07.10.25

UNIT - IV

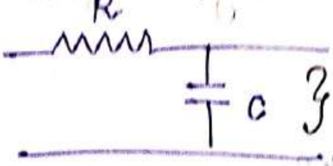
Filters

* Removes unwanted signal.
* To allow/stop set of frequencies

Lower order frequencies:

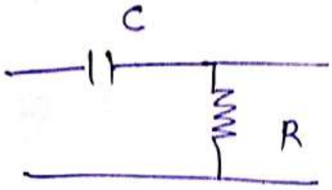
→ LPF
→ HPF
→ BPF
→ BSF

LPF

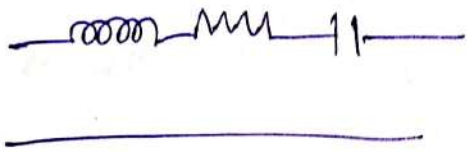


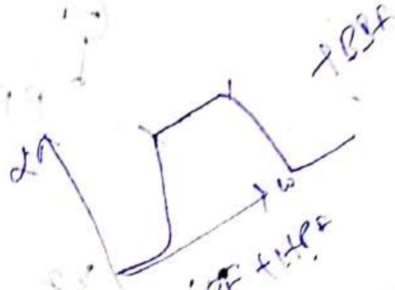
} drops, allows low frequency on hence cap takes high freq.

HPF

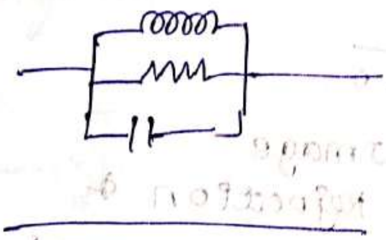


BPF





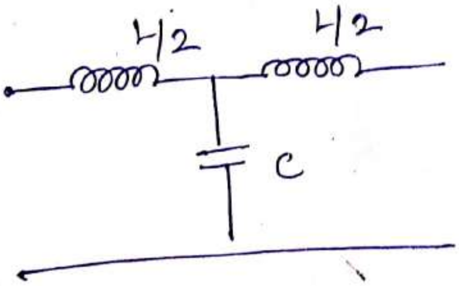
BSF



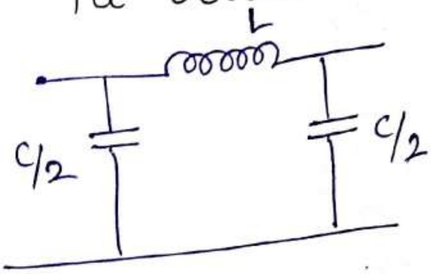
Higher order frequencies

LPF

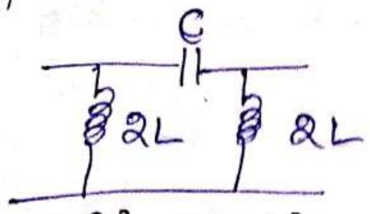
T. section



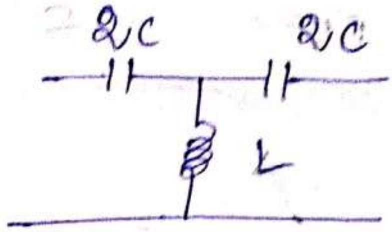
Pi section



HPF



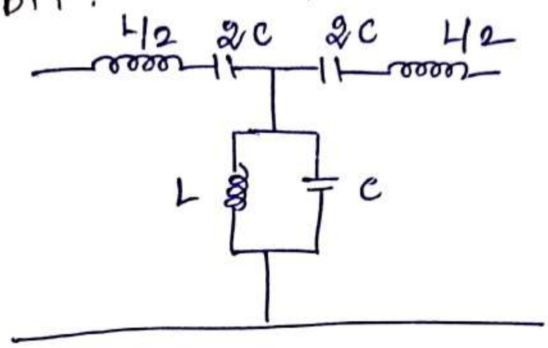
Pi section



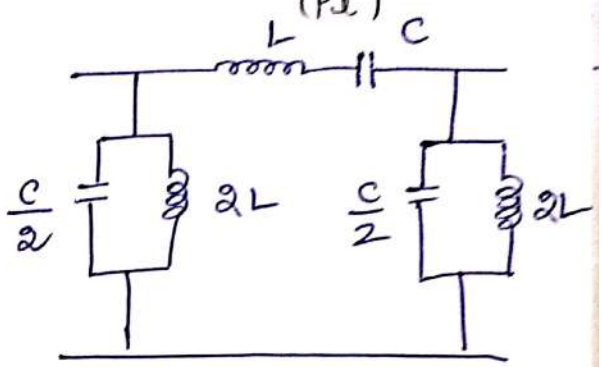
T section

BPF:

(T)

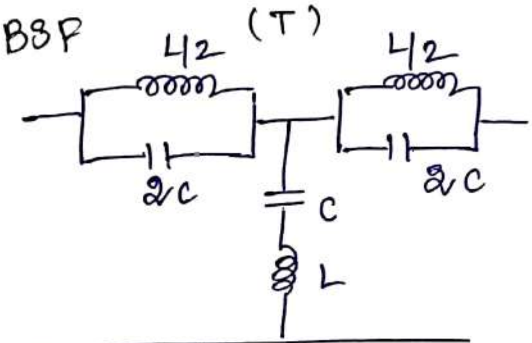


(Pi)

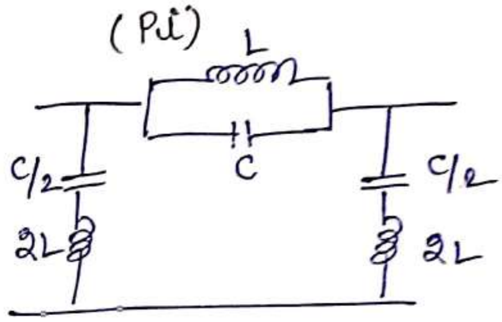


BSF

(T)



(Pi)



propagation constant

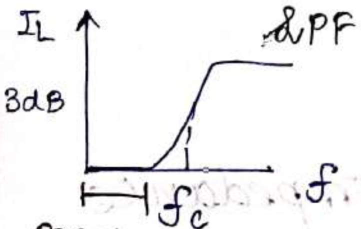
$\gamma = \alpha + j\beta$ α = attenuation constant.

β = phase constant

pass band $\alpha = 0$

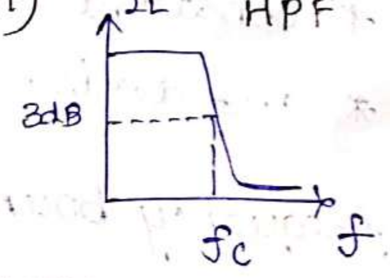
stop band $\gamma \simeq \alpha \uparrow$ (higher quantity)

pass band characteristics (wrt Insertion loss)
(Attenuation)

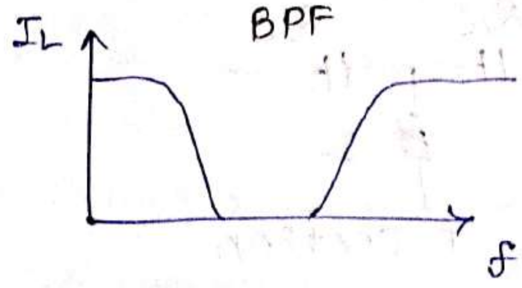


pass band.

Half power taken (3dB)
Insertion loss less
in pass band

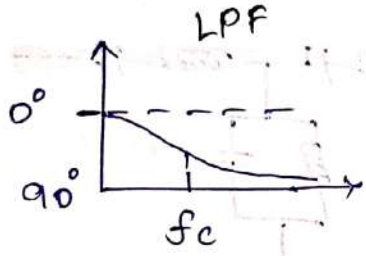


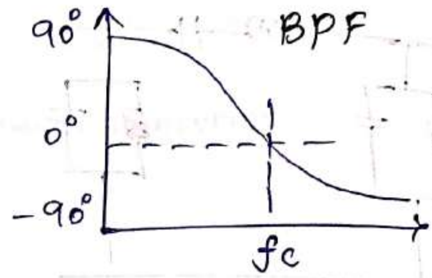
I_L is higher

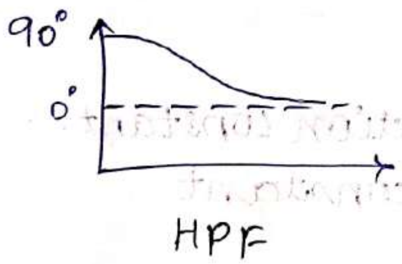


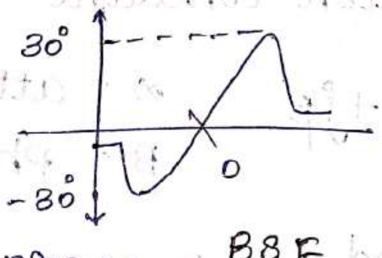
∴ Realtime loss is more important on purchasing a component I_L wrt filter is known.

Phase constant:









with attenuation + phase can define pass band characteristics
classical methods:

+ Image parameters methods

  * constant K

  * m - derived

At frequency boundaries → Impedance match → No reflections → classify LPF, HPF ...

→ Insertion loss method

* Tuning for specific frequency.

* Involves N/W synthesis for Butterworth and chebyshev.

Impedance Matching :

→ Design filter section T/pi so that input - output impedance match at boundaries ensuring minimum reflections.

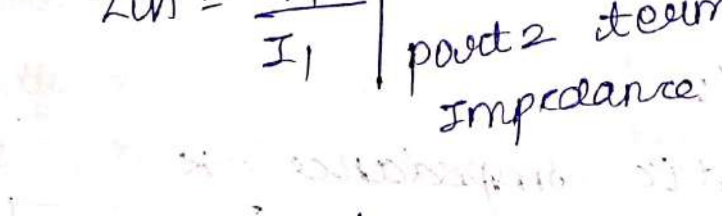
Image parameter methods principles are

→ Image Impedance

→ propagation constant.

Let $Z_{in} = Z_{out} = Z_I$ → symmetrical network.

To find Impedance at input side considering output is matched with input Impedance (Terminated) Image.



$Z_{in} = \frac{V_1}{I_1}$ | port 2 terminated Image Impedance (of Zin) $Z_{I,2}$

$Z_{out} = \frac{V_2}{I_1}$ | port 1 terminated with $Z_{I,1}$ (Image)

Scanned with CamScanner

For series Impedance $= Z_1$ and shunt Impedance $= Z_2$

For constant - K

T-section:

Image Impedance $Z_I = \sqrt{Z_1 Z_2 + Z_1^2/4}$

$$\cosh(\gamma) = 1 + \frac{Z_1}{2Z_2}$$

π - section:

$$Z_{img} = \sqrt{\frac{Z_1}{4}(Z_1 + 4Z_2)}$$

$$\cosh(\gamma) = 1 + \frac{Z_2}{2Z_1}$$

Low pass filter :

series Impedance as $j\omega L$

shunt Impedance as $\frac{1}{j\omega C}$

$Z_{imag} = 50.$

Relation between Input & output Impedance:

$\therefore K^2 = Z_1 Z_2$

characteristic Impedance $= K$

$\omega_c = \frac{1}{\sqrt{LC}}$ (cut off freq)

$$\boxed{K = \sqrt{\frac{L}{C}}}$$

$$Z_I = \sqrt{Z_1 Z_2 + Z_1^2/4}$$

$$= \sqrt{j\omega L \cdot \frac{1}{j\omega C} + \frac{(j\omega L)^2}{4}}$$

$$\boxed{\omega_c = \frac{1}{\sqrt{LC}}}$$

$\omega < \omega_c \Rightarrow$ pass band $\alpha = 0$

$\omega > \omega_c \Rightarrow$ stop band $\alpha =$ present.

HPF

$$\omega_c = \frac{1}{\sqrt{LC}}$$

$\omega < \omega_c$ = stop band

$\omega > \omega_c$ = pass band

BPF

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}} \qquad \omega_2 = \frac{1}{\sqrt{L_2 C_2}}$$

08.10.25

1. Design a constant K - T section low pass filter with a cut off frequency of 10 MHz with a matched impedance of 50 Ω. Construct the design to High pass filter

2. Design a Band pass filter whose center frequency is 50 MHz with a BW of 10 MHz terminated with 50 Ω impedance.

Design a Band stop filter using the same credential.

