BFF3302 SENSOR AND INSTRUMENTATION SYSTEM

Signal Conditioning Elements: Filter

By

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Chapter Description

- Aims
  - Obtain basic knowledge about electronic, measurement, sensors, and instrumentation
  - Able to analyse particular sensor, instrument, and measurement situation.

- Expected Outcomes
  - Determine general treatment of instrument elements and their characteristic
  - Analyse transducer elements, intermediate elements, and data acquisition system (DAQ)
  - Determine principles of the work and derive mathematical model of sensors for measuring motion and vibration, dimensional metrology, force, torque and power, pressure, temperature, flow and acoustics

- References

  - B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.
  - Introduction to signal processing, instrumentation, and control : an integrative approach / Joseph Bentsman Hackensack, NJ : World Scientific Pub., 2016
  - Transducers for instrumentation / M. G. Joshi, New Delhi, India : Infinity, 2017
  - Instrumentation and measurement in electrical engineering / editor : Harinirina Randrianarisoa, New York : Arcler Press, 2017

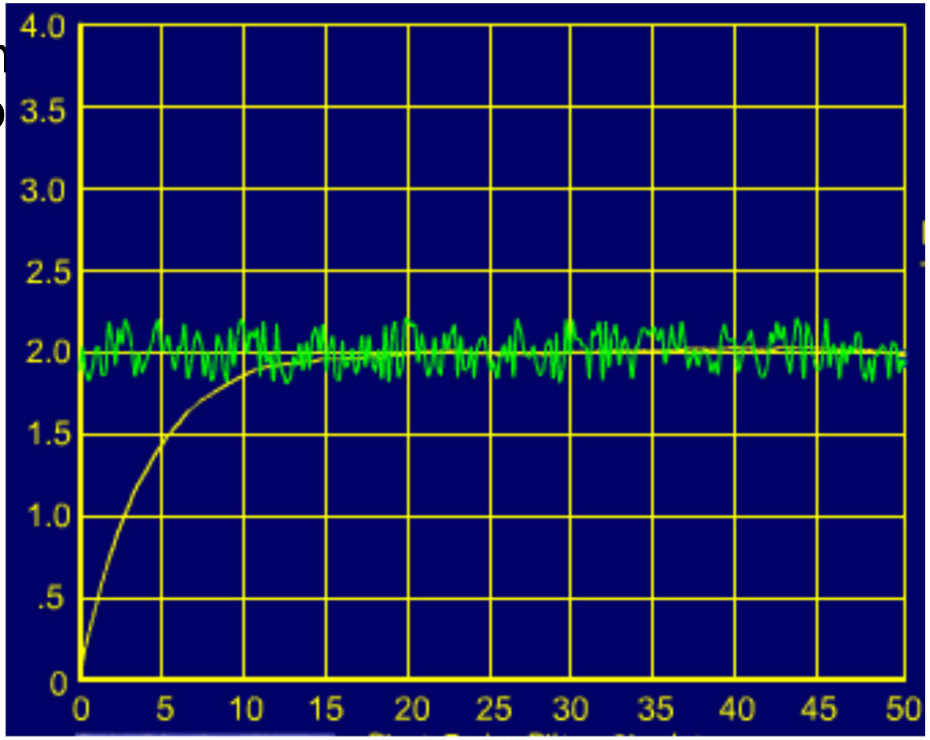
Filters

- Filters are meant **to remove unwanted signals** from the desired transducer signal so as not to obscure the effect of the latter.

- Filters can be mechanical, electrical, pneumatic or hydraulic.

Why we need amplifiers in sensor data acquisition system?

- Purpose electronic filter → **selectively pass or reject frequency bands**.
- In a common, the signals coming from sensors have a noisy measurements that have differen frequencies and are not useful to be read and recorded.
- Example: pressure sensor.
- Noise: +/- 0.2V of 2.0 V.
- Signal: 2V.



Filter

- Filtering → removing a certain band of frequencies from a signal and permitting the others to be transmitted.

- Filter can be defined as an **AC circuit** that **separates some frequencies** from others within a mixed-frequency signals.

- Filters - used in electronic systems → emphasize signals in certain frequency ranges & reject signals in other frequency ranges.

- Ideally, a filter will not **add new frequencies, nor will it change the component frequencies** of that signal.
- Filter → change the relative amplitudes of the various frequency components and/or their phase relationships.

Filters

The reference junction of a thermocouple is kept in ice, contained in a thermos flask, the insulation if which protects the systems from ambient temperature changes.

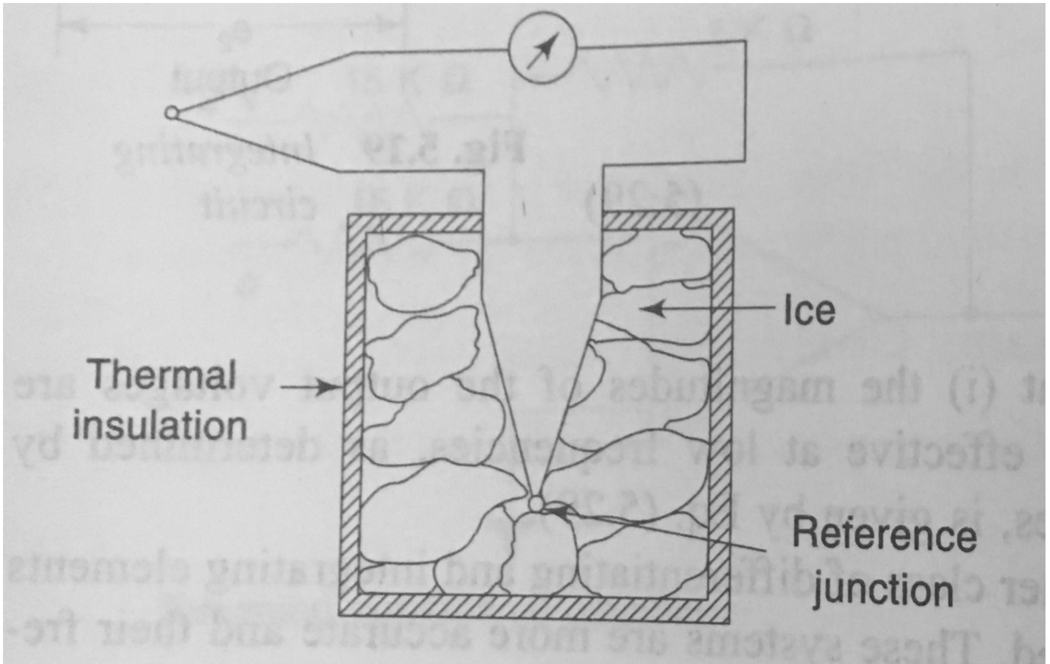


Fig. 5.22 *A typical mechanical filter (thermal insulation) provided in thermocouple device*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Filters

A delicate instrument is shown mounted on vibration isolators, to isolate the instrument from disturbing vibration inputs.

