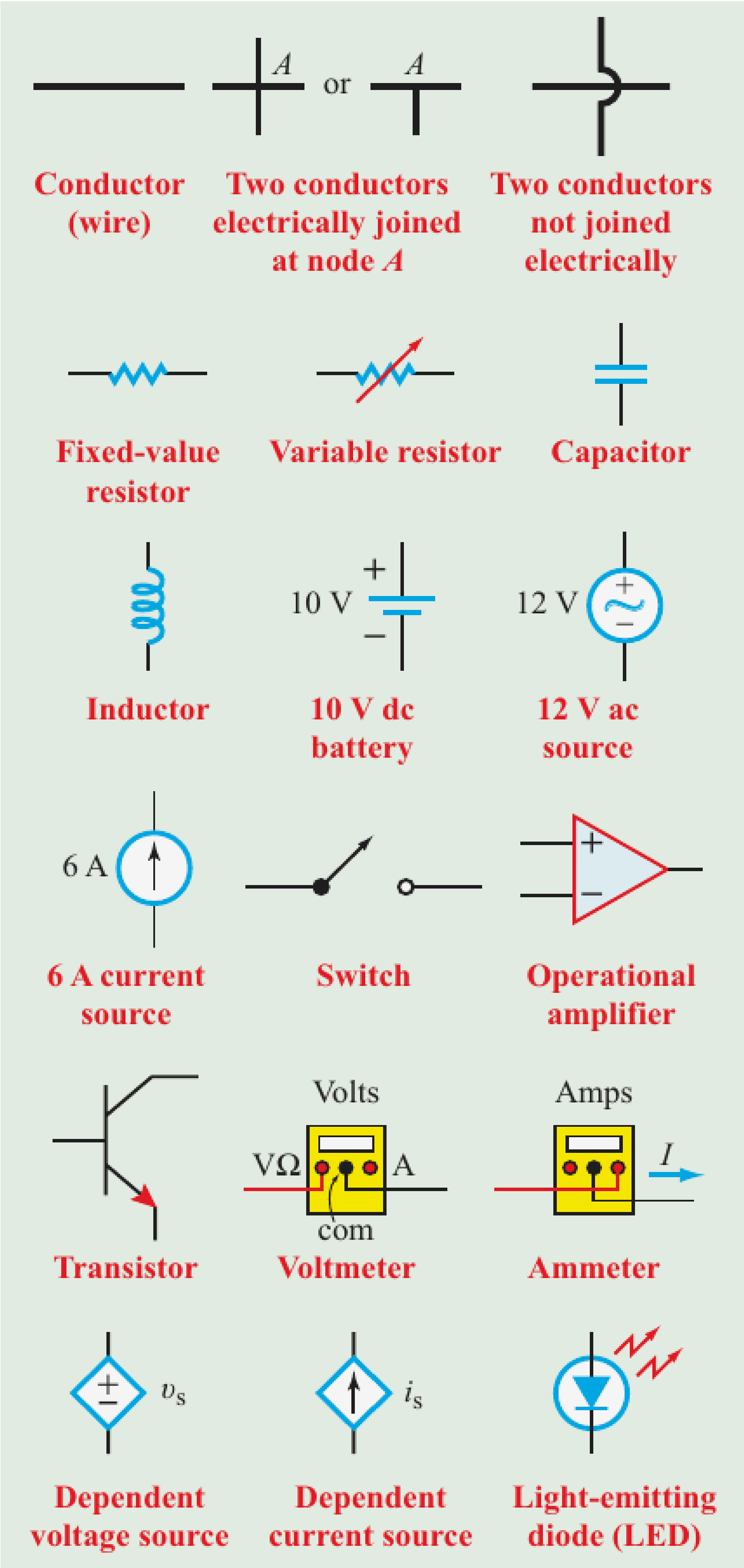
