Filter Design

Me lol

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Notes

- The question papers for 81 Bhadra, Baisakh, 80 Bhadra, Baisakh and 79 Bhadra may seem repeated but they are not.
- This is because 2 question papers are used: EX606 (our BEI) and EX704 (old BEX course).
- Our EX606 will be highlighted `with this font` for clarity. EX704 will be kept as is.

Contents

1 Introduction

(4 Hours/7 Marks)

1.1 Filter and its importance in communication

1. What is (analog) Filter? [1] (**81 Bh**,**80 Bh**,**74 Ch**, 81 Ba)
2. List out the applications of filter networks. [2] (81 Ba)

   |→What is its importance of filter in communication? [2] (**74 Ch**)
3. Explain the basic steps to be followed while designing a filter. [3] (**81 Bh**, **79 Bh**)
4. What are the differences between active filter and passive filter? [3] (79 Ba)

1.2 Kinds of filters in terms of frequency response

1. Define the terms: Insertion gain and Insertion loss with neat diagram. [2] (**80 Bh**)
2. Define the following terms with the help of illustrations: Passband, Stopband, Transition band, Roll-off and bandwidth. [4] (**79 Bh**)
3. Define all-pass filter. [1] (**74 Ch**) [2] (**76 Ch**)
4. Where is all-pass filter used since it passes all the frequency components? [4] (**76 Ch**)

   |→Why do we need all pass filter if it passes all the frequency components? [3] (76 Ash)

   |→What is the importance of all pass filter in filter design? [1] (**80 Bh, 74 Ch**)
5. Define α_{max}, α_{min}, half power frequency, bandwidth, insertion loss and insertion gain with necessary figures. [6] (**75 Ch**, 72 Ka)
6. Define and explain the following terms with necessary diagrams: α_p, α_s, ω_p ω_s. [4] (74 Ash)

   |→and define passband, stopband and bandwidth with figures. [7] (70 Asa)
7. Define α_{max}, α_{min} and half power bandwidth with necessary diagrams. [3] (**70 Ch**)

1.3 Ideal response and response of practical filters

1. What are the characteristics of ideal filter? [1] (81 Ba)
2. What are the ideal and practical filters? [3] (80 Ba)
3. Explain the ideal response and practical response of filters. [3] (**74 Ch**)

1.4 Normalization and denormalization in filter design

1. Define normalization and denormalization. [2] (73 Shr) [3] (**73 Ch**, 71 Shr)

2. Explain the significance of normalization and denormalization during filter design.
[2] (**81 Bh**, **80 Bh**, 80 Ba, **78 Bh**, **72 Ch**, **69 Ch**) [3] (**79 Bh**, 76 Ash, 71 Shr)

1.5 Impedance (magnitude) scaling and frequency scaling

1. Define scaling. [1] (**81 Bh**, 74 Ash)

   |→What is frequency scaling? [1] (81 Ba)

2. Derive the relations for frequency scaling. [3] (**81 Bh**, 81 Ba)

   |→Explain magnitude scaling with necessary derivations. [3] (79 Ba)

3. What is the importance of scaling in filter design? [2] (75 Ash, 73 Shr, 71 Ch)
   |→with examples. [2] (81 Ba) [4] (81 Ba)

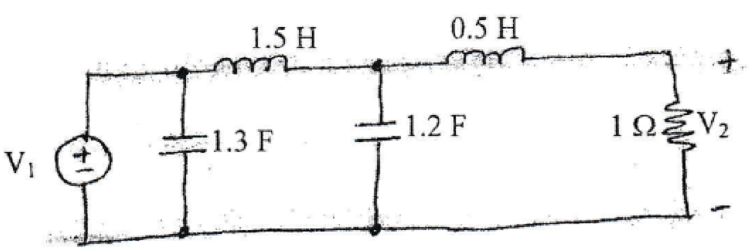
4. Derive element scaling equation.
[3] (74 Ash) [4] (**81 Bh, 79 Bh, 80 Bh**, 81 Ba, 75 Ash) [5] (**80 Bh, 71 Ch**, **69 Ch**, 80 Ba)

1.6 Numericals of EX704

1. At frequency f = 20KHz and f = 30KHz a filter is designed to attenuate the input signal by 78dB and 90dB respectively. Find the amplitude of the output signal if the 30KHz input signal has amplitude of 1V. [4] (**78 Bh**, **70 Ch**)

2. Following ckt is an LPF designed at normalization frequency of $w_0 = 1$rad/s. Apply frequency and magnitude scaling so that $w_0 = 10^5$rad/s and practically realizable elements. [4] (**73 Ch**)
(and no circuit has been found in any source yet)

3. The following is a pass filter with $\omega_p = 1$rad/s. Modify the circuit so that it becomes a low pass filter with a pass band of 1000rad/s and a load resistance of 75Ω. [3] (**72 Ch**)



2 Approximation Methods

(8 Hours/14 Marks)

2.1 Approximation and its importance in filter design

1. What is approximation in filter design? [1] (81 Ba)

2.2 Butterworth response, Butterworth pole locations, Butterworth filter design from specifications

1. What are the characteristics of Butterworth response? [3] (**79 Bh**,**73 Ch**)
   |→What are the characteristics of Butterworth filter? [2] (**75 Ch**)

2. Derive the expression to calculate the order of a Butterworth low pass filter.
   [4] (**80 Bh, 79 Bh**,**80 Bh**,**79 Bh**,**78 Bh**,**75 Bh**, 75 Ash) [5] (**69 Ch**)

3. Derive the transfer function of a normalized 4^{th} Butterworth low pass approximation.[4] (**81 Bh**)
   |→derive for 5^{th} [4] (**73 Ch**)

4. Calculate the minm order of Butterworth filter with the following specifications: [3] (**81 Bh**)
   $\omega_p/\omega_s = 1.5$ $\alpha_{max} = 1\text{dB}$, $\alpha_{min} = 25\text{dB}$

5. Estimate the order of Butterworth filter, along with pole locations and transfer functions, having following specifications:
   a. $\omega_p/\omega_s = 1.5$ $\alpha_{max} = 1\text{dB}$, $\alpha_{min} = 20\text{dB}$ [2+4] (75 Ash)
   b. $\omega_p = 1000\text{rad/s}$, $\omega_s = 2000\text{rad/s}$ $\alpha_{max} = 0.5\text{dB}$, $\alpha_{min} = 20\text{dB}$ [3+3] (**80 Bh**,**80 Bh**)

6. Calculate the order of Butterworth filter with the following specifications:
   a. $\omega_p = 2000\text{rad/s}$, $\omega_s = 3000\text{rad/s}$ $\alpha_{max} = 1\text{dB}$, $\alpha_{min} = 12\text{dB}$ [3] (**79 Bh**)
   b. $\omega_p = 2000\text{rad/s}$, $\omega_s = 3000\text{rad/s}$ $\alpha_{max} = 0.5\text{dB}$, $\alpha_{min} = 22\text{dB}$ [3] (**78 Bh**)
   c. $\omega_p = 1000\text{rad/s}$, $\omega_s = 2000\text{rad/s}$ $\alpha_{max} = 1\text{dB}$, $\alpha_{min} = 20\text{dB}$ [3] (**75 Ch**)
   d. $\omega_p = 200\text{rad/s}$, $\omega_s = 2000\text{rad/s}$ $\alpha_{max} = 0.1\text{dB}$, $\alpha_{min} = 30\text{dB}$ [3] (**69 Ch**)