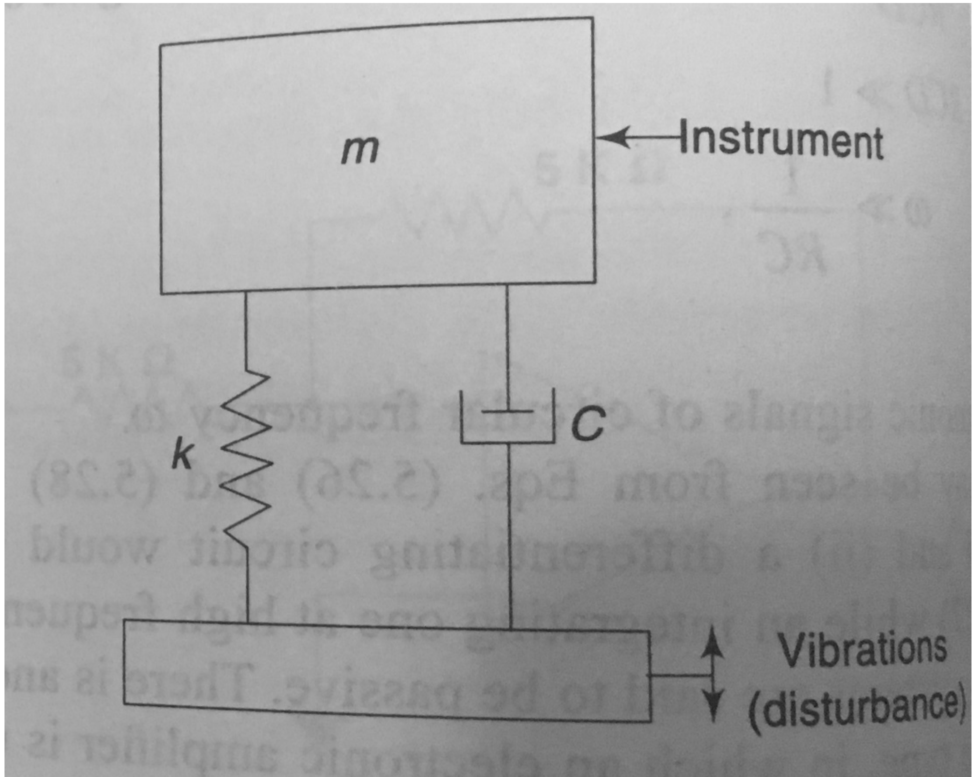


Fig. 5.23 *Isolators for filtering vibrations*

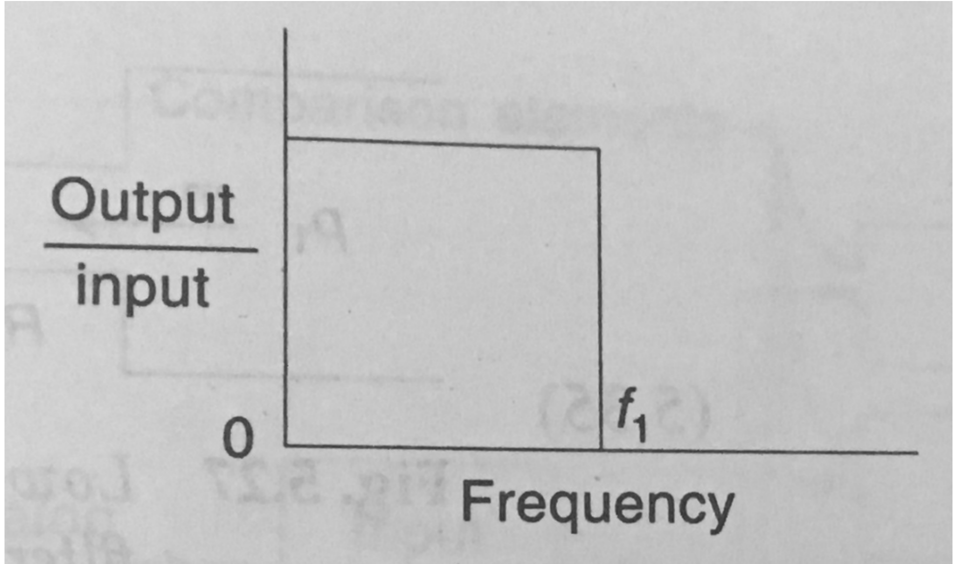
B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

- The **amplitude ratio** of output of the filter to the input is plotted against frequency.

- This is the ideal filter characteristics, while in actual filters, the output to input amplitude ratio does not vary sharply.

