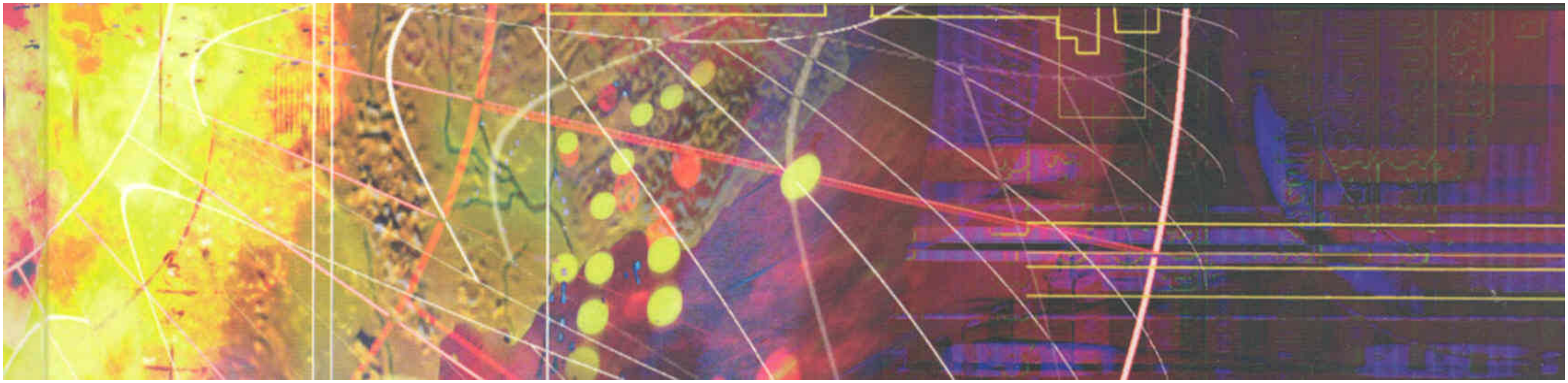
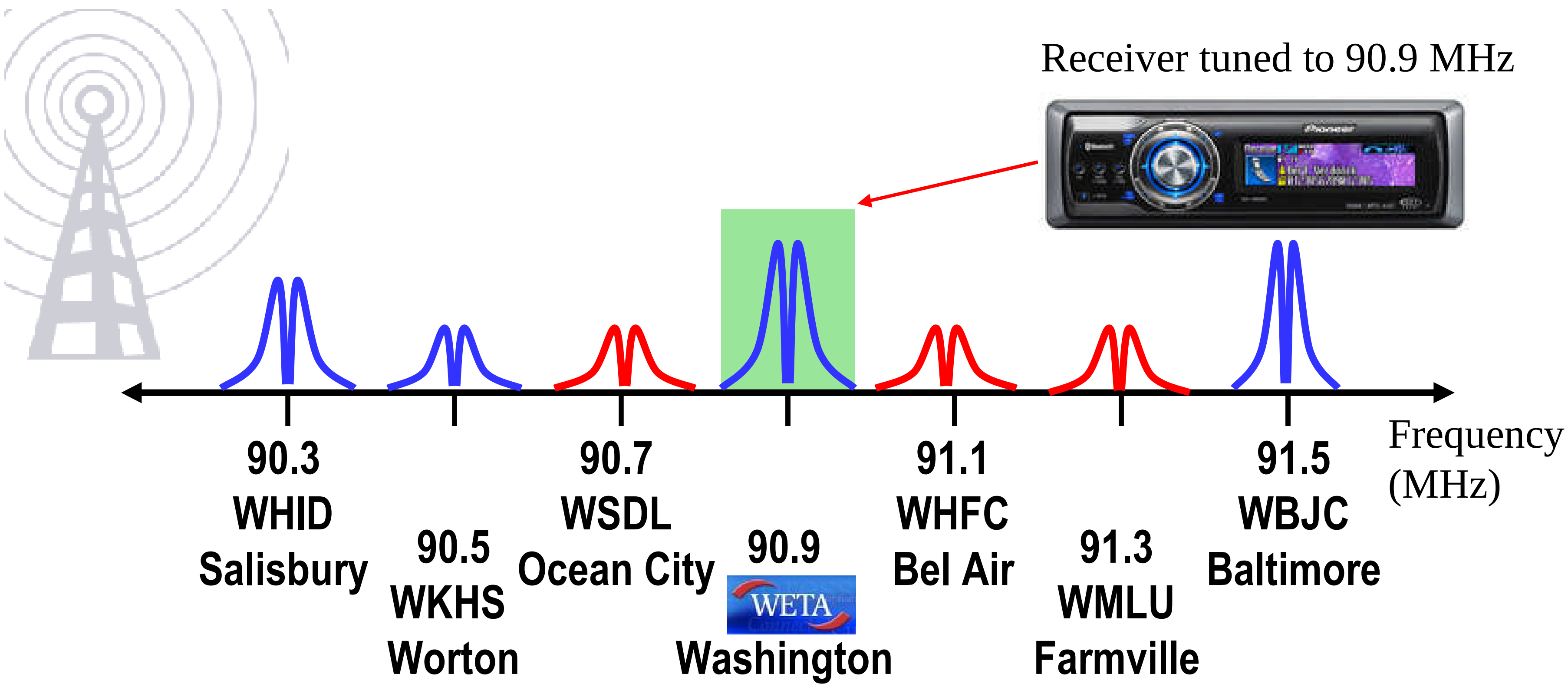