2.3 Chebyshev and inverse Chebyshev characteristics, network functions and pole zero locations

1. What are the characteristics of chebyshev magnitude response? [3] (81 Ba, 80 Ba)
   |→characteristics of chebyshev filter. [2] (76 Ash)

2. What are the characteristics of inverse Chebyshev response? [2] (**81 Bh**, 74 Ash)

3. Derive the expression to calculate the order of a lowpass Chebyshev filter.
   [3] (**81 Bh**,**74 Ch**) [4] (**76 Ch**, 80 Ba) [5] (**70 Ch**, 76 Ash, 71 Shr) [6] (79 Ba)
   |→also derive for response. [7] (**79 Bh**)
   |→and then prove that locus of its pole is an ellipse centered at origin. [4] (**81 Bh**)
   |→
   |→Show that the poles of chebyshev filter lie on an ellipse. Also show the major and minor axes. [7] (**73 Ch**)

4. Derive the expression to calculate the order of inverse Chebyshev low pass filter. [3] (**81 Bh**)
   [4] (74 Ash) [5] (**72 Ch**,**71 Ch**, 81 Ba, 80 Ba, 70 Asa)

5. Calculate inverse Chebyshev poles and zeros for given specifications: $\boldsymbol{\alpha_{min}} = 18$dB, $\boldsymbol{\alpha_{max}} = 0.25$dB, $\boldsymbol{\omega_s} = 1400$rad/sec and $\boldsymbol{\omega_p} = 1000$rad/sec. [5] (**81 Bh**)

6. Determine the minimum order n of CLPF for following specifications.
$\alpha_p = 1$dB, $\alpha_s = 25$dB and $(\omega_s/\omega_p) = 1.5$, where the symbols have their usual meanings.

7. Find the minimum order with its transfer function, of CLPF having the specifications:
a. $\omega_p/\omega_s = 1.5$rad/s $\alpha_{max} = 1$dB, $\alpha_{min} = 25$dB [3] (80 Ba)
b. $\omega_p = 1$rad/s, $\omega_s = 2.33$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 22$dB [8] (72 Ka)

8. Estimate the order of CLPF with the following specifications:
a. $\omega_p = 100$Krad/s, $\omega_s = 140$Krad/s $\alpha_{max} = 0.25$dB, $\alpha_{min} = 18$dB [3] (81 Ba)
b. $\omega_p = 1500$rad/s, $\omega_s = 4500$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 20$dB [3] (81 Ba)
c. $\omega_p = 2000$rad/s, $\omega_s = 2000$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 22$dB [3] (**79 Bh**)
d. $\omega_p = 2000$rad/s, $\omega_s = 3000$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 22$dB [3] (79 Ba)
e. $\omega_p = 1000$rad/s, $\omega_s = 1500$rad/s $\alpha_{max} = 0.25$dB, $\alpha_{min} = 20$dB [3] (**76 Ch**)
f. $\omega_p = 1000$rad/s, $\omega_s = 2500$rad/s $\alpha_{max} = 0.25$dB, $\alpha_{min} = 40$dB [3] (76 Ash)
g. $\omega_p = 3200$Hz, $\omega_s = 9800$Hz $\alpha_{max} = 0.4$dB, $\alpha_{min} = 52$dB [3] (**74 Ch**)
h. $\omega_p = 1000$rad/s, $\omega_s = 1400$rad/s $\alpha_{max} = 0.25$dB, $\alpha_{min} = 18$dB [3] (**71 Ch**)
i. $\omega_p = 1000$rad/s, $\omega_s = 2000$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 20$dB [3] (71 Shr)
j. $\omega_p = 1000$rad/s, $\omega_s = 2500$rad/s $\alpha_{max} = 0.1$dB, $\alpha_{min} = 20$dB [3] (**70 Ch**)
k. $\omega_p = 1000$rad/s, $\omega_s = 1800$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 18$dB [3] (70 Asa)

9. Estimate the order of ICLPF with the following specifications:
a. $\omega_p = 1000$rad/s, $\omega_s = 1800$rad/s $\alpha_{max} = 0.5$dB, $\alpha_{min} = 25$dB [3] (80 Ba)
b. $\omega_p = 10000$rad/s, $\omega_s = 20000$rad/s $\alpha_{max} = 0.4$dB, $\alpha_{min} = 16$dB [2] (74 Ash)
c. $\omega_p = 1000$rad/s, $\omega_s = 1400$rad/s $\alpha_{max} = 0.25$dB, $\alpha_{min} = 18$dB [2] (**72 Ch**)

2.4 Characteristics of Cauer (elliptic) response

1. What are the characteristics of Elliptic Response? [3] (73 Shr, 71 Shr)

2. Compare elliptical response with chebyshev and inverse chebyshev response [2+2] (73 Shr)
$|\rightarrow$compare with inverse chebyshev response. [3] (71 Shr)

2.5 Bessel-Thomson approximation of constant delay

1. What is constant delay filter?
[1] (**80 Bh**,**70 Ch**, 81 Ba, 80 Ba, 79 Ba, 76 Ash, 74 Ash, 73 Shr, 70 Asa) [2] (**75 Ch**,**69 Ch**, 80 Ba, 75 Ash)

2. What is significance of constant delay filter? [1] (**76 Ch**, 80 Ba, 76 Ash) [2] (79 Ba)

3. What are the characteristics of Bessel-Thomson filter? [2] (**78 Bh**)

4. Derive a transfer function of a second order constant delay filter.
[3] (80 Ba, 73 Shr) [4] (**74 Ch**, 76 Ash, 74 Ash)

5. Find the transfer function of 3rd order Bessel Thomson low pass filter.
[3] (**79 Bh**,**75 Ch**, 79 Ba) [4] (**80 Bh**,**80 Bh**,**78 Bh**,**76 Ch**,**69 Ch**, 81 Ba, 75 Ash) [5] (80 Ba)
$|\rightarrow$for 4th order. [3] (**71 Ch**)

6. What are the steps involved in designing constant delay filter? Explain with example.[5] (**70 Ch**)
$|\rightarrow$same question, but with example of 2nd order filter. [5] (70 Asa)

2.6 Delay Equalization

1. What is delay and delay equalization? Explain with necessary figures [2+3] (**79 Bh**)
   |→What is delay equalization? [1] (**72 Ch**. 72 Ka)
2. What do you mean by phase and gain equalization. [2] (**81 Bh**)
3. What is the importance of all pass filters in delay equalization? [2] (**79 Bh**) [3] (**71 Ch**)
4. Mention the importance of delay equalization. [3] (74 Ash)
5. How is delay equalization done? Explain with necessary figures. [3] (72 Ka) [4] (**72 Ch**)

