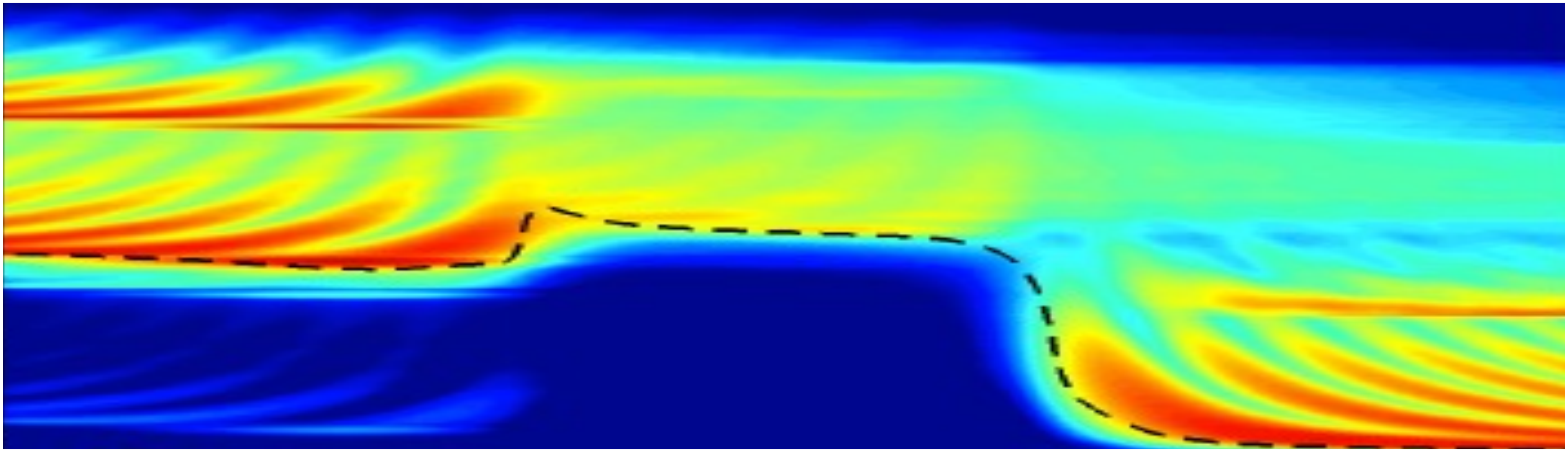

EECS 16B
Designing Information Devices and Systems II
Lecture 8

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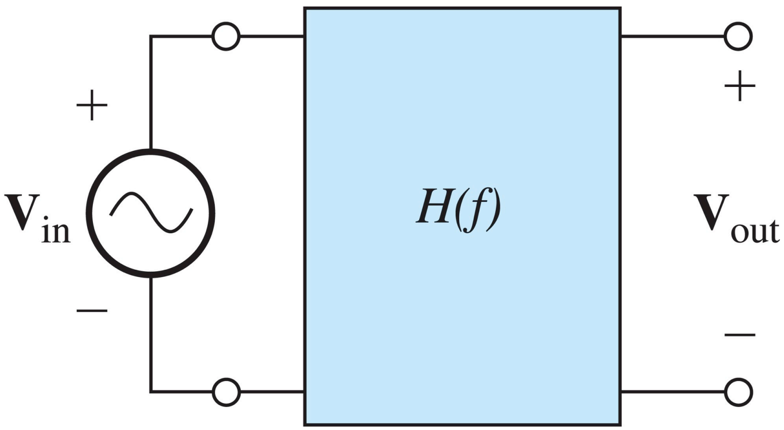
Transient Response

- Outline
  - High Pass Filters
  - Series and Parallel Resonance
  - Amplifiers and Devices