EE303 Lesson 5: Filters

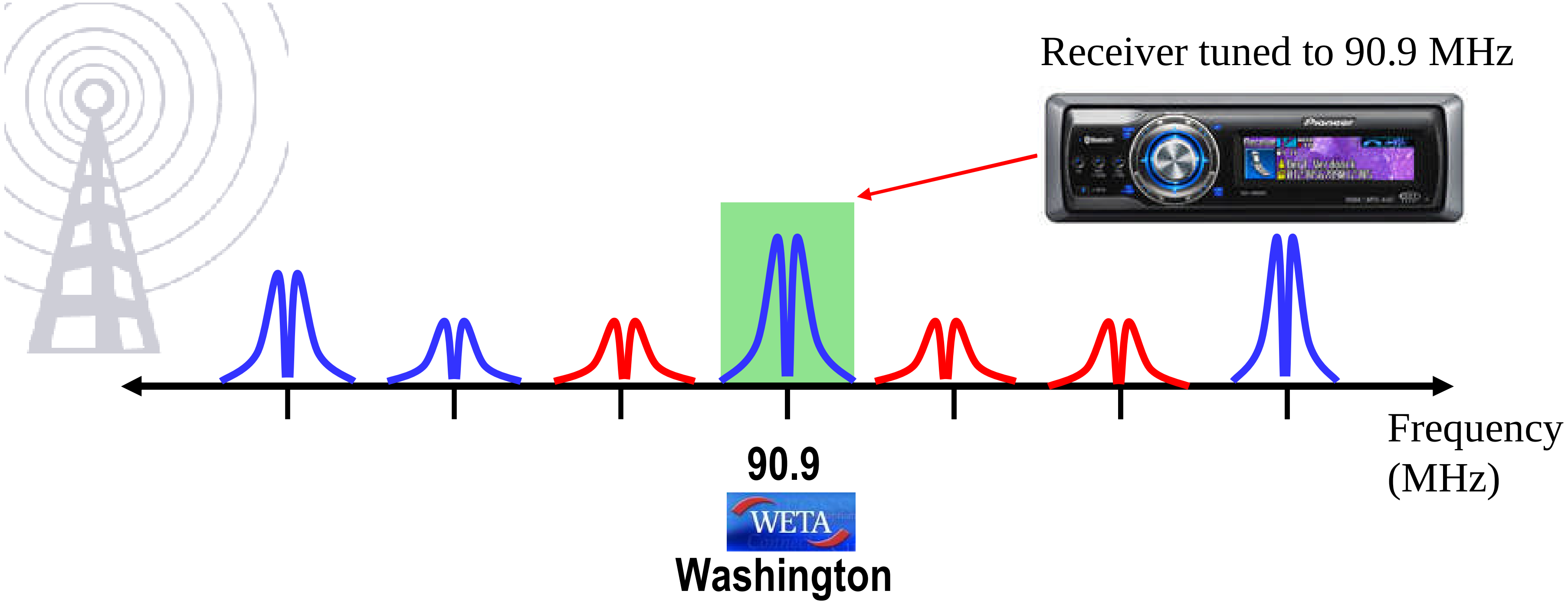
Tuning a radio

- Consider tuning FM radio station.
- What allows your radio to isolate one station from all of the adjacent stations?



Filters

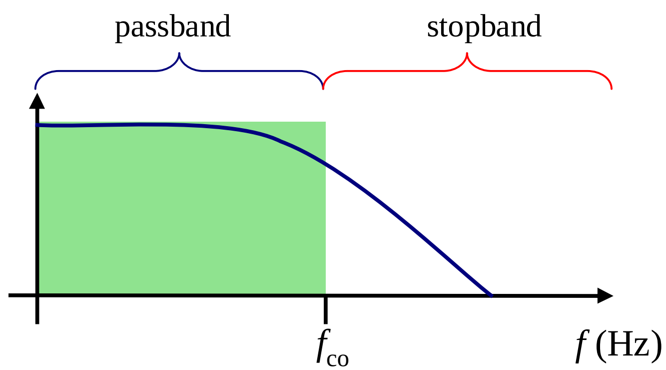
- A **filter** is a frequency-selective circuit.
- Filters are designed to pass some frequencies and reject others.



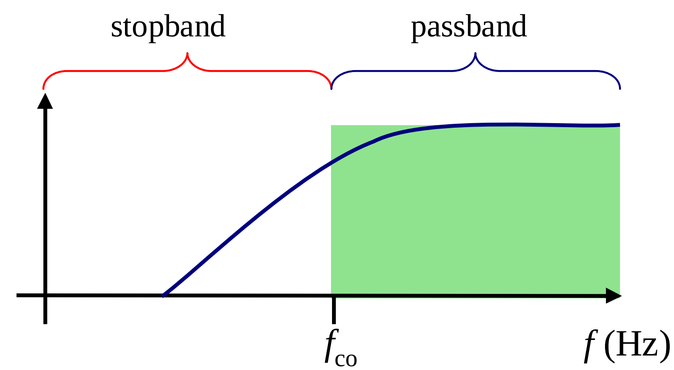
Basic kinds of filters

- There are four basic kinds of filters:
  - **Low-pass filter**. Passes frequencies below a critical frequency called the cutoff frequency and attenuates those above.
  - **High-pass filter**. Passes frequencies above critical frequency but rejects those below.
  - **Bandpass filter**. Passes only frequencies in a narrow range between upper and low cutoff.
  - **Bandstop filter**. Rejects or stops frequencies in a narrow range but passes others.