3 Frequency transformation

(2 Hours/4 Marks)

3.1 Frequency transformation and its importance in filter design

1. What is frequency transformation (**FT**)?
   [1] (**79 Bh**,**81 Ba**,**78 Bh**,**76 Ch**,**75 Ch**,**69 Ch**, 80 Ba, 79 Ba, 76 Ash, 74 Ash, 72 Kar) [2] (**74 Ch**,**73 Ch**)

2. What is the importance of FT? [1] (**78 Bh**,**75 Ch**,**70 Ch**, 81 Ba, 76 Ash, 75 Ash, 70 Asa) [2] (**71 Ch**)

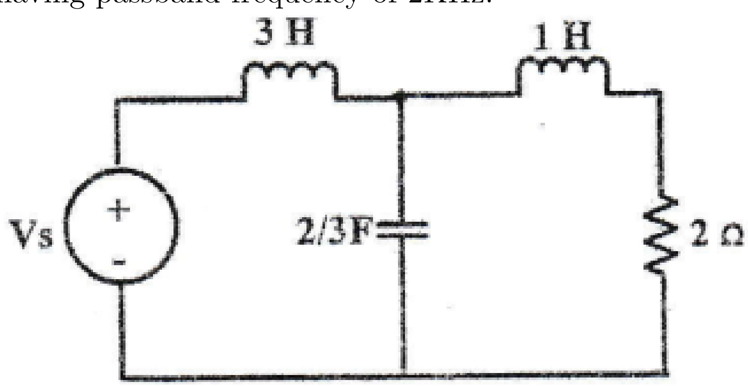
3. How FT reduces the design steps required to design a filter? [1] (**80 Bh**)

4. What are the application of FT in filter design? [1] (80 Ba) [2] (**72 Ch**)

3.2 Lowpass to highpass transformation

1. How can you obtain a high pass filter from a given low pass filter? Explain with suitable example. [4] (**72 Ch**, 80 Ba, 80 Ba)

2. The following LPF has passband frequency ω_p of 1 rad/s. Transform it into a highpass filter having passband frequency of 2KHz. [4] (73 Shr)



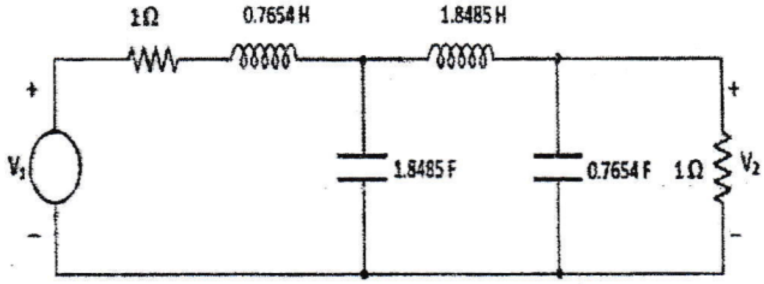
3.3 Lowpass to bandpass transformation

1. Describe the frequency transformation from LPF to BPF with a suitable example.
   [3] (**70 Ch**,**69 Ch**) [4] (74 Ash, 70 Asa) [5] (81 Ba, 81 Ba, 71 Shr)
   |→Derive the expression of RLC for FT from normalized LPF to BPF. [5] (**79 Bh**)

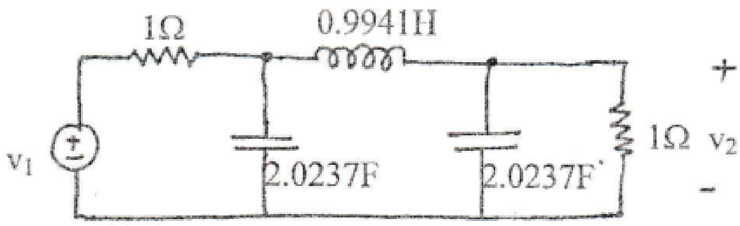
2. Design a Band pass filter having center frequency at 1500 rad/sec and bandwidth 300 rad/sec from a 4$^{\text{th}}$ order Butterworth low pass resistively terminated lossless filter. *[Refer Table].*
   [4] (**81 Bh**)
   |→ω_0 = 1 Krad/s, BW = 100 rad/s. [5] (**78 Bh**)

3. Obtain the BPF from LPF given in figure 1 having center frequency 10^4 rad/s and bandwidth of 9.9 x 10^4 rad/s. [4] (**73 Ch**)

4. Obtain a bandpass filter having $\omega_1 = 100$ rad/s and $\omega_2 = 1000$ rad/s from following LPF at normalized frequency. [4] (74 Ash)



5. The ckt given below is an LPF having passband frequency of 1 rad/s. Obtain a bandpass filter having $\omega_0 = 2000$ rad/s and B = 400 rad/s. [3] (**71 Ch**)

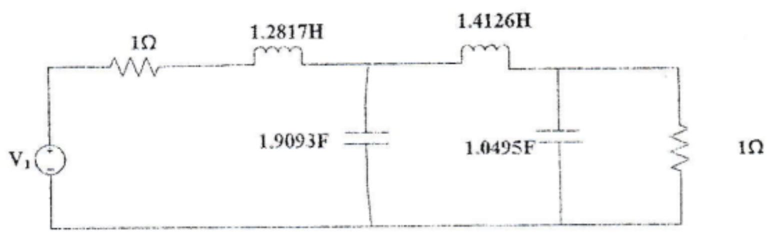


3.4 Lowpass to bandstop transformation

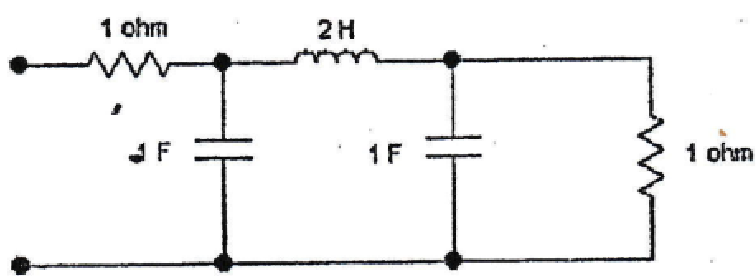
1. Explain the frequency transformation technique from a prototype LPF to BSF with necessary derivations. [3] (72 Kar) [4] (**81 Bh**,**74 Ch**, 79 Ba)

2. Design a bandstop filter having center frequency 2000rad/s and bandwidth 400 rad/s from a 3rd order Butterworth low pass filter. *[Refer Table]* [4] (**80 Bh, 79 Bh**,**76 Ch**,**75 Ch**)
   $|\rightarrow$from fourth order. [4] (75 Ash)

3. Following circuit is a low pass filter having $\alpha_p = 1$dB and $\omega_\mathrm{p} = 1$ rad/s. Obtain a bandpass filter $\omega_0 = 400$ rad/s and bandwidth of 150 rad/s. [4] (**80 Bh**)



4. Following filter has cutoff frequency at 1 rad/s. Transform it into a band pass filter having center frequency at 1000 rad/s and bandwidth of 1000 rad/s. [3] (76 Ash)



4 Properties and Synthesis of Passive Networks

(7 Hours/13 Marks)

4.1 One-port passive circuits

4.1.1 Properties of passive circuits, positive real functions

1. What are the required properties of a function to be realizable? [3] (71 Shr)

4.1.2 Properties of lossless circuits

1. Write the properties of lossless one port network. [2] (**81 Bh**, 76 Ash, 74 Ash) [3] (**78 Bh**,**76 Ch**)
2. How can you determine whether the given function is a valid lossless function or not? [3] (81 Ba)
3. Determine whether the following are lossless function or not? State with reason. [3+3+3] (**78 Bh**)

   $Z(s) = \frac{s^4+9s^2+8}{s^3+4s}2 \qquad Z(s) = \frac{s^3+s}{s^4+12s^2+32} \qquad Z(s) = \frac{s^3+4s}{s^4+4s^2+3}$

   Realize one of the valid lossless function using Foster Series and Cauer I methods.