Classification of filters

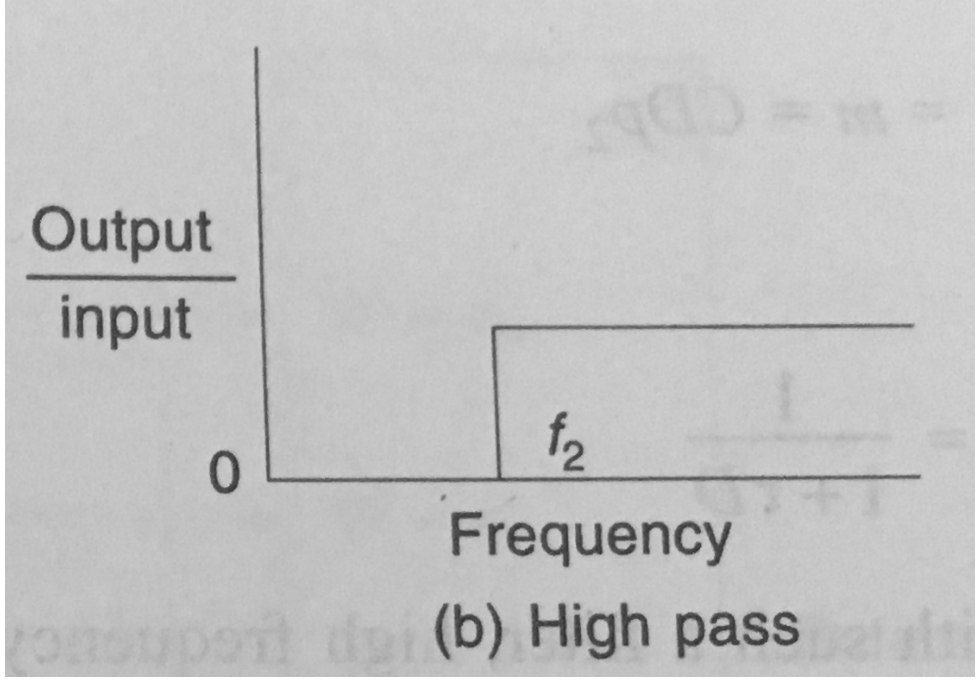


(a) Low pass

The low pass filter will pass signals of low frequencies till frequency $\boldsymbol{f_1}$.

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

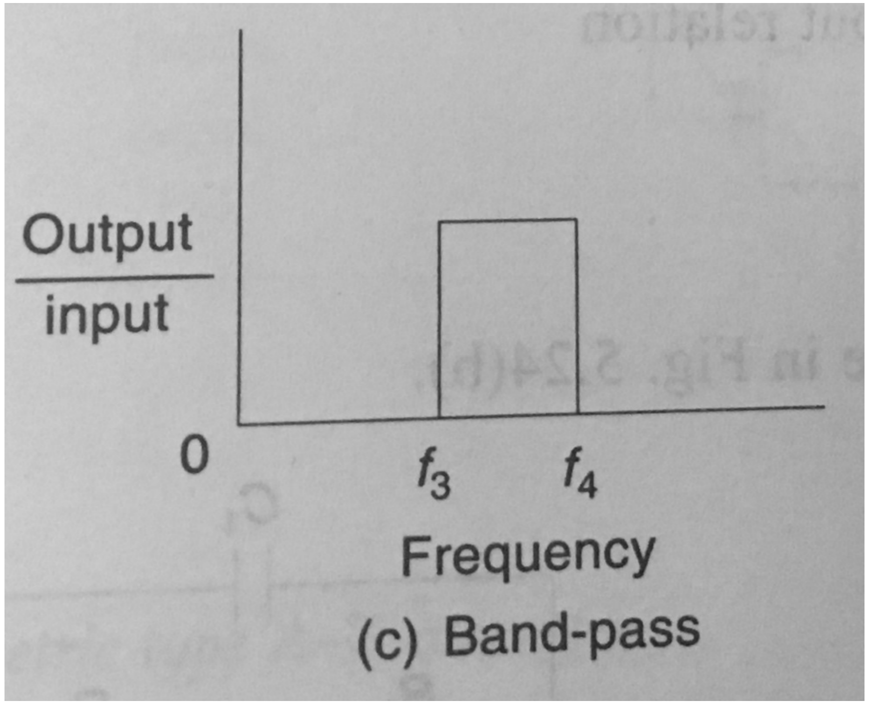


The high pass filter will pass signals from frequency f_2 onwards.

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

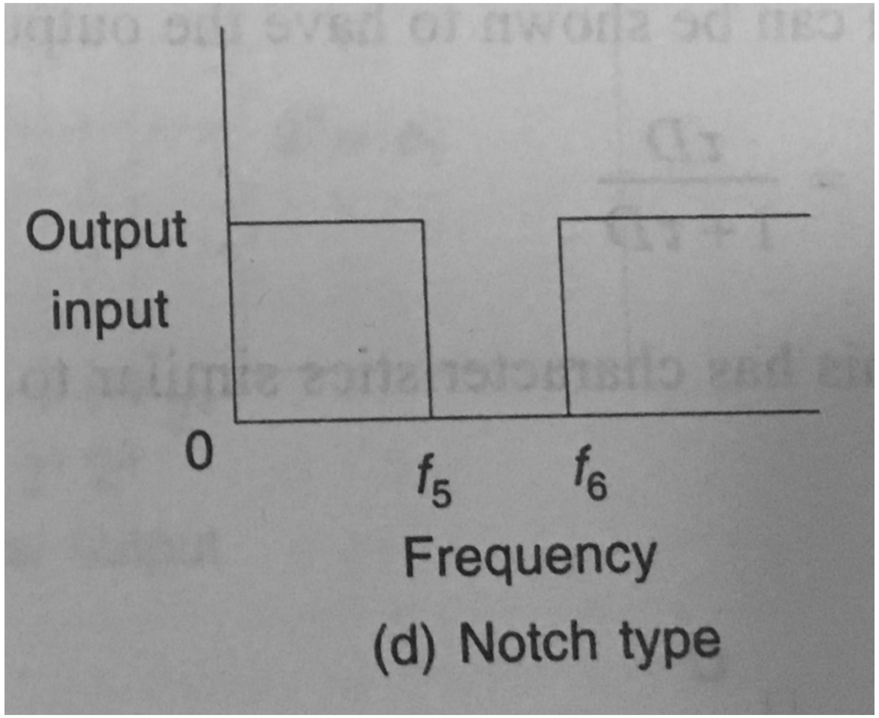
The band-pass filter will only pass signals which lie between frequency f_3 and f_4.



B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

The notch type filter will block all signals that have frequencies between f_5 and f_6 while all others will appear in the output.