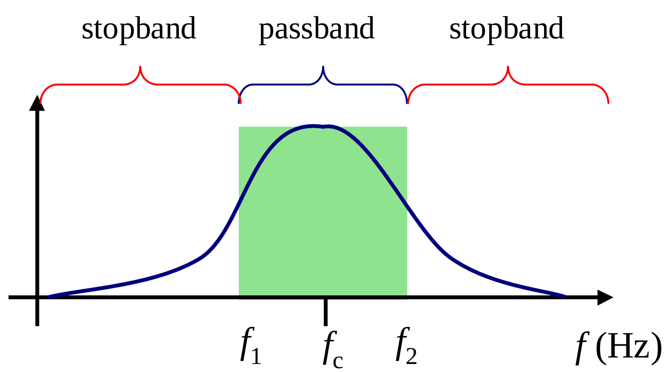
Basic kinds of filters



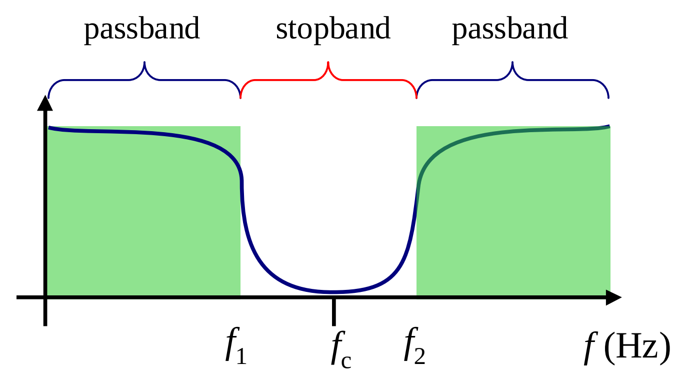
Low-pass filter response



High-pass filter response



Bandpass filter response



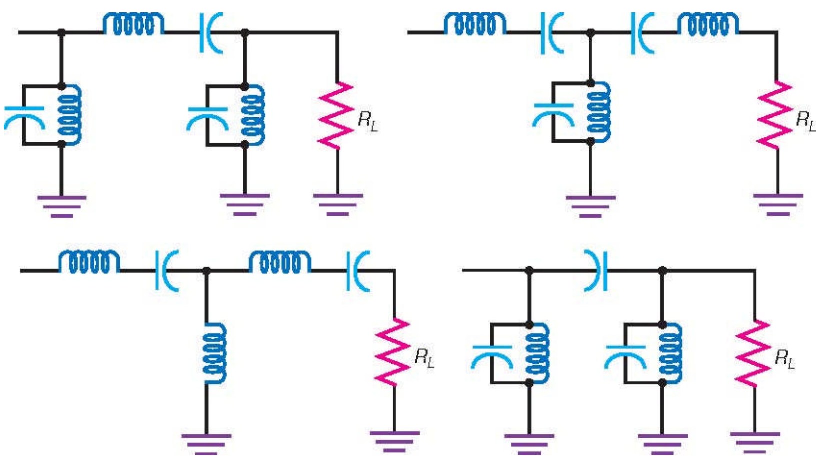
Bandstop filter response

Filters construction

- There are numerous ways to construct filters.
- **Passive** filters a composed of only passive components (resistors, capacitors, inductors) and do not provide amplification.
- **Active** filters typically employ RC networks and amplifiers with feedback and offer a number of advantages.

Filter circuits

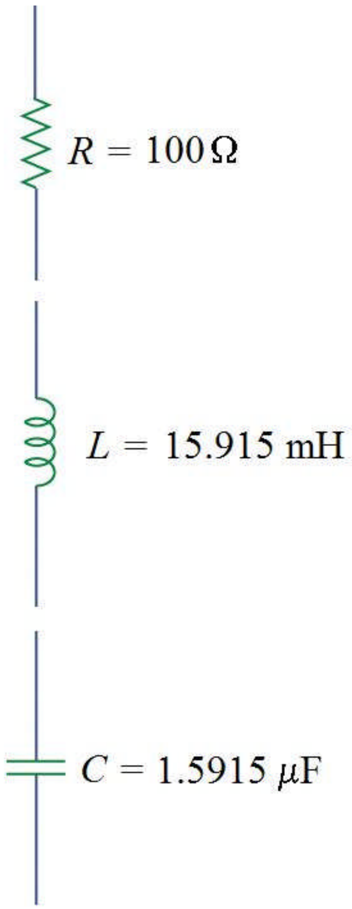
- Filter circuits depend on the fact that the impedance of capacitors and inductors is a function of frequency.



Some common bandpass filter circuits

Example Problem 1

Calculate the impedance of a resistor, a capacitor and an inductor at the following frequencies.



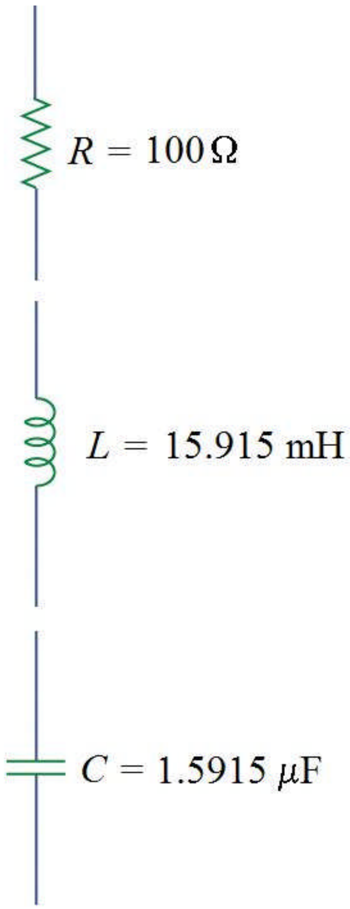
$$Z_C = \frac{-j}{2\pi f C}$$

$$Z_L = j2\pi f L$$

f	100 Hz	1000 Hz	10,000 Hz
R			
Z_L			
Z_C			

Example Problem 1

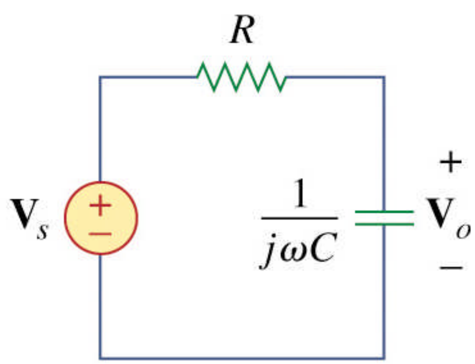
Calculate the impedance of a resistor, a capacitor and an inductor at the following frequencies.



