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4. Zero property: Sum of products of any one row or column of S-matrix multiplied by the complex conjugate of the corresponding elements of any other row or column is zero. MW1-14

$$\sum_{i=1}^{n} S_{ik} S_{ij}^{*} = 0 \quad \text{where } k = 0,1,2,\dots n$$
$$j = 0,1,2,\dots n$$

k & j are the row or column of the matrix

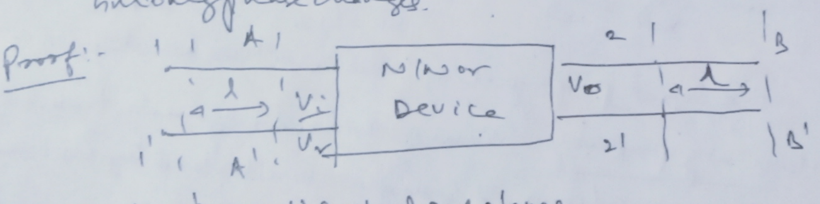
eg:- For a 2×2 matrix, if we consider 1st & 2nd row

$$S_{11} S_{21}^{*} + S_{12} S_{22}^{*} = 0$$

5. phase shifting property:-

Reference plane in μwave device ckts shifts due to o.c/s.c, frequency change etc. Under these conditions magnitude of S-parameter remains same but only phase changes.

Proof:-



(1-1'), (2-2') Initial ref planes
(A-A'), (B-B') New — " —

For Initial ref plane $V_r = SV_i$

If plane shifts by a distance 'l', then voltages experiences a phase change of $\pm \beta l$

i.e $V_r e^{j\beta l} = S V_i e^{-j\beta l}$

or $V_r = S' V_i$ where $S' = S e^{-j2\beta l}$ —(1)

S-matrix for new ref plane

From (1) it is clear that mag of S remains same but phase

Advantages of S-parameters:-

1. Source generally remains constant. Besides freq measurement we also consider VSWR, power, phase etc. If 'a' is the incident signal & 'b' is the reflected signal then
   $VSWR = b/a$, power $|a|^2$ or $|b|^2$, phase $\tan^{-1} b/a$ etc.
   Such direct correspondence not possible in Z, Y, ABCD, h parameters.
2. Unitary property helps in quickly test power balance or lossless characteristics of device/N/w.
3. S-parameters are linearly related to amplitudes of a & b.
4. ——"—— can be easily related to other parameters

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}, \quad \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & -B \\ C & -D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}, \quad \begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

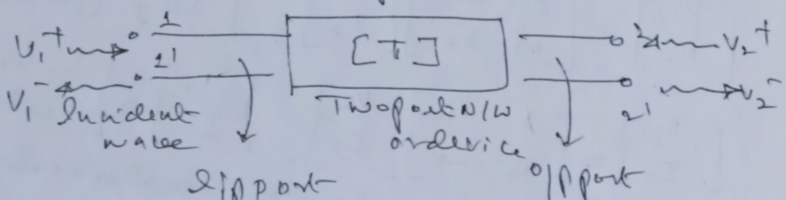
5. Principles of ckt analysis done to LF are also applicable of μwaves. (i.e various laws)
6. If ref. plane changes, just incorporate phase in S-matrix.

T-Matrix or Transmission Matrix

This is usefull in studying the properties of cascaded N/w or stages. T-matrix directly relates i/p & o/p parameters. If we multiply matrices of individual N/ws in cascade we get overall matrix of the combination.

T-matrix relates i/p port-incident & reflected waves (Independent Variables) to o/p port — " — (dependent " —). It is usefull in analysis of Filters, amplifiers, Transmitter ckts, SHR (Superheterodyne Receiver) stages etc.

T — constitutes chain scattering parameters or scattering transfer parameters.



$$\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} V_2^- \\ V_2^+ \end{bmatrix}$$

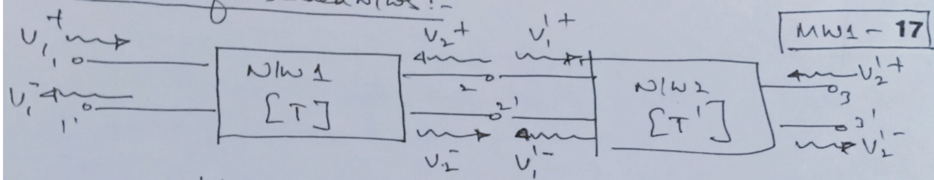
S & T are related as,

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{S_{21}} & \frac{S_{22}}{S_{21}} \\ \frac{S_{11}}{S_{21}} & S_{12} - \frac{S_{11} S_{22}}{S_{21}} \end{bmatrix}$$

lly

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} T_{21}/T_{11} & T_{22} - \frac{T_{21} T_{12}}{T_{11}} \\ \frac{1}{T_{11}} & \frac{T_{12}}{T_{11}} \end{bmatrix}$$

T-Matrix of cascaded N/Ws :-



At jun 2-2', $V_2^+ = V_1'^-$ & $V_2^- = V_1'^+$ —(1)

W.K.T for N/W 1 $\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} V_2^- \\ V_2^+ \end{bmatrix}$ —(2)