4.1.3 Synthesis of LC one-port circuits, Foster and Cauer circuits

1. What are the properties of LC driving point impedance function? [3] (**79 Bh**, 81 Ba)
2. Which of the function is LC driving point impedance function? [2+3] (**79 Bh**)

   $Z(s) = \frac{8s^3+10s}{s^4+6s^2+5}, \qquad Z(s) = \frac{s^4+5s^2+4}{s^3+9s}$

3. Which of the following function is lossless and why? Find the Cauer-I and Foster-I expansion for the corresponding lossless function. [2+3+3] (**81 Bh**)

$$Z(S) = \frac{S^2+10S+24}{S^2+8S+15}$$
$$Z(S) = \frac{S^5+10S^3+24S}{S^4+6S^2+5}$$

4. Synthesize the given LC function in Foster I and Foster II networks: [6] (**81 Bh**)

   $F(s) = \frac{s(s^2+2)(s^2+4)}{(s^2+1)(s^2+3)}$

5. Synthesize the given LC impedance in Foster II and Caer I networks: [3+3] (**79 Bh**)

   $Z(s) = \frac{(s^2+1)(s^2+3)}{s(s^2+2)}$

6. Realize the fllowing function using Cauer I and Foster II method. [3+3] (74 Ash)

   $Z(s) = \frac{s(s^2+4)}{(s^2+2)(s^2+6)}$

7. Realize the given function using Cauer-I and Cauer-II method. [6] (72 Ka)

   $Z(s) = \frac{4s^4+40s^2+36}{s^3+4s}$

8. Realize the following LC function using Cauer II method. $Z(s) = \frac{s(s^2+3)}{(s^2+1)(s^2+4)}$ [4] (70 Asa)

9. Which of the following function is valid LC driving point impedance function? State with reason.
$$Z(s) = \frac{8s^3 + 10s}{s^4 + 6s^2 + 5}, \qquad Z(s) = \frac{(s^2+4)(s^2+9)}{(s^2+16)(s^2+25)}$$ [3+3] (81 Ba)
Find the Cauer second from of valid driving point impedance function.

10. Which of the following functions are the valid LC impedance function? State with reason.
$$Z(s) = \frac{(s^2+2)(s^2+4)}{s(s^2+1)(s^2+3)}, \qquad Z(s) = \frac{(s^1+1)(s^2+3)}{(s^2)(s^2+4)}, \qquad Z(s) = \frac{(s^2+1)(s^2+3)}{s(s^2+2)(s^2+4)}$$
Pick one valid LC impedance function and realize it in Foster I and Cauer II form.
[3+3+3] (81 Ba)

11. Which of the following is valid lossless function? State with reason.
$$Z(s) = \frac{(s^2+4)(s^2+5)}{(s^2+s^2)(s^2+10)}, \qquad Z(s) = \frac{s^4+4s^2+3}{s(s^2+2)}, \qquad Z(s) = \frac{s^6+4s^4+8s^2}{s^3+3s}$$
Pick one of the valid LC lossless functions and synthesize it using
$|\rightarrow$Foster II and Cauer II methods. [3+3+3] (**80 Bh**)
$|\rightarrow$Foster series nd cauer I methods. [2+3+3] (**80 Bh**)

12. Which of the following functions are LC driving point impedance function and why?
$$Z_1(s) = \frac{(s^2+1)(s^2+5)}{(s^2+2)(s^2+10)} \qquad Z_2(s) = \frac{5s(s^2+5)}{(s^2+1)(s^2+2)}$$
$$Z_3(s) = \frac{2(s^2+1)(s^2+9)}{s(s^2+4)} \qquad Z_4(s) = \frac{4(s+2)(s+5)}{(s+1)(s+4)}$$
Pick one of the valid LC driving point impedance and synthesize it in Foster-I and Cauer-I form.
[2+3+3] (79 Ba)

13. Which of the following function is LC one port driving point impedance function? Explain with suitable reason. [2+3+3] (**76 Ch**)
$$Z(s) = \frac{(s^2+1)(s^2+9)}{s(s^2+4}, \qquad Z(s) = \frac{s(s^2+4)(s^2+5)}{(s^2+3)(s^2+6)}$$
Realize a valid lossless one part function using Foster II and Cauer II methods.

14. Which of the following are valid LC function? State with reason. Realize one LC function using Cauer-I and Cauer-II method. [2+3+3] (76 Ash)
$$Z(s) = \frac{(s^2+1)(s^2+3)}{s(s^2+2)} \qquad Z(s) = \frac{s(s^2+2)}{(s^2+3)(s^2+4)}$$

15. Determine whether the following functions are lossless function or not? State with reason.
$$Z(s) = 2\frac{s^4+9s^2+8}{s^3+4s} \qquad Z(s) = \frac{s^3+s}{s^4+12s^2+32} \qquad Z(s) = \frac{s^4+4s}{s^4+4s+3}$$ Realize one of the valid lossless function using Foster Series method and Cauer II method.
[3+3+3] (**75 Ch**)

16. Which of the following is LC lossless functions and why? Pick one of the valid LC lossless functions and realize it using Foster-I and Cauer-I form. [3+3] (75 Ash)
$$Z_1(s) = \frac{s(s^2+4)(s^2+6)}{(s^2+3)(s^2+9)} \qquad Z_2(s) = \frac{(s^2+3)(s^2+6)}{s(s^2+4)(s^2+9)}$$
$$Z_3(s) = \frac{(s^2+4)(s^2+6)}{s(s^2+3)(s^2+9)} \qquad Z_4(s) = \frac{(s^2+3)(s^2+6)}{(s^2+4)(s^2+9)}$$

17. Which of the following functions are LC driving point impedance function and why?
$$Z(s) = \frac{s^4+10s^2+9}{s^4+4s} \qquad Z(s) = \frac{s^3+4s}{s^4+5s^2+6}$$ [2+3+3] (73 Shr)

Also find the Foster parallel and cauer I form of the valid LC driving point impedance function.

