Electronics II

Lecture 18
Filters I

Muhammad Tilal
Department of Electrical Engineering
CIIT Attock Campus

Previous Lecture

- Operational Amplifier
  - Inverting and non inverting amplifiers.
  - Summing and Subtraction Circuits using Op-amp
  - Op amp Integrator.

Session Overview

Topic	Filters
Concepts	Basic Filter Concepts, Low Pass Filter, High Pass Filter, Band Pass Filters, Band Stop Filters, Filter Parameters.
Recommended Reading	Section 14-6 of [1] Section 11-5 of [2] Sections 1.0, 1.1, 1.4 of [3]
Keywords	Active Filters, Low Pass, High Pass, Band Pass, Band Stop.

Some important Concepts

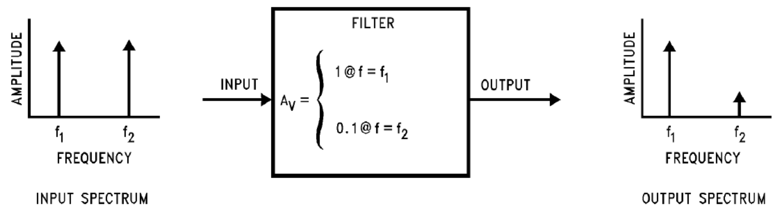
- Some important concepts must be reviewed before starting the topic. These are
- **Frequency:** Frequency can be mentioned in *'Hertz'* or *'Radians per second'.*
- **Decibels (dB):** Gain can be specified in *'dB'* or *'linear'* scale. *Voltage gain (dB)= 20log(Vo/Vin)*.
- **Phase:** Phase can be specified in *'Degrees'* or *'Radians'*.

- Other concepts include
  - Poles.
  - Zeros.
  - Bode Plots.
  - Magnitude Response.
  - Phase Response.

  - Bandwidth.
  - Cut off Frequency.
  - Pass Band.
  - Stop Band.

Filters

- A filter is a device that allows signals with specific frequencies to pass through it while attenuating all the other signals.
- In other words a filter will neither add any new frequencies to the signal nor change the component frequencies but it will only change the amplitude and phase components w.r.t. certain frequencies.
- Generally, filter has a gain which is dependent on the frequencies (An elaboration of this point will be made in a later portion of the lecture).



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Filter Response

- Generally, filters are defined by their frequency domain effects so most analytical and graphical description of filter characteristics are done in frequency domain.
- Typical curves include
  - Gain vs Frequency.
  - Phase vs Frequency.
- Mathematically, frequency domain behavior of the filter is described by '*transfer function*' or '*network function'*.
- Transfer function is ratio of the Laplace transforms of output and input signals.
- Voltage transfer function can be written as
  - $H(s)= V_{out}(s)/ V_{IN}(s)$
  - Where $V_{out}(s)$= Output voltage.
  - $V_{in}(s)$= Input voltage.
  - s = complex frequency variable.
- The filter transfer function defines the filter's response to any arbitrary signal.
- But mostly the filter response to the sinusoids is required.
- Transfer function can be subdivided into two categories namely amplitude response and phase response.

Filter Response

Amplitude Response

- The transfer function magnitude response vs frequency is *amplitude* or (sometimes called) *frequency* response of the filter.
- It provides information on filter's ability to distinguish between the frequencies.
- $|H(jw)| = | V_{out}(jw) / V_{IN}(jw) |$

Phase Response

- Phase response represents the amount of phase shift introduced in the sinusoidal signals as a function of frequency.
- Phase shift is very important when dealing with the complex signals where timing relationship between different signal components is critical.
- $\arg H(jw) = \arg(V_{out}(jw) / V_{IN}(jw))$

Classification on the Basis of Circuitry

Passive Filters

- Passive filters are constructed using passive components which include resistors, capacitors and inductors.
- Passive filters have following advantages
  - Simple to implement (only low order).
  - Require no power supplies.
  - Have no bandwidth limitations.
- Passive filters have following disadvantages
  - Have thermal noise.
  - No signal gain.
  - Higher order filters need complex design (inaccurate and expensive)

Active Filters

- Active filters employ active components such as transistors and operational amplifiers along with resistors and capacitors.
- Active filters have following advantages
  - Accurate desired parameters (Input and output impedances).
  - Provide gain.
- Active filters have following disadvantages
  - Limited bandwidth.
  - Require power supplies.
  - Also generate noise.

Classification on the Basis of Design Types

(Only two are considered here)

Butterworth

- Also called maximally flat filter because of less gain variation in the pass band.
- Gain falls at less steeper rate outside pass band.
- Frequency response within the pass band is closer to the ideal filter.