Ill^y for N/W 2 $\begin{bmatrix} V_1'^+ \\ V_1'^- \end{bmatrix} = \begin{bmatrix} T_{11}' & T_{12}' \\ T_{21}' & T_{22}' \end{bmatrix} \begin{bmatrix} V_2'^- \\ V_2'^+ \end{bmatrix}$ —(3)

Eq (3) in eq (2) gives

$$\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} T_{11}' & T_{12}' \\ T_{21}' & T_{22}' \end{bmatrix} \begin{bmatrix} V_2'^- \\ V_2'^+ \end{bmatrix}$$

$$LHS = [T]_{Tot} \begin{bmatrix} V_2'^- \\ V_2'^+ \end{bmatrix}$$

where $[T]_{Tot} = [T][T']$

This can be extended for 'n' stages

Microwave Filters:-

"They are two port, reciprocal, passive, linear devices which attenuate heavily the unwanted signal frequencies while passing desired frequencies".

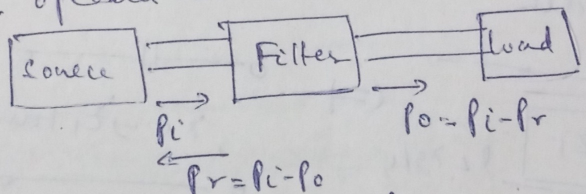
There are three types:-

1) * Reflective type or Insertion loss type:- uses cap & Induct elements producing ideally zero refl. loss in P.B & high attn in S.B.

2) * Absorptive type:- They dissipate unwanted signal internally & pass the wanted signal.

3) * Lossy filter:- Uses lossy material to produce heavy loss for rejected signal & less loss for wanted signal.

Here we consider only the 1st type.
μwave filter operates between a source & a load of 50Ω.



Insertion loss = $IL_{dB} = 10\log\frac{P_i}{P_o} = 10\log\frac{P_i}{P_i - P_r} = 10\log\frac{1}{1-|\Gamma|^2}$

where Γ is the volt refl. coeff. $= \sqrt{P_r/P_i}$

Return loss $= 10\log P_i/P_r = 10\log\frac{1}{|\Gamma|^2}$

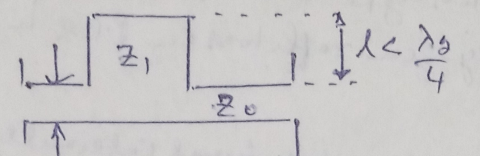
Microwave filter parameters:- Design parameters are Insertion loss, Return loss, Group delay, Pass b.w, Stop band attn, f_c, I/P to O/P impedances, order of the filter, slope

MW 1-20

Group delay (T_d) is important for multifrequency or pulsed signals. This determines the freq. dispersion.

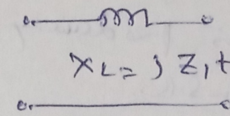
$$T_d = \frac{1}{2\pi}\frac{d\phi_t}{df} \quad \text{where } \phi_t = \text{Transmitted phase.}$$

Filter elements are realized using a section of w.g or coaxial lines or strip or flat strip lines, or cavity resonators or resonant irises.



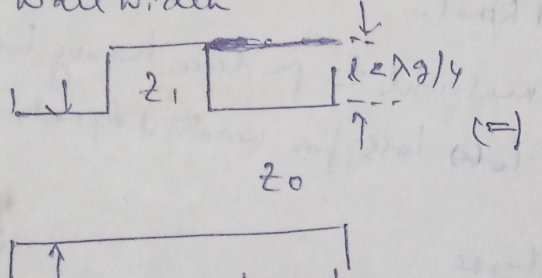
b = w.g with narrow wall width

⟺



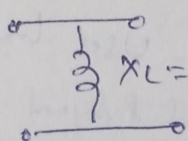
$X_L = jZ_1 \tan\frac{2\pi l}{\lambda_g}$

Inductor

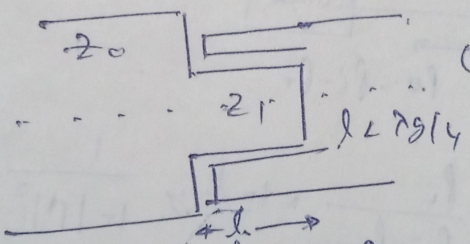


b = w.g with broad wall width

⟺

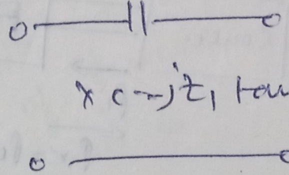


$X_L = jZ_1 \tan\frac{2\pi l}{\lambda_g}$

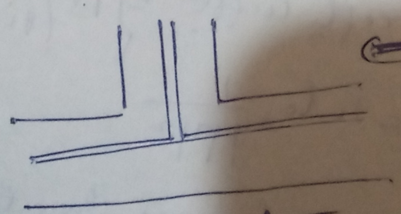


Co-axial line gap

⟺

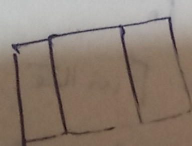


$X_C = -jZ_1 \tan\frac{2\pi l}{\lambda_g}$

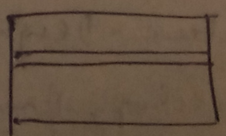


Coaxial-T

⟺



Inductive Iris



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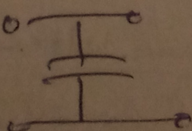
