وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا

Analog IC Design

Lecture 02
Review on Circuits Basics

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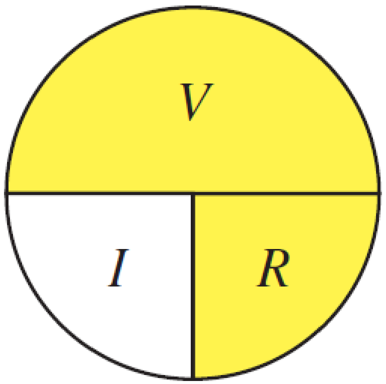
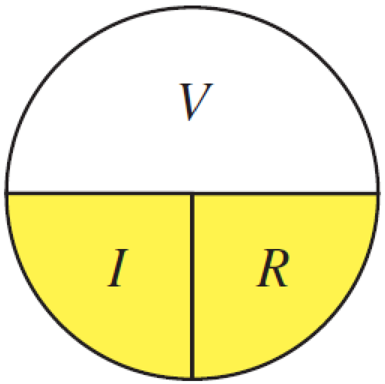
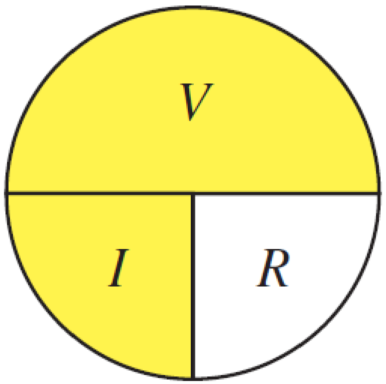
Ohm’s Law



$$I = \frac{V}{R}$$



$$V = IR$$



$$R = \frac{V}{I}$$

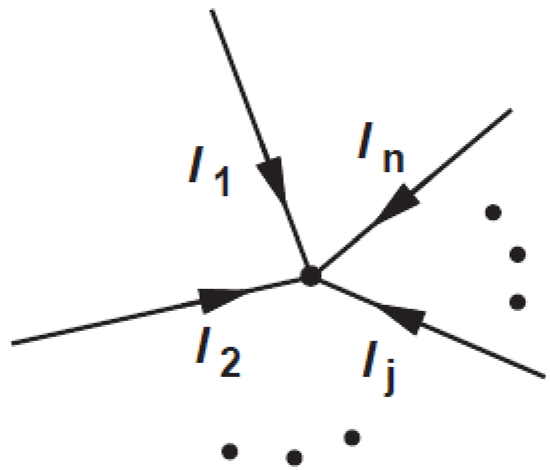
[Floyd, 2014]

Kirchhoff Current Law (KCL)

- The sum of all currents flowing into a node is zero

$$\Sigma I = 0$$

$$I_1 + I_2 + \cdots + I_j + \cdots + I_n = 0$$



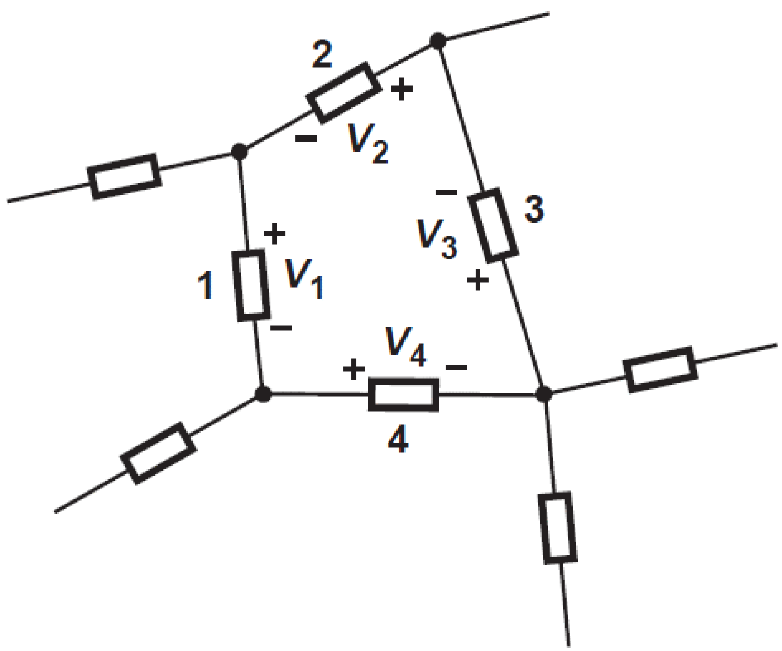
[Razavi, 2014]

Kirchhoff Voltage Law (KVL)

- The sum of all voltage drops around any closed loop is zero

$$\Sigma V = 0$$

$$V_1 + V_2 + V_3 + V_4 = 0$$



 [Razavi, 2014]