f	100 Hz	1000 Hz	10,000 Hz
R	100 Ω	100 Ω	100 Ω
Z_L	j10 Ω	j100 Ω	j1000 Ω
Z_C	-j1000 Ω	-j100 Ω	-j10 Ω

RC low-pass filter

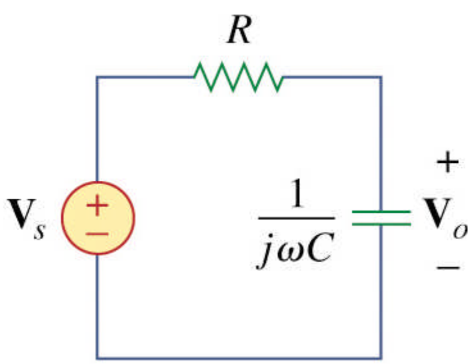
- What is the ratio of the output voltage ($\mathbf{V}_o$) to the input voltage ($\mathbf{V}_s$)?



RC low-pass filter

- What is the ratio of the output voltage ($\mathbf{V}_o$) to the input voltage ($\mathbf{V}_s$)?

$$\mathbf{V}_o = \frac{\mathbf{Z}_C}{\mathbf{R} + \mathbf{Z}_C}\mathbf{V}_s$$

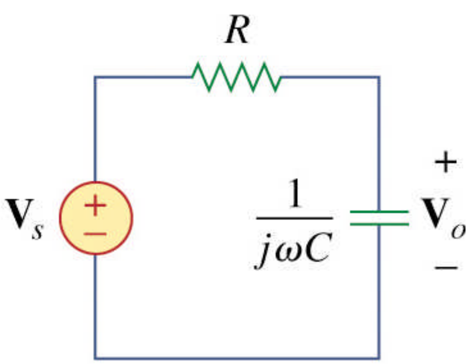


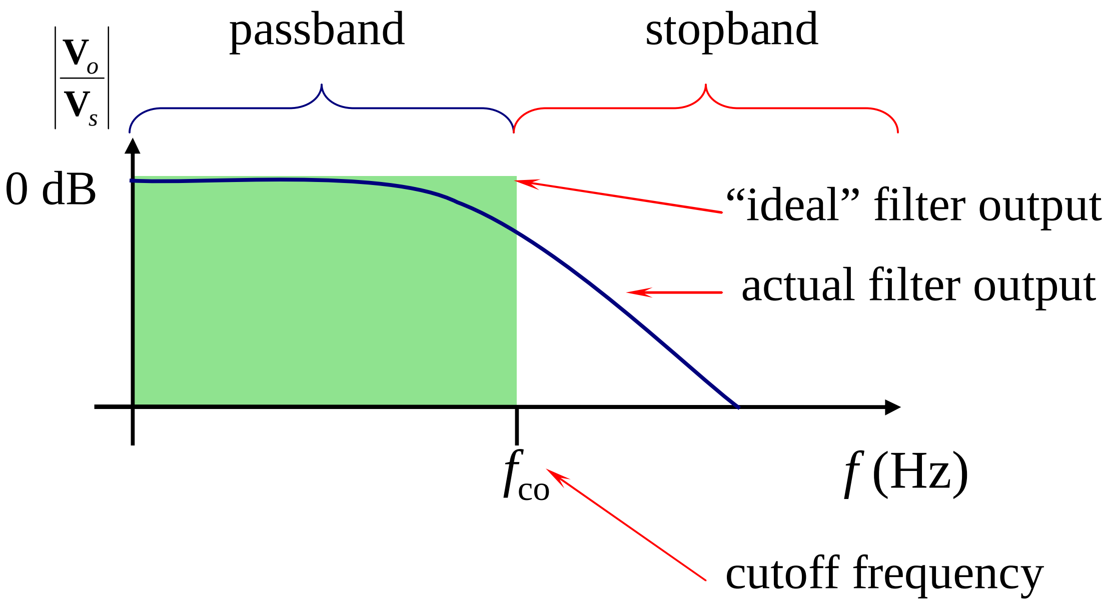
$$\frac{\mathbf{V}_o}{\mathbf{V}_s} = \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{1}{1 + j\omega RC}$$

$$\left|\frac{\mathbf{V}_o}{\mathbf{V}_s}\right| = \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

RC low-pass filter

- A **low-pass filter** passes frequencies below a critical frequency called the cutoff frequency and attenuates those above.





RC low-pass filter response

Cutoff frequency

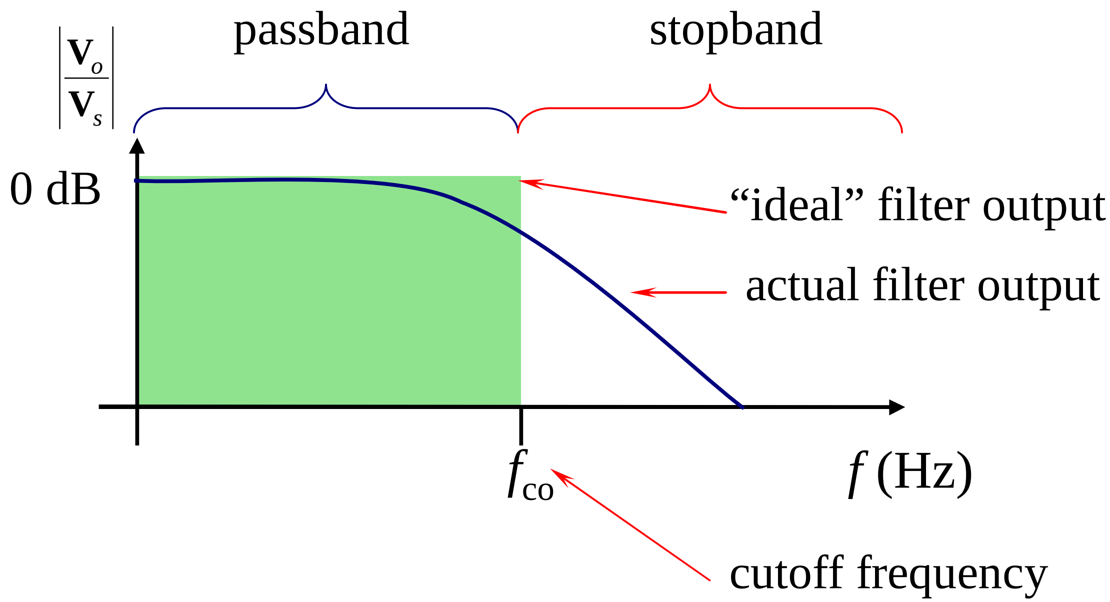
- The cutoff frequency is frequency at which the output amplitude is 70.7% of the input.

