_s) C_i}$$


20 log |T(j ω)|
20 log |K|
3 dB
20 dB
−20 dB / dec
ω
(log scale)
ωo/10
ωo
10 ωo

Voltage Amplifier