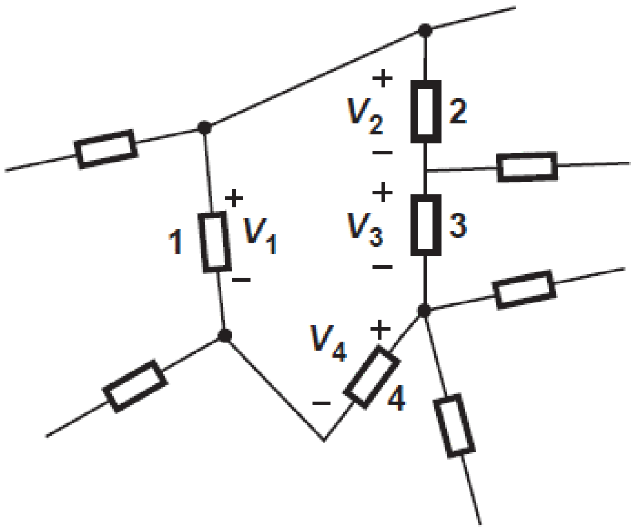
Kirchhoff Voltage Law (KVL)

- The sum of all voltage drops around any closed loop is zero

$$\Sigma V = 0$$

$$-V_1 + V_2 + V_3 + V_4 = 0$$

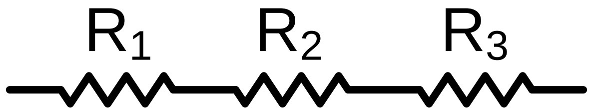
$$V_1 = V_2 + V_3 + V_4$$



[Razavi, 2014]

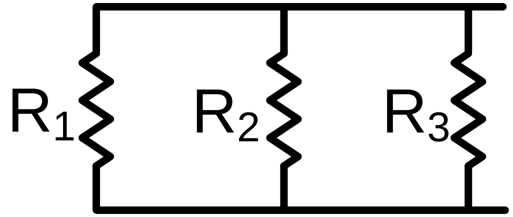
Resistor Combinations

- Resistors in series: Largest resistance dominates



$$R_{eq} = R_1 + R_2 + R_3$$

- Resistors in parallel: Smallest resistance dominates

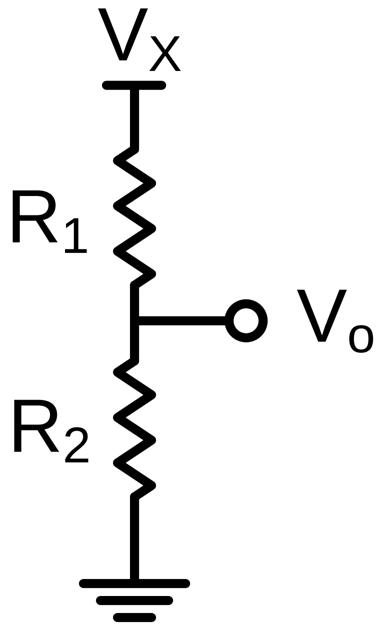


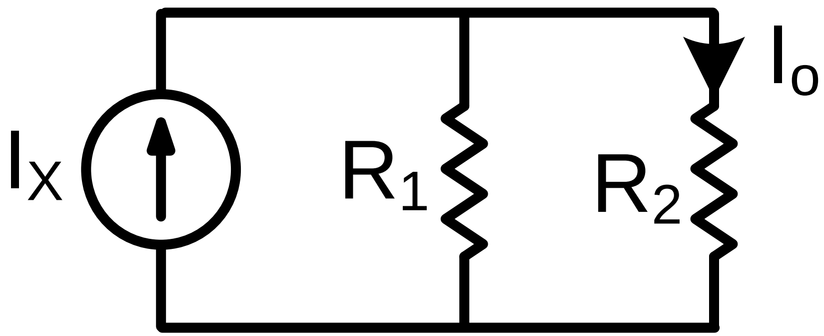
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Voltage and Current Dividers