- Reading- Hambley text sections 6.4, 6.5, 6.6, 6.7,slides

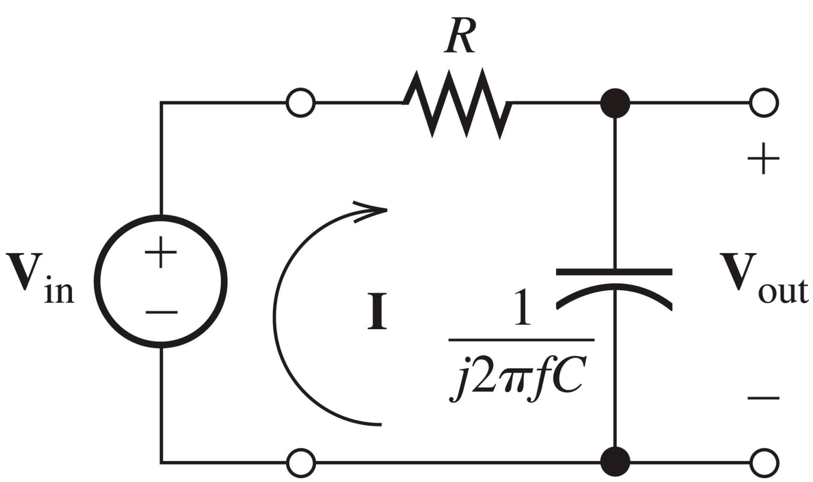
Recap: Concept of Transfer Function



$$H(f) = \frac{V_{out}}{V_{in}}$$

$H(f)$ is a complex number

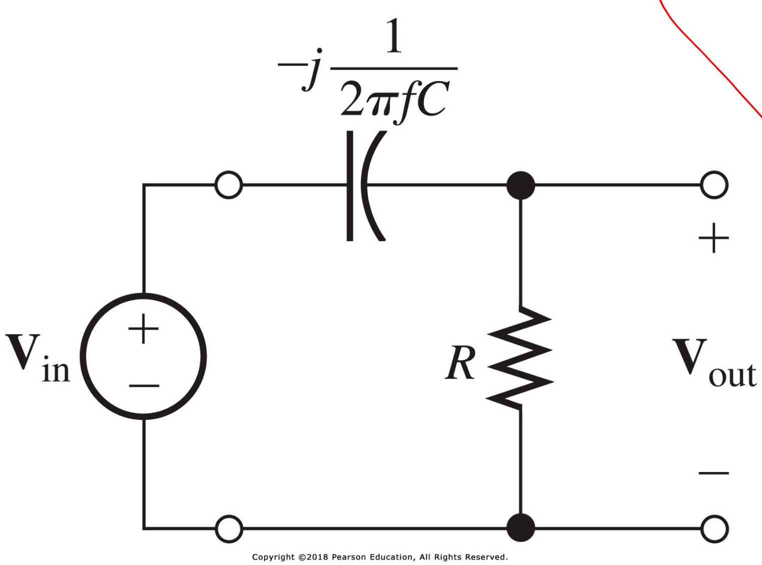
Recap:First order low pass filter



$$H(f) = \frac{1}{\sqrt{\left(1 + \frac{f^2}{f_B^2}\right)}} \angle - \tan^{-1}\left(\frac{f}{f_B}\right)$$

$$f_B = \frac{1}{2\pi RC}$$

First order High Pass Filter



$$\frac{1}{a-jb}$$

$$H(f) = \frac{V_{out}}{V_{in}}$$

$$= \frac{\dfrac{R}{\cancel{V_{in}}}}{\dfrac{R + \frac{1}{j\omega C}}{\cancel{V_{in}}}}$$

$$= \frac{1}{1 - j\frac{1}{\omega RC}}$$

$$= \frac{1}{1 - j\frac{\omega_B}{\omega}}$$

$$= \frac{1}{\sqrt{1 + \frac{\omega_B^2}{\omega^2}}} \angle \tan^{-1}\frac{\omega_B}{\omega}$$

$$H(f) = \frac{1}{\sqrt{1+\left(\frac{f_B}{f}\right)^2}} \angle \tan^{-1}\frac{f_B}{f}$$