B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

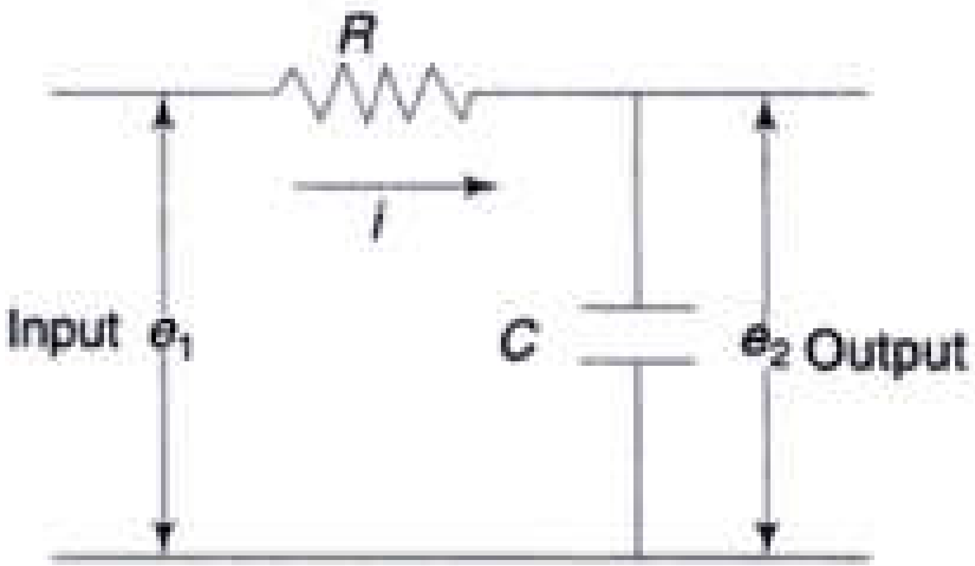
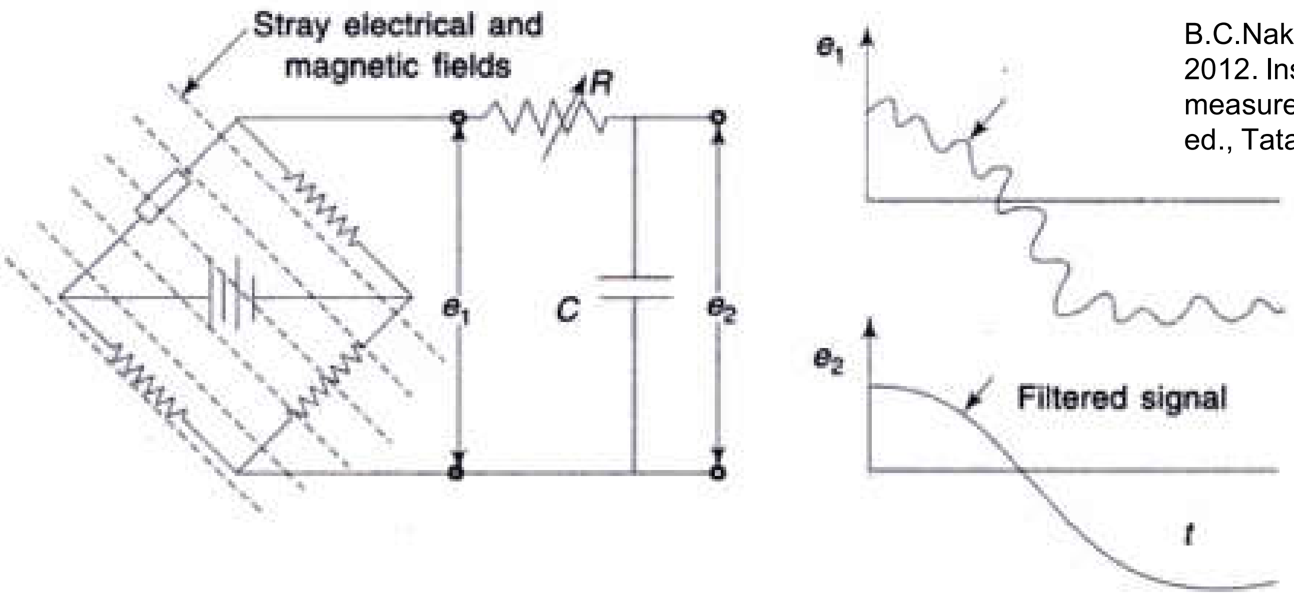


Fig. 5.25 *Low pass electrical filter*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

- A low pass filter has been used with a resistance **strain gauge bridge** for filtering the unwanted noise signals of high frequency.



B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Fig. 5.26 *A low pass filter used with a resistance strain gage bridge*

Classification of filters

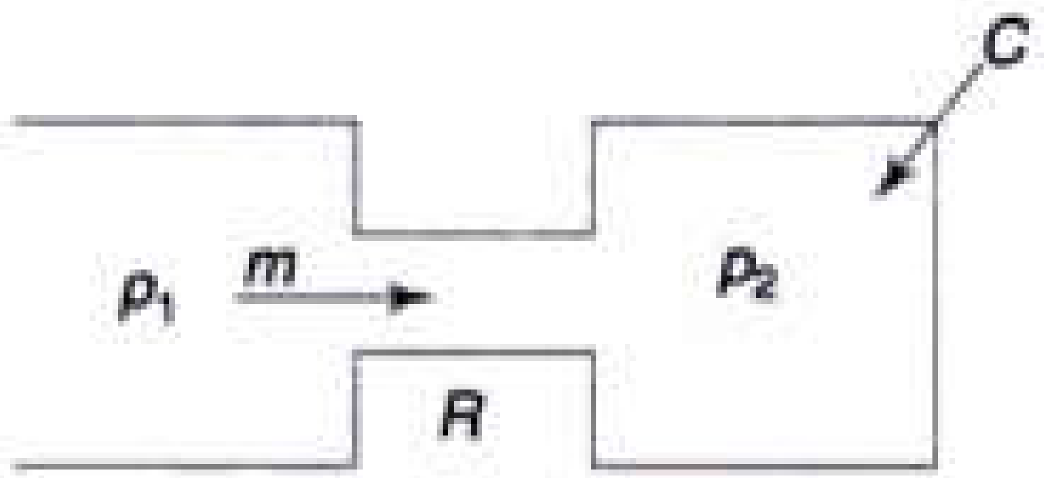


Fig. 5.27 *Low pass pneumatic filter*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

Usage of low pass filter along with a high pass filter will result in a band-pass filter.