$$\left|\frac{\mathbf{V}_o}{\mathbf{V}_s}\right| = \frac{1}{\sqrt{1+(\omega RC)^2}} = \frac{1}{\sqrt{2}}$$

which implies

$$\omega_{\text{co}} = \frac{1}{RC} \quad \text{[rad/sec]}$$

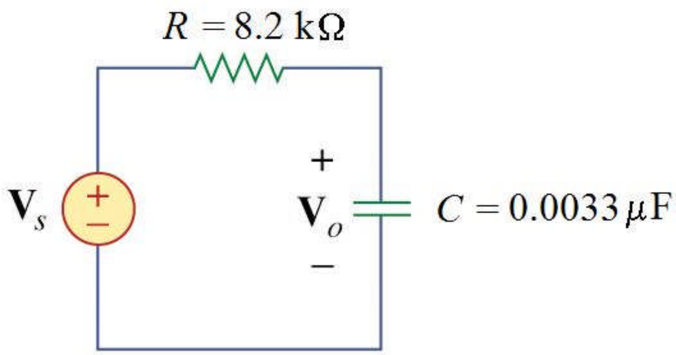
or $$f_{\text{co}} = \frac{1}{2\pi RC} \quad \text{[Hz]}$$



RC low-pass filter response

Example Problem 2

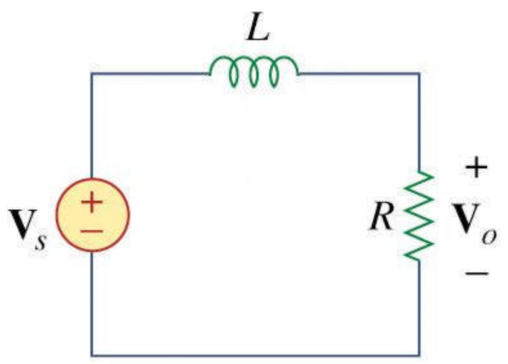
What is the cutoff frequency of a single-section RC low-pass filter with $R = 8.2\ \mathrm{k\Omega}$ and $C = 0.0033\ \mu\mathrm{F}$?

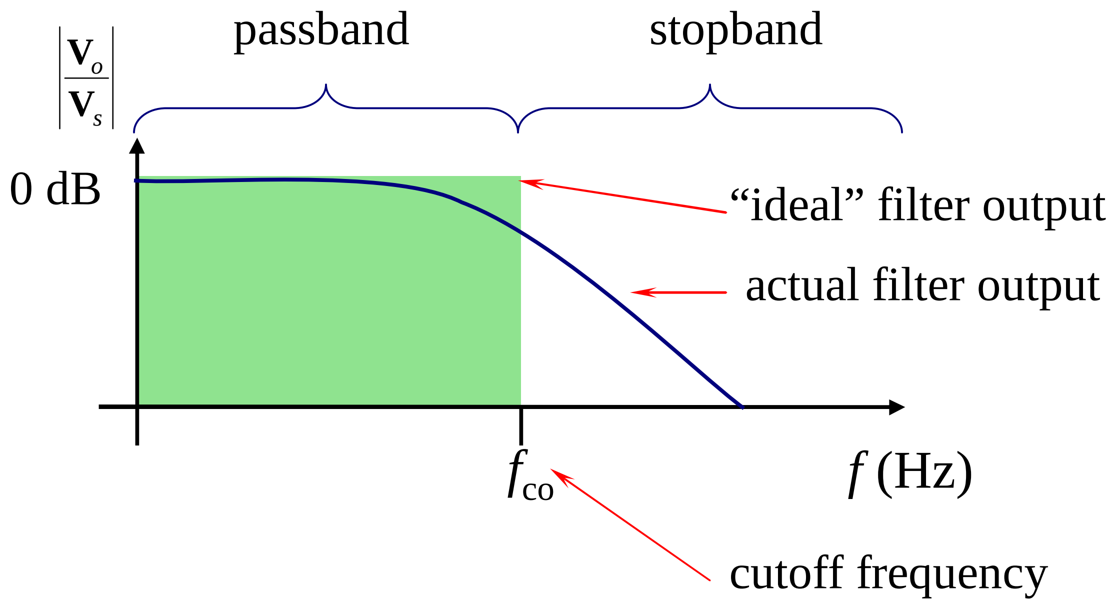


RL low-pass filter

- A low-pass filter can also be implemented with a resistor and inductor, the cutoff frequency is given