First order High Pass Filter

$$H(f) = \frac{1}{\sqrt{1+\frac{f_B^2}{f^2}}} \angle \tan^{-1}\left(\frac{f_B}{f}\right)$$

$$|H(f)|_{dB} = 20\log_{10}\left(\frac{1}{\sqrt{1+\left(\frac{f_B}{f}\right)^2}}\right)$$

$$= 20\log_{10}\left[1+\left(\frac{f_B}{f}\right)^2\right]^{-1/2}$$

$$= -10\log_{10}\left[1+\left(\frac{f_B}{f}\right)^2\right]$$

$$f \ll f_B \rightarrow |H(f)|_{dB} \cong -10\log_{10}\left(\frac{f_B}{f}\right)^2$$

$$= -20\log_{10}\frac{f_B}{f}$$

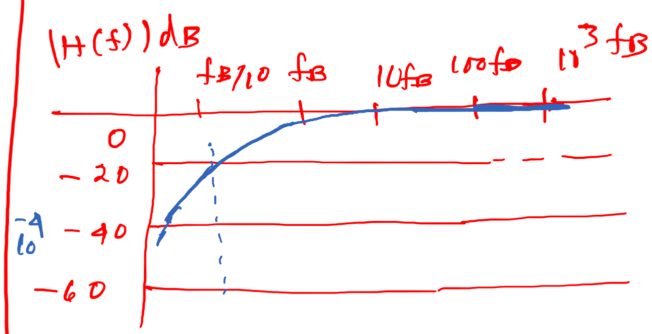
$$|H(f)|_{dB} = 20\log_{10} f - 20\log_{10} f_B$$

$f = f_B$, $|H(f)|_{dB} = -10\log_{10} 2$

$= -3$

$f \gg f_B$, $|H(f)|_{dB} \cong -10\log_{10} 1$

$= 0$

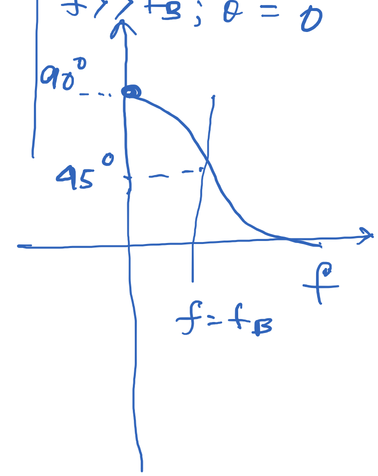


$f \ll f_B$

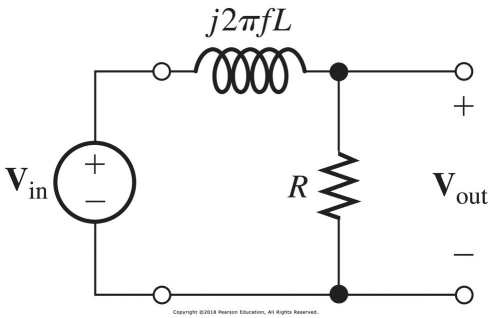
$\theta = \tan^{-1}\frac{f_B}{f} = 90^\circ$