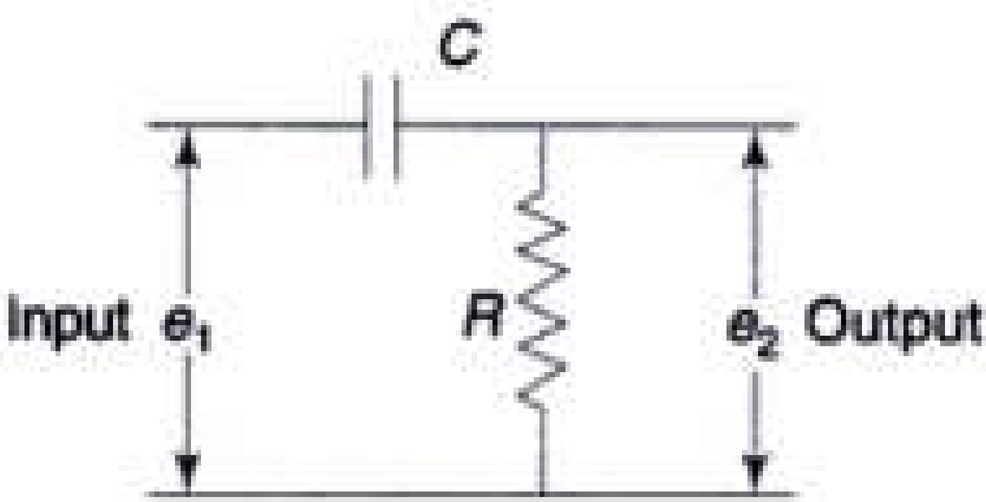


Fig. 5.28 *High pass electrical filter*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Classification of filters

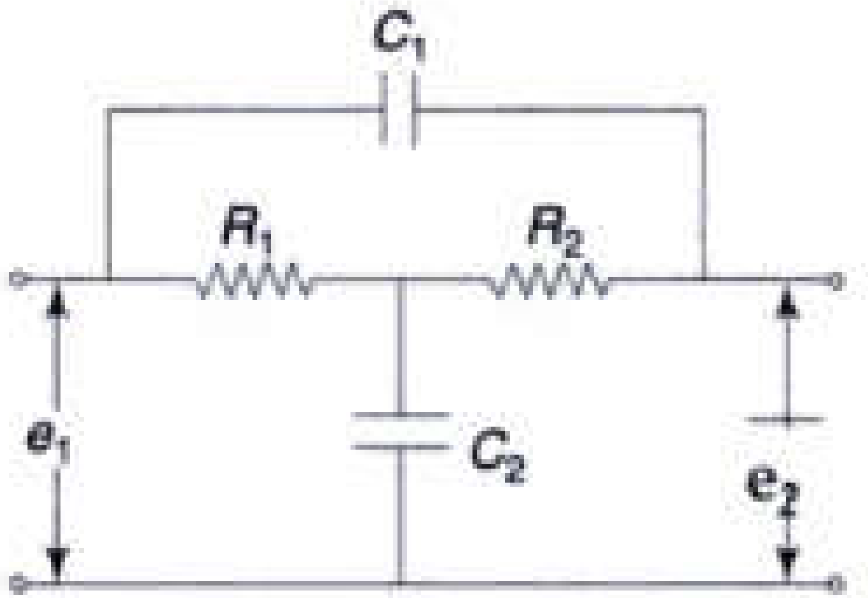


Fig. 5.29 *Notch type electrical filter*

B.C.Nakra and K.K. Chaudhry, 2012. Instrumentation measurement and analysis, 3rd ed., Tata-McGraw-Hill.

Fundamental of Filter

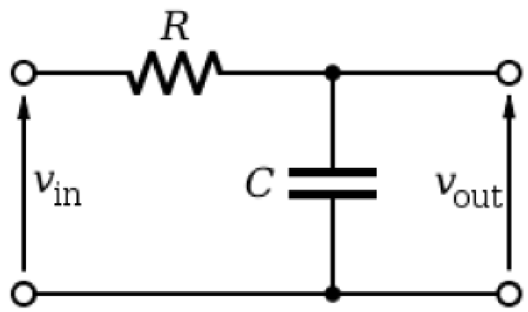
- In the filters, there are relation between output/input signal and frequency, we call it frequency domain behavior.
- Frequency-domain → **transfer function** by ratio between input and output signal
- In electronic filters, the voltage transfer function can therefore equal to:

$$H = \frac{V_{out}(\omega)}{V_{inp}(\omega)}$$

where Vin & Vout = input and output signal voltages and ω *is* frequency.

- The **amplitude** and **phase response** of filter are calculated from transfer function.

$$H = \frac{V_{out}(\omega)}{V_{inp}(\omega)}$$



magnitude is

$$|H(j\omega)| = \left|\frac{V_{OUT}(j\omega)}{V_{IN}(j\omega)}\right|$$

phase is:

$$\arg H(j\omega) = \arg \frac{V_{OUT}(j\omega)}{V_{IN}(j\omega)}$$

Fundamental of Filter

- Bode diagram is used to draw the Amplitude and Phase of filter's transfer functions:

The amplitude is common calculated in dB which can be derived from transfer function as:

$$|H(j\omega)| = 20\log\left|\frac{V_{out}}{V_{in}}\right| = 20\log V_{out} - 20\log V_{in}$$

The phase response of filter are calculated in degree/rad from transfer function

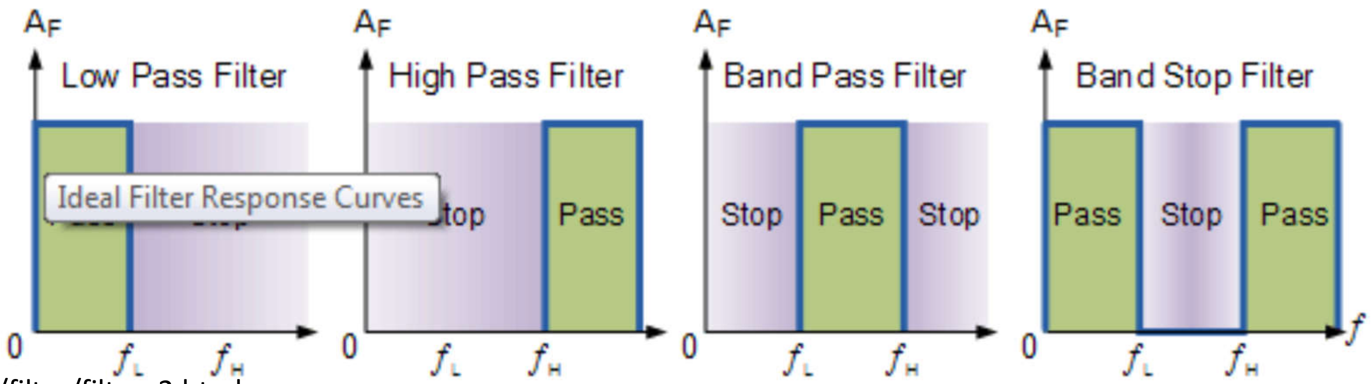
$$\angle H(j\omega) = arctan(zero) - actan(poles)$$