$$V_o = V_X \cdot \frac{R_2}{R_1 + R_2}$$

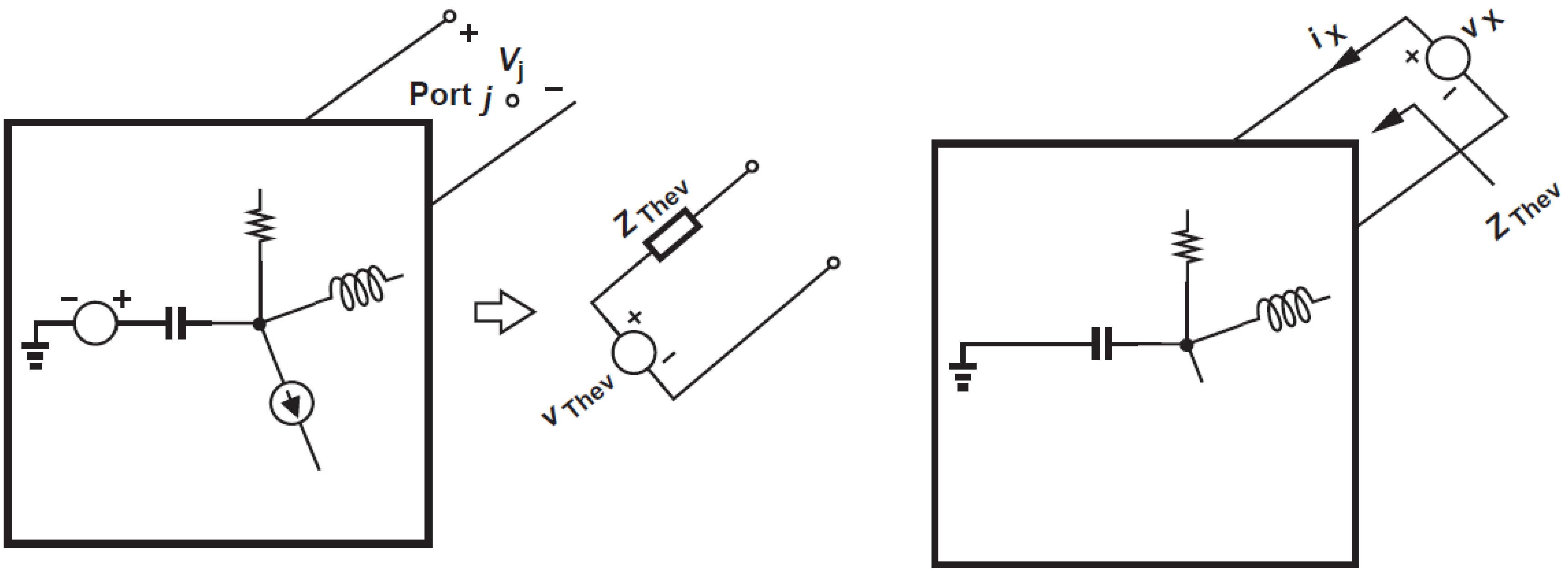
$$I_o = I_X \cdot \frac{R_1}{R_1 + R_2}$$





Thevenin Equivalent

$$V_{Thev} = V_{o.c.}$$



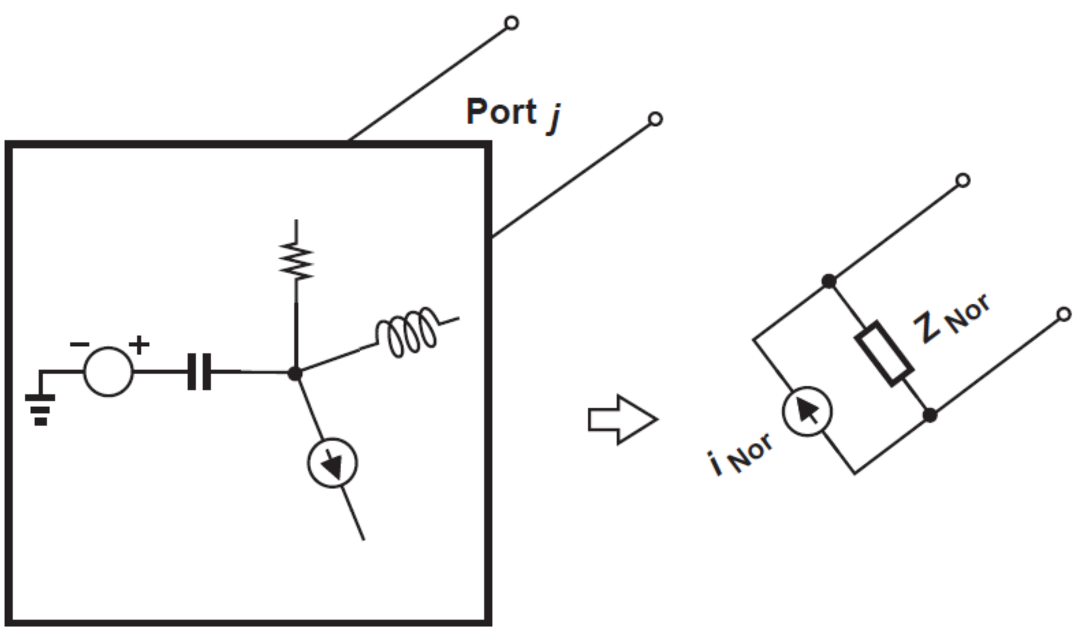
[Razavi, 2014]