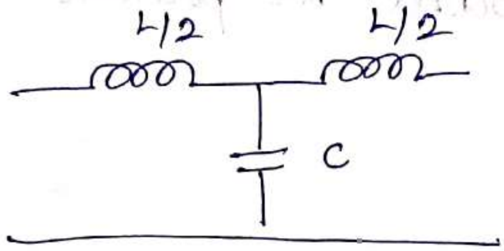
3. construct a Low pass and high pass π filter using (Q1) credentials

Soln

1. T-section:

$f_c = 10\,MHZ$; $R_0 = 50\,\Omega$

LPF



$K = R_0 = 50\,\Omega$

$2\pi f_c = \omega_c = 2\pi \times 10 \times 10^6 = 62.831 \times 10^6\ rad$

$K^2 = \underset{\uparrow series}{Z_1}\, Z_2 \rightarrow shunt.$

$= j\omega L \cdot \frac{1}{j\omega C}$

$K^2 = \frac{L}{C} \Rightarrow K = \sqrt{\frac{L}{C}} \Rightarrow C = \frac{L}{K^2}$ and $L = K^2 C$

$\omega_c = \frac{1}{\sqrt{LC}} \Rightarrow \omega_c = \frac{1}{\sqrt{K^2 C \cdot C}} = \frac{1}{\sqrt{K^2 C^2}}$

$\omega_c = \frac{1}{KC}$

$$\boxed{C = \frac{1}{K\omega_c}}$$

Scanned with CamScanner

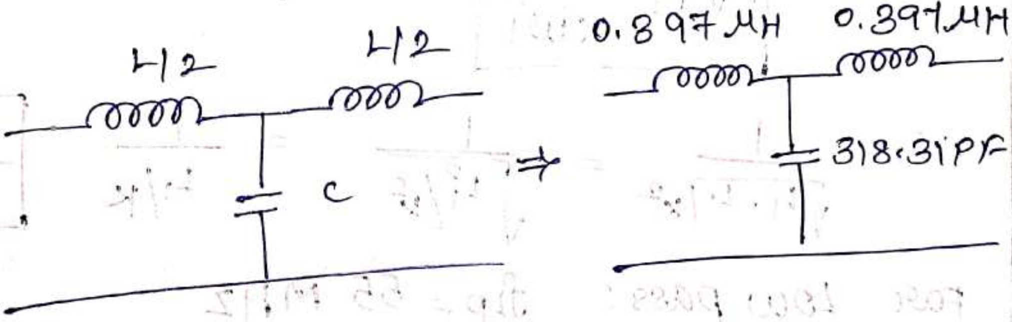
$$\omega_c = \frac{1}{\sqrt{L \cdot L/K^2}} = \frac{1}{\sqrt{L^2/K^2}} = \frac{1}{L/K}$$

$$\omega_c = \frac{K}{L} \Rightarrow \boxed{L = \frac{K}{\omega_c}}$$

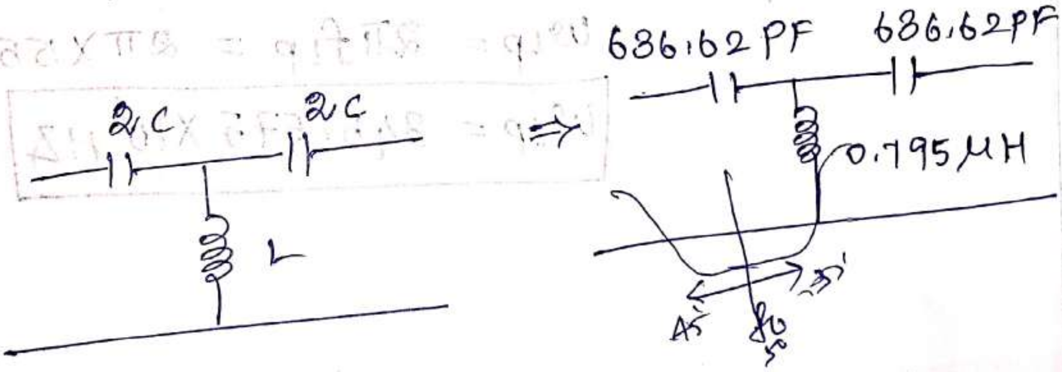
$$C = \frac{1}{50 \times 62.831 \times 10^6} = 318.31\,pF \qquad \boxed{C = 318.31\,pF}$$

$$L = \frac{50}{62.831 \times 10^6} = 795.785\,nH \qquad \boxed{L = 0.795\,\mu H}$$

LPF:



HPF



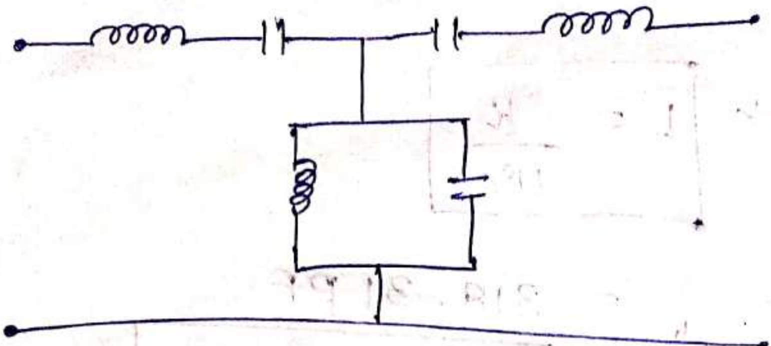
2. BPF $f_0 = 50\,MHZ$ $BW = 10\,MHZ$

$f_{LP} = 45\,MHZ$

$f_{HP} = 55\,MHZ$

Constant-K Filter (Bandpass)

⇒ T- section:



$K^2 = L/C \Rightarrow K = \sqrt{L/C}$. $C_1 = \frac{L}{K^2}$ and $L = K^2 C$

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{K^2 C_1 \cdot C_1}} = \frac{1}{K C_1}$$

$$\boxed{C_1 = \frac{1}{K\omega_1}}$$

$$\omega_1 = \frac{1}{\sqrt{L_1 \cdot L_1/K^2}} = \frac{1}{\sqrt{L_1^2/K^2}} = \frac{1}{L_1/K} \qquad \boxed{\frac{K}{\omega_1} = L_1}$$

For low pass: $f_{LP} = 45\,MHZ$

$$\omega_{LP} = 2\pi \times 45 \times 10^6$$

$$\omega_{LP} = 282.74\,MHZ$$

Limitations on constant K

→ Amplitudes are not easily shaped (no smooth transition)

→ Non linear phase nearer to cutoff

→ Image Impedance are dependable on frequency

→ Difficult to match impedances

$$C = \frac{1}{K\omega_c}$$

$$C = \frac{1}{50 \times 2\pi \times 45 \times 10^6}$$

$$\boxed{C = 70.735\,PF}$$

$$L = \frac{K}{\omega_c}$$

$$= \frac{50}{2\pi \times 45 \times 10^6}$$

$$\boxed{L = 176.838\,nH}$$

For High pass:

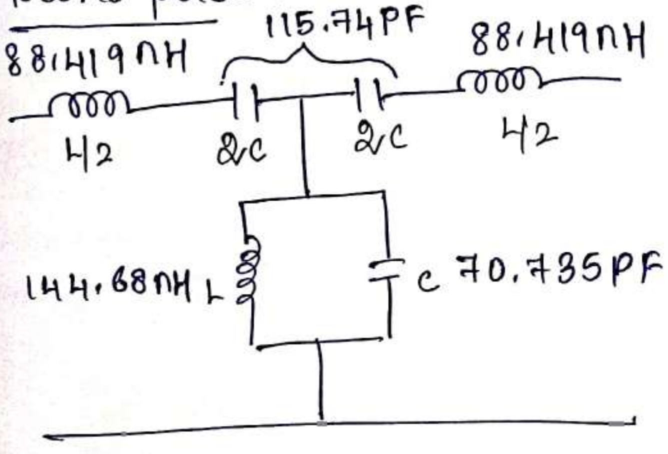
$$C = \frac{1}{K\omega_c} = \frac{1}{50 \times 2\pi \times 55 \times 10^6}$$

$$\boxed{C = 57.874\,PF}$$

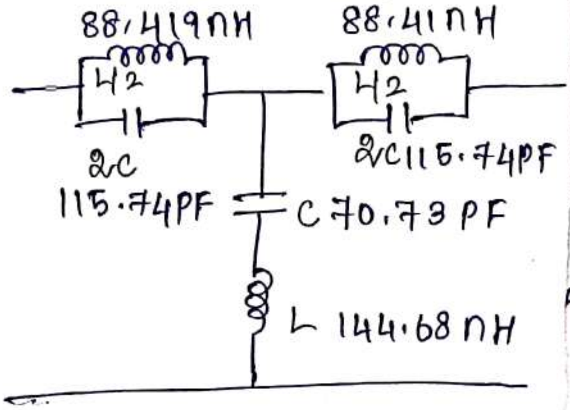
$$L = \frac{K}{\omega_c} = \frac{50}{2\pi \times 55 \times 10^6}$$

$$\boxed{L = 144.68\,nH}$$

Band pass:



Band stop:



π - section

$$C = \frac{2}{K\omega_c}$$

$$L = \frac{K}{2\omega_c}$$

Low pass

$$C = \frac{2}{50 \times 2\pi \times 45 \times 10^6} = 141.471\,pF$$

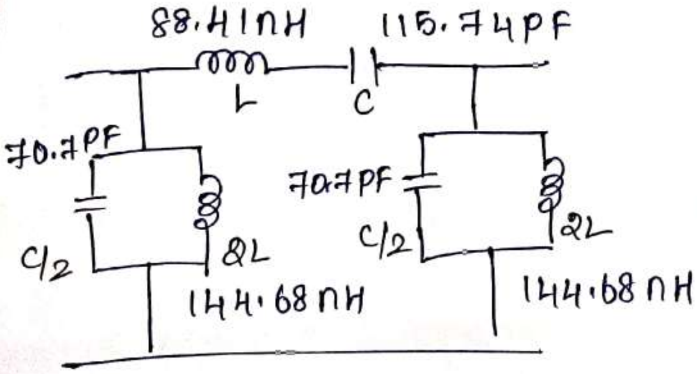
$$L = \frac{K}{2\omega_c} = \frac{50}{2 \times 2\pi \times 45 \times 10^6} = 88.419\,nH$$

High pass

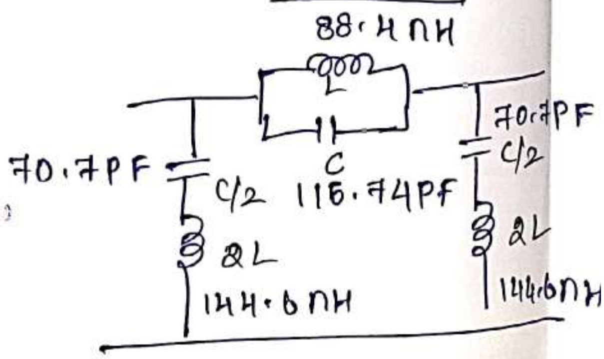
$$C = \frac{2}{K\omega_c} = \frac{2}{50 \times 2\pi \times 55 \times 10^6} = 0.115\,nH = 115.74\,pF$$

$$L = \frac{K}{2\omega_c} = \frac{50}{2 \times 2\pi \times 55 \times 10^6} = 72.34\,nH$$

Band pass



Band stop



3. Pi network:

For π section,

$$K^2 = \frac{4L}{C}$$

$$C = \frac{4L}{K^2} \quad \text{and} \quad 4L = K^2 C$$

$$L = \frac{K^2 C}{4}$$

For C

$$\omega_c = \frac{1}{\sqrt{LC}}$$

$$\omega_c = \frac{1}{\sqrt{\frac{K^2C}{4} \cdot C}} = \frac{1}{\sqrt{\frac{K^2C^2}{4}}} = \frac{1}{\frac{KC}{2}}$$

$$\omega_c = \frac{2}{KC}$$

$$\boxed{C = \frac{2}{K\omega_c}}$$

For L

$$\omega_c = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{L \cdot \frac{4L}{K^2}}}$$

$$= \frac{1}{\sqrt{\frac{4L^2}{K^2}}}$$

$$= \frac{1}{\frac{2L}{K}} = \frac{K}{2L}$$

$$\omega_c = \frac{K}{2L}$$

$$\boxed{L = \frac{K}{2\omega_c}}$$

$f_c = 10MHZ$

$Z_0 = 50\Omega$

$$C = \frac{2}{K\omega_c}$$

$\omega_c = 2\pi f_c = 2\pi \times 10 \times 10^6 = 62.832 MHZ.$

$$C = \frac{2}{50 \times 62.832 \times 10^6}$$

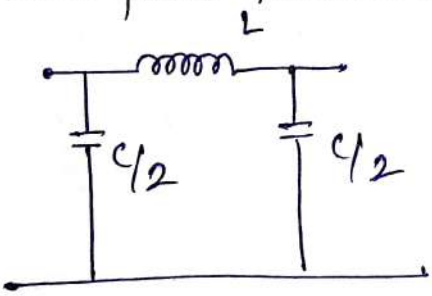
$$\boxed{C = 636.62 pF}$$

$$L = \frac{K}{2\omega_c} = \frac{50}{2 \times 62.832 \times 10^6}$$

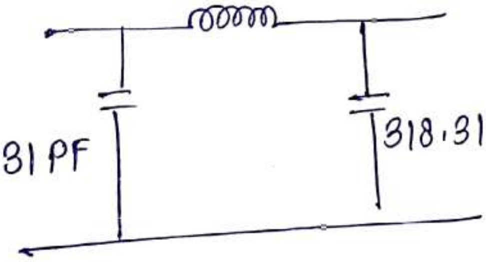
$$\boxed{L = 397.886 nH / 0.398 \mu H}$$

Design:

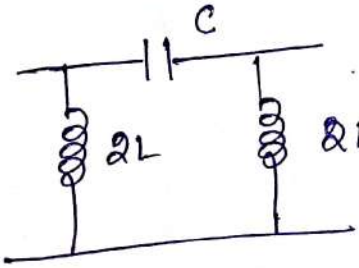
i) Low pass filter:



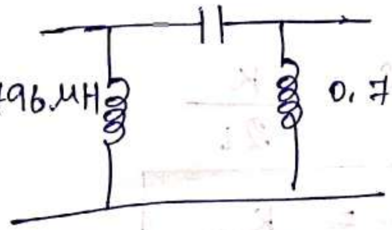
⇒



ii) High pass Filter:



⇒



constant K - section

1) T- section:

$$K = \sqrt{Z_1 Z_2 + Z_1^2/4}$$

$$K = \sqrt{j\omega L \cdot \frac{1}{j\omega C} + \frac{(j\omega L)^2}{4}}$$

$$K = \sqrt{\frac{L}{C} + \frac{(-\omega^2 L^2)}{4}}$$

$$K^2 = \frac{L}{C} - \frac{\omega^2 L^2}{4} \qquad \omega <<<$$

$$\boxed{K^2 = L/C}$$

2) π - section:

$$K = \sqrt{\frac{Z_1}{4}(Z_1 + 4Z_2)}$$

$$= \sqrt{\frac{Z_1^2}{4} + 4 Z_1 Z_2}$$

$$= \sqrt{\frac{-\omega^2 L^2}{4} + \frac{4L}{C}}$$

$$K = \sqrt{4L/C}$$

$$\boxed{K^2 = \frac{4L}{C}}$$

13.10.25

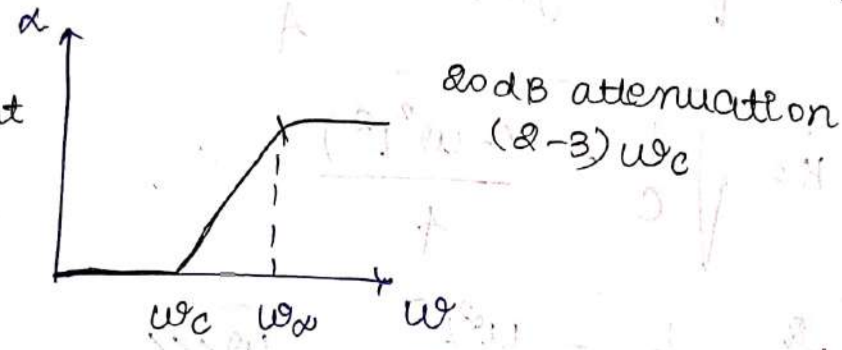
m-derived Filter:

constant K-filter

1. Non-constant Image Impedance
(Frequency ∝ Image Impedance)

2. slow attenuation rate near cut-off

Constant K LPF



To address these drawback → m-derived

LPF T section:

a) constant K

$Z_1 = j\omega L$

$Z_2 = \frac{1}{j\omega C}$

For m-derived:

$Z_1' = mZ_1$

To retain Image Impedance how our Z_2' should be

we know that

$$Z_{1T} = \sqrt{Z_1 Z_2 + \frac{Z_1^2}{4}}$$

$$= \sqrt{Z_1' Z_2' + \frac{(Z_1')^2}{4}}$$

$$z_1' z_2' + \frac{(z_1')^2}{4} = z_1 z_2 + \frac{z_1^2}{4}$$

$$z_1' z_2' = z_1 z_2 + \frac{z_1^2}{4} - \frac{(z_1')^2}{4}$$

$$(m z_1) z_2' = z_1 z_2 + \frac{z_1^2}{4} - \frac{m^2 z_1^2}{4}$$

$$m z_1 z_2' = z_1 z_2 + \frac{z_1^2}{4}(1-m^2)$$

$$z_2' = \frac{z_1 z_2}{m z_1} + \frac{\frac{z_1^2}{4}(1-m^2)}{m z_1}$$

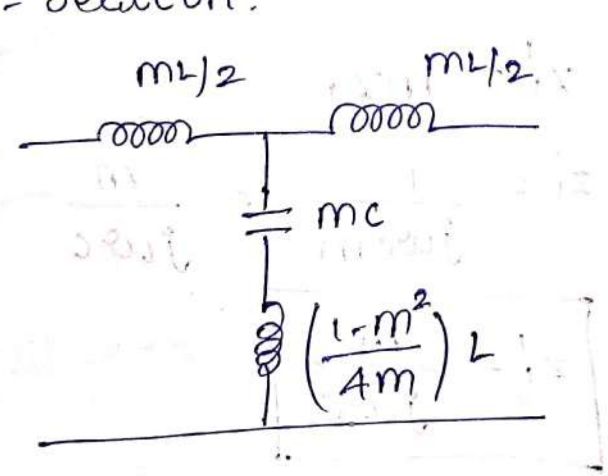
$$\boxed{z_2' = \frac{z_2}{m} + \frac{z_1}{4m}(1-m^2)}$$

$$z_1' = m z_1 = m \cdot j\omega L$$

$$z_2' = \frac{1}{j\omega c m} + j\omega L \frac{(1-m^2)}{4m}$$ (Both L & C) component.

m - derived

T - section:



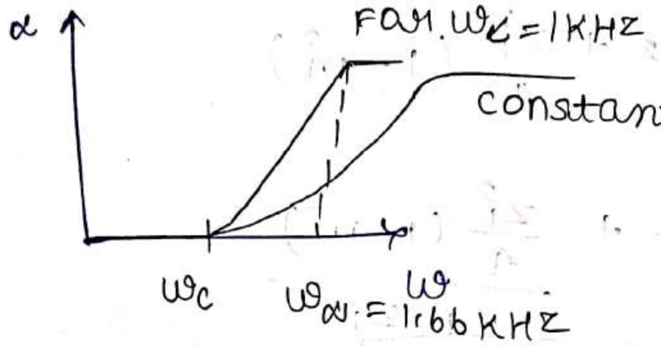
$0 < m < 1$

If $m=1$ then constant K filter

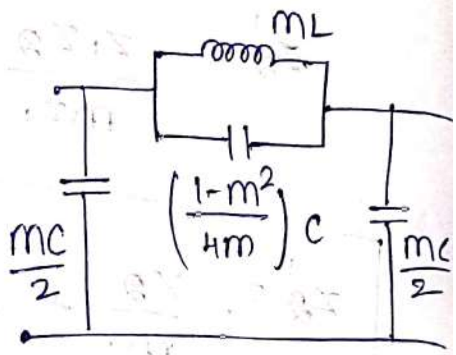
$$\omega_\infty = \frac{\omega_c}{\sqrt{1-m^2}} \qquad m<1$$

If $\omega_c = 1\,KHZ$ and $m = 0.8$ then

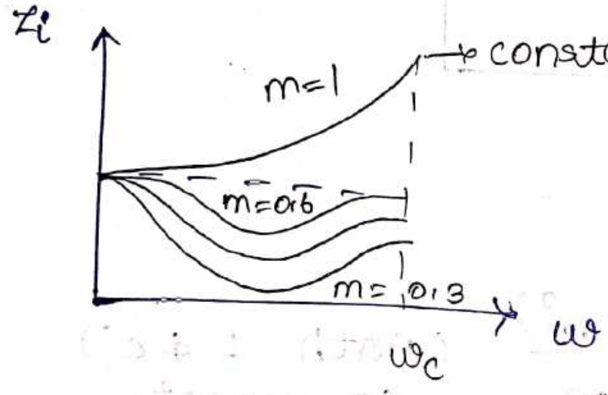
$$\omega_\infty = \frac{1\,KHZ}{\sqrt{1-(0.8)^2}} = 1.66\,KHZ$$



LPF π



$m = 0.6$ for real time



At pass band, fluctuations when $m = 0.3$ but compensated by $m=0.6$ with short circuit (better) in attenuation

High pass Filter

For constant K

$$Z_1 = \frac{1}{j\omega C} \qquad Z_1' = mZ_1$$

$$Z_2 = j\omega L \qquad Z_1' = \frac{1}{j\omega C m} = \frac{m}{j\omega C}$$

$$\boxed{Z_1' = \frac{m}{j\omega C}}$$

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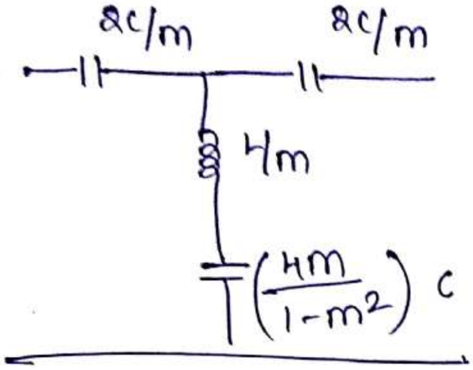
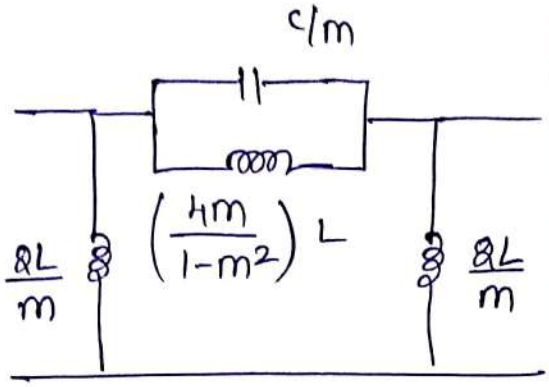
$$Z_2' = \frac{j\omega L}{m} + \frac{1}{j\omega C}\left(\frac{1-m^2}{4m}\right)$$

For m - derived



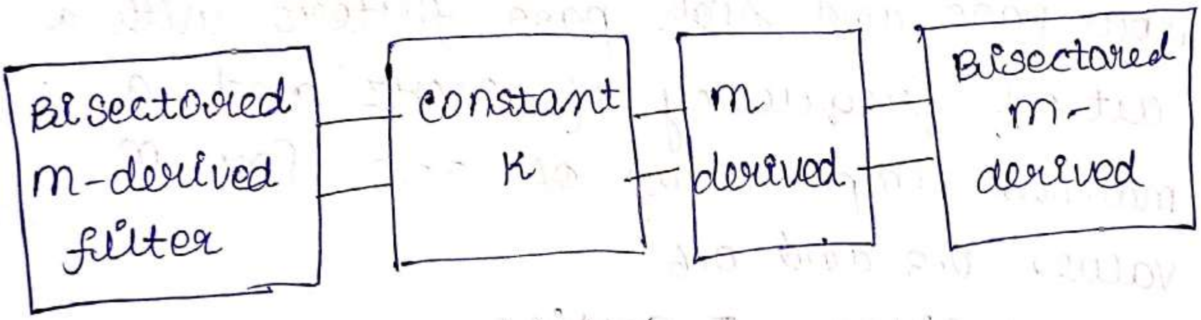
T- section



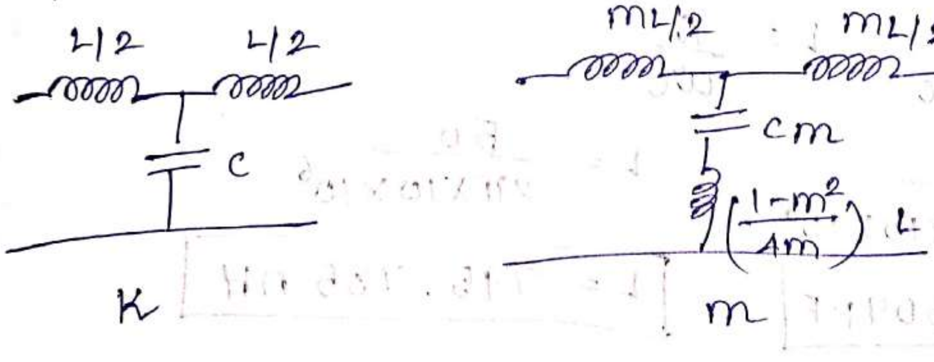
pi section

composite Filter:

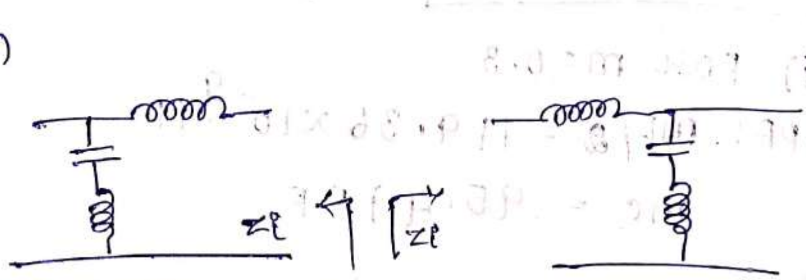
constant K with m derived along with Impedance matching network.