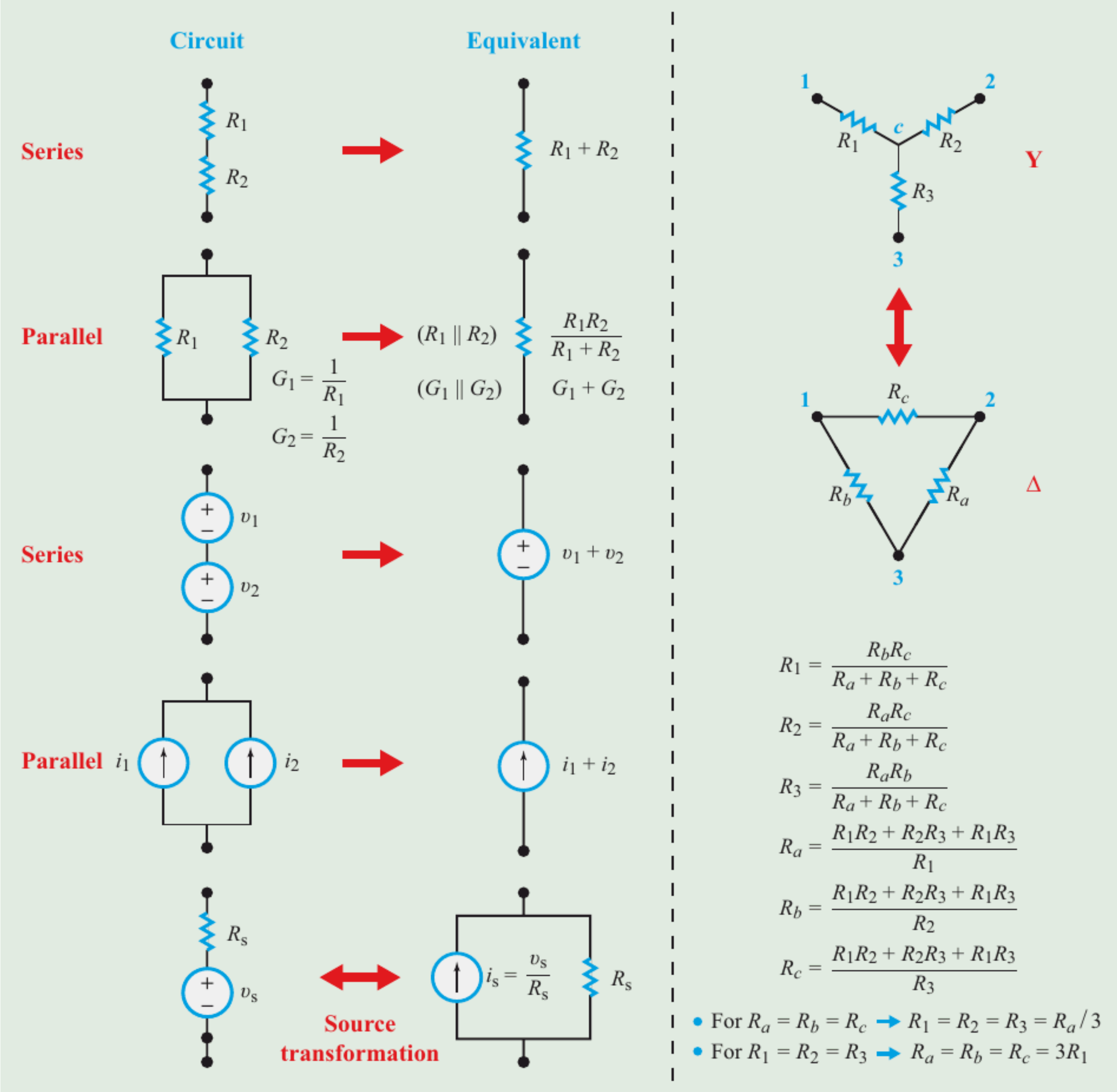