Norton Equivalent

$$I_{Nor} = I_{s.c.}$$

$$Z_{Nor} = Z_{Thev}$$

$$V_{Thev} = V_{o.c.} = I_{Nor} \times Z_{Nor}$$

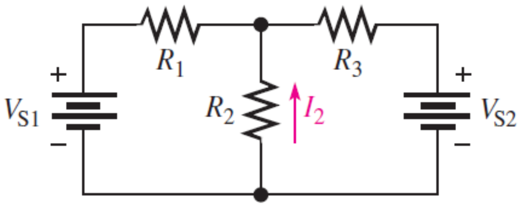


Superposition Theorem

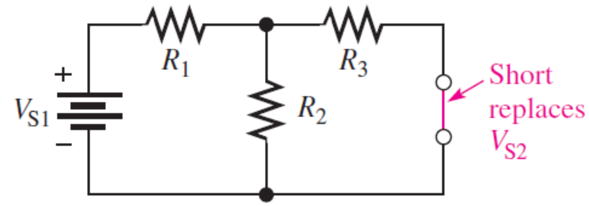
- Deactivate all independent sources except one
  - Independent voltage source → s.c.
  - Independent current source → o.c.
  - Do NOT deactivate dependent sources
- Solve the circuit
- Repeat the previous two steps for every source
- Algebraically add all the results

We use this frequently to separate AC and DC solutions

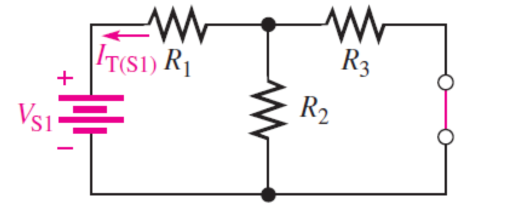
Superposition Theorem



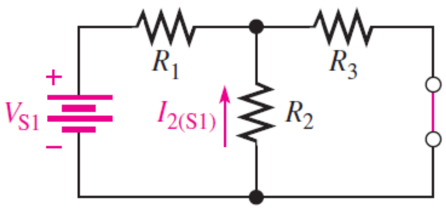
(a) Problem: Find I_2.



(b) Replace V_{S2} with zero resistance (short).

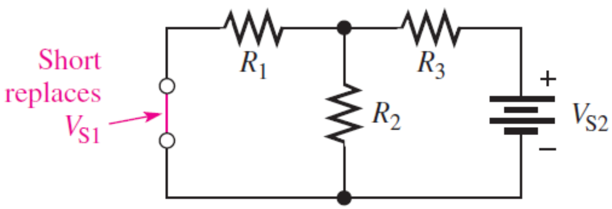


(c) Find R_T and I_T looking from V_{S1}:
$R_{T(S1)} = R_1 + R_2 \parallel R_3$
$I_{T(S1)} = V_{S1}/R_{T(S1)}$

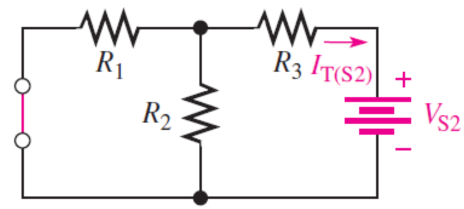


(d) Find I_2 due to V_{S1}:

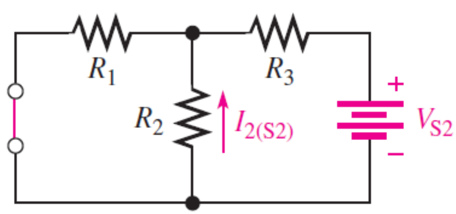
$$I_{2(S1)} = \left(\frac{R_3}{R_2 + R_3}\right) I_{T(S1)}$$



(e) Replace V_{S1} with zero resistance (short).

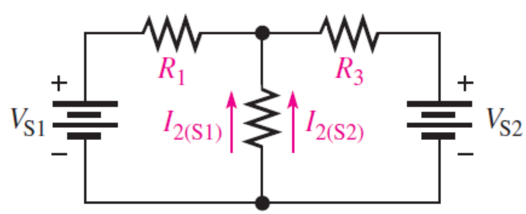


(f) Find R_T and I_T looking from V_{S2}:
$R_{T(S2)} = R_3 + R_1 \parallel R_2$
$I_{T(S2)} = V_{S2}/R_{T(S2)}$



(g) Find I_2 due to V_{S2}:

$$I_{2(S2)} = \left(\frac{R_1}{R_1 + R_2}\right) I_{T(S2)}$$



(h) Restore the original sources. Algebraically add $I_{2(S1)}$ and $I_{2(S2)}$ to get the actual I_2 (they are in same direction):
$I_2 = I_{2(S1)} + I_{2(S2)}$