$f = f_B$, $\theta = 45^\circ$

$f \gg f_B$; $\theta = 0$

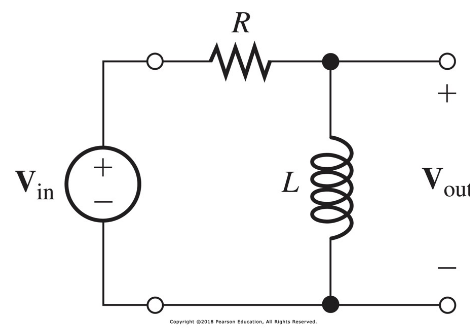


Low Pass and High Pass Filters with Inductors



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

$$\omega_L = \frac{R}{L}$$



$$V_{out} = \frac{R}{R+j\omega L} V_{in}$$

$$\therefore \frac{V_{out}}{V_{in}} = H(f) = \frac{1}{1+j\frac{\omega}{(R/L)}}$$

$$= \frac{1}{1+j\frac{\omega}{\omega_L}}$$

$$= \frac{1}{1+j\, f/f_L}$$

similar form to a RC LP filter

$$V_{out} = \frac{j\omega L}{R+j\omega L}$$

$$= \frac{1}{1+\frac{R}{j\omega L}}$$

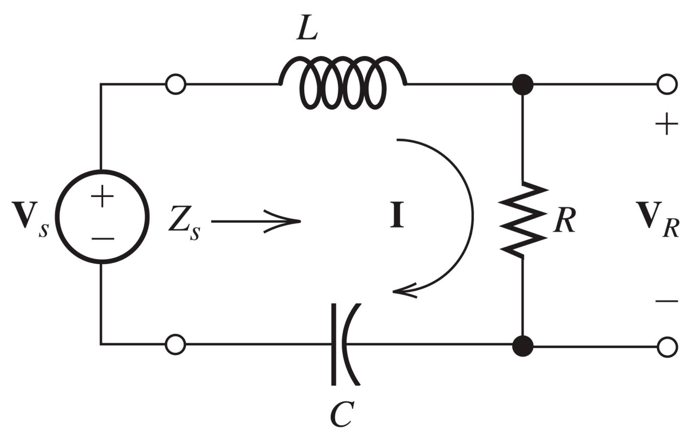
$$= \frac{1}{1-j\frac{\omega_L}{\omega}}$$

$$= \frac{1}{1-j(f_L/f)}$$

same form as RC HP filter

Resonant Circuits

Series Resonance



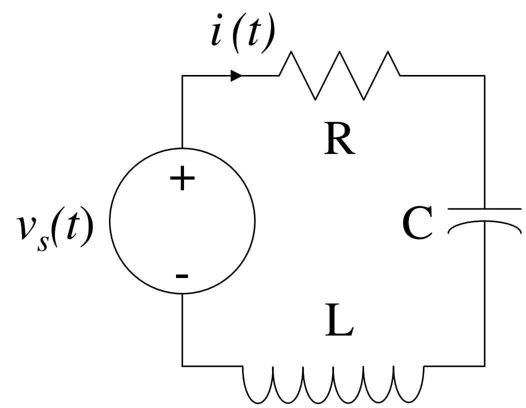
Recap: R-L-C circuits: Response in time

$$\frac{d^2v_c}{dt^2} + \frac{1}{(L/R)}\frac{dv_c}{dt} + \frac{1}{LC}v_c = \frac{v_s}{LC}$$

$$2\alpha = \frac{1}{L/R} \Rightarrow \alpha = \frac{R}{2L}$$

$$\omega_0^2 = \frac{1}{LC}$$

$$\frac{d^2v_c}{dt^2} + 2\alpha\frac{dv_c}{dt} + \omega_0^2 v_c = \frac{v_s}{LC}$$



Homogeneous solution

$$\frac{d^2v_c}{dt^2} + 2\alpha\frac{dv_c}{dt} + \omega_0^2 v_c = 0$$

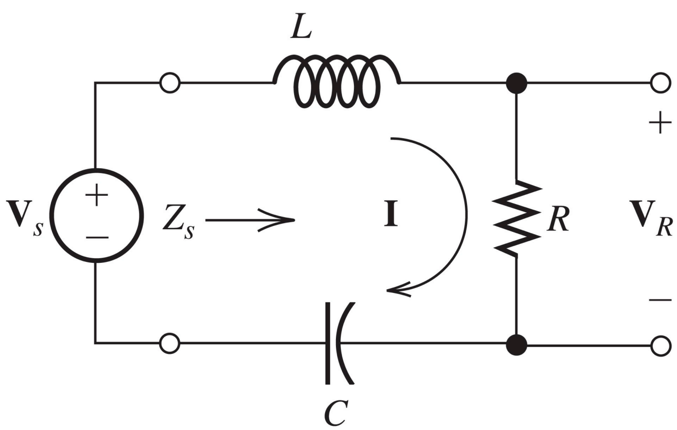
From previous discussions we have seen that an exponential solution works