$$f_{co} = \frac{R}{2\pi L} \quad \text{[Hz]}$$

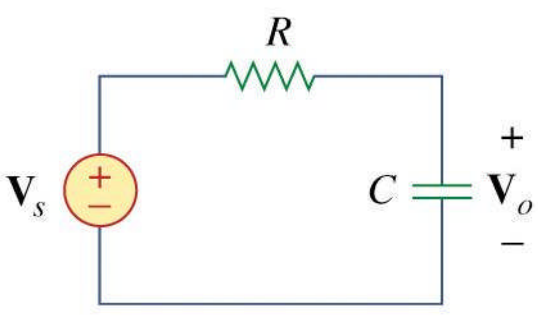




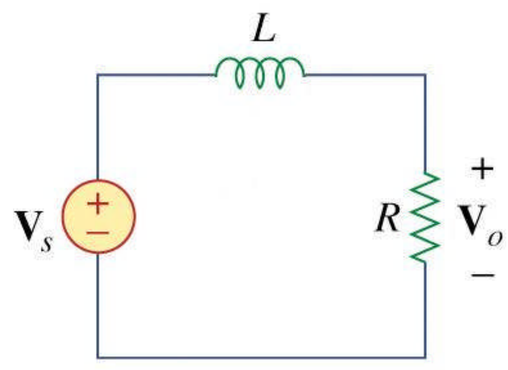
RL low-pass filter response

Filters

- Notice the placement of the elements in *RC* and *RL* low-pass filters.



RC low-pass filter

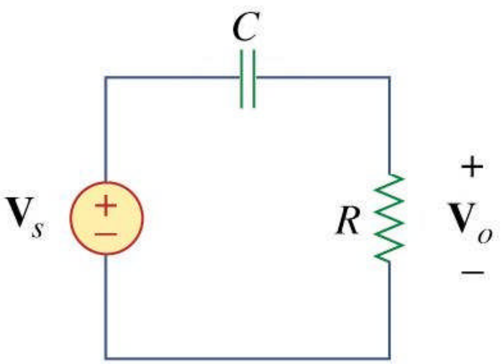


RL low-pass filter

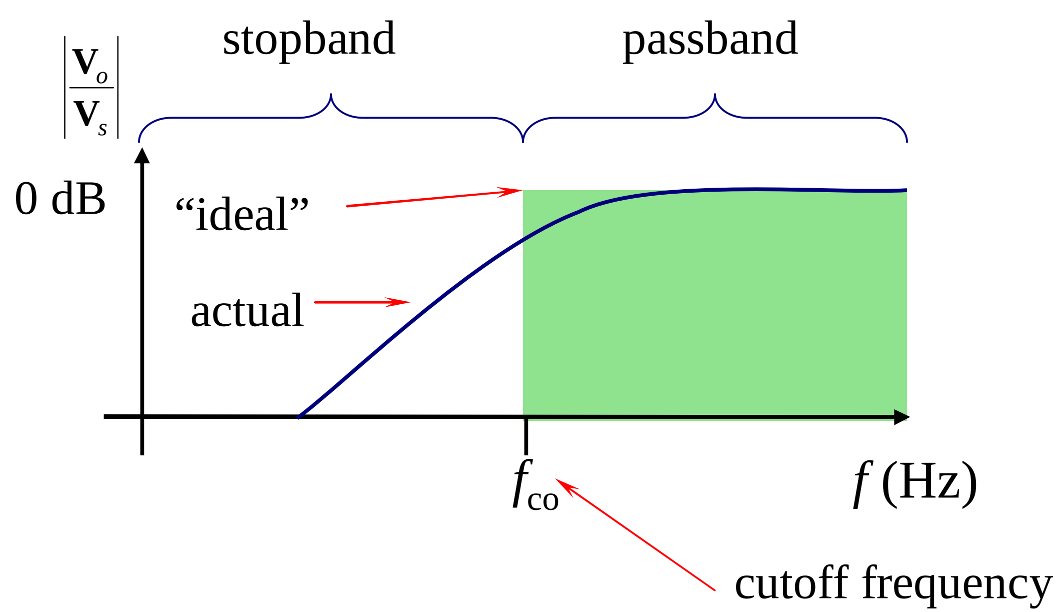
- What would result if the position of the elements were switched in each circuit?

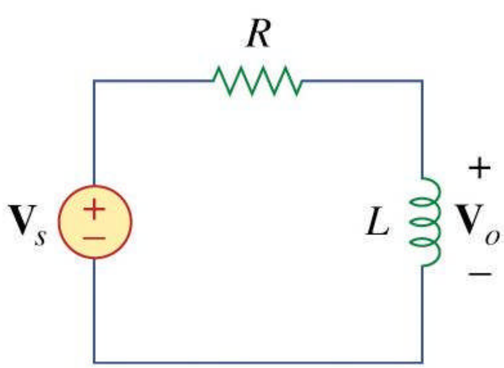
High-pass filter

- Switching elements results in a high-pass filter.



$$f_{co} = \frac{1}{2\pi RC} \quad \text{or} \quad f_{co} = \frac{R}{2\pi L} \quad [\text{Hz}]$$