[Floyd, 2014]

Capacitance

$$Q = CV$$

$$i = \frac{dQ}{dt} = C\,\frac{dV}{dt}$$

$$V = V_o \cos\omega t = V_o \cdot Re\left\{e^{j\omega t}\right\} \;\Rightarrow\; V_o e^{j\omega t}$$

$$i = C\,\frac{dV}{dt} = j\omega C\left(V_o e^{j\omega t}\right) = j\omega C \cdot V$$

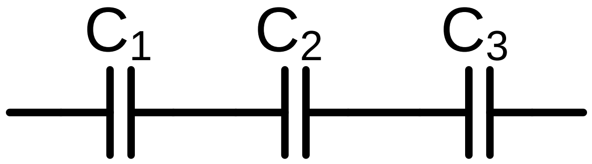
$$Z = \frac{V}{i} = \frac{1}{j\omega C} = \frac{1}{sC} \;\;\Rightarrow\;\; X_C = \frac{1}{\omega C}$$

$$\omega \uparrow\uparrow \;\Rightarrow\; X_C \to 0 \;\Rightarrow\; s.c.$$

$$\omega \downarrow\downarrow \;\Rightarrow\; X_C \to \infty \;\Rightarrow\; o.c.$$

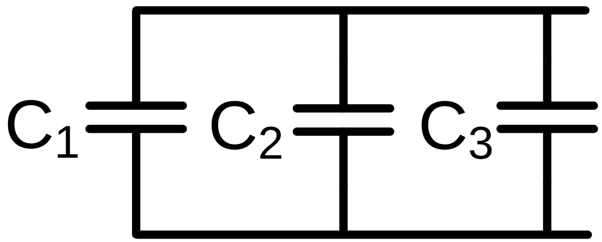
Capacitance Combinations

- Capacitors in series: Smallest capacitor dominates



$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

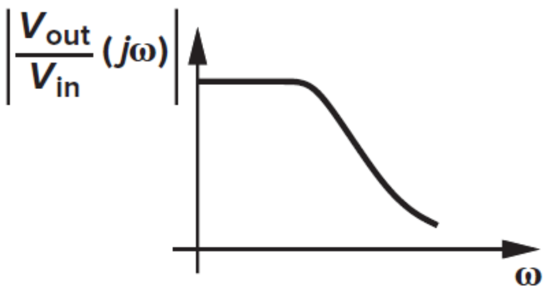
- Capacitors in parallel: Largest capacitor dominates



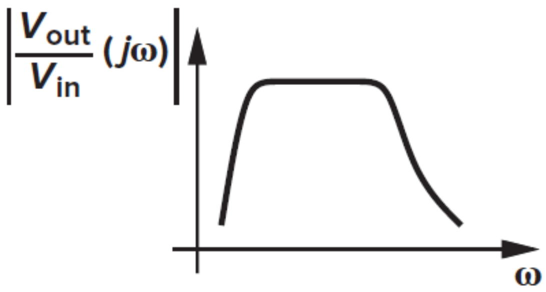
$$C_{eq} = C_1 + C_2 + C_3$$

Frequency Response

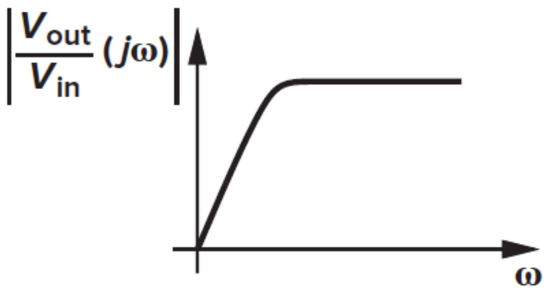
LPF



BPF



HPF



[Razavi, 2014]

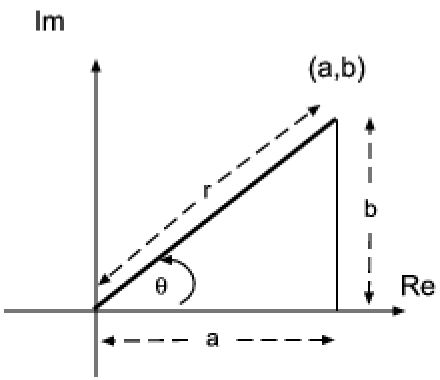
Poles and Zeros

- Transfer function

$$H(s) = \frac{N(s)}{D(s)}$$

- Zeros: roots of numerator => $N(s)$
- Poles: roots of denominator => $D(s)$
- Frequency response: $s \Rightarrow j\omega$

$$H(j\omega) = \frac{V_{out}(j\omega)}{V_{in}(j\omega)} = |H(j\omega)|e^{j\phi}$$