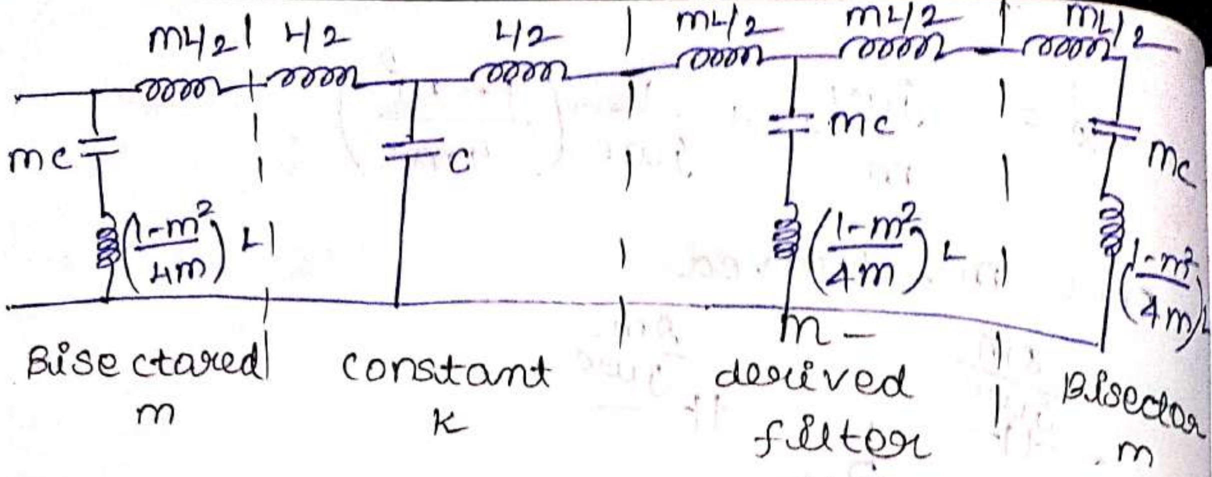


composite Low pass filter

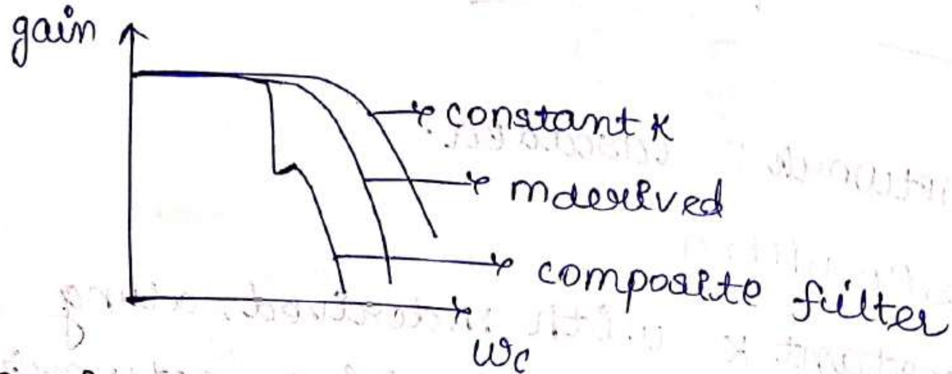


Bisectored m





sharp cut off - freq in feasible way for composite



4. Design a m-derived T and pi section low pass and high pass filters with a cut off frequency of 10 MHZ and a matched impedance of 50Ω for m values 0.3 and 0.6

Low pass filter - T section

T - section:

$$C = \frac{1}{K\omega_c} \quad L = \frac{K}{\omega_c}$$

$$C = \frac{1}{50 \times 2\pi \times 10 \times 10^6} \qquad L = \frac{50}{2\pi \times 10 \times 10^6}$$

$$\boxed{C = 318.309\,PF} \qquad \boxed{L = 795.785\,nH}$$

i) For m = 0.3

LPF: $mL/2 = 119.36 \times 10^{-9}\,H$

$mc = 95.49\,PF$

$\left(\frac{1-m^2}{4m}\right)L = \left(\frac{1-0.3^2}{4\times0.3}\right)L = 54.3123\,nH$

HPF: $\frac{2C}{m} = 2122.06\,PF$ $\quad L/m = 2652.61\,nH$

$\left(\frac{4m}{1-m^2}\right)C = \left(\frac{4\times0.3}{1-0.3^2}\right)C = 419.748\,PF.$

ii) For $m=0.6$

LPF: $mL/2 = 238.73\,nH$ $\quad mC = 190.98\,PF$

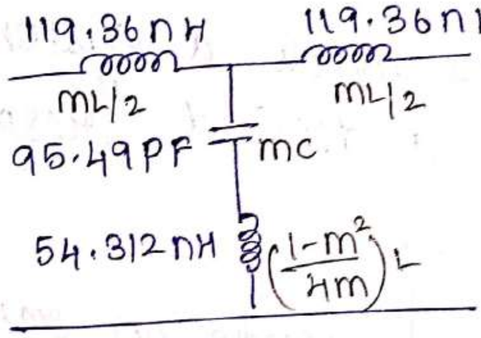
$\left(\frac{1-m^2}{4m}\right)L = \left(\frac{1-0.6^2}{4\times0.6}\right)L = 76.395\,nH$

HPF: $\frac{2C}{m} = 1061.03\,PF$ $\quad L/m = 1326.30\,nH$

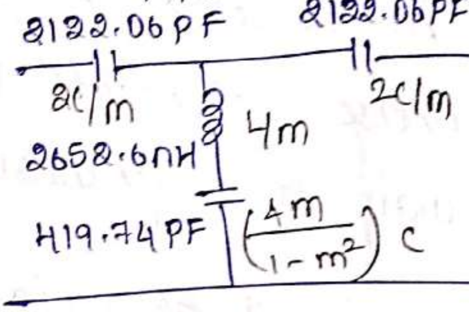
$\left(\frac{4m}{1-m^2}\right)C = \left(\frac{4\times0.6}{1-0.6^2}\right)C = 1193.658\,PF$

For $m=0.3$

LPF:

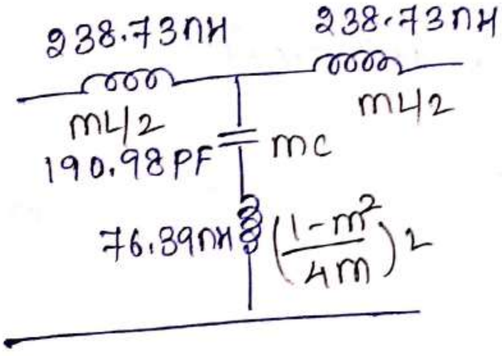


HPF

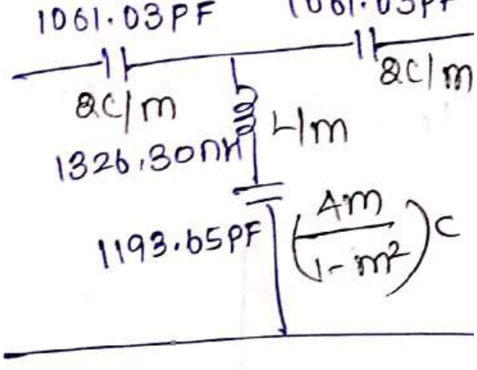


For $m=0.6$

LPF:



HPF



14.10.25

Filter design:

→ pass band → zero Insertion loss

→ stop band → Infinite attenuation

→ pass band → linear phase → To avoid signal distortion

In Image parameter method; there is no methodical way of improving the design

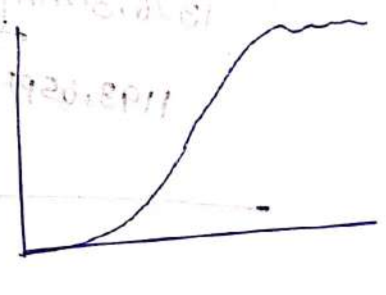
Insertion loss method:

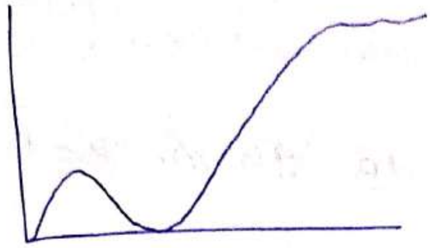
→ High degree of control over the pass band and stop band amplitude and phase characteristics with a systematic way to synthesize a desired response

* Binomial
* chebyshev
* linear phase

Depends on response polynomial

For flat response → Binomial





For sharp cutoff chebyshev.

ripples → chebyshev.

Define Insertion loss and then with matching L, C components.

For linear phase and flat response we go for linear phase method.

Insertion loss:

$$I_L = 10 \log (\text{power loss ratio})$$

$$\text{power loss ratio} = \frac{P_{in}}{P_{load}}$$

In terms of reflection coefficients

$$= \frac{1}{1-|\Gamma|^2} \qquad \Gamma = \frac{Z_{in}-Z_0}{Z_{in}+Z_0}$$

Binomial (Flat response):

$$\text{power loss ratio } PLR = 1+K^2\left(\frac{\omega}{\omega_c}\right)^{2N}$$

N = order of filter (highest degree of pole → order of system)

At the edge of boundary ($\omega = \omega_c$)

$$PLR = 1+K^2 \quad \therefore \quad \begin{aligned} &K=0 \text{ (ideal case)} \\ &K=1 \text{ (3dB loss expected)} \end{aligned}$$

$(PLR)_{dB} = 3$

For reference of $-3\,dB$ then $k=1$

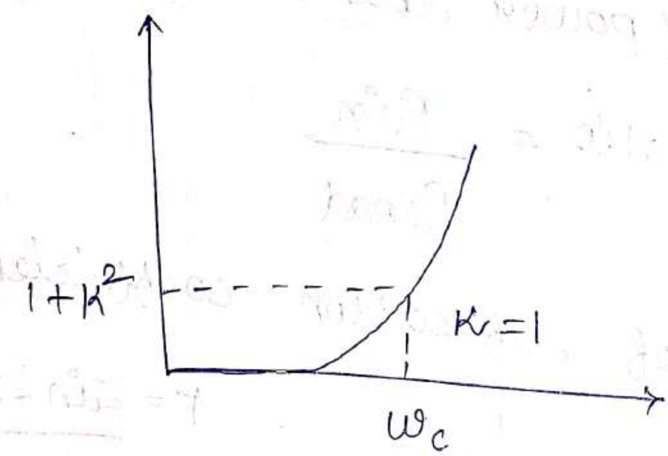
If $k=1$ then

$$PLR = 1 + \left(\frac{\omega}{\omega_c}\right)^{2N}$$

if $\omega >>> \omega_c$

$20N$ slope/decade

if $\omega << \omega_c = 0.$



chebyshev Response:

$$PLR = 1 + k^2 T_N^2\left(\frac{\omega}{\omega_c}\right)$$

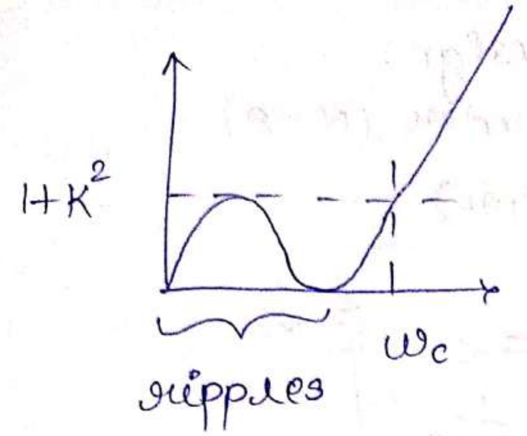
$$PLR = 1 + T_N^2\left(\frac{\omega}{\omega_c}\right)$$ 3dB reference $k=1$

At Edge of Boundary $\omega = \omega_c$

$$PLR = 1 + T_N^2(1)$$

$= 20\,dB$/decade

Scanned with CamScanner



Equiripple in pass band response

linear phase response:

$$\phi(\omega) = A\omega\left[1 + P\left(\frac{\omega}{\omega_c}\right)^{2N}\right]$$

P = constant

Group delay : $\tau_d = \frac{d(\phi(\omega))}{d\omega}$

$$\tau_d = A\left[1 + P(2N+1)\left(\frac{\omega}{\omega_c}\right)^{2N}\right]$$

phase change depends on order and constant.

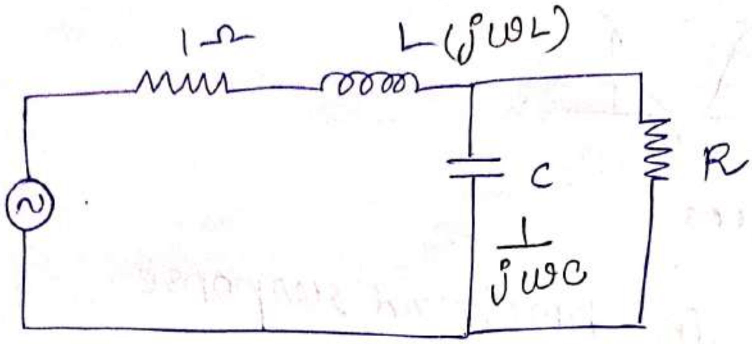
Amplitude vary : 20N slope/decade

Design steps involved in Insertion loss method:

- Filter specification
- Low pass filter design
- scaling of frequency/conversion
- Implementation.