Chebyshev

- Chebyshev has more gain variation in the pass band.
- Gain falls at a steeper rate outside pass band.
- Frequency response outside pass band is closer to the ideal filter.

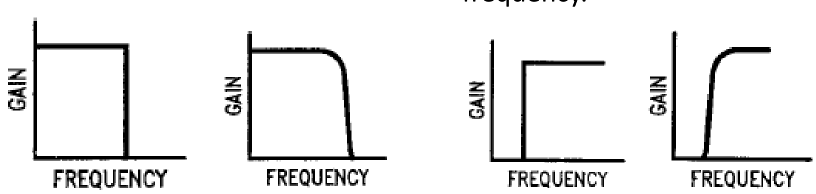
Classification on the Basis of Allowed Frequencies

Low Pass Filter

- Passes all the frequencies below the cut off frequency and blocks all the frequencies above the cut off frequency.

High Pass Filter

- Passes all the frequencies above the cut off frequency while blocks all the frequencies below the cut off frequency.



Ideal Practical Ideal Practical

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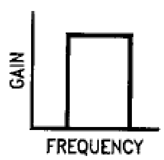
Classification on the Basis of Allowed Frequencies

Band Pass Filter

- Passes all the frequencies within certain specified range of frequencies within upper cut off and lower cutoff frequencies.

Band Stop Filter Filter

- Stops all the frequencies within certain specified range of frequencies.



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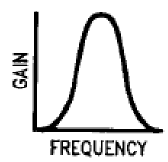

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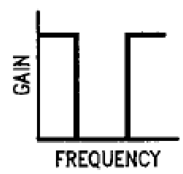

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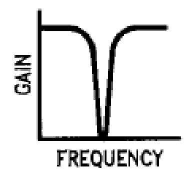

Practical

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Filter Approximations and Properties

- The ideal filter is characterized by very sharp transition between the pass band and the stop band.
- The ideal filter response separates the filter response between the two bands perfectly.
- Practically, the ideal response is not physically realizable but the filter response can be made closer to the ideal.
- This approximation to the ideal filter depends upon our goal and certain properties are important in this regard.
- These properties include
  - Filter order.
  - Ultimate roll off rate.
  - Attenuation rate near the cut off frequency.
  - Transient response.
  - Monotonicity.
  - Pass band ripple.
  - Stop band ripple.

Filter Properties

Filter Order

- Filter order is of prime importance because it is directly related to the number of components used to design a filter.
- So filter order indirectly influences the cost, physical size and complexity of design.
- Higher order filters are expensive, take more space and complex to design.
- Higher order filters are better! Why?

Ultimate Roll Off

- Usually expressed as amount of attenuation in dB for a given ratio of frequencies.
- Most common units include dB/octave and dB/decade. (octave? decade?)
- Different filters have different attenuation slopes and depends on the specific design.

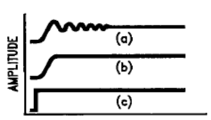
Filter Properties

Attenuation Rate near the Cut Off Frequency

- It is the rate at which the filter response drops near the cut off frequency.
- If the frequency to be passed and frequency to be stopped are very close, a larger attenuation rate near the cut off is required.

Transient Response

- Amplitude response show the filter behavior to the steady state sinusoidal input signals.
- Practically much complex signals can be applied to the filter input so the transient response must be considered.



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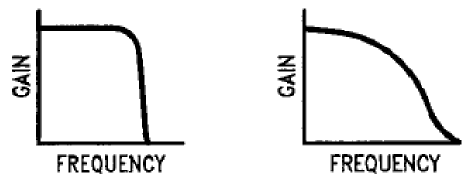
Filter Properties

Monotonicity

- A filter has a monotonic amplitude response if its gain slope never changes sign.
- This implies that gain always increases with the increasing frequency or always decreases with the increasing frequency.
- This is applicable only in high pass and low pass filters whereas band pass and band stop cannot have this property for their total bandwidth.



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References

[1] Robert L. Boylestad, *Electronic Devices and Circuit Theory,* 8th Edition, Pearson Education Inc, ISBN: 81-7808-590-9.

[2] Theodore F. Bogart, Jeffery S. Beasley, Guilermo Rico, Electronics Devices and Circuits, 6th Edition, Pearson Education Inc, ISBN: 978-81-775-8887-3

[3] Kerry Lacanette. Application Note 779: A Basic Introduction to Filters- Active, Passive and Switched Capacitor, Texas Instruments, Literature Number: SNOA224A, April 2010 .
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