A
or
A
Conductor (wire)
Two conductors electrically joined at node A
Two conductors not joined electrically
Fixed-value resistor
Variable resistor
Capacitor
+
10 V
−
12 V
Inductor
10 V dc battery
12 V ac source
6 A
6 A current source
Switch
+
−
Operational amplifier
Volts
VΩ
A
com
Amps
I
Transistor
Voltmeter
Ammeter
v_s
i_s
Dependent voltage source
Dependent current source
Light-emitting diode (LED)

Table 2-5: Equivalent circuits.

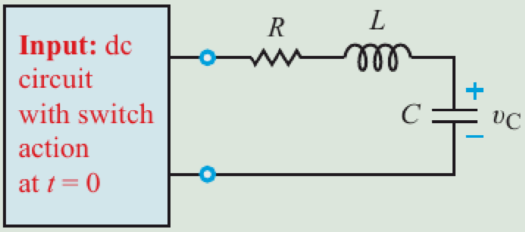
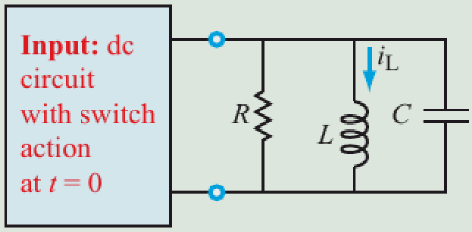


To Determine	Method	Can Circuit Contain Dependent Sources?	Relationship
υ_{Th}	Open-circuit υ	Yes	$\upsilon_{Th} = \upsilon_{oc}$
υ_{Th}	Short-circuit i (if R_{Th} is known)	Yes	$\upsilon_{Th} = R_{Th} i_{sc}$
R_{Th}	Open/short	Yes	$R_{Th} = \upsilon_{oc}/i_{sc}$
R_{Th}	Equivalent R	No	$R_{Th} = R_{eq}$
R_{Th}	External source	Yes	$R_{Th} = \upsilon_{ex}/i_{ex}$
$i_N = \upsilon_{Th}/R_{Th}$; $R_N = R_{Th}$			

$$\frac{R_{Th}^2}{4V_{Th}} = P_{max}$$

Method	Common Use
Ohm's law	Relates V, I, R. Used with all other methods to convert $V \Leftrightarrow I$.
R, G in series and $\parallel$	Combine to simplify circuits. R in series adds, and is most often used. G in $\parallel$ adds, so may be used when much of the circuit is in parallel.
Y-Δ or Π-T	Convert resistive networks that are not in series or in $\parallel$ into forms that can often be combined in series or in $\parallel$. Also simplifies analysis of bridge circuits.
Voltage/current dividers	Common circuit configurations used for many applications, as well as handy analysis tools. Dividers can also be used as combiners when used "backwards."
Kirchhoff's laws (KVL/KCL)	Solve for branch currents. Often used to derive other methods.
Node-voltage method	Solves for node voltages. Probably the most commonly used method because (1) node voltages are easy to measure, and (2) there are usually fewer nodes than branches and therefore fewer unknowns (smaller matrix) than KVL/KCL.
Mesh-current method	Solves for mesh currents. Fewer unknowns than KVL/KCL, approximately the same number of unknowns as node voltage method. Less commonly used, because mesh currents seem less intuitive, but useful when combining additional blocks in cascade.
Node-voltage by-inspection method	Quick, simplified way of analyzing circuits. Very commonly used for quick analysis in practice. Limited to circuits containing only independent current sources.
Mesh-current by-inspection method	Quick, simplified way of analyzing circuits. Very commonly used for quick analysis in practice. Limited to circuits containing only independent voltage sources.
Superposition	Simplifies circuits with multiple sources. Commonly used for both calculation and measurement.
Source transformation	Simplifies circuits with multiple sources. Commonly used for both calculation/design and measurement/test applications.
Thévenin and Norton equivalents	Very often used to simplify circuits in both calculation and measurement applications. Also used to analyze cascaded systems. Thévenin is the more commonly used form, but Norton is often handy for analyzing parallel circuits. Source transformation allows easy conversion between Thévenin and Norton.
Input/output resistance (R_{in}/R_{out})	Commonly used to evaluate when cascaded circuits can be analyzed individually or when full circuit analysis or a buffer is needed.