18. Which of the following is LC lossless function and why? Pick one of the valid LC lossless functions and synthesize it using Foster and Cauer methods. [2+3+3] (**72 Ch**)
$Z_1(s) = \dfrac{s(s^2+4)(s^2+9}{(s^2+2)(s^2+10}$ $\quad Z_2(s) = \dfrac{(s^2+2)(s^2+10)}{s(s^2+5)}$ $\quad Z_3(s) = \dfrac{s^2+25}{s(s^2+5)(s^2+50)}$

19. Which of the following functions are LC driving point impedance function and why? Also find the Foster series and Caucer II Realization of the valid LC driving point impedance function.
$Z(s) = 2\dfrac{(s^2+4)(s^2+16}{(s^2+1)(s^2+9}$ $\quad Z(s) = 4\dfrac{(s+2)(s+5)}{(s+1)(s+4)}$ [2+3+3] (**71 Ch**)

20. Which of the following functions are LC driving point impedance function and why? Pick one of the valid LC driving point impedance and synthesize it in Foster-I and Caver-I form:
$Z_1(s) = \dfrac{(s^2+1)(s^2+5}{(s^2+2)(s^2+10)}$ $\quad Z_2(s) = \dfrac{5s(s^4+4)}{(s^2+1)(s^2+3)}$ [2+3+3] (**70 Ch**)
$Z_3(s) = \dfrac{2(s^2+1)(s^2+9)}{s(s^2+4)}$ $\quad Z_4(s) = 4\dfrac{(s+2)(s+5)}{(s+1)(s+4)}$

21. Which of the following functions are LC driving point impedance and why? [4+3] (**69 Ch**)
$Z(s) = \dfrac{s(s^2+4)}{(s^2+9)(s^2+16)},$ $\quad Z(s) = \dfrac{s(s^2+1)(s^2+9)}{(s^2+4)(s^2+16)}$
$Z(s) = \dfrac{s(s^2+4)}{2(s^2+1)(s^2+9)},$ $\quad Z(s) = \dfrac{2(s+1)(s+3)}{(s+2)(s+4)}$
Also find the Cauer II realization of the valid LC driving point impedance function.

22. Synthesize a two port LC ladder to satisfy the following open circuit impedance parameters:
$z_{21}(s) = \dfrac{k(s^2+9}{s(s^2+4}$; $z_{22}(s) = \dfrac{(s^2+1)}{s(s^2+4)}$ [7] (72 Ka)

4.1.4 Properties and synthesis of RC one-port circuits

1. What are the properties of RC impedance function? [2] (**74 Ch**) [3] (**75 Ch**, 80 Ba, 80 Ba)
|→Explain with example. [4] (70 Asa)

2. Synthesize the given RC impedance in Foster and Cauer form. [3+3] (80 Ba)
$Z(s) = \dfrac{3(s+2)(s+4)}{s(s+3)}$

3. Which of the following are valid RC driving point impedance function and why? [5] (80 Ba)
$Z(s) = \dfrac{\text{(s+3)(s+6)}}{\text{(s+1)(s+5)}},$ $\quad Z(s) = \dfrac{\text{2(s+1)(s+3)}}{\text{(s+2)(s+4)}}$
Find Foster form of valid RC driing point impedance function.

4. Which of the following is valid RC impedance function? State with reason. Pick a valid RC impedance function and realize it using foster I and cauer I method. [2+3+3] (**74 Ch**)
$z(s) = \dfrac{s(s^2+2)}{(s^2+1)}$ $\quad z(s) = \dfrac{(s+1)(s+5)}{(s+3)(s+7)}$
$z(s) = \dfrac{(s+4)(s+7)}{(s+1)(s+5)}$ $\quad z(s) = \dfrac{(s+1)(s+3)}{(s+4)(s+5)}$

5. Which of the following functions are lossless impedance function? State with reason.
[2+3+3] (**73 Ch**)

$$\frac{(s^2+1)(s^2+9)}{(s^2+4)(s^2+16)} \qquad \frac{s(s^2+4)}{(s^2+1)(s^2+3)} \qquad \frac{2(s^2+1)(s^2+9)}{s(s^2+4)} \qquad \frac{s^5+4s^3+5s}{s^4+5s^2+6}$$

Synthesize one of the valid lossless impedance function using Foster I and Cauer I forms.

6. Which of the following function is valid RC admittance function? State with reason. Realize one of the RC admittance function in Foster II and RC ladder form. [2+3+3] (71 Shr)

$$Y(s) = \frac{(s+1)(s+3)}{(s+2)(s+4)}, \qquad Y(s) = \frac{(s^2+1)(s^2+3)}{(s^2+2)(s^2+4)}$$

$$Y(s) = \frac{(s+2)(s+4)}{(s+1)(s+3)}, \qquad Y(s) = \frac{(s+1)(s+3)}{s(s+2)(s+4)}$$

4.2 Two-port Passive Circuits

1. What do you mean by 2-port network? [1] (**81 Bh**)

4.2.1 Properties of passive two-port circuits, residue condition, transmission zeros

1. Explain the properties of lossless two port function. [3+3] (71 Shr)
2. What is called poles and transmission poles. [1] (**80 Bh**)
3. Define transmission zeros in two port network.
   [1] (**80 Bh**,**80 Bh**,**76 Ch**,**75 Ch**,**74 Ch**,**73 Ch**,**72 Ch**,**71 Ch**,**70 Ch**, 81 Ba, 80 Ba, 79 Ba, 75 Ash, 70 Asa) [2] (**79 Bh**)
4. How can zeros of transmission be realized in ckts?
   |→Explain with suitable diagrams. [4] (**79 Bh**,**76 Ch**) [5] (**75 Ch**, 81 Ba)
   |→Explain with examples. [3] (79 Ba) [4] (**74 Ch**,**73 Ch**,**72 Ch**,**71 Ch**, 70 Asa)
5. What are the different ways of producing zeros in a network realization? [3] (**80 Bh**)
   |→Explain with examples. [5] (80 Ba)
6. Explain the conversion of Z parameters in terms of Y parameters with necessary derivation for a two port passive network. [5] (**81 Bh**)
7. Explain the series connection of two 2 port networks with figure and derivation. [4] (**81 Bh**)

4.2.2 Synthesis of two-port LC and RC ladder circuits based on zero-shifting by partial pole removal

1. What is zero shifting? [2] (81 Ba)

2. How is zero shifting useful for two port networks synthesis? Explain with examples. [4] (81 Ba)

3. What is zero shifting by partial removal of pole? [1] (73 Shr)
   |→Explain w/ suitable example. [3] (**80 Bh**, 75 Ash) [4] (**71 Ch**,**69 Ch**) [5] (80 Ba)
   |→Explain its signficance with example. [5] (**78 Bh**)

4. Explain importance of zero shifting in two port network synthesis. [2] (**69 Ch**)

5. What do you mean by partial removal and complete of pole in the synthesis of 2-port lossless ladder network? Explain w/ examples. [6] (**79 Bh**)
   |→How can two-port passive circuits be synthesized using zero-shifting by partial pole removal? Explain. [4] (73 Shr)