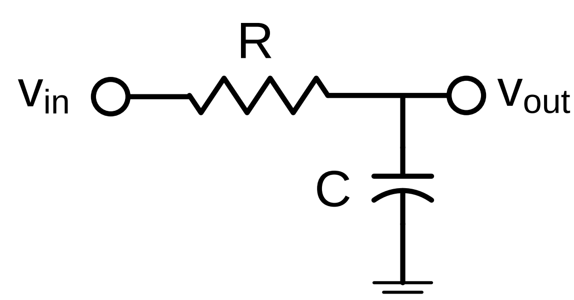
- Magnitude$(a + jb) = \sqrt{a^2 + b^2}$
- Phase$(a + jb) = \tan^{-1}\frac{b}{a}$

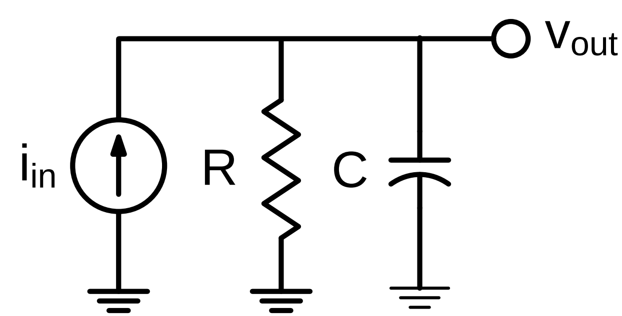
1st Order LPF

$$H(s) = \frac{v_{out}}{v_{in}} = \frac{1/sC}{R + 1/sC} = \frac{1}{1 + sRC} = \frac{1}{1 + s\tau}$$

$$H(j\omega) = \frac{v_{out}}{v_{in}} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega RC} = \frac{1}{1 + \frac{j\omega}{\omega_c}}$$

- $\tau = RC$: time constant
- $\omega_c = \frac{1}{\tau} = \frac{1}{RC}$: cutoff/corner frequency
- Poles: $s_p = -\frac{1}{\tau} = -\omega_c$
- Zeros: ?
- $|H(j\omega)| = \frac{1}{\sqrt{1+\left(\frac{\omega}{\omega_c}\right)^2}}$
- $P\left(H(j\omega)\right) = -\tan^{-1}\frac{\omega}{\omega_c}$