Table 6-1: Step response of RLC circuits for $t \geq 0$.

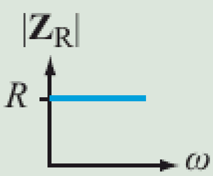
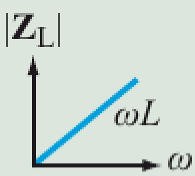
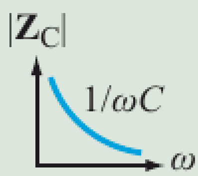
Series RLC	Parallel RLC
	
Total Response	**Total Response**
Overdamped $(\alpha > \omega_0)$	**Overdamped** $(\alpha > \omega_0)$
$\upsilon_C(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} + \upsilon_C(\infty)$	$i_L(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} + i_L(\infty)$
$A_1 = \dfrac{\frac{1}{C}\, i_C(0) - s_2[\upsilon_C(0) - \upsilon_C(\infty)]}{s_1 - s_2}$	$A_1 = \dfrac{\frac{1}{L}\, \upsilon_L(0) - s_2[i_L(0) - i_L(\infty)]}{s_1 - s_2}$
$A_2 = \dfrac{\frac{1}{C}\, i_C(0) - s_1[\upsilon_C(0) - \upsilon_C(\infty)]}{s_2 - s_1}$	$A_2 = \dfrac{\frac{1}{L}\, \upsilon_L(0) - s_1[i_L(0) - i_L(\infty)]}{s_2 - s_1}$
Critically Damped $(\alpha = \omega_0)$	**Critically Damped** $(\alpha = \omega_0)$
$\upsilon_C(t) = (B_1 + B_2 t)e^{-\alpha t} + \upsilon_C(\infty)$	$i_L(t) = (B_1 + B_2 t)e^{-\alpha t} + i_L(\infty)$
$B_1 = \upsilon_C(0) - \upsilon_C(\infty)$	$B_1 = i_L(0) - i_L(\infty)$
$B_2 = \frac{1}{C}\, i_C(0) + \alpha[\upsilon_C(0) - \upsilon_C(\infty)]$	$B_2 = \frac{1}{L}\, \upsilon_L(0) + \alpha[i_L(0) - i_L(\infty)]$
Underdamped $(\alpha < \omega_0)$	**Underdamped** $(\alpha < \omega_0)$
$\upsilon_C(t) = e^{-\alpha t}(D_1 \cos \omega_d t + D_2 \sin \omega_d t) + \upsilon_C(\infty)$	$i_L(t) = e^{-\alpha t}(D_1 \cos \omega_d t + D_2 \sin \omega_d t) + i_L(\infty)$
$D_1 = \upsilon_C(0) - \upsilon_C(\infty)$	$D_1 = i_L(0) - i_L(\infty)$
$D_2 = \dfrac{\frac{1}{C}\, i_C(0) + \alpha[\upsilon_C(0) - \upsilon_C(\infty)]}{\omega_d}$	$D_2 = \dfrac{\frac{1}{L}\, \upsilon_L(0) + \alpha[i_L(0) - i_L(\infty)]}{\omega_d}$

Auxiliary Relations

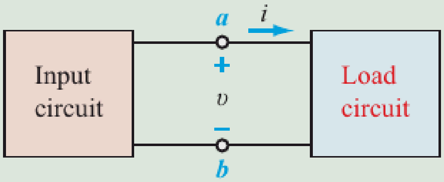
$$\alpha = \begin{cases} \dfrac{R}{2L} & \text{Series RLC} \\[2ex] \dfrac{1}{2RC} & \text{Parallel RLC} \end{cases} \qquad \omega_0 = \frac{1}{\sqrt{LC}} \qquad \omega_d = \sqrt{\omega_0^2 - \alpha^2}$$

$$s_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2} \qquad s_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2}$$