Lets try: $v_c(t) = Ae^{st}$

$$As^2e^{st} + 2\alpha Ase^{st} + \omega_0^2 Ae^{st} = 0$$

$$\Rightarrow \boxed{s^2 + 2\alpha s + \omega_0^2 = 0}$$

Series Resonance



$$Z = R + j\omega L - \frac{j}{\omega C}$$

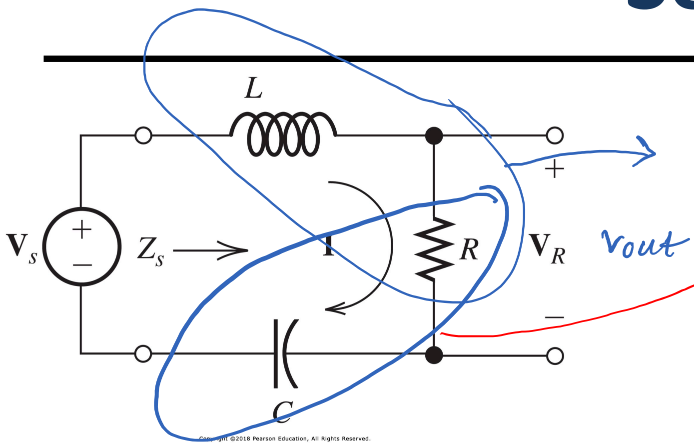
what happens at $\omega = \omega_0$?

$$Z = R + j\omega L\left[1 - \frac{1}{\omega^2 LC}\right]$$

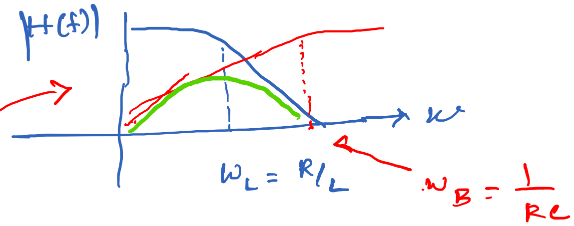
$$= R + j\omega L\left[1 - \frac{\omega_0^2}{\omega^2}\right] = R\Big|_{\omega=\omega_0}$$

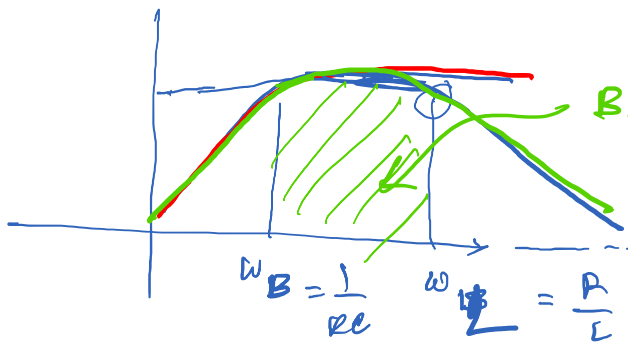
At resonance, all reactive impedances sum up to zero

Series Resonance



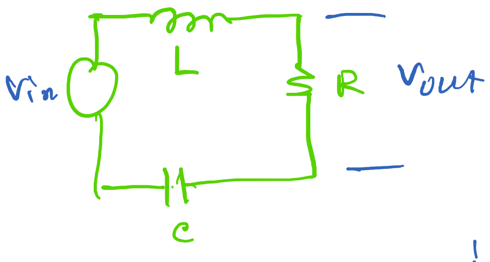
Qualitatively





BAND PASS FILTER

Series Resonance



$$V_{out} = IR$$

$$I = \frac{V_{in}}{\underbrace{R + j\omega L - \frac{j}{\omega C}}_{Z}}$$

$$V_{out} = \frac{R}{Z} v_{in}$$

$$Z = R + j\omega L - \frac{j}{\omega C}$$

$$V_{out} = \frac{R}{Z} v_{in}$$

$$H(f) = \frac{V_{out}}{V_{in}} = \frac{R}{R + j\omega L - \frac{j}{\omega C}}$$

$$= \frac{R}{R + j\omega L\left(1 - \frac{\omega_0^2}{\omega^2}\right)}$$

$$H(f) = \frac{1}{1 + \frac{j\omega L}{R}\left(1 - \frac{\omega_1^2}{\omega^2}\right)}$$