5 Design of Resistivety-Terminated Lossless Fitter

(4 Hours/7 Marks)

5.1 Properties of resistively-terminated lossless ladder circuits, transmission and reflection coefficients

1. What is reflection coefficient? [1] (**79 Bh**,**80 Bh**,**70 Ch**, 73 Shr, 70 Asa) [1.5] (74 Ash)
2. What is transmission coefficient? [1] (**71 Ch**,**69 Ch**, 80 Ba, 73 Shr) [1.5] (74 Ash)
3. What information do you get from transmission coefficient? [1] (**75 Ch**,**71 Ch**,**69 Ch**, 80 Ba)
4. Describe the significance of reflection coefficient. [2] (**80 Bh**, 80 Ba)
5. What information do you get from reflection coefficient? [1] (**75 Ch**,**74 Ch**)
6. What information do you get when the value of reflection coefficient is zero? [1] (**78 Bh**, 81 Ba)
7. What do you understand when the transmission coefficient has unity value? [1] (72 Ka)
8. Derive the expression for reflection coefficient for a resistively terminated LC ladder network. [5] (**71 Ch**, 80 Ba)
9. What is transmission coefficient? What information do we get from it? [2] (80 Ba)
10. Realize the 3rd order Butterworth high pass filter using transfer function of LPF as $T(S) = \dfrac{1}{(S+1)(S^2+S+1)}$ in the form of doubly terminated LC ladder with $R_1 = R_2 = 1\Omega$. [5] (**81 Bh**)
11. Design a third order Butterworth low pass using a doubly terminated lossless ladder such that the transmission coefficient is $T(s) = \dfrac{1}{(s+1)(s^2+s+1)}$; with $R1 = 1\Omega$ and $R2 = 4\Omega$. [5] (79 Ba)
12. Design low pass filter using a doubly terminated lossless ladder such that the transmission coefficient is $T(s) = \dfrac{1}{(s+1)(s^2+s+1)}$; Having $R1 = 1\Omega$, and $R2 = 4\Omega$. [7] (76 Ash)
13. Realize the 3rd order Butterworth high pass filter in the form of doubly terminated ladder with $R_1 = R_2 = 1\Omega$. [6] (**80 Bh**)
14. Design a third order Butterworth low pass filter using Resistively terminated lossless ladder with equal termination of 1Ω. *[Refer Table]* [5] (**74 Ch**,**69 Ch**, 70 Asa) [6] (**70 Ch**, 72 Ka)
15. Design a third order Butterworth low pass filter using Resistively terminated lossless ladder with equal termination of 1Ω. *[Refer Table]* [5] (**78 Bh**) [6] (**81 Bh**, 81 Ba)
16. Realize a third order Butterworth low pass filter using resistively terminated lossless ladder with $R_1 = 1\Omega$ and $R_2 = 4\Omega$. *[Refer Table]* [5] (**79 Bh**)
17. Derive the 3rd order Butterworth low pass filter resistively-terminated lossless network with unequal termination of $R_1 = 1\Omega$ and $R_2 = 4\Omega$. [5] (**80 Bh**) [6] (**79 Bh**) [7] (**72 Ch**, 75 Ash)
18. Design a third order Butterworth low pass filter using a doubly terminated lossless ladder having $R_1 = 1\Omega$ and $R_2 = 4\Omega$. *[Refer Table]* [6] (**76 Ch**)

19. Design a second order Butterworth low pass filter using resistively terminated terminated lossless ladder with equal termination of 1Ω. $\mathrm{T(s)} = \dfrac{1}{s^2+\sqrt{2}s+1}$

[5] (**75 Ch**)

5.2 Synthesis of LC ladder circuits to realize all-pole lowpass functions

1. (assumed) What is GIC? How can it be used to avoid shunt inductors in LC ladder circuit?

   [5] (81 Bh)

2. What is GIC? How Antonious' GIC can be used to simulate grounded inductor? Explain with necessary figures and derivations. [6] (71 Shr)

3. Realize the following transfer function using LC Ladder with equal termination of $\mathrm{R_1} = \mathrm{R_2} = 1\Omega$.
   $T(s) = \dfrac{1}{s^2+\sqrt{2}s+1}$ [5] (80 Ba)

5.3 Synthesis of LC ladder circuits to realize functions with finite transmission zeros

1. How resistively terminated ladder network can be realized with finite transmission zeroes? Explain.

   [4] (73 Shr)
2. Design a 3^{rd} order Butterworth HPF in doubly-terminated LC ladder network. [5] (**81 Bh**)
3. Synthesize $\mathrm{T(s)} = \dfrac{1}{s^3+2s^2+2s+1}$ in LC ladder circuit terminated with $\mathrm{R_1} = \mathrm{R_2} = 1\Omega$.

   [5] (74 Ash)
4. Realize the third order Butterworth lowpass transfer function $\mathrm{T(s)} = \dfrac{1}{s^3+2s^2+2s+1}$ in the form of resistively terminated LC ladder with $\mathrm{R_1} = 1\Omega$and $\mathrm{R2} = 2\Omega$. [6] (**73 Ch**)

6 Active Filter

(7 Hours/12 Marks)

6.1 Fundamentals of Active Filter Circuits

6.1.1 Active filter and passive filter

1. What is active filter? [1] (**78 Bh**)
2. Differentiate active and passive filter. [2] (**80 Bh**) [4] (76 Ash)
3. What are the advantages of active filters over passive filters? [2] (81 Ba) [3] (**76 Ch**, 70 Asa)
4. What are the different techniques of designing higher order active filters? Discuss briefly. [4] (70 Asa)

6.1.2 Ideal and real operational amplifiers, gain-bandwidth product

6.1.3 Active building blocks: amplifiers, summers, intregrators

6.1.4 First order passive sections and active sections using inverting and non-inverting op-amp configuration

1. Realize a system using non-inverting op-amp configuration with
   |→zero at -5 and pole at -3 and having high frequency gain of 2. [5] (**81 Bh**)
   |→zero at s = -4, pole at s = -8 and high frequency gain of 2. [5] (**79 Bh**)
   |→zero at s = -2, pole at s = -5 and high frequency gain of 2. [3] (**71 Ch**)
   |→zero at 1000, pole at 100 and dc gain of 5. [3] (**76 Ch**)
   |→zero at -1000 pole at -100 with DC gain of 10. [5] (80 Ba)
   |→zero at -800, pole at -400, DC gain of 4. [5] (81 Ba)
2. Realize the following transfer function using non-inverting op-amp configuration.
   |→T(s) = $\frac{4(s+2)}{s+1}$ [3] (**80 Bh**)
   |→T(s) = $\frac{4(s+200)}{s+100}$ [4] (**80 Bh**)
   |→T(s) = $\frac{s+8}{s+2}$ [3] (76 Ash) [4] (**78 Bh**, 81 Ba, 72 Ka)
   |→T(s) = $7\frac{s+400}{s+200}$ (no inductors in design) [4] (**69 Ch**)
3. Realize the following transfer function by cascading two first order sections using inverting op-amp configuration.
   T(s) = $\frac{12}{s^2+8s+12}$ [5] (**72 Ch**) [6] (**79 Bh**)