Low pass Filter design:

Let it be second order ($N=2$)



$\boxed{\omega_c = 1\ rad/sec}$

Acceptable range of loss $= 3dB$

so $\boxed{K=1}$

Binomial method:

$$(PLR) = 1 + K^2\left(\frac{\omega}{\omega_c}\right)^{2N} = \frac{1}{1-|\Gamma|^2}$$

suppose $K=1$ then

$$= 1 + \left(\frac{\omega}{\omega_c}\right)^{2N} = 1 + \left(\frac{\omega}{\omega_c}\right)^4$$

Butterworth

$$(PLR) = 1 + \omega^4 \quad \text{—— (1)}$$

$$Z_{in} = j\omega L + \frac{R(1 - j\omega RC)}{1 + \omega^2 R^2 C^2}$$

$Z_0 = R = 1\ \Omega$ = normalised impedance (50 Ω)

$$\Gamma = \frac{Z_{in} - 1}{Z_{in} + 1} = \frac{|Z_{in}+1|^2}{2(Z_{in} + Z_{in}^*)}$$

$$PLR = \frac{1}{1-|\Gamma|^2}$$

$$= 1 + \frac{1}{4R}\left[(1-R)^2 + (R^2C^2 + L^2 - 2LCR^2)w^2 + (L^2C^2R^2)w^4\right] \quad (2)$$

If no frequency component through (1) then $w=0$ and $PLR=1$

If $R=1$, $w=0$ then from (2) $PLR=1$

Equate w^2 in (1) and (2)

$$R^2C^2 + L^2 - 2LCR^2 = 0$$

wkt $\boxed{R=1}$

$$C^2 + L^2 - 2LC = 0$$

$$(C-L)^2 = 0$$

$$\boxed{C=L} \quad (3)$$

Equating w^4 from (2) and (1)

$$L^2C^2R^2 = 1/4 \qquad \frac{1}{4}L^2C^2R^2 = 1$$

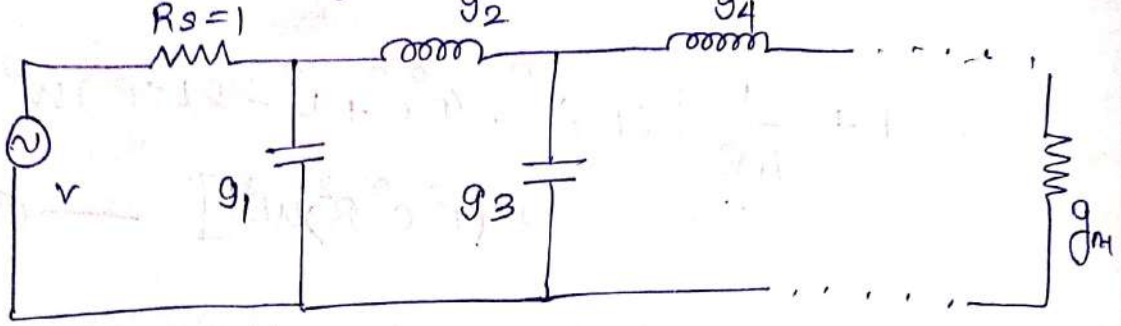
$$L^2C^2 = 1/4 \qquad L^2C^2 = 4$$

From (3) $\qquad L^4 = 4$

$$L = C = \frac{1}{\sqrt{2}} \qquad L = \sqrt{2} = C$$

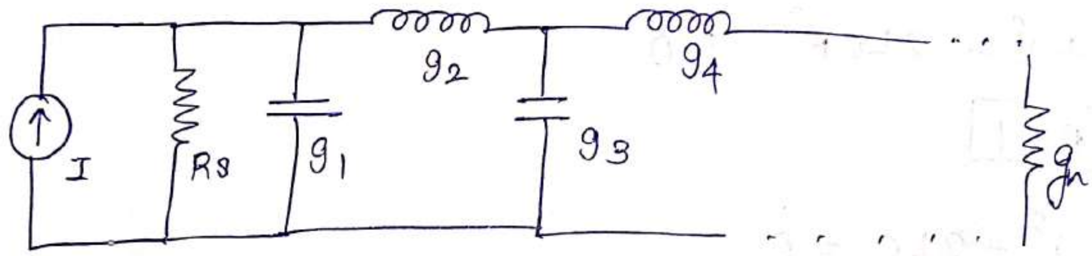
$$\boxed{L=C=1.414}$$

For n - order it goes in a ladder way



Irrespective of order n ; R = 1

In chebyshev
odd number = 1
Even number = 1,98



Filter Transformation:

- Impedance Transformation:
- Frequency Transformation
- Low pass filter converted to High pass, Bandpass and Band stop.

Impedance Transformation:

$R_S = R_0$

$\boxed{R_S' = R_0}$

For Butterworth $R_0 = 1$ for all (at last)

$\boxed{R_L' = R_0 R_L}$

If $50\,\Omega$ is varied then new R_L found

$L' = R_0 L$

$C' = \frac{C}{R_0}$

Due to Impedance change

Frequency Transformation: change in frequency

$PLR'(\omega) = PLR\left(\frac{\omega}{\omega_c}\right)$

$$\left.\begin{aligned} jX_L &= j\omega L \\ jB_K &= \frac{1}{j\omega C} \end{aligned}\right\} \omega = \omega_c = 1$$

$\omega \leftarrow \frac{\omega}{\omega_c}$

$\boxed{\omega' = 1/\omega_c}$

Due to change

other than $\omega_c = 1\,rad/s$ and $\omega = 1$

$jX_L = j\omega L_K' = j\left(\frac{\omega}{\omega_c}\right)L$

$j\cancel{B_K} = \frac{1}{j\omega C'} = j\left(\frac{\omega}{\omega_c}\right)C_K$

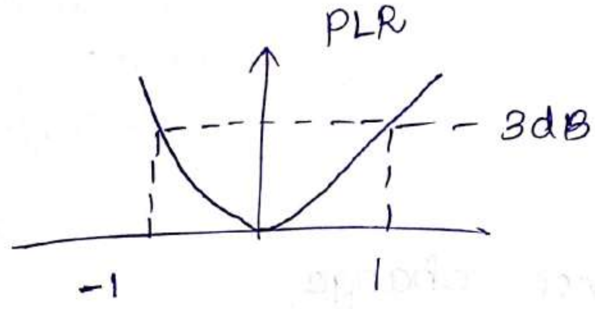
$jB_K = j\omega C_K' = j\left(\frac{\omega}{\omega_c}\right)C_K$

Impedance & frequency change:

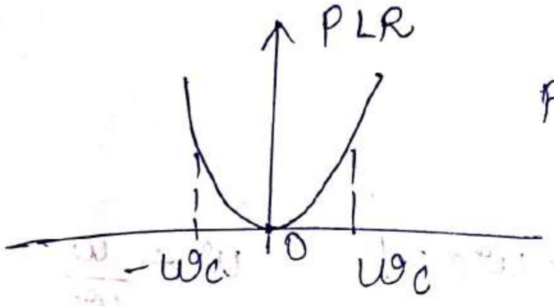
$$j\omega L_k' = j\left(\frac{\omega}{\omega_c}\right) L R_0$$

$$j\omega C' = j\left(\frac{\omega}{\omega_c}\right)\cdot \frac{C}{R_0}$$

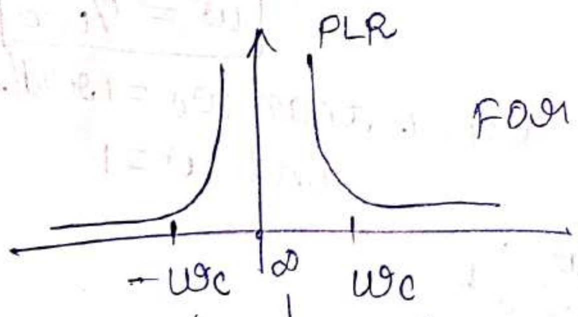
conversion from LPF to HPF



Due to frequency translation



For LPF



For HPF.

so open ended

Frequency Translation:

LPF: $\omega \leftarrow \frac{\omega}{\omega_c} = 1 \leftarrow \frac{1}{\omega_c}$ $\omega = 1$

HPF: $\frac{-\omega_c}{\omega}$ for $\omega = 1$ then $-\omega_c$

Impedance Translation & Frequency

LPF:

$$L_K' = \frac{L_K R_0}{\omega_c} \qquad C_K' = \frac{C_K}{R_0 \omega_c}$$

L_K, C_K from g_1, g_2 in table

R_0 : last value in table

ω_c : New frequency

HPF:

series and shunt changes

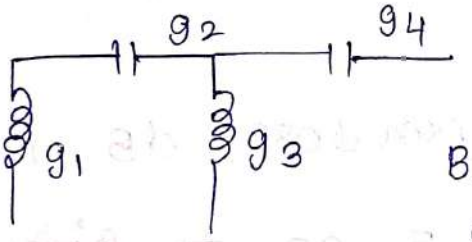
$$C_K' = \frac{1}{R_0 \omega_c L_K}$$

Reverse since HPF

$$jX_K = -j \underbrace{\left(\frac{\omega_c}{\omega}\right)}_{} L = \frac{1}{j\omega C_K}$$

$$L_K' = \frac{R_0}{\omega_c C_K}$$

For HPF



But we have g_1 & g_2 as (C and L) (changing component value alone)

15.10.25

1. Design maximally flat LPF with a cut off frequency of 2GHz impedance of 50 Ω and atleast 15dB insertion loss at 3GHz compare with an equiripple of 3dB and linear phase filter has the same order.

To design filter:

→ LPF

→ Flat, Equiripple and linear phase

Given

$f_c = 2\,GHZ$

$\omega = \underbrace{3\,GHZ}_{f} \times 2\pi$; $I_L = 15\,dB$ (Insertion loss)

$Z = 50\Omega$

$Z_S = 50\Omega$

i) Butterworth filter: a) LPF — Table 8.3, Fig 8.26

$$L_K' = \frac{R_0 L_K}{\omega_c} \qquad C_K' = \frac{C_K}{R_0 \omega_c}$$

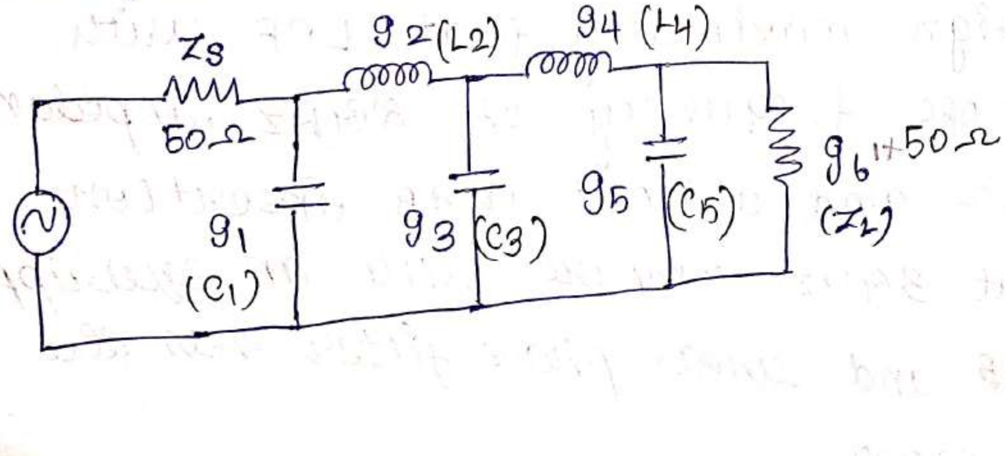
N → depends on IL

$$\frac{\omega}{\omega_c} - 1 = \frac{3\times10^9}{2\times10^9} - 1 = 0.5$$

Attenuation (Insertion loss) $dB = 15\,dB$

comes between 4 and 5 go to higher value hence $\boxed{n=5}$

· LPF for n=5



From Table 8.3 (pozar)

$n = 5$

$g_1 = 0.6180 = C_1$

$g_2 = 1.6180 = L_2$

$g_3 = 2.0000 = C_3$

$g_4 = 1.6180 = L_4$

$g_5 = 0.6180 = C_5$

$g_6 = 1.0000$

$g_6 \times 50 = 50\,\Omega$ hence last $R = 50\,\Omega$

For $g_1 = C_K$

$$C_K' = \frac{C_K}{R_0 \times \omega_c} = \frac{0.6180}{50 \times 2\pi \times 2 \times 10^9} = 0.983\,\text{PF}$$

For g_2

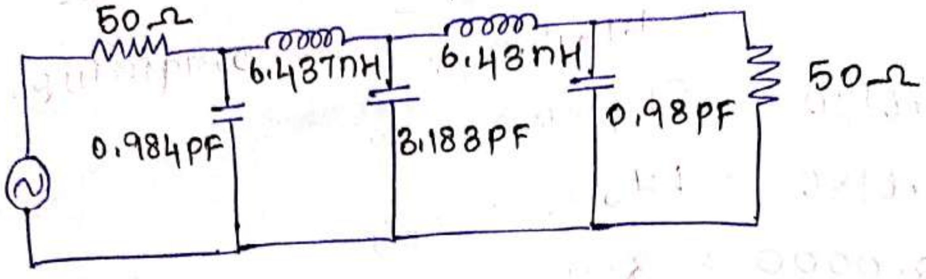
$$L_K' = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 1.6180}{2\pi \times 2 \times 10^9} = 6.437\,\text{nH}$$

For g_3 $$C_K' = \frac{C_K}{R_0 \times \omega_c} = \frac{2}{50 \times 2\pi \times 2 \times 10^9} = 3.183\,\text{PF}$$

For g_4 $$L_K' = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 1.6180}{2\pi \times 2 \times 10^9} = 6.43\,\text{nH}$$

For g_5 $$C_K' = \frac{C_K}{R_0 \times \omega_c} = \frac{0.6180}{50 \times 2\pi \times 2 \times 10^9} = 0.98\,\text{PF}$$

Butterworth Low pass filter:



b) High pass Filter:

Now: $g_1 = 0.6180$ From maximally flat table

$g_2 = 1.6180$

$g_3 = 2$

$g_4 = 1.6180$

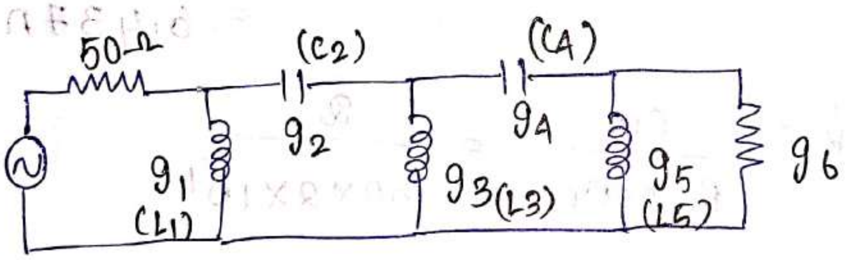
$g_5 = 0.6180$

$g_6 = 1PF.$

$$C_K' = \frac{1}{R_0 \omega_c L_K}$$

$$L_K' = \frac{R_0}{\omega_c C_K}$$

Take respective (g_n) values from LPF



For g_1 $L_1 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 0.6180}$

$L_1 = 6.438\,nH$

For g_2 $C_2 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 1.6180}$

$= 0.984\,PF$

For g_3

$$L_3 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 2}$$

$$= 1.989\,nH.$$

For g_4

$$C_4 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 1.6180}$$

$$= 0.984\,PF.$$

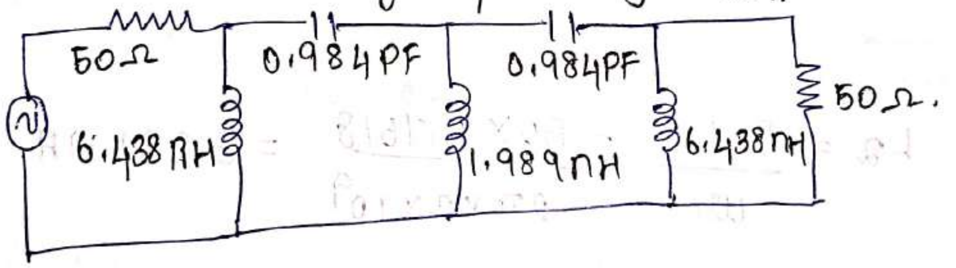
For g_5

$$L_5 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 0.6180}$$

$$= 6.438\,nH.$$

$g_6 = 1 \times 50 = 50\Omega$

Butterworth High pass filter:



ii) chebyshev filter: (From Table 8.4)

a) LPF:

For a Equiripple of 3dB

From the Table,

since same order $n=5$

$g_1 = 3.4817$

$g_2 = 0.7618$

$g_3 = 4.5381$

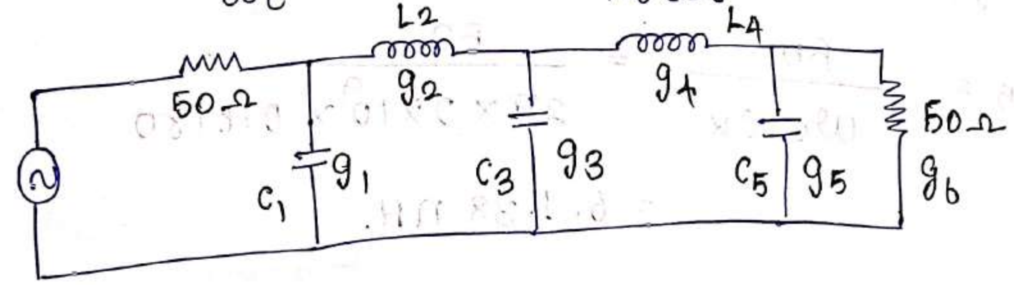
$g_4 = 0.7618$

$g_5 = 3.4817$

$g_6 = 1$

$g_6 \times 50 = 50\,\Omega.$

$$L_K' = \frac{R_0 L_K}{\omega_c} \quad ; \quad C_K' = \frac{C_K}{R_0 \omega_c}$$



For $\underline{g_1}$ $$C_1 = \frac{C_K}{R_0 \times \omega_c} = \frac{3.4817}{50 \times 2\pi \times 2 \times 10^9} = 5.541\,\text{PF}$$

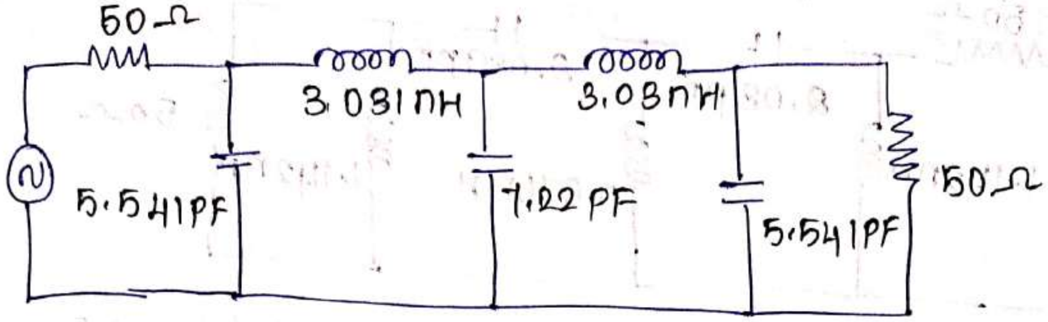
For g_2 $$L_2 = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 0.7618}{2\pi \times 2 \times 10^9} = 3.031\,\text{nH}$$

For g_3 $$C_3 = \frac{C_K}{R_0 \times \omega_c} = \frac{4.5381}{50 \times 2\pi \times 2 \times 10^9} = 7.222\,\text{PF}$$

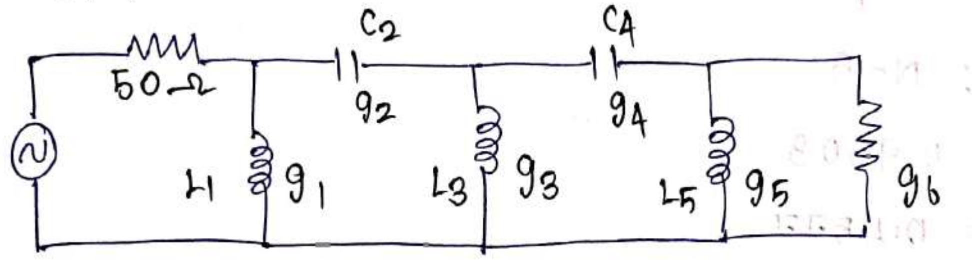
For g_4 $$L_4 = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 0.7618}{2\pi \times 2 \times 10^9} = 3.03\,\text{nH}$$

For g_5 $$C_5 = \frac{C_K}{R_0 \times \omega_c} = \frac{3.4817}{50 \times 2\pi \times 2 \times 10^9} = 5.541\,\text{PF}$$

chebyshev Low pass Filter:



b) HPF:



$$C_K' = \frac{1}{R_0 \omega_c L_K} \quad ; \quad L_K' = \frac{R_0}{\omega_c C_K}$$

For g_1

$$L_1 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 3.4817}$$

$$L_1 = 1.142\,nH$$

For g_2

$$C_2 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 0.7618}$$

$$= 2.08\,PF$$

For g_3

$$L_3 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 4.5381} = 0.876\,nH$$

For g_4

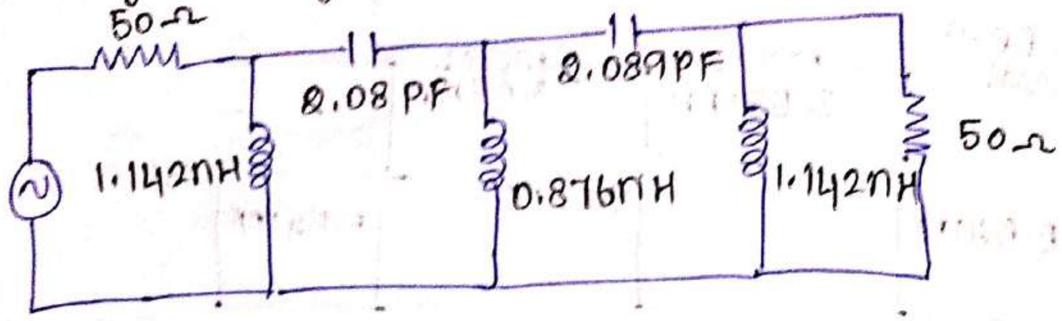
$$C_4 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 0.7618}$$

$$= 2.089\,PF$$

For g_5

$$L_5 = \frac{R_0}{\omega_c C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 3.4817} = 1.142\,nH$$

Chebyshev Highpass Filter:



iii) Linear phase Filters (From Table 8.5)

a) LPF: $N=5$

$g_1 = 0.9303$

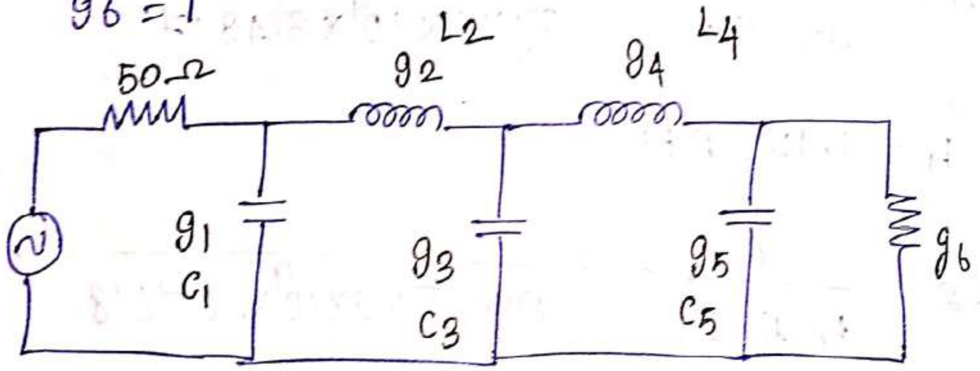
$g_2 = 0.4577$

$g_3 = 0.3312$

$g_4 = 0.2090$

$g_5 = 0.0718$

$g_6 = 1$



$$L_K' = \frac{R_0 L_K}{\omega_c} \qquad C_K' = \frac{C_K}{R_0 \omega_c}$$

For $\underline{g_1}$

$$C_1 = \frac{C_K}{R_0 \omega_c} = \frac{0.9303}{50 \times 2\pi \times 2 \times 10^9} = 1.4806\,PF$$

For $\underline{g_2}$

$$L_2 = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 0.4577}{2\pi \times 2 \times 10^9} = 1.821\,nH$$

For g_3 :

$$C_3 = \frac{C_K}{R_0 \omega_c} = \frac{0.3312}{50 \times 2\pi \times 2 \times 10^9} = 0.1527\,pF$$

For g_4

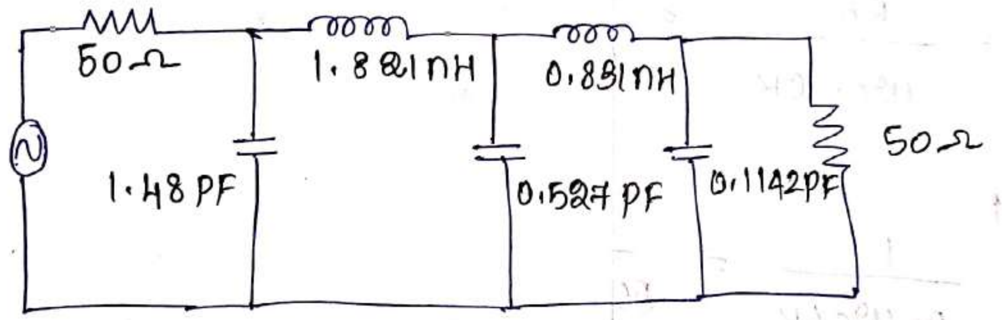
$$L_4 = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 0.2090}{2\pi \times 2 \times 10^9} = 0.831\,nH$$

For g_5

$$C_5 = \frac{C_K}{R_0 \omega_c} = \frac{0.0718}{50 \times 2\pi \times 2 \times 10^9} = 0.1142\,pF.$$

$g_6 \times 50 = 50\Omega.$

Linear phase Low pass Filter:



b) HPF :

$g_1 = 0.9303$

$g_2 = 0.4577$

$g_3 = 0.3312$

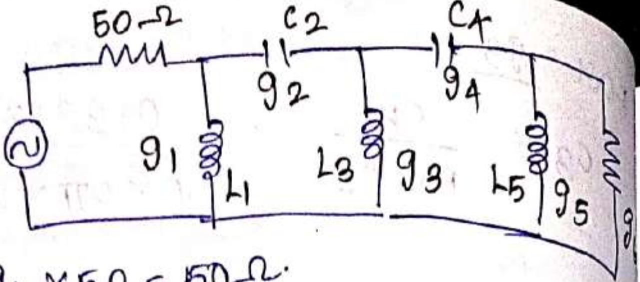
$g_4 = 0.2090$

$g_5 = 0.0718$

$g_6 = 1$

$$C_K' = \frac{1}{\omega_c R_0 L_K}$$

$$L_K' = \frac{R_0}{\omega_c C_K}$$



$g_6 \times 50 = 50\Omega$.