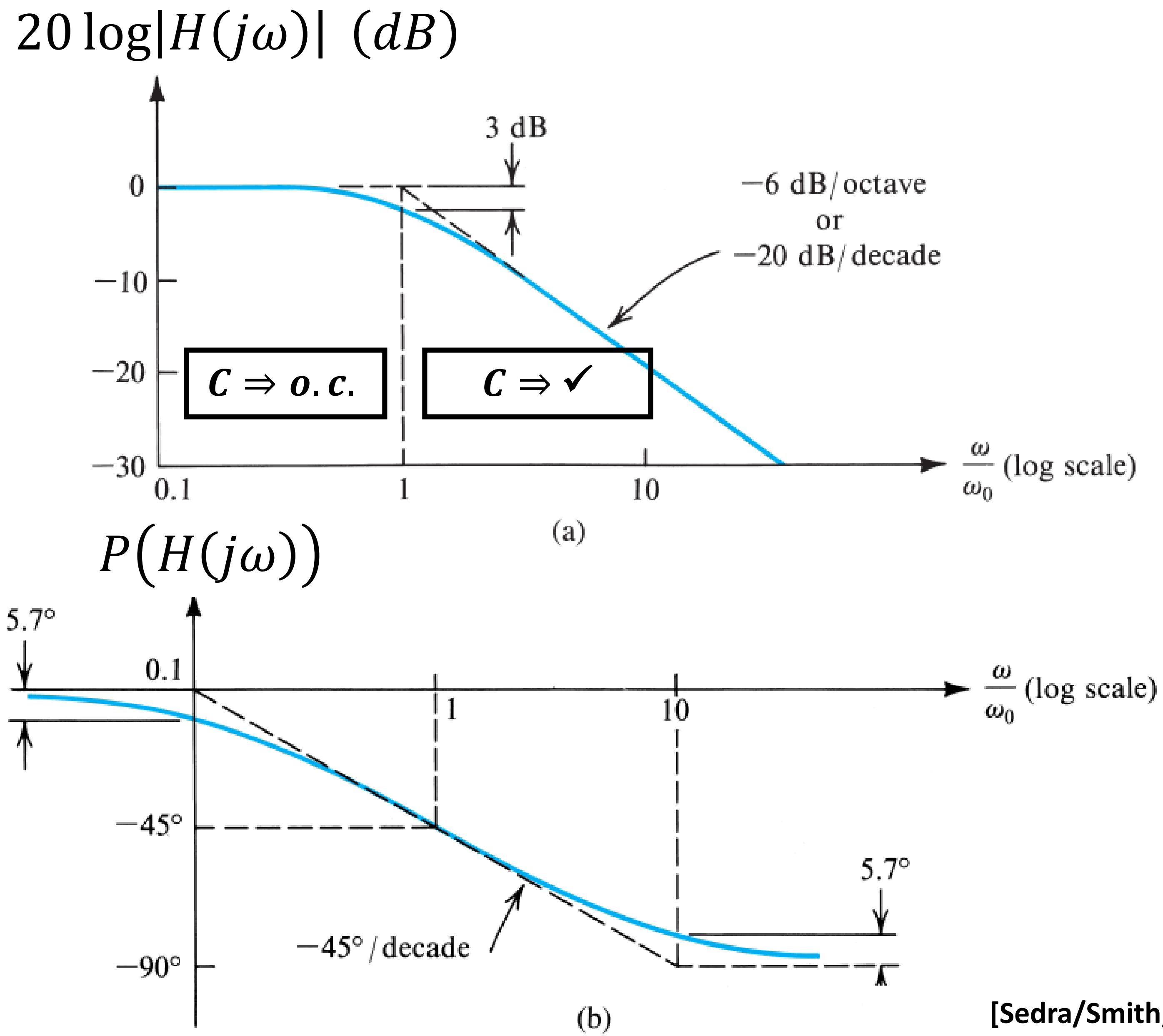




Bode Plot Rules

<table>
<tr><th></th><th>Pole</th><th>Zero</th></tr>
<tr><td>Magnitude</td><td>-20 dB/decade
Actual Mag @ pole: -3 dB</td><td>+20 dB/decade
Actual Mag @ zero: +3 dB</td></tr>
<tr><td rowspan="2">Phase</td><td rowspan="2">-90^{o}
Actual Phase @ pole: -45^{o}</td><td>LHP zero:
$+90^{o}$
Actual Phase @ zero: $+45^{o}$</td></tr>
<tr><td>RHP zero:
-90^{o}
Actual Phase @ zero: -45^{o}</td></tr>
</table>

1^{st} Order LPF

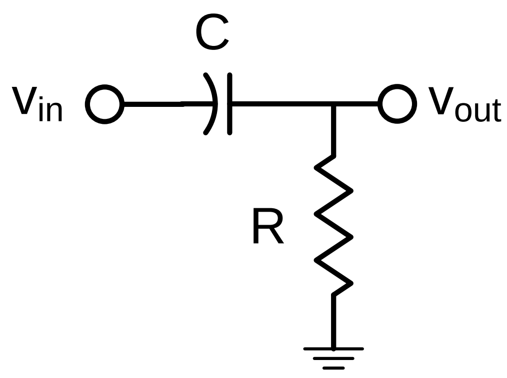


1st Order HPF

$$H(s) = \frac{v_{out}}{v_{in}} = \frac{R}{R + 1/sC} = \frac{sRC}{1 + sRC} = \frac{s\tau}{1 + s\tau}$$

$$H(j\omega) = \frac{v_{out}}{v_{in}} = \frac{R}{R + 1/j\omega C} = \frac{j\omega RC}{1 + j\omega RC} = \frac{\frac{j\omega}{\omega_c}}{1 + \frac{j\omega}{\omega_c}}$$