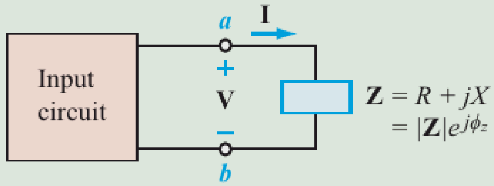
$x(t)$		$\mathbf{X}$
$A\cos\omega t$	$\leftrightarrow$	A
$A\cos(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j\phi}$
$-A\cos(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi\pm\pi)}$
$A\sin\omega t$	$\leftrightarrow$	$Ae^{-j\pi/2}=-jA$
$A\sin(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi-\pi/2)}$
$-A\sin(\omega t+\phi)$	$\leftrightarrow$	$Ae^{j(\phi+\pi/2)}$
$\frac{d}{dt}(x(t))$	$\leftrightarrow$	$j\omega\mathbf{X}$
$\frac{d}{dt}[A\cos(\omega t+\phi)]$	$\leftrightarrow$	$j\omega Ae^{j\phi}$
$\int x(t)\,dt$	$\leftrightarrow$	$\frac{1}{j\omega}\mathbf{X}$
$\int A\cos(\omega t+\phi)\,dt$	$\leftrightarrow$	$\frac{1}{j\omega}Ae^{j\phi}$

Property	R	L	C
v–i	$v=Ri$	$v=L\frac{di}{dt}$	$i=C\frac{dv}{dt}$
V–I	$\mathbf{V}=R\mathbf{I}$	$\mathbf{V}=j\omega L\mathbf{I}$	$\mathbf{V}=\frac{\mathbf{I}}{j\omega C}$
Z	R	$j\omega L$	$\frac{1}{j\omega C}$
dc equivalent	R	Short circuit	Open circuit
High-frequency equivalent	R	Open circuit	Short circuit
Frequency response			

Time Domain



Phasor Domain



$\mathbf{Z} = R + jX = |\mathbf{Z}|e^{j\phi_z}$

Time Domain		Phasor Domain
$v(t) = V_m \cos(\omega t + \phi_v)$	⟷	$\mathbf{V} = V_m e^{j\phi_v}$
$i(t) = I_m \cos(\omega t + \phi_i)$	⟷	$\mathbf{I} = I_m e^{j\phi_i}$
$V_{rms} = V_m/\sqrt{2}$	⟷	$\mathbf{V}_{rms} = V_{rms}e^{j\phi_v}$
$I_{rms} = I_m/\sqrt{2}$	⟷	$\mathbf{I}_{rms} = I_{rms}e^{j\phi_i}$

Complex Power

$$\mathbf{S} = \frac{1}{2}\mathbf{V}\mathbf{I}^* = \mathbf{V}_{rms}\mathbf{I}^*_{rms} = P_{av} + jQ$$

Real Average Power

$$P_{av} = \mathfrak{Re}\,[\mathbf{S}] = V_{rms}I_{rms}\cos(\phi_v - \phi_i) = I^2_{rms}R = V^2_{rms}R/|\mathbf{Z}|^2$$

Reactive Power

$$Q = \mathfrak{Im}\,[\mathbf{S}] = V_{rms}I_{rms}\sin(\phi_v - \phi_i) = I^2_{rms}X = V^2_{rms}X/|\mathbf{Z}|^2$$