For g_1

$$L_1 = \frac{R_0}{\omega_c \cdot C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 0.9303} = 4.276\,nH$$

For g_2:

$$C_2 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 0.4577}$$

$$= 3.477\,PF$$

For g_3

$$L_3 = \frac{R_0}{\omega_c \cdot C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 0.3312} = 12.01\,nH$$

For g_4

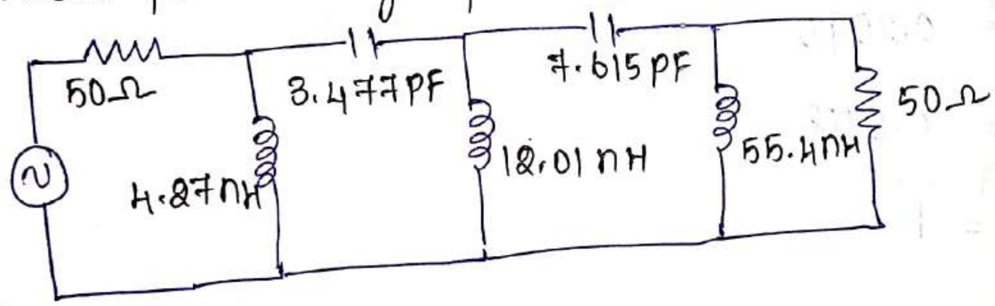
$$C_4 = \frac{1}{R_0 \omega_c L_K} = \frac{1}{50 \times 2\pi \times 2 \times 10^9 \times 0.2090}$$

$$= 7.615\,PF$$

For g_5

$$L_5 = \frac{R_0}{\omega_c \cdot C_K} = \frac{50}{2\pi \times 2 \times 10^9 \times 0.0718} = 55.41\,nH$$

Linear phase High pass filter:



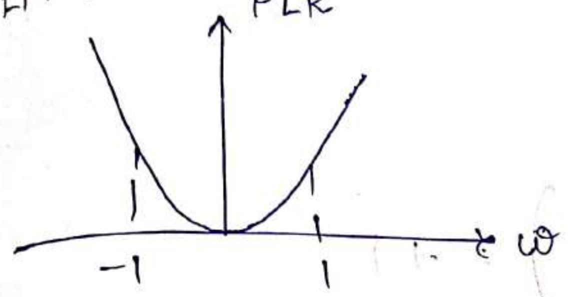
16.10.25

Frequency Translation:

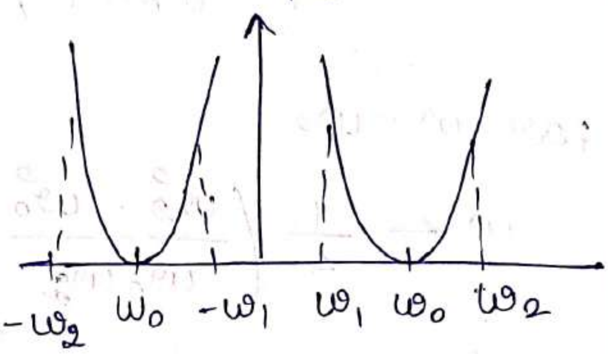
LPF to BPF and BSF

$\omega_c = 1$; $K = 1$

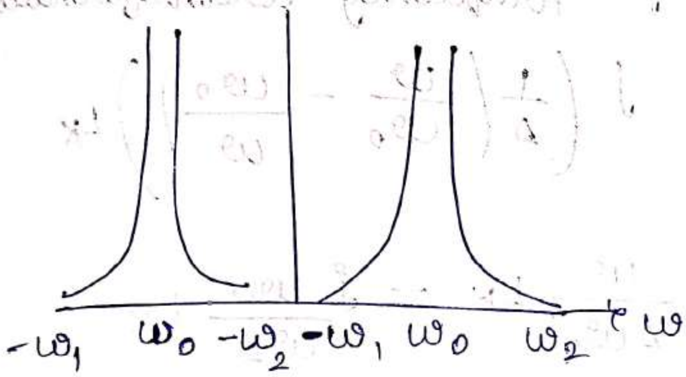
LPF :



BPF :



BSF :



$$\omega \leftarrow \frac{\omega_0}{\omega_2 - \omega_1}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$$

$$\omega \leftarrow \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

If $\omega = \omega_0$

$\omega \leftarrow 0$ (LPF)

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For $\omega = \omega_1$

$$\omega \leftarrow \frac{1}{\Delta}\left(\frac{\omega_1}{\omega_0} - \frac{\omega_0}{\omega_1}\right)$$

$$\Rightarrow \frac{1}{\Delta}\left(\frac{\omega_1^2 - \omega_0^2}{\omega_0 \omega_1}\right) = -1$$

For, $\omega = \omega_2$

$$\omega \leftarrow \frac{1}{\Delta}\left(\frac{\omega_2^2 - \omega_0^2}{\omega_0 \omega_2}\right) = +1$$

For LPF generally Frequency transformation

$$jX_K = j\omega L_K = j\left(\frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right)L_K$$

$$= j\frac{\omega}{\Delta\omega_0}L_K - \underbrace{j\frac{\omega_0}{\omega\Delta}L_K}_{HPF}$$

LPF → HPF

$$j\frac{\omega_0}{\omega\Delta}L_K = \frac{1}{j\omega C_K}$$

$$= j\omega L_K' - j/\omega C_K + j\frac{\omega}{\Delta\omega_0}L_K$$

<u>series arm</u>

For L_K'

$$\frac{j\omega}{\Delta\omega_0}L_K = j\omega L_K'$$

$$\boxed{L_K' = \frac{R_0 L_K}{\Delta\omega_0}}$$

$$\frac{-j\omega_0}{\Delta\omega} L_K = \frac{-j}{\omega C_K'}$$

$$\boxed{C_K' = \frac{\Delta}{R_0 \omega_0 L_K}}$$

$$\boxed{\begin{aligned} \omega_0 &= \sqrt{\omega_1 \omega_2} \\ \Delta &= \frac{\omega_2 - \omega_1}{\omega_0} \end{aligned}}$$

shunt arm:

$$jB_K = j\omega C_K$$

$$= j\left(\frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right) C_K$$

$$\frac{j\omega}{\Delta\omega_0} C_K - \frac{j\omega_0}{\Delta\omega} C_K$$

Equate:

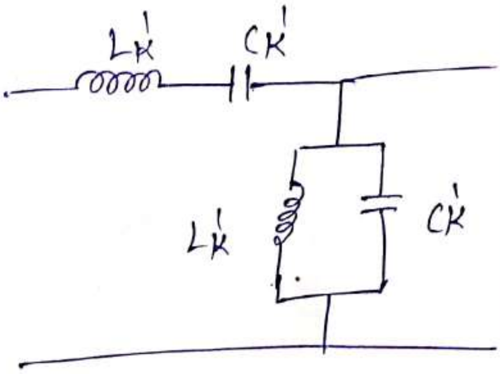
$$j\omega C_K' - j/\omega L_K'$$

$$\frac{j\omega C_K}{\Delta\omega_0} = j\omega C_K'$$

$$\boxed{C_K' = \frac{C_K}{\Delta\omega_0 R_0}}$$

$$\frac{-j\omega_0}{\Delta\omega} C_K = \frac{-j}{\omega L_K'}$$

$$\boxed{L_K' = \frac{\Delta R_0}{\omega_0 C_K}}$$



Band stop filter:

$$\omega \leftarrow -\frac{1}{\Delta}\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)^{-1}$$

series arm:

$$L_K' = \frac{\Delta L_K R_0}{\omega_0}$$

$$C_K' = \frac{1}{\omega_0 \Delta L_K \cdot R_0'}$$

shunt arm

$$L_K' = \frac{R_0}{\omega_0 \Delta C_K}$$

$$C_K' = \frac{\Delta C_K}{R_0 \omega_0}$$

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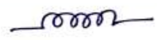
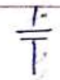
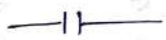
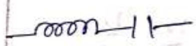
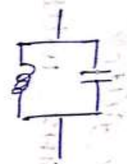
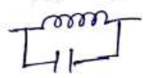
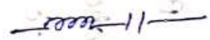
	Series	Shunt	Series structure	Shunt structure
Lowpass Filter:	$L_K' = \frac{L_K}{\omega_c} \cdot R_0$	$C_K' = \frac{C_K}{R_0 \omega_c}$		
High pass Filter:	$C_K' = \frac{1}{R_0 \omega_c L_K}$	$L_K' = \frac{R_0}{\omega_c C_K}$		
Band pass Filter:	$L_K' = \frac{L_K R_0}{\Delta \omega_0}$ (LPF) $C_K' = \frac{\Delta}{R_0 \omega_0 L_K}$ (HPF)	$L_K' = \frac{\Delta R_0}{\omega_0 C_K}$ (HPF) $C_K' = \frac{C_K}{\Delta \omega_0 R_0}$ (LPF)		
Bandstop Filter:	$L_K' = \frac{\Delta L_K R_0}{\omega_0}$ $C_K' = \frac{1}{\omega_0 \Delta L_K R_0}$	$L_K' = \frac{R_0}{\omega_0 \Delta C_K}$ $C_K' = \frac{\Delta C_K}{R_0 \omega_0}$		

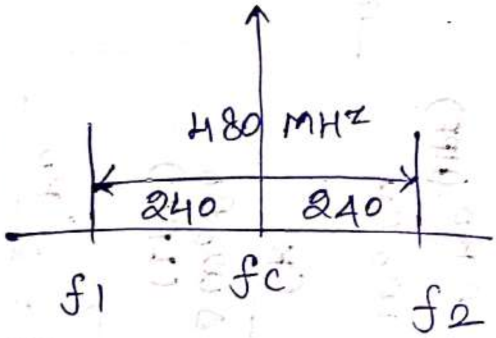
2. consider order of filter is 4, to design BPF solve for Butterworth and chebyshev filter of 0.5 dB ripple $f_c = 2.4\,GHz$ with Impedance BW ratio of 20%.

Given: $N = 4$

$(2.4 \times 10^9) \times 20/100$

$f_c = 2.4\,GHz \Rightarrow 480\,MHz$.

$f_c = 480\,MHz$



2.4 GHz
.48 GHz

$$\begin{array}{r} 2.4\,GHz \\ 0.48\,GHz \; (-) \\ \hline 2.16\,GHz \\ \hline \end{array} \qquad \begin{array}{r} 2.4\,GHz \\ 0.48\,GHz \; (+) \\ \hline 2.64\,GHz \\ \hline \end{array}$$

$f_1 = 2.16\,GHz$

$f_2 = 2.64\,GHz$

$\omega_c = 2\pi \times 2.4 \times 10^9$

$\omega_c = 15.07 \times 10^9\ rad/s$

$\omega_1 = 2\pi \times 2.16 \times 10^9 = 13.5716 \times 10^9\ rad/s$

$\omega_2 = 2\pi \times 2.64 \times 10^9 = 16.5876 \times 10^9\ rad/s$

$\omega_0 = \sqrt{\omega_1 \omega_2} = 15.004 \times 10^{9}\ rad/s$

$= 15 \times 10^9\ rad/s.$

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$$

$$\Delta = \frac{(16.15876 - 13.5716) \times 10^9}{15 \times 10^9}$$

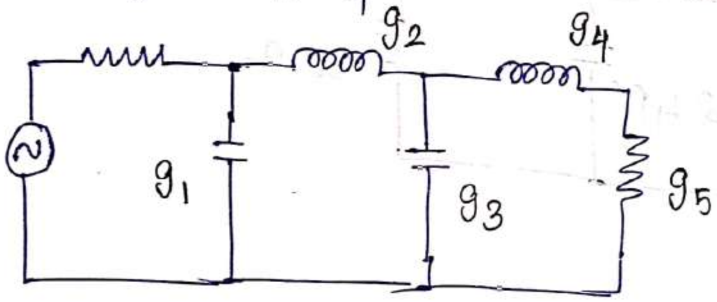
$$\boxed{\Delta = 0.201}$$

i) Butterworth filter:

Low pass:

$$L_K' = \frac{R_0 L_K}{\omega_c} \qquad C_K' = \frac{C_K}{R_0 \omega_c}$$

LPF for $n=4$



$g_1 = 0.7654 \qquad g_5 = 1$

$g_2 = 1.8478$

$g_5 \times 50 = 1 \times 50 = 50\,\Omega$

$g_3 = 1.8478$

$g_4 = 0.7654$

For g_1

$$C_K' = \frac{C_K}{R_0 \omega_c} = \frac{0.7654}{50 \times 2\pi \times 2.4 \times 10^9}$$

$$C_K' = 1.015 \times 10^{-12}\ F$$

For g_2

$$L_K' = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 1.8478}{2\pi \times 2.4 \times 10^9}$$

$$= 6.126\ nH$$

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For g_3

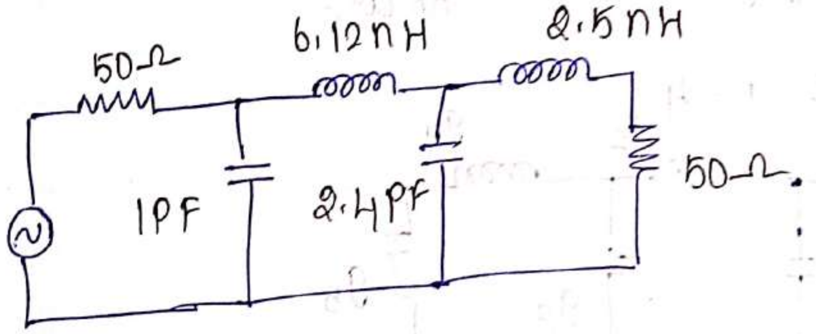
$$C_K' = \frac{C_K}{R_0 \omega_c} = \frac{1.8478}{50 \times 2\pi \times 2.4 \times 10^9}$$

$$C_K' = 2.4507 \, pF$$

For g_4

$$L_K' = \frac{R_0 L_K}{\omega_c} = \frac{50 \times 0.7654}{2\pi \times 2.4 \times 10^9}$$

$$L_K' = 2.5378 \, nH$$



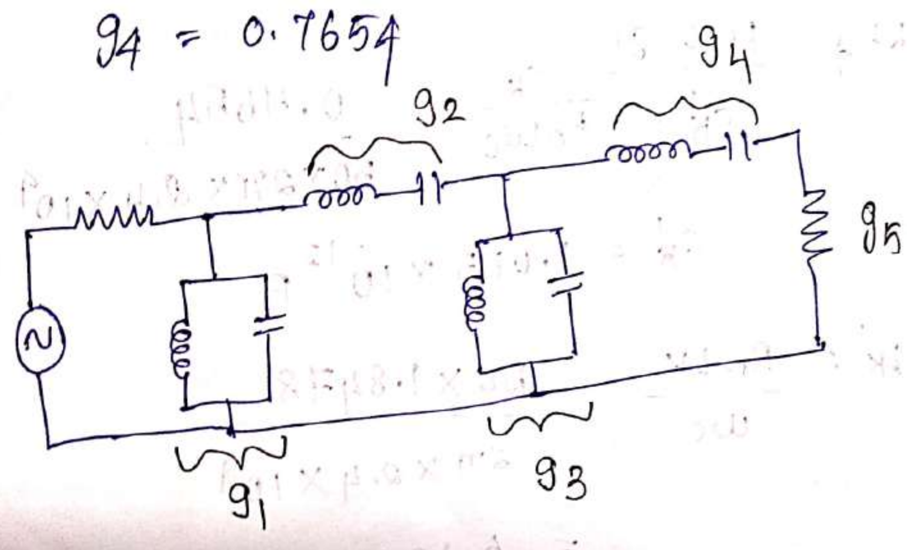
Band pass

$g_1 = 0.7654$

$g_2 = 1.8478 \quad g_5 = 1$

$g_3 = 1.8478$

$g_4 = 0.7654$



series

$$L_K' = \frac{L_K R_0}{\Delta \omega_0}$$

$$C_K' = \frac{\Delta}{R_0 \omega_0 L_K}$$

shunt

$$L_K' = \frac{\Delta R_0}{\omega_0 C_K}$$

$$C_K' = \frac{C_K}{\Delta \omega_0 R_0}$$

shunt (g_1)

$$L_K' = \frac{\Delta R_0}{\omega_0 C_K} = \frac{0.201 \times 50}{2\pi \times 90^9 \times 2.4 \times 0.7654}$$

$$\boxed{L_K' = 0.8707 \, nH}$$

$$C_K' = \frac{C_K}{\Delta \omega_0 R_0} = \frac{0.7654}{0.201 \times 2\pi \times 2.4 \times 10^9 \times 50}$$

$$\boxed{C_K' = 5.050 \, PF}$$

series (g_2)

$$L_K' = \frac{L_K R_0}{\Delta \omega_0} = \frac{1.8478 \times 50}{0.201 \times 2\pi \times 2.4 \times 10^9}$$

$$\boxed{L_K' = 30.481 \, nH}$$

$$C_K' = \frac{\Delta}{R_0 \omega_0 L_K} = \frac{0.201}{50 \times 2\pi \times 2.4 \times 10^9 \times 1.8478}$$

$$\boxed{C_K' = 0.14427 \, PF}$$

shunt (g_3)

$$L_K' = \frac{\Delta R_0}{\omega_0 C_K} = \frac{0.201 \times 50}{2\pi \times 2.4 \times 10^9 \times 1.8478}$$

$$\boxed{L_K' = 0.3606 \, nH}$$

$$C_K' = \frac{C_K}{\Delta \omega_0 R_0}$$

$$C_K' = \frac{1.8478}{0.201 \times 2\pi \times 2.4 \times 10^9 \times 50}$$

$$\boxed{C_K' = 12.1926\ pF}$$

series (g_4)

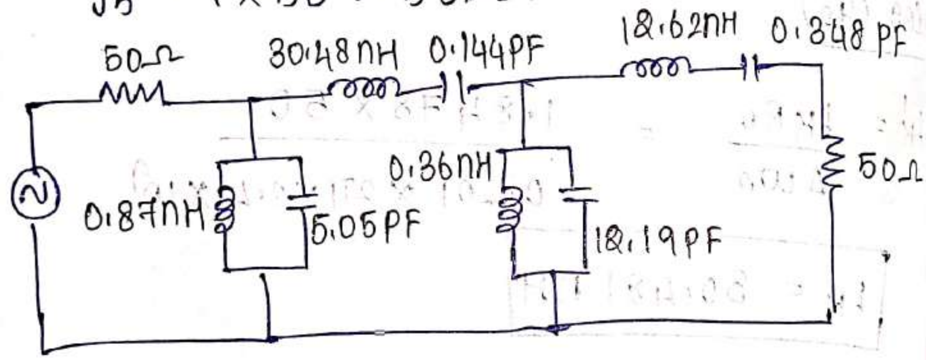
$$L_K' = \frac{L_K R_0}{\Delta \omega_0} = \frac{0.7654 \times 50}{0.201 \times 2\pi \times 2.4 \times 10^9}$$

$$\boxed{L_K' = 12.6261\ nH}$$

$$C_K' = \frac{\Delta}{R_0 \omega_0 L_K} = \frac{0.201}{50 \times 2\pi \times 2.4 \times 10^9 \times 0.7654}$$

$$\boxed{C_K' = 0.3482\ PF}$$

$g_5 = 1 \times 50 = 50\Omega.$



ii) chebyshev filter: (0.5 dB ripple)

$g_1 = 1.6703$

$g_2 = 1.1926$

$g_3 = 2.3661$

$g_4 = 0.8419$

$g_5 = 1.9841$

shunt (g_1)

$$L_K' = \frac{\Delta R_0}{\omega_0 C_K} = \frac{0.201 \times 50}{2\pi \times 2.4 \times 10^9 \times 1.6703} = 0.399\,nH$$

$$C_K' = \frac{C_K}{\Delta \omega_0 R_0} = \frac{1.6703}{0.201 \times 2\pi \times 2.4 \times 10^9 \times 50} = 11.02\,PF$$

series (g_2)

$$L_K' = \frac{L_K R_0}{\Delta \omega_0} = \frac{1.1926 \times 50}{2\pi \times 2.4 \times 10^9 \times 0.201} = 19.67\,nH$$

$$C_K' = \frac{\Delta}{R_0 \omega_0 L_K} = \frac{0.201}{50 \times 2\pi \times 2.4 \times 10^9 \times 1.1926} = 0.22\,PF$$

shunt (g_3)

$$L_K' = \frac{\Delta R_0}{\omega_0 C_K} = \frac{0.201 \times 50}{2\pi \times 2.4 \times 10^9 \times 2.3661} = 0.281\,nH$$

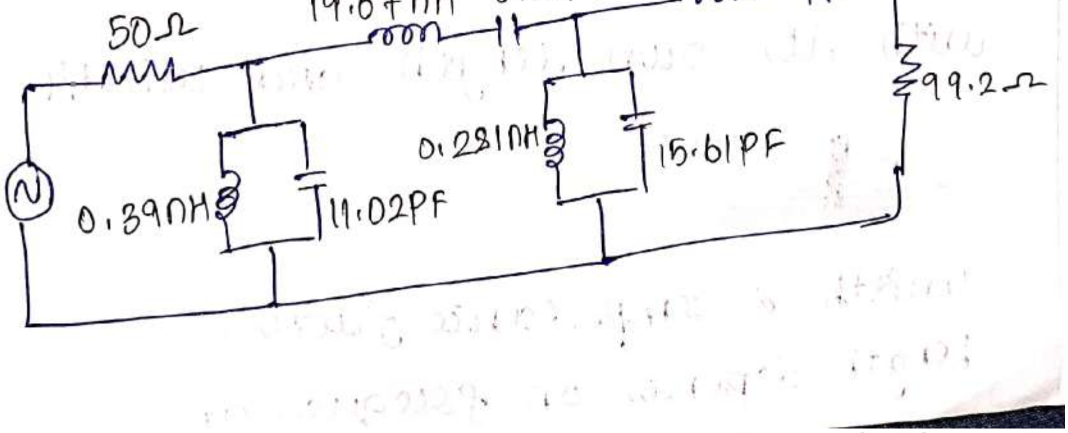
$$C_K' = \frac{C_K}{\Delta \omega_0 R_0} = \frac{2.3661}{0.201 \times 2\pi \times 2.4 \times 10^9 \times 50} = 15.61\,PF$$

series (g_4)

$$L_K' = \frac{L_K R_0}{\Delta \omega_0} = \frac{0.8419 \times 50}{0.201 \times 2\pi \times 2.4 \times 10^9} = 13.88\,nH$$

$$C_K' = \frac{C_K}{R_0 \omega_0 L_K} = \frac{0.201}{50 \times 2\pi \times 2.4 \times 10^9 \times 0.8419} = 0.316\,PF$$

$$g_5 = 1.9841 \times 50 = 99.205\,\Omega$$



25.10.25

Drawback

→ Limited range of lumped components

→ connection line : frequency variation

To overcome this we go for filter Implementation

→ Richard's transformation

→ Kurodas' transformation

Richard's Transformation ;

→ Translating $\omega \rightarrow \Omega$ (ohm).

$$\Omega = j \tan \beta l$$

$$= j \tan\left(\frac{\omega}{V_p} l\right)$$

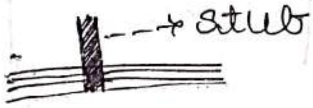
$$jX_L = j\omega L = j\Omega L = L \tan(\beta l)$$

$$jB_C = j\omega C = j\Omega C = C \tan(\beta l)$$

$L \tan\beta l$ → representation of short circuit stub, impedance L

C ⇒ open circuited stub, impedance $\frac{1}{C}$

stub : Extension of transmission line with its own length and width.



width ∝ Impedance factor

Length depends on frequency

Let $\omega_c = 1$ / Impedance = 1

$\tan\beta l = \Omega = 1$

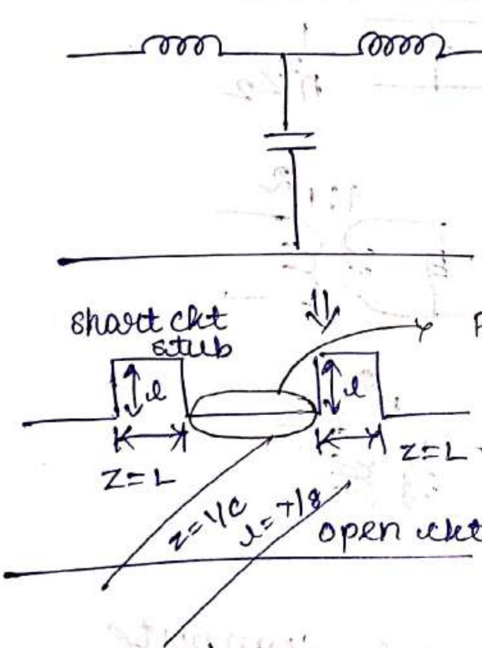
$\beta l = \tan^{-1}(1) = \pi/4$

$$l = \frac{\pi/4}{\beta}$$

$$l = \frac{\pi/4}{2\pi/\lambda} \Rightarrow \frac{\pi}{4} \times \frac{\lambda}{2\pi}$$

$\boxed{l = \frac{\lambda}{8}}$ = Normalised Impedance Repeats every $4\omega_c$.

Frequency changes, in terms of λ it varies (length varies)



Frequency variation occurs if it length as $\lambda/2$ but on constant $\lambda/8$

Kuroda's transformation:

→ physically seperate Tx line stubs

→ Transform series stub to shunt stub and shunt stub to series stub

→ change impractical characteristic impedance into more realistic

1) 

physical seperation

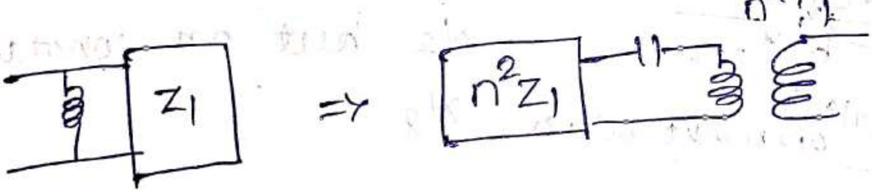
2) 

connecting line. $\frac{Z_2}{n^2}$

$n^2 = 1 + \frac{Z_2}{Z_1}$

can nullify frequency variations

Impedance values

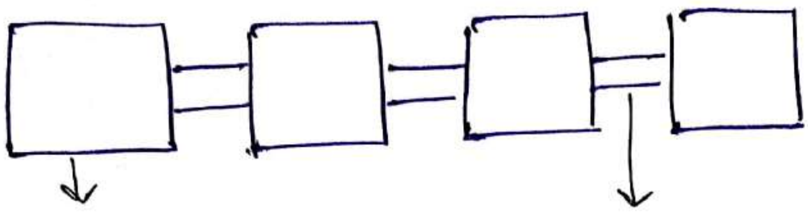


Take Impedance value and compute length inbetween impedances.

→ series impedance check 2nd one Impedance $Z_1 n^2$ and compute L

→ For shunt capacitor take Z_2/n^2

stepped Impedance:



larger Impedance short

Higher Impedance = L
smaller Impedance = C

$$\beta l = \frac{L R_o}{Z_l}$$

$$\beta l = \frac{C Z_L}{R_o}$$

couple line BP filter design.