$$= \frac{1}{1 + j\frac{L}{R}\left(\omega - \frac{\omega_0^2}{\omega}\right)}$$

$$= \frac{1}{1 + j\frac{\omega_0 L}{R}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)}$$

$$= \frac{1}{1 + j\underbrace{\frac{\omega_0 L}{R}}_{Q_s}\left(f/f_0 - \frac{f_0}{f}\right)}$$

Series Resonance

$$H(f) = \frac{1}{1 + jQ_s\left(f/f_0 - f_0/f\right)}$$

$$= \frac{\angle \tan^{-1} Q_s\left(f/f_0 - f_0/f\right)}{\sqrt{1 + Q_s^2\left(f/f_0 - f_0/f\right)^2}}$$

At

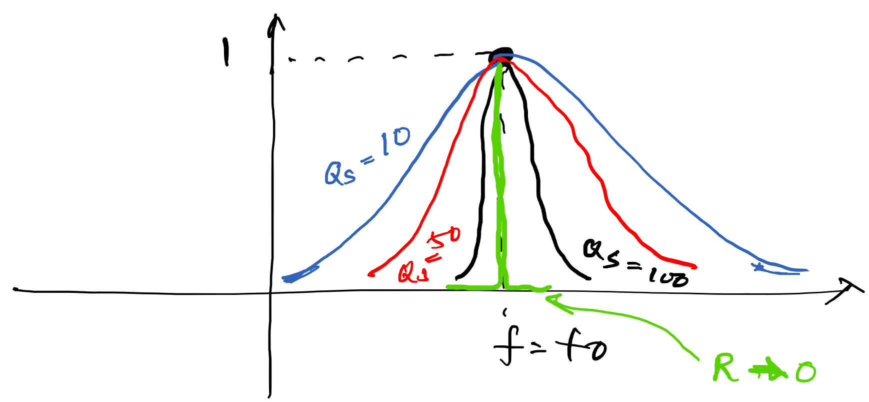
$f = f_0$, $\quad |H(f)| = \dfrac{1}{\sqrt{1 + Q_s^2\left(f/f_0 - f_0/f\right)^2}}$