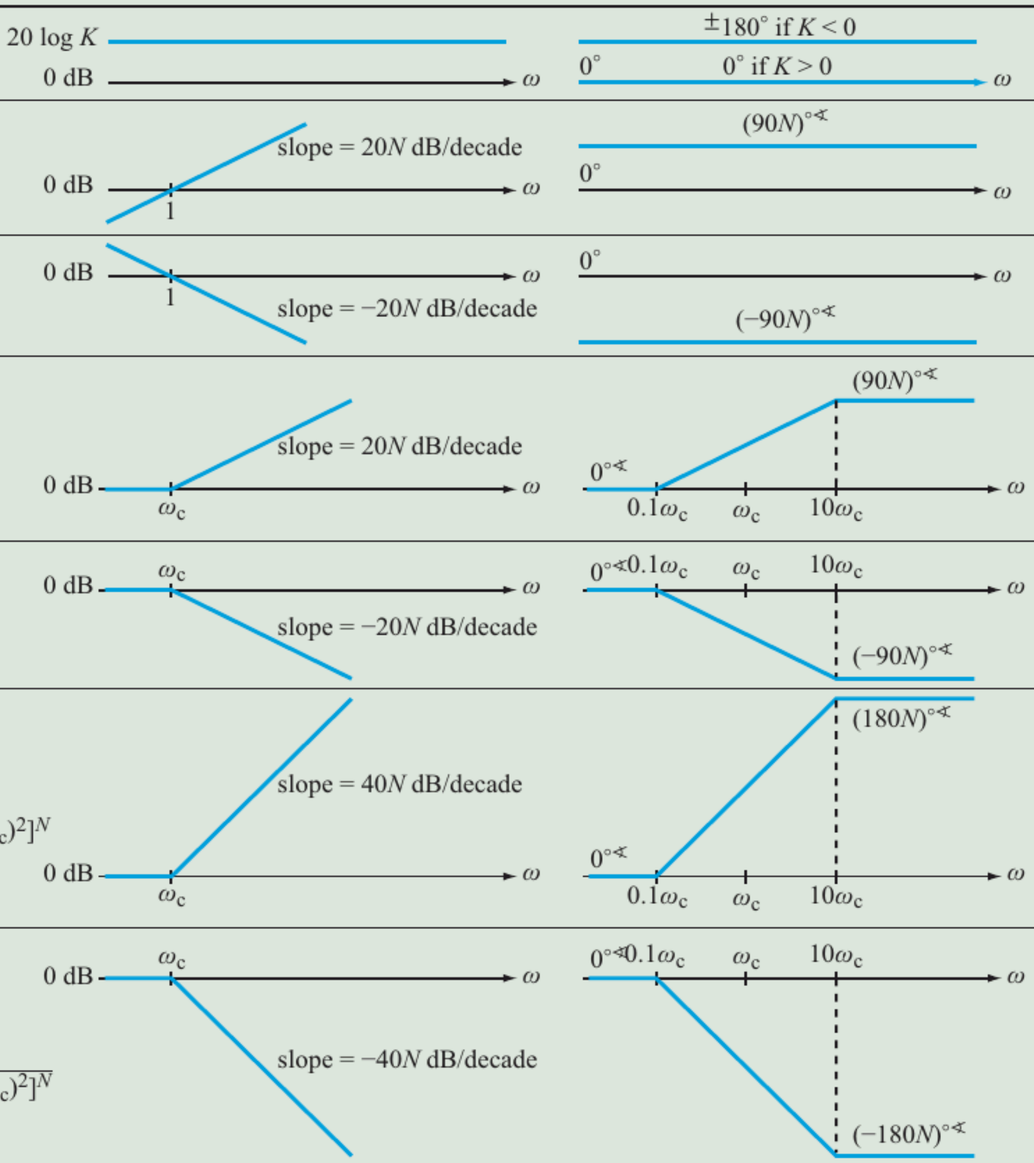
Apparent Power

$$S = |\mathbf{S}| = \sqrt{P^2_{av} + Q^2} = V_{rms}I_{rms} = I^2_{rms}|\mathbf{Z}| = V^2_{rms}/|\mathbf{Z}|$$

$$\mathbf{S} = Se^{j(\phi_v - \phi_i)} = Se^{j\phi_z}$$
$$\phi_z = \phi_v - \phi_i$$