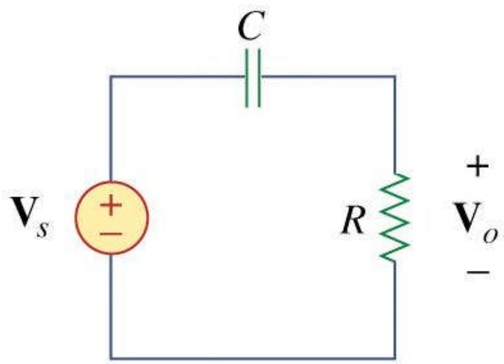




high-pass filter response

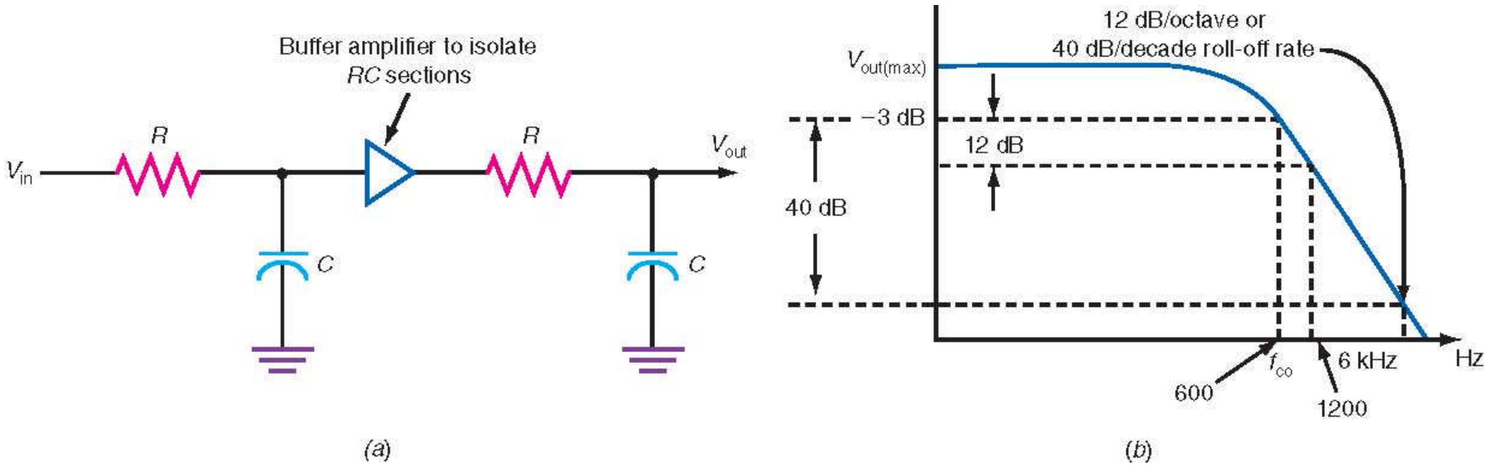
Example Problem 3

What resistor value R will produce a cutoff frequency of 3.4 kHz with a 0.047–μF capacitor? Is this a high-pass or low-pass filter?



Improving filter response

- One method of creating a more selective filter is to cascade filter stages.

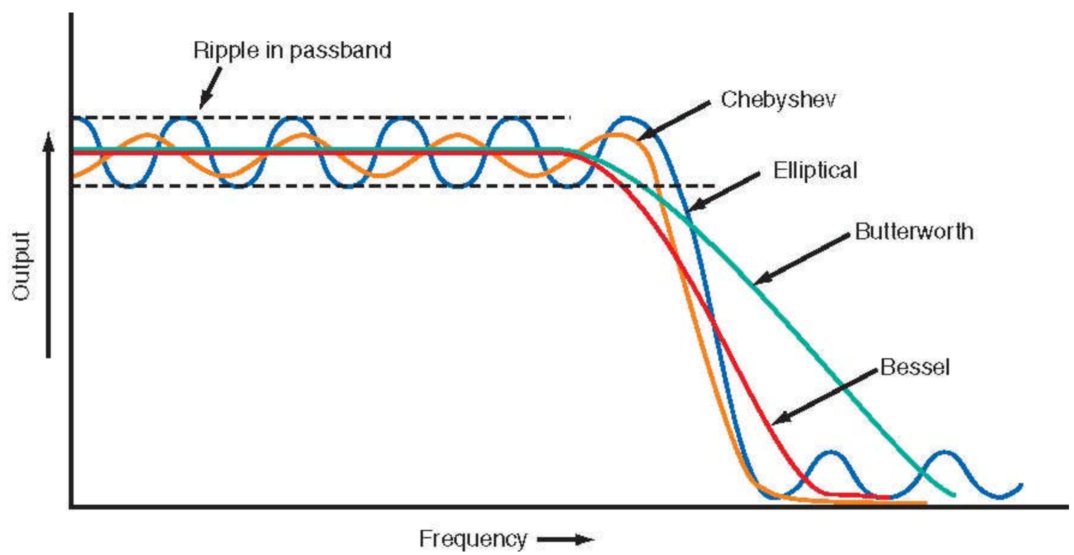


Two stage *RC* filter

- The attenuation of this two-stage filter is 40 dB/decade instead of 20 dB/decade.

