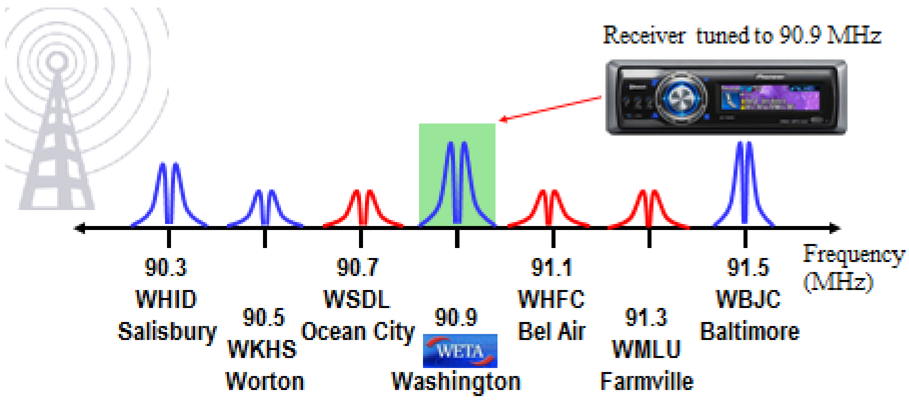
EE302 Lesson 5

Sources: (1) Course materials developed by CDR Hewitt Hymas, USN
(2) Frenzel, Principles of Electronic Communication Systems, 3rd ed., McGraw Hill, 2008

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



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

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 the critical frequency but rejects those below.
- **Bandpass filter**. Passes only frequencies in a narrow range between upper and low cutoff frequencies.
- **Band-reject filter**. Rejects or stops frequencies in a narrow range but passes others.

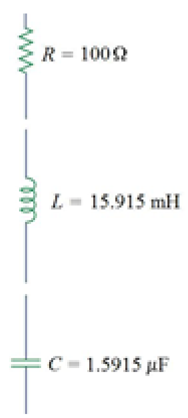
Filters are categorized as active or passive:

- **Passive** filters are 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.

How do filters work?

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

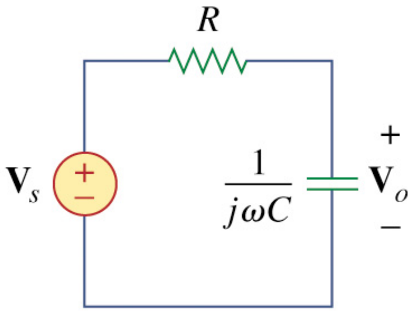
Example:



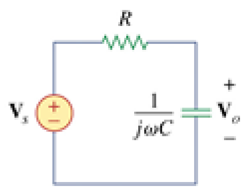
$$Z_C = \frac{-j}{2\pi f C} \qquad Z_L = j2\pi f L$$

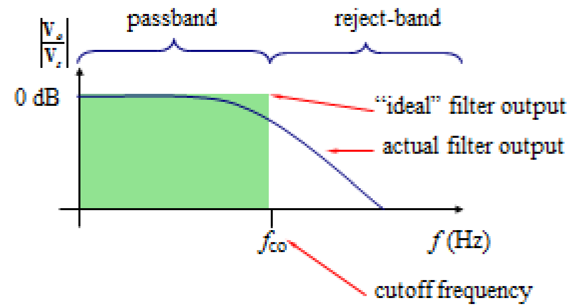
f	100 Hz	1000 Hz	10,000 Hz
R	100 Ω	100 Ω	100 Ω
Z_L	j10 Ω	j100 Ω	j1000 Ω
Z_C	-j1000 Ω	-j100 Ω	-j10 Ω

The RC Low-Pass Filter Consider the circuit below. What is the ratio of the output voltage ($\mathbf{V}_o$) to the input voltage ($\mathbf{V}_s$)?



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 the frequency at which the output voltage amplitude is 70.7% of the input value (i.e., -3 dB).

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

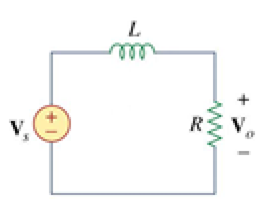
which implies

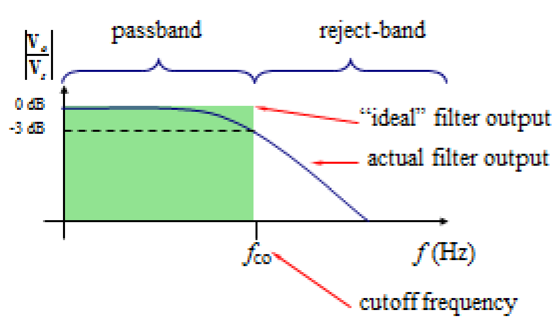
$$\omega_{\text{co}} = \frac{1}{RC} \quad \text{[rad/sec]}$$

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

The RL Low-Pass Filter A low-pass filter can also be implemented with a resistor and inductor; the cutoff frequency is given by:

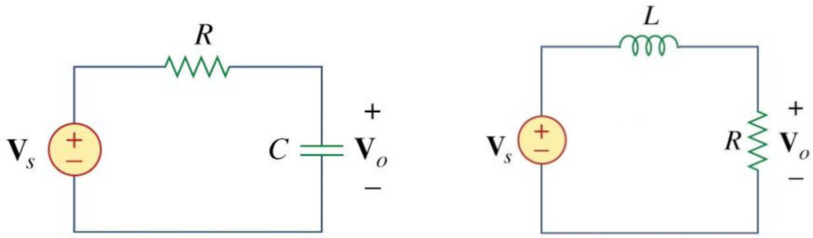
$$f_{\text{co}} = \frac{R}{2\pi L} \quad \text{[Hz]}$$





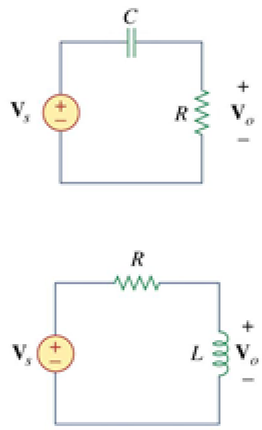
RL low-pass filter response

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

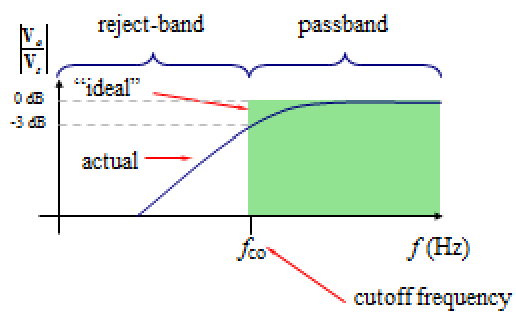


What would result if the position of the elements were switched in each circuit?

High-pass Filters Switching elements results in a high-pass filter.

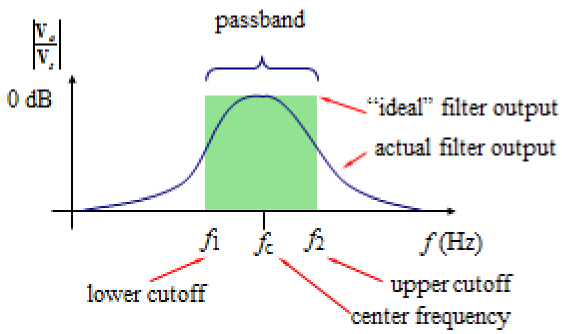


$$f_{co} = \frac{1}{2\pi RC} \quad \text{or} \quad f_{co} = \frac{R}{2\pi L} \quad \text{[Hz]}$$



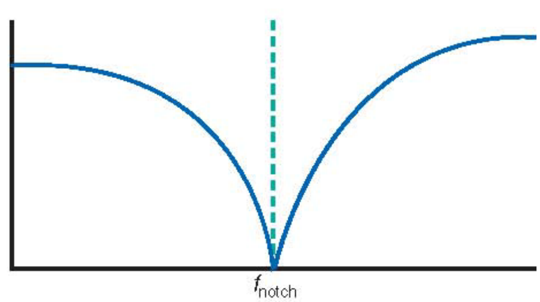
High-pass filter response

Bandpass Filter A **bandpass filter** passes frequencies over a narrow range between lower and upper cutoff frequencies.



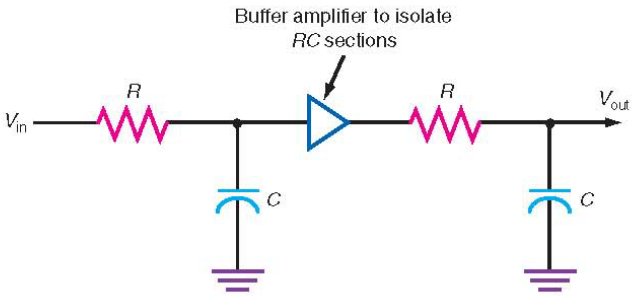
LC bandpass filter response

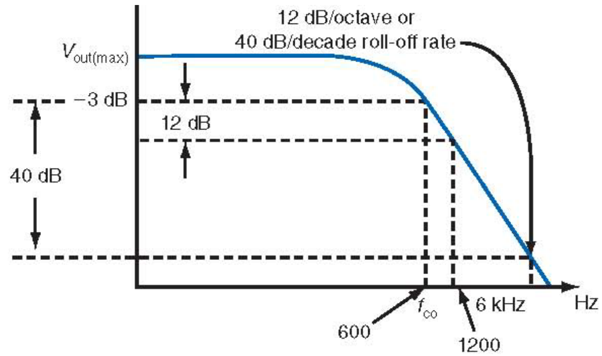
Band-Reject Filter Also known as a band-stop or notch filter. This filter attenuates a narrow range of frequencies around a center frequency point