Passive Filters

- **Passive filters** consist of passive components such as **resistors**, **capacitors** and **inductors** and have **no amplifying elements** (transistors, op-amps, etc) → have **no signal gain**, → **their output** level is normally **less than the input**.

- Filters are named according to the frequency range of signals that allowed to pass through them, while blocking or "attenuating" the rest. Common used filter are:

- Low-pass filter
- High-pass filter
- Band-pass filter
- Band-stop filter



http://www.electronics-tutorials.ws/filter/filter_2.html

Passive Filters : Low-pass filter

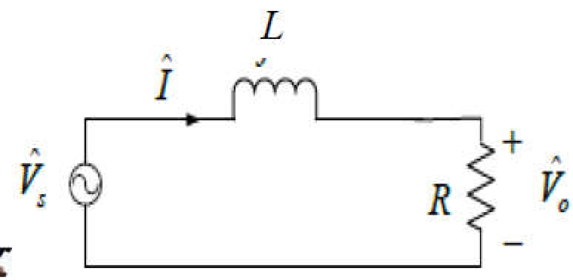
- Low-pass filter →easy passage to low-frequency signals and difficult passage to high-frequency signals.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

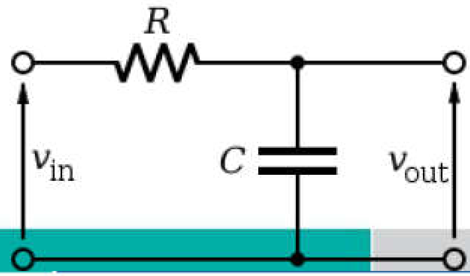
$$X_L = \omega L = 2\pi f L$$

- There are two basic low pass filters:
  - **inductive low-pass** filter and
  - **capacitive low-pass** filter.

$$Z = R + JX$$



- The reactance in capacitor and inductor depends on the frequency, however in resistor not;



Passive Filters : Low-pass filter

What happened physically to the signal that come in and come out in low-pass filter?

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$X_C \propto \frac{1}{f} \qquad X_L \propto f$$

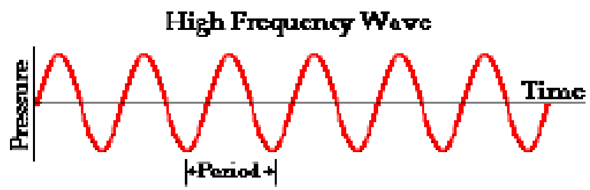
$$X_L = \omega L = 2\pi f L$$

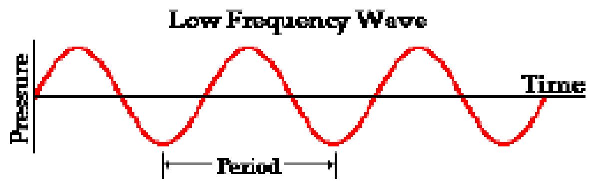
For capacitor: As the frequency increases → reactance (measured in ohms) decreases.

Likewise as the frequency across the capacitor decreases its reactance value increases.

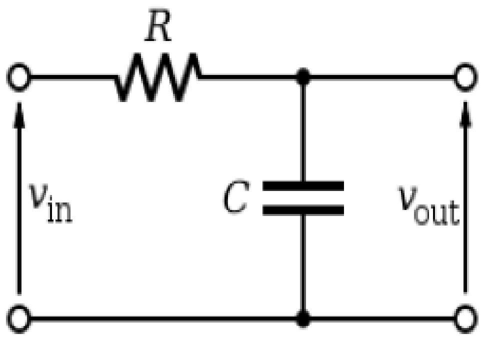
This is called ➔ capacitors **complex impedance**.

For the inductor, the reactance will be proportional to the frequency

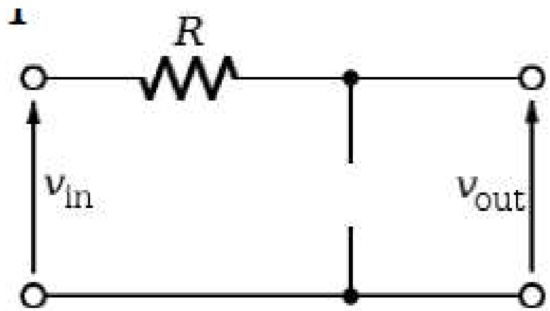




Passive Filters : Low-pass filter

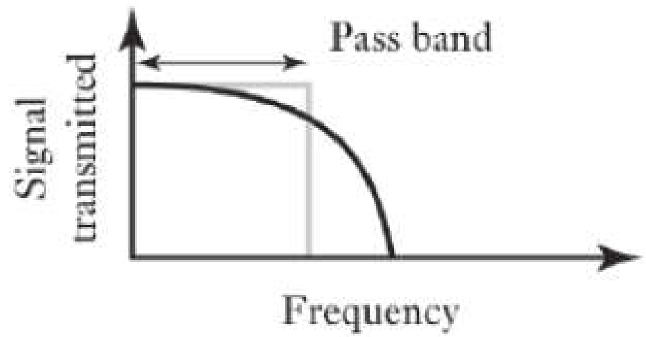


$$Vout = Vin\frac{Xc}{R + jXc} = Vin\frac{Xc}{\sqrt{R^2 + Xc^2}}$$



In the **small frequency** the **reactance of capacitor is very high** (infinity) and it cause no current pass there. The output will be equal to *Vin-V*$_R$.