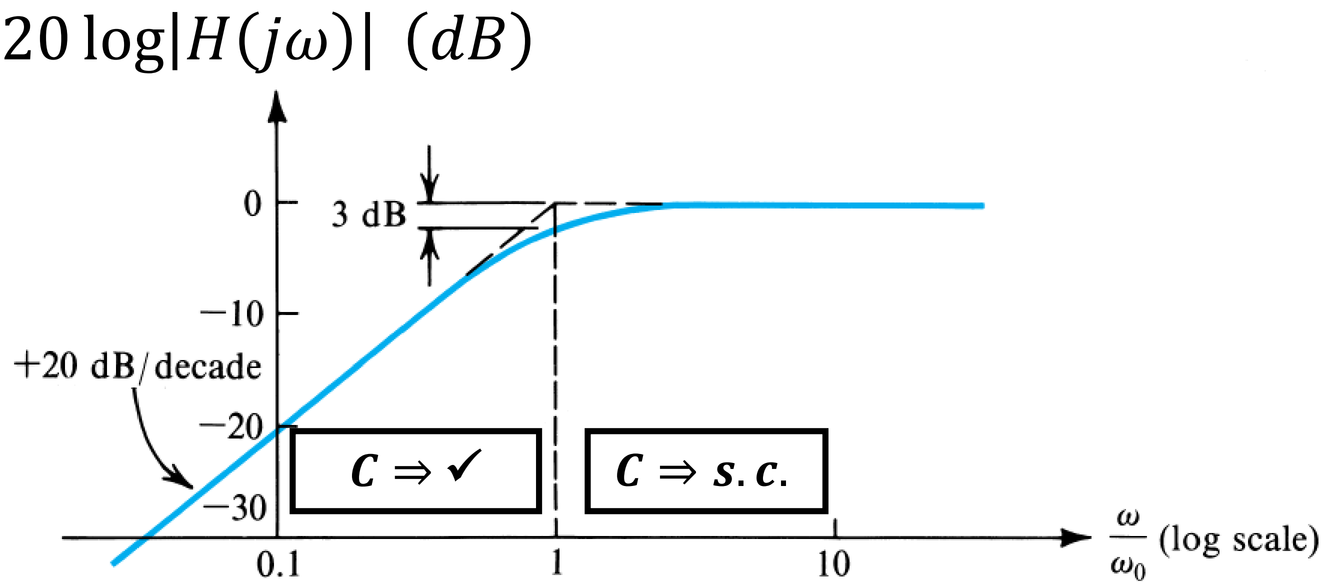
- Poles: $s_p = -\frac{1}{\tau} = -\omega_c$
- Zeros: $s_z = 0$
- $|H(j\omega)| = \frac{\frac{\omega}{\omega_c}}{\sqrt{1+\left(\frac{\omega}{\omega_c}\right)^2}}$
- $P\big(H(j\omega)\big) = 90^o - \tan^{-1}\frac{\omega}{\omega_c}$



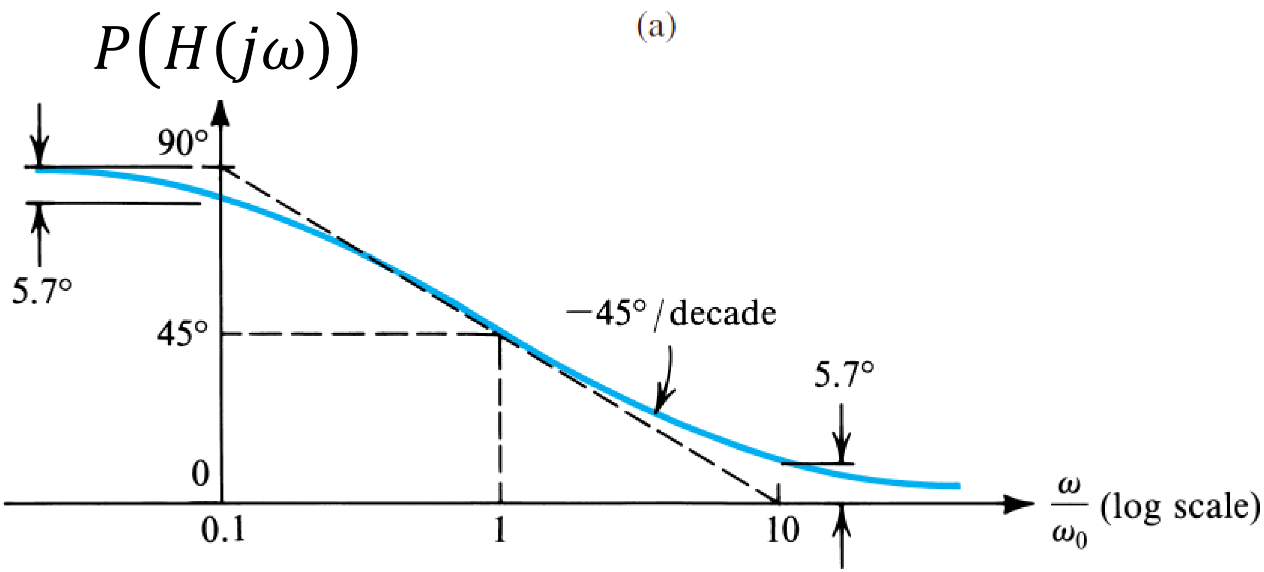
Bode Plot Rules

	Pole	Zero
Magnitude	-20 dB/decade Actual Mag @ pole: -3 dB	+20 dB/decade Actual Mag @ zero: +3 dB
Phase	-90^o Actual Phase @ pole: -45^o	LHP zero: $+90^o$ Actual Phase @ zero: $+45^o$ RHP zero: -90^o Actual Phase @ zero: -45^o

1st Order HPF



(a)



(b)

Thank you!