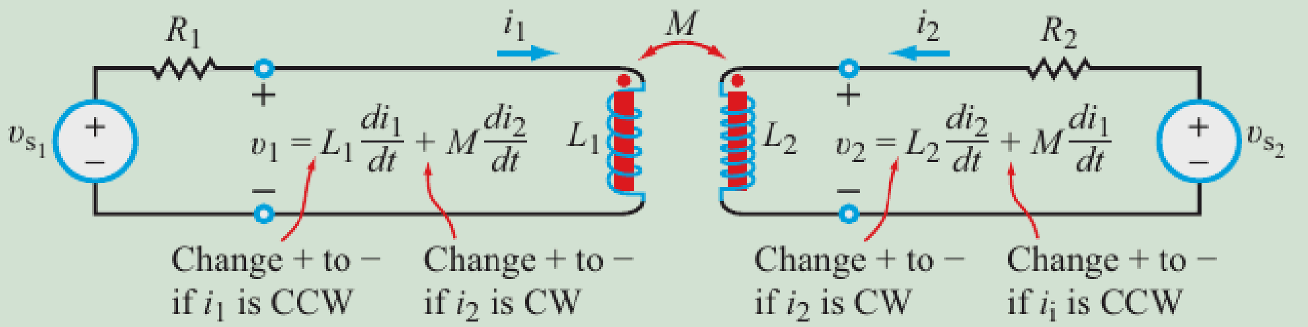
Power Factor

$$pf = \frac{P_{av}}{S} = \cos(\phi_v - \phi_i) = \cos\phi_z$$

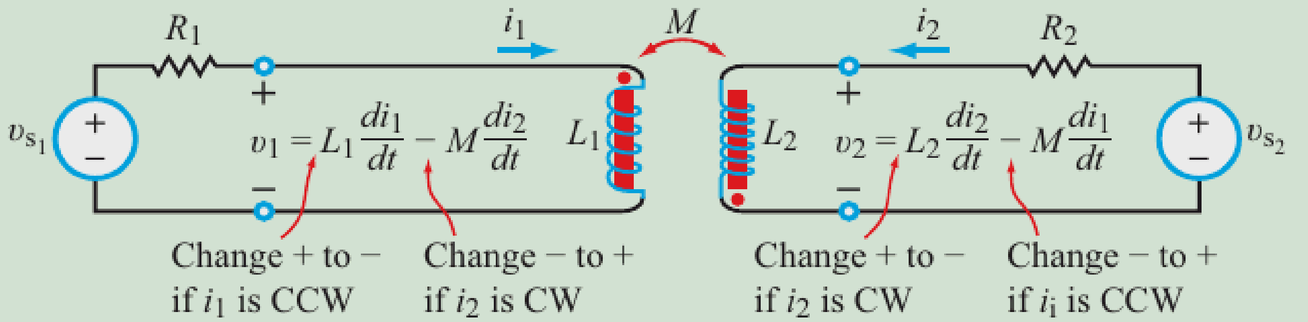


Factor	Bode Magnitude	Bode Phase
Constant K	$20\log K$; 0 dB; ω	$\pm 180^\circ$ if $K < 0$; 0°; 0° if $K > 0$; ω
Zero @ Origin $(j\omega)^N$	0 dB; 1; slope = $20N$ dB/decade; ω	$(90N)^{\circ\sphericalangle}$; 0°; ω
Pole @ Origin $(j\omega)^{-N}$	0 dB; 1; slope = $-20N$ dB/decade; ω	0°; $(-90N)^{\circ\sphericalangle}$; ω
Simple Zero $(1 + j\omega/\omega_c)^N$	0 dB; ω_c; slope = $20N$ dB/decade; ω	$0^{\circ\sphericalangle}$; $0.1\omega_c$; ω_c; $10\omega_c$; $(90N)^{\circ\sphericalangle}$; ω
Simple Pole $\left(\frac{1}{1 + j\omega/\omega_c}\right)^N$	0 dB; ω_c; slope = $-20N$ dB/decade; ω	$0^{\circ\sphericalangle}$; $0.1\omega_c$; ω_c; $10\omega_c$; $(-90N)^{\circ\sphericalangle}$; ω
Quadratic Zero $[1 + j2\xi\omega/\omega_c + (j\omega/\omega_c)^2]^N$	0 dB; ω_c; slope = $40N$ dB/decade; ω	$0^{\circ\sphericalangle}$; $0.1\omega_c$; ω_c; $10\omega_c$; $(180N)^{\circ\sphericalangle}$; ω