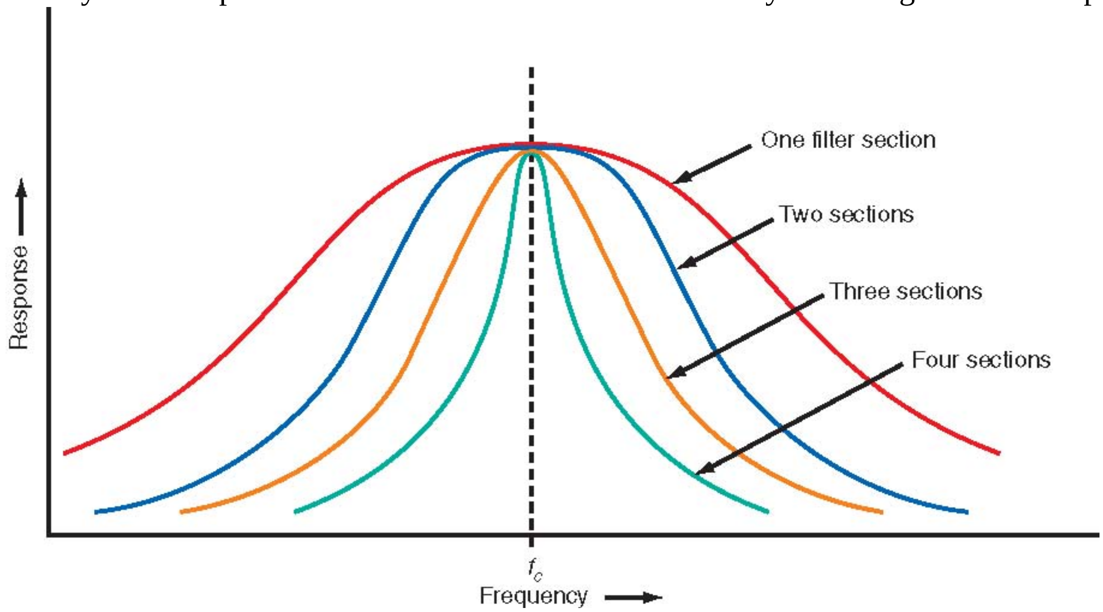
Improving Filter Response

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

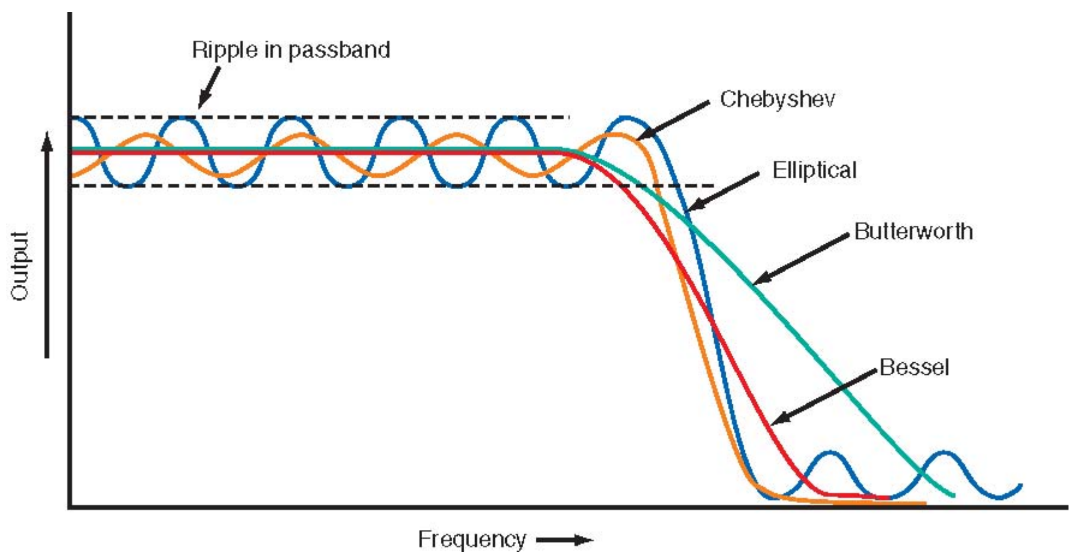




Improved selectivity with steeper "skirts" on the curve can be obtained by cascading several bandpass sections.

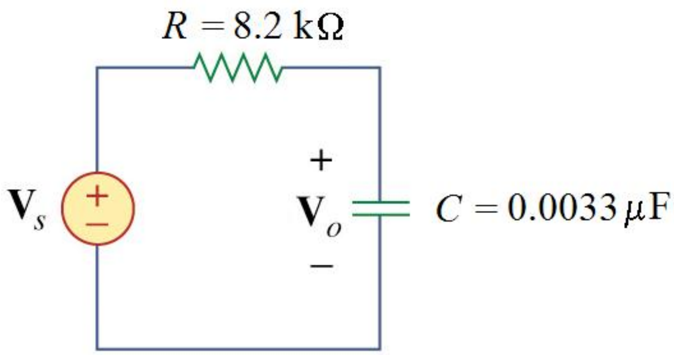


At higher frequencies (> 100 kHz), it is more common to find filters made with inductors and capacitors (called *LC filters*). The response curves of the major families of filters are shown below.



Example Problem 1

What is the cutoff frequency of a single-section *RC* low-pass filter with R = 8.2 kΩ and C = 0.0033 µF?



Example Problem 2

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?