

# FILTER DESIGN

## ENEX 301

**Lecture** : 3  
**Tutorial** : 1  
**Practical** : 3/2

**Year : III**  
**Part : I**

### **Course Objectives:**

The objective of this course is to provide a comprehensive understanding of analog filters and their applications. It focuses on analog filter circuits and developing skills required to design both passive and active filters based on given specifications.

### **1 Introduction (6 hours)**

- 1.1 Filter, its evolution and importance
- 1.2 Lowpass, highpass, bandpass, bandstop, allpass, passive and active filters
- 1.3 Filter response: Ideal (Brick wall) response and practical response
- 1.4 Filter parameters: Gain, attenuation, passband, stopband and transition band
- 1.5 Filter transfer function, frequency response, poles, zeros and their roles
- 1.6 Normalization and de-normalization in filter design
- 1.7 Impedance (Magnitude) scaling and frequency scaling

### **2 Approximation Methods (9 hours)**

- 2.1 Approximation and its importance in filter design
- 2.2 Low pass approximations methods
- 2.3 Butterworth approximation
- 2.4 Chebyshev (Chebyshev type I) approximation
- 2.5 Inverse Chebyshev (Chebyshev type II) approximation
- 2.6 Cauer (Elliptic) approximation
- 2.7 Bessel-Thomson response
- 2.8 Delay equalization

### **3 Frequency Transformation (2 hours)**

- 3.1 Frequency transformation and its importance in filter design
- 3.2 Low pass to high pass transformation
- 3.3 Low pass to band pass transformation
- 3.4 Low pass to band stop transformation

- 4 Properties and Synthesis of Passive Networks (8 hours)**
- 4.1 One-port passive circuits
    - 4.1.1 Properties of passive circuits, positive real functions
    - 4.1.2 Properties of lossless function
    - 4.1.3 Synthesis of LC one-port circuits, Foster and Cauer realization
    - 4.1.4 Properties and synthesis of RC one-port circuits
  - 4.2 Two-port passive circuits
    - 4.2.1 Properties of passive two-port circuits, residue condition, transmission zeros
    - 4.2.2 Synthesis of two port LC and RC ladder circuits based on zero shifting by partial removal of a pole
- 5 Design of Resistively-Terminated Lossless Filters (4 hours)**
- 5.1 Properties of resistively-terminated lossless ladder circuit, transmission and reflection coefficients
  - 5.2 Synthesis of LC ladder circuits to realize all-pole low pass functions and functions with finite transmission zeros
- 6 Design of Active Filters (12 hours)**
- 6.1 First order active filters (Bilinear)
    - 6.1.1 Review of op-amp characteristics
    - 6.1.2 First order active filters using inverting and non-inverting op-amp configurations
  - 6.2 Second order active filters (Biquads)
    - 6.2.1 Tow-Thomas biquad circuit, design of lowpass active filter using Tow-Thomas biquad circuit
    - 6.2.2 Highpass, bandpass, bandstop and allpass filter using Tow-Thomas biquad circuit
    - 6.2.3 Sallen-key biquad circuit
    - 6.2.4 Gain reduction and gain enhancement
    - 6.2.5 RC-CR transformation
  - 6.3 Higher order active filters
    - 6.3.1 Cascade of biquads
    - 6.3.2 Active simulation of passive filters: Using simulated inductor and FDNR; Using Leapfrog simulation of LC ladders
- 7 Sensitivity (2 hours)**
- 7.1 Sensitivity and importance of sensitivity analysis
  - 7.2 Single parameter sensitivity
  - 7.3 Centre frequency and Q-factor sensitivity
  - 7.4 Sensitivity of biquads and passive filters

## 8 Other Filters

(2 hours)

- 8.1 Switched capacitor filters
- 8.2 Current mode filters
- 8.3 Adaptive filters
- 8.4 Current conveyors

### Tutorial

(15 hours)

- 1. Magnitude and frequency scaling: Design of a filter at required frequency with practically realizable elements from normalized filter using scaling
- 2. Calculation of order and transfer function using Butterworth, Chebyshev, inverse Chebyshev filter for given lowpass specifications
- 3. Design of filter at required frequency range from normalized filter using frequency transformation
- 4. Synthesis of one port LC and RC functions
- 5. Synthesis of two port LC and RC ladder
- 6. Synthesis of resistively terminated lossless filters
- 7. Synthesis of first order active filters
- 8. Synthesis of second order active filters using Tow-Thomas biquad circuit and Sallen-Key biquad circuit
- 9. Synthesis of higher order active filters using cascade of biquads, simulated inductors, FDNR and Leapfrog simulation
- 10. Sensitivity analysis of active and passive filters

### Practical

(22.5 hours)

- 1. Analysis of passive and active filter circuits
- 2. Design of passive filters at required frequency with practically realizable values from a normalized filter circuit
- 3. Design of active filters using Tow-Thomas biquad circuit
- 4. Design of active filters using Sallen-Key biquad circuit
- 5. Design of higher order active filters using simulated inductors and FDNR
- 6. Design of higher order active filters using Leapfrog simulation

### Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapters	Hours	Marks distribution*
1	6	9
2	9	12
3 and 5	6	9
4	8	9
6	12	15
7 and 8	4	6
<b>Total</b>	<b>45</b>	<b>60</b>

\* There may be minor deviations in marks distribution.

## References

1. Raut, R., Swamy, M. N. S. (2010). Modern analog filter analysis and design. Wiley-VCH.
2. Schaumann, R., Van Valkenburg, M. E. (2001). Design of analog filters. Oxford University Press.
3. Su, K. L. (2002). Analog filters. Springer.
4. Chen, W.-K. (2009). Passive, active and digital filters. CRC Press.
5. Thede, L. D. (2004). Practical analog and digital filter design. Artech House.