Quadratic Pole $\frac{1}{[1 + j2\xi\omega/\omega_c + (j\omega/\omega_c)^2]^N}$	0 dB; ω_c; slope = $-40N$ dB/decade; ω	$0^{\circ\sphericalangle}$; $0.1\omega_c$; ω_c; $10\omega_c$; $(-180N)^{\circ\sphericalangle}$; ω

Magnetic Coupling



(a) Dots on same ends



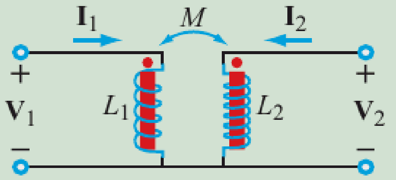
(b) Dots on opposite ends

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

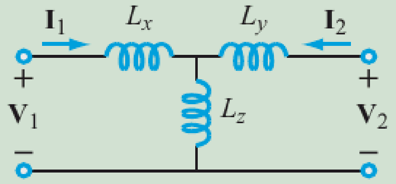
Mathematical and Physical Models (continued)

Equivalent Circuits

(a) Transformer

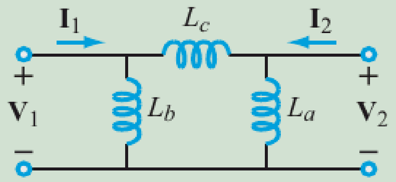


(b) T-equivalent circuit



$L_x = L_1 - M$
$L_y = L_2 - M$
$L_z = M$

(c) Π-equivalent circuit



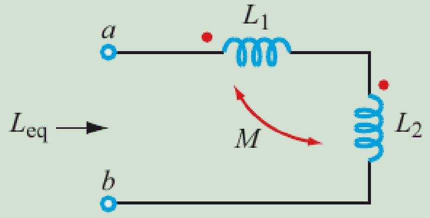
$$L_a = \frac{L_1 L_2 - M^2}{L_1 - M}$$

$$L_b = \frac{L_1 L_2 - M^2}{L_2 - M}$$

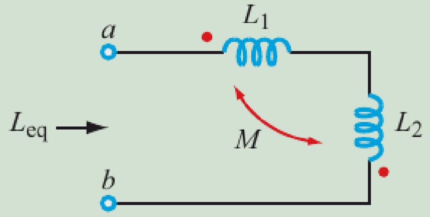
$$L_c = \frac{L_1 L_2 - M^2}{M}$$

Replace M with $-M$ if dots are on opposite ends.

Equivalent Inductance



$$L_{eq} = L_1 + L_2 + 2M$$



$$L_{eq} = L_1 + L_2 - 2M$$

Ideal Transformer

$$\frac{\mathbf{V}_2}{\mathbf{V}_1} = n$$

$$\frac{\mathbf{I}_2}{\mathbf{I}_1} = \frac{1}{n}$$

$$\mathbf{Z}_{in} = \frac{\mathbf{V}_1}{\mathbf{I}_1} = \frac{1}{n^2}\frac{\mathbf{V}_2}{\mathbf{I}_2} = \frac{\mathbf{Z}_L}{n^2}$$