6.2 Second order active sections (biquads)

1. What is quality factor and center frequency of LP biquad filter? Explain with diagram. [3] (**79 Bh**)

6.2.1 Tow-Thomas biquad circuit, design of active filter using TowThomas biquad

1. Draw the circuit diagram of Tow-Thomas Biquad ckt and derive its transfer function.
   [3] (**70 Ch**) [4] (**80 Bh**,**80 Bh**,**78 Bh**,**74 Ch**,**71 Ch**,**69 Ch**, 80 Ba, 79 Ba, 76 Ash, 73 Shr, 71 Shr)

2. Design a second order Butterworth LPF having half power frequency of 5 kHz using Tow-Thomas biquad circuit. Your final ckt should have all capacitors of 0.001μF. [4] (71 Shr)

3. Design Tow-Thomas biquad circuit with given info

Poles ($\sigma \pm j\omega$)	**DC Gain**	**Capacitor**	**Other Criteria / Notes**	**Marks & Year**
$-450 \pm j893.03$	1.5	–	Practically realizable values	[4] (**80 Bh**,**80 Bh**,**74 Ch**)
TF: $\dfrac{-2000}{s^2+500s+10^6}$	–	–	Realize LPF from given transfer function	[4] (73 Shr) [5] (**79 Bh**)
$-1000 \pm j8994.03$	1.89	0.01μF	–	[5] (**71 Ch**)
$-500 \pm j2449.49$	2	0.1μF	–	[5] (**70 Ch**)
$-750 \pm j661.44$	2	0.01μF	–	[4] (**69 Ch**)
$-400 \pm j3979.95$	4	–	Practically realizable values	[4] (80 Ba)
$-400 \pm j3979.95$	1.5	0.001μF	–	[4] (76 Ash)
$-400 \pm j3979.95$	1.5	0.001μF	–	[4] (76 Ash)
$-24000 \pm j32000$	2	–	Practically suitable elements	[4] (**78 Bh**)
$577 \pm j816.8$	2	0.01μF	–	[4] (79 Ba)
$-10000 \pm j17320.51$	2.5	0.001μF	–	[6] (80 Ba)

6.2.2 Sallen-Key biquad circuit and Multiple-feedback biquad (MFB) circuit

1. Draw the circuit diagram of Sallen-Key LP biquad ckt and derive the transfer function.
   [4] (**76 Ch**,**75 Ch**,**73 Ch**, 81 Ba, 75 Ash, 74 Ash, 70 Asa) [5] (**81 Bh**, 72 Ka)

2. How can you obtain highpass filter from lowpass one with Sallen-key biquad? [2] (74 Ash)

3. Design the second order lowpass Butterworth filter having half power frequency of 12KHz using Sallen-Key biquad circuit. [4] (74 Ash)
   $$\text{T(s)} = \frac{1}{s^2+\sqrt{2}s+1}$$

4. Design a 4$^{\text{th}}$ order Butterworth LPF using cascaded two Sallen-Key biquads having half power frequency of 1 kHz and largest capacitor of 0.1 μF in your final circuit. [8] (**79 Bh**)

5. Derive the transfer function of low pass sallen-key biquad filter *[Refer Table]*. The half power frequency should be 10kHz. Make the largest capacitance 0.01μF and overall gain be 1.
   [4+4] (81 Ba)

6. Design second order butterworth LPF using half power frequency of 10Khz using Sallen Key biquad. In your final design the value of capacitor must be 0.01μF and feedback resistors should also be equal. [4] (72 Ka)

7. Design a second order Butterworth LPF having half power frequency of 4kHz using Sallen-Key circuit. Your final circuit should have all capacitors of 0.01μF. Perform gain compensation if necessary. [4] (70 Asa)

8. Derive the transfer function of Sallen-Key LPF. Using Sallen and Key ckt, design an LPF having ω_0 of 1000 rad/s, quality factor of 0.866 and gain of 2. [4] (**73 Ch**)

9. Design ckt for transfer function T(s) = $\frac{1}{s^2 + 0.76s + 1}$ using Sallen-Key LPF. In your final design, capacitors must be 0.01μF and feedback resistors should be equal. [4] (**76 Ch**,**75 Ch**)

10. Design a second order Butterworth LPF using Sallen-Key biquad. In your final design the values of capacitors must be 0.01 μF and feedback resistors should be equal. [4] (75 Ash)

11. Realize the normalized transfer function of $\frac{1}{s^2 + s + 1}$ using Sallen-Key biquad circuit. In your final design, the half power frequency should be 1.8kHz and all capacitances of 10nF. [4] (81 Ba)

12. Design Sallen key LPF filter for fourth order Butter worth filter. The final circuit should have ω_0 = 10,000 rad/s and have practically realizable elements. [8] (**72 Ch**)

13. How is excess gain compensated in Sallen-Key circuit? Explain. [5] (**74 Ch**)
    $|\rightarrow$explain with necessary derivations and diagrams. [5] (80 Ba)

14. Why gain enhancement is needed in Sallen-Key biquad? Explain the gain enhancement in Sallen Key LP biquad. [2+4] (**81 Bh**)

15. How can gain enhancement be performed in Sallen-Key circuit? Explain with necessary diagram. [5] (73 Shr, 71 Shr)

16. Design a 4$^{\text{th}}$ order Butterworth LPF using cascade two MFB biquads with dc gain equal to unity and half power frequency at 1000rad/s. Make the largest capacitance 0.1 μF in your final circuit. [8] (**81 Bh**)

17. Design a MFB LP biquad for the transfer function as $T(s) = \frac{5}{s^2 + 1.2s + 1}$ [4] (**81 Bh**)

6.2.3 Cain reduction and gain enhancement

6.2.4 RC-CR transformation

7 Sensitivity

(3 Hours/5 Marks)

7.1 Sensitivity and importance of sensitivity analysis

1. What is sensitivity? [1] (81 Ba)
2. What is sensitivity analysis in filter design? [1] (81 Bh)
3. What is the importance of sensitivity analysis in filter design? [2] (80 Ba)
4. What information do you get when the sensitivity of y with respect to x is 0.1? [1] (80 Bh)

7.2 Definition of single parameter sensitivity

1. Explain the single parameter and multi-parameter sensitivity. [2] (81 Ba)

7.3 Centre frequency and Q-factor sensitivity

1. Perform sensitivity analysis for center frequency ω_0 of Tow Thomas low pass filter with respect to all the resistors and capacitors present in the circuit. [3] (80 Bh)

7.4 Sensitivity properties of biquads

1. Perform the sensitivity analysis of coo of Sallen-Key lowpass biquad filter. [4] (81 Ba)
2. Perform the sensitivity analysis of quality factor (Q) in Tow Thomas low pass biquad. [5] (81 Bh)
3. Explain the importance of sensitivity analysis in the design of filter. [2] (81 Ba)
4. Perform the sensitivity analysis of Ω_0 of sallen-key lowpass biquad filter. [5] (81 Ba) [4] (80 Ba)