In the case of **high frequency** , the reactance ***Xc* will be near to zero**, and it will like short circuit and *Vout=Vc =0*



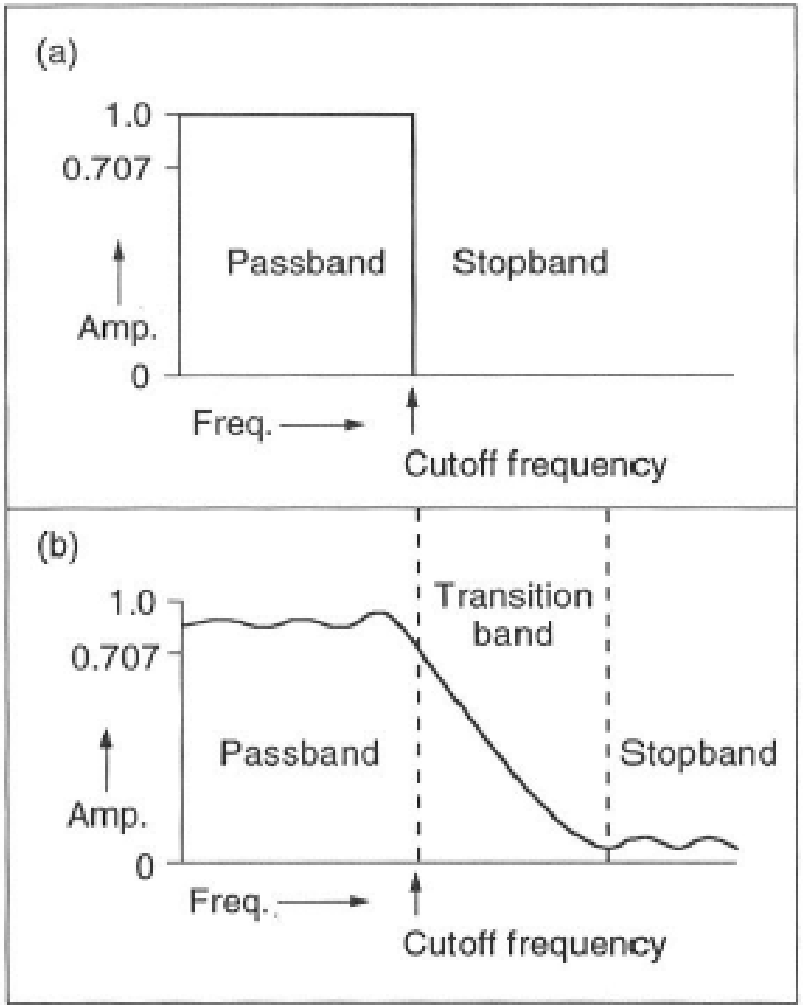
Passive Filters : Low-pass filter

$$if\ H = \frac{Vout}{Vin} = \frac{1}{1 + j\omega RC} = 1 \rightarrow \omega = 0$$

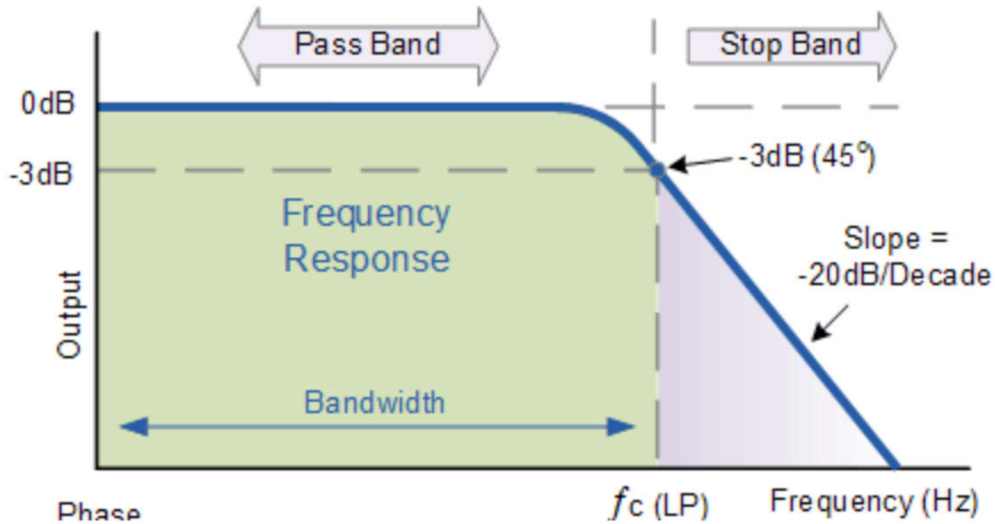
$$H = \frac{1}{\sqrt{2}} \rightarrow \omega = \frac{1}{RC};\ f_c = \frac{1}{2\pi RC}$$

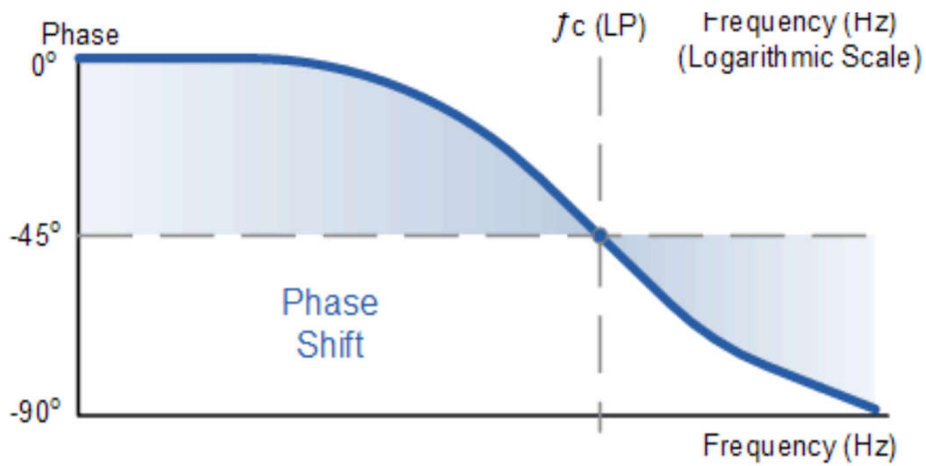
- This is **CUT OFF frequency** (***fc***) which determine the boundary between stopping and passing band;
- Technically CUTOFF frequency ➔ frequency at which the **output voltage is 70.7% of that pass band**.
- The **Pass Band**: the range of frequencies passed by the filter.
- The **Stop Band**: the range not passed by the filter.