$= 1$

$f \gg f_0$, $\quad |H(f)| \simeq \dfrac{1}{\sqrt{Q_s^2 (f/f_0)^2}}$

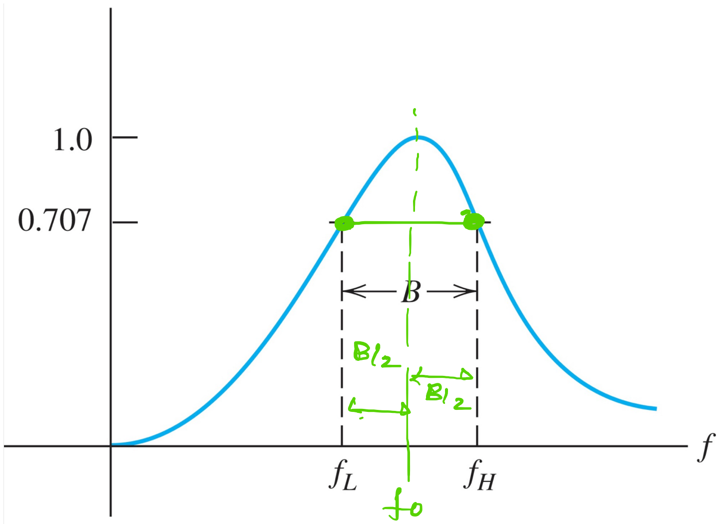
$= \dfrac{1}{Q_s} f_0/f \simeq 0$

$f \ll f_0$, $\quad |H(f)| \simeq \dfrac{1}{Q_s}\dfrac{f}{f_0} \simeq 0$



$$Q_s = \frac{\omega_0 L}{R}$$

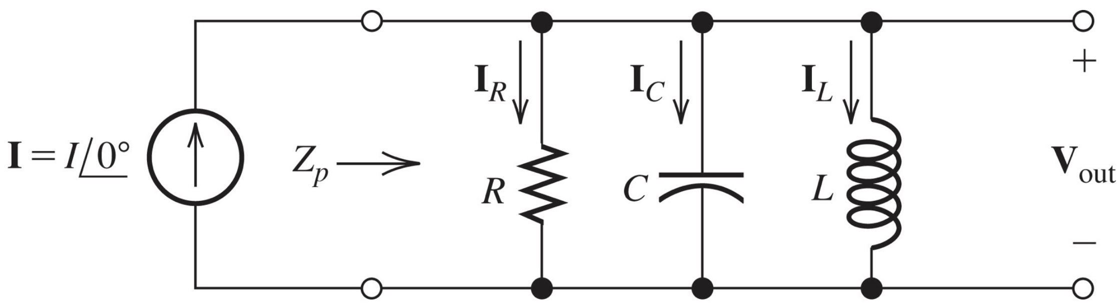
Series Resonance Bandpass Filter



Half-power frequencies are defined as the frequencies where the magnitude of the transfer function has fallen by a factor of $\frac{1}{\sqrt{2}} = 0.707$

It can be shown that $B = f_H - f_L = \frac{f_0}{Q_s}$

Parallel Resonance



$$H(f) = \frac{V_{out}}{I}$$

$$V_{out} = I Z_p$$

$$\frac{V_{out}}{I} = Z_p = \frac{1}{1/R + j\omega C + \frac{1}{j\omega L}}$$

$$= \frac{1}{1/R + j\omega C\left[1 - \frac{\omega_0^2}{\omega^2}\right]}$$

$$= \frac{R}{1 + j\omega_0 RC\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}$$

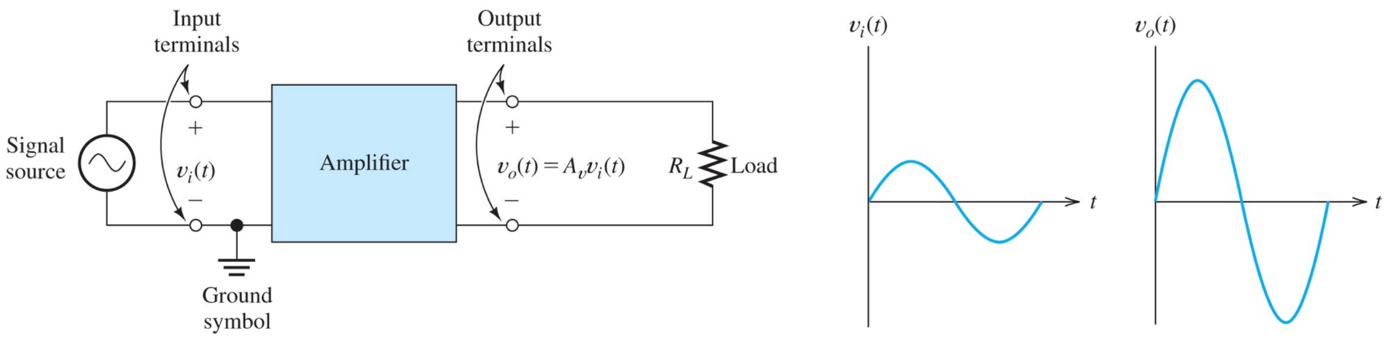
$$Q_s = \frac{\omega_0 L}{R}$$

$$Q_p = \omega_0 RC$$

$$= \frac{R}{1 + jQ_p\left(f/f_0 - f_0/f\right)}$$

$\boxed{\text{same form as series resonant ckt}}$

Active Devices



- Active devices are made of semiconductors
- Semi-conductors are materials whose resistance is in between a metal and insulator

Half

- More interestingly, one is able to change the resistance of the semiconductor materials by using external control such as voltage or current