7.5 Sensitivity of passive circuits

8 Design of High-Order Active Filters

(6 Hours/11 Marks)

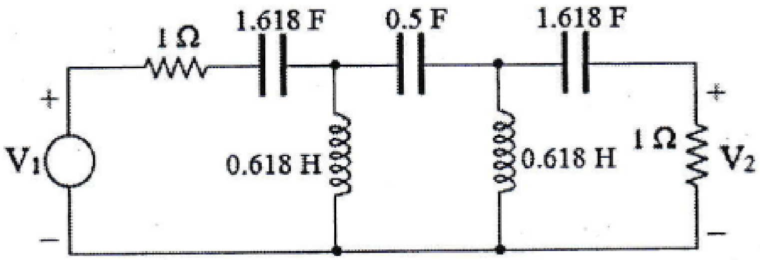
8.1 Cascade of biquads

8.1.1 Sequencing of filter blocks, center frequency, Q-factor and gain

8.2 Active simulation of passive filters

8.2.1 Ladder design with simulated inductors

1. What is a generalized impedance converter (GIC)? [1] (81 Ba)
2. How can you simulate the grounded inductor using GIC? [3] (81 Ba)
3. From the LC ladder given in figure below, design a highpass filter with a half power frequency of 5 kHz and the largest capacitance of 10nF using inductor simulation. [5] (81 Ba)



8.2.2 Ladder design with frequency dependent negative resistors (FDNR)

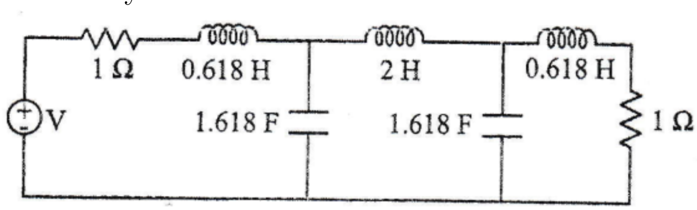
1. What is FDNR? How can you use FDNR to avoid the inductor in filter design? [4] (80 Bh)

2. What is FDNR? How can it be realized? [1+3] (80 Ba)

3. What is Bruton Transformation? Design the 4^{th} order Butterworth low pass filter with half power frequency 2,000 rad/sec and practically realizable elements using FDNR. *[Refer Table].* [2+4] (81 Bh)

4. Design third order Butterworth low pass filter having half power frequeuncy 4000rad/s using FDNR. *[Refer Table].* [6] (80 Bh)

5. Realize the following passive filter using FDNR, having ω_0 = 25000rad/s and practical element values in your final circuit. [5] (80 Ba)



8.2.3 Leapfrog simulation of ladders

1. Design the 4^{th} order Butterworth LPF in doubly-terminated network using Leapfrog simulation. The necessary information is listed in the given table below: [8] (81 Ba)

Order(n)=4 and LPF	R_1=1	L_1=0.7654	C_2=1.848	L_3=1.848	C_4 = 0.7654	R_2=1

9 Switched-Capacitor Filters

(4 Hours/7 Marks)

9.1 The MOS switch and switched capacitor

1. What is the importance of switched capacitor filters? [2] (81 Ba)

2. Why do we need switched capacitor to simulate resistor in MOS technology? [2] (80 Ba)

9.2 Simulation of resistor by switched capacitor

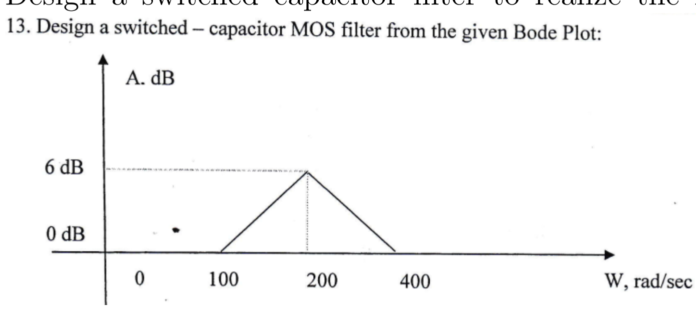
1. What is Switch capacitor filter? Design a switched capacitor filter to realize the transfer function. [6] (81 Ba)
   $T(s) = \dfrac{(s + 200)(s + 800}{(s + 400)^2}$

2. Why are resistors are replaced by switched capacitors in modern IC technology? [1] (81 Bh) [2] (80 Bh)

3. How can you simulate a resistor using switched capacitor? Explain w/ necessary derivations. [4] (80 Ba)

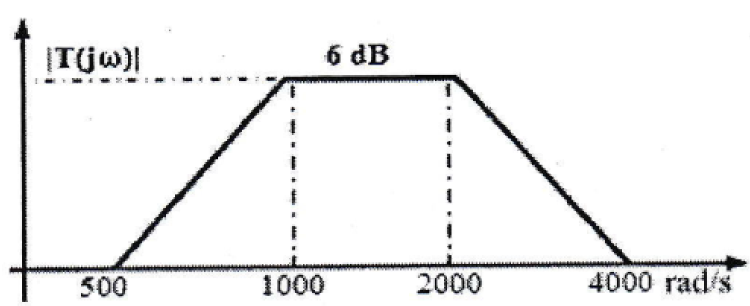
9.3 Switched-capacitor circuits for analog operations: addition, subtraction, multiplication and integration

1. Design a switched capacitor filter to realize the magnitude response given by the plot below:



[6] (81 Bh)

2. What is the importance of switched capacitor filters? Design a switched capacitor filter to realize the magnitude response specified by the following Bode Plot. [5] (81 Ba)



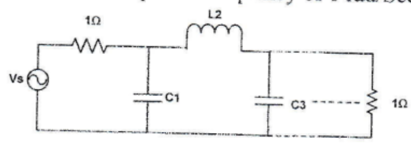
3. How summer, inverting integrator and non-inverting integrator can be realized using switched capacitor? Explain with necessary diagrams and expressions. [4] (80 Bh)

9.4 First-order and second-order switched-capacitor circuits

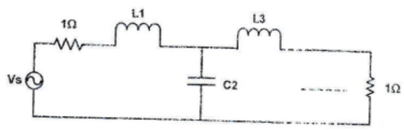
10 Tables

10.0.1 81 Bh/80 Bh

Table: Elements values for doubly terminated Butterworth low pass filter normal to half power frequency of 1 rad/Sec



n	C1	L2	C3	L4	C5
2	1.414	1.414			
3	1	2	1		
4	0.7654	1.848	1.848	0.7654	
5	0.618	1.618	2	1.618	0.618
n	L1	C2	L3	C4	L5



10.0.2 81 Ba

Pole location for Butterworth low pass filter with half power frequency 1 rad/s

n=2	n=3	n=4	n=5
- 0.7071068 ± j 0.7071068	- 0.50 ± j 0.86603	- 0.3826834 ± j 0.9238795	- 0.809017 ± j 0.5877852
	- 1.0	- 0.9238795 ± j 0. 3826834	- 0.309017 ± j 0. 9510565
			-1.0