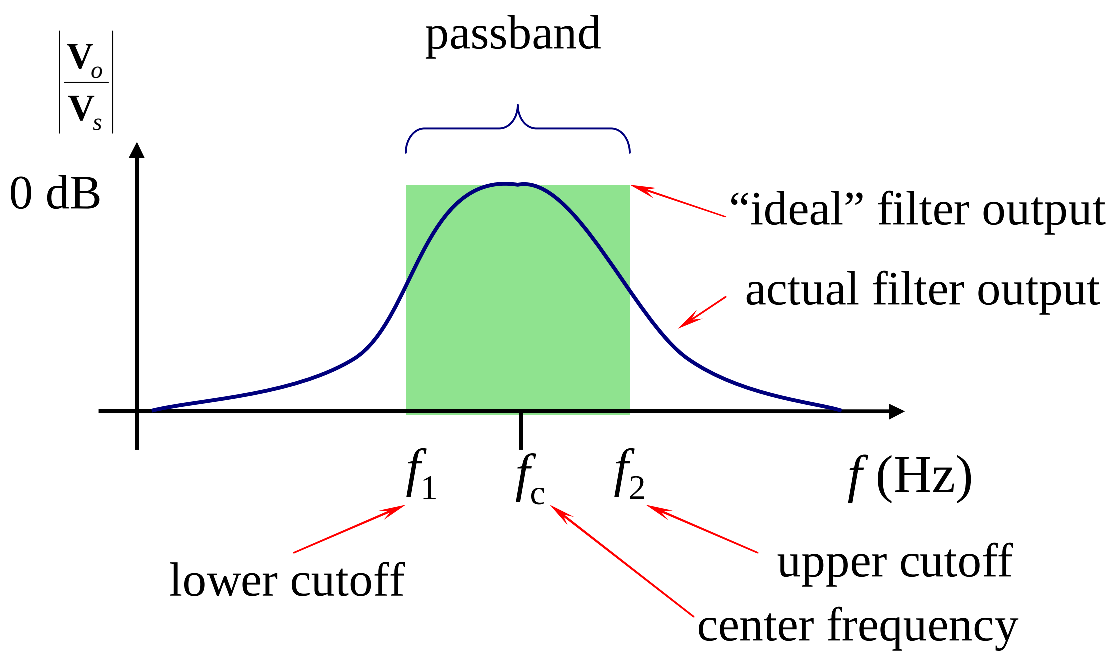
LC Filters

- At higher frequencies (> 100-kHz), it is more common to find LC filters made with inductors and capacitors.
- The response curves of the major families of filters are shown below.



Bandpass filter

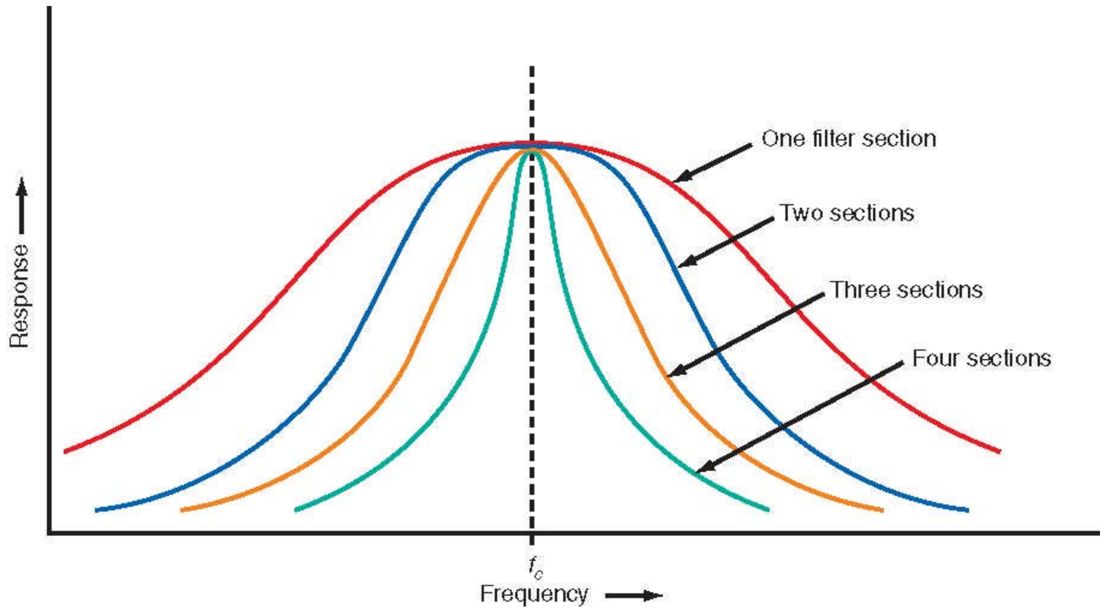
- A **bandpass filter** passes frequencies below a critical frequency called the cutoff frequency and attenuates those above.



LC bandpass filter response

Cascading bandpass filter

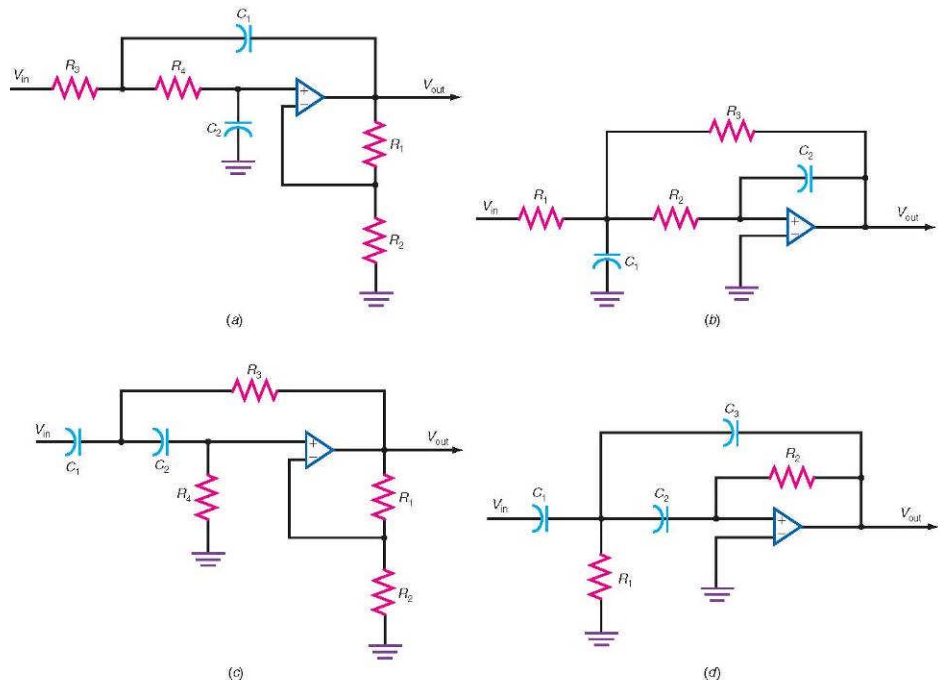
- Improved selectivity with steeper “skirts” on the curve can be obtained by cascading several bandpass sections.



How cascading filter sections narrow the bandwidth and improve selectivity.

Active filters

- Active filters incorporate *RC* networks and amplifiers with feedback to produce low-pass, high-pass, bandpass and bandstop responses.



Active bandpass and notch filters.