Attenuation dB (decibels) = $10\log\frac{P_{out}}{P_{in}} = 20\log\frac{V_{out}}{V_{in}}$



Low-pass filter



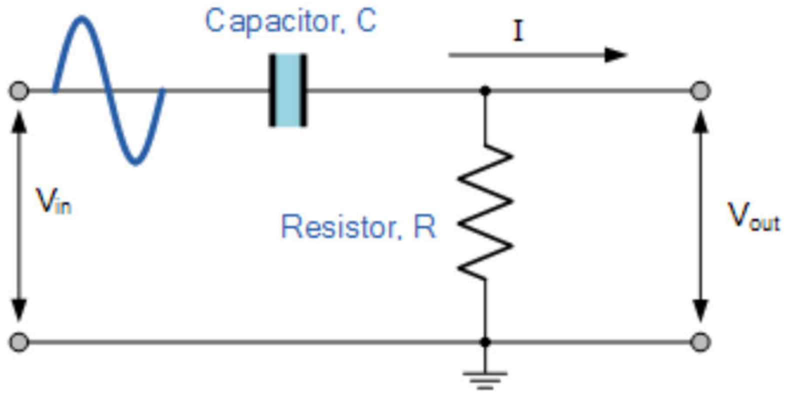


http://www.electronics-tutorials.ws/filter/filter_2.html

Passive Filters : High-pass filter

- Similar to previous analysis of LPF ➔ **reactance of the capacitor in RC is very high at low frequencies** so the capacitor acts like an open circuit and blocks any input signals at Vin until the cut-off frequency point (ƒc) is reached.

- **Above this cut-off frequency → reactance of the capacitor has reduced sufficiently → short circuit → allow the input signal to pass directly to the output**.



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Passive Filters : High-pass filter

For RC circuit

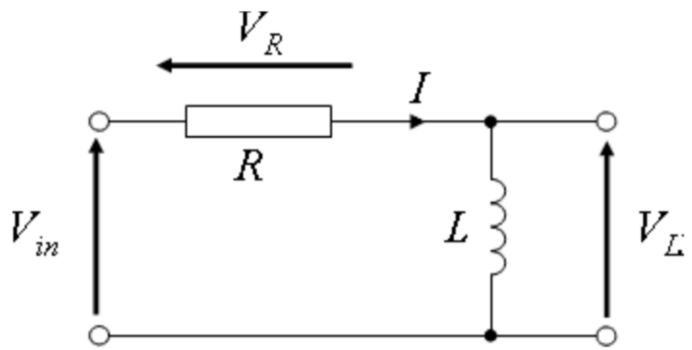
$$H = \frac{Vout}{Vin} = \frac{R}{R+\frac{1}{j\omega c}} = \frac{j\omega RC}{1+j\omega RC}$$

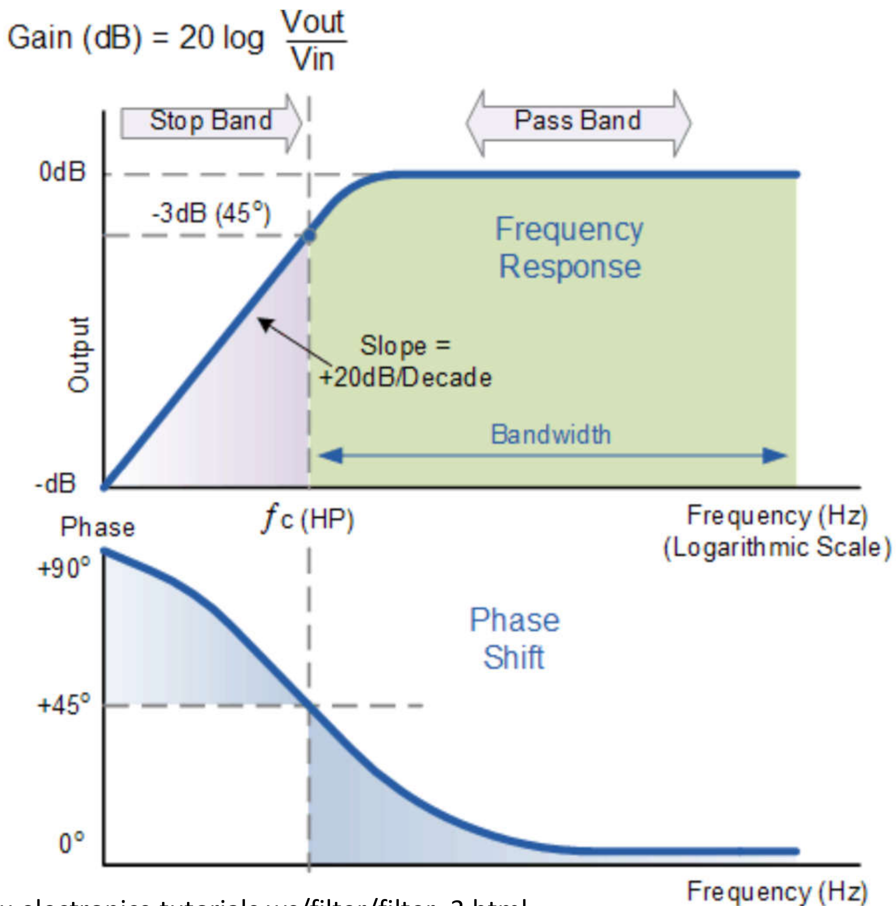
$$H = \frac{Vout}{Vin} = \frac{1}{\sqrt{2}} \rightarrow \omega = \frac{1}{RC};\ f_c = \frac{1}{2\pi RC}$$

For RL circuit

$$\frac{Vout}{Vin} = \frac{j\omega L}{R + j\omega L}$$

$$H = \frac{Vout}{Vin} = \frac{1}{\sqrt{2}} \rightarrow \omega = \frac{R}{L};\ f_c = \frac{R}{2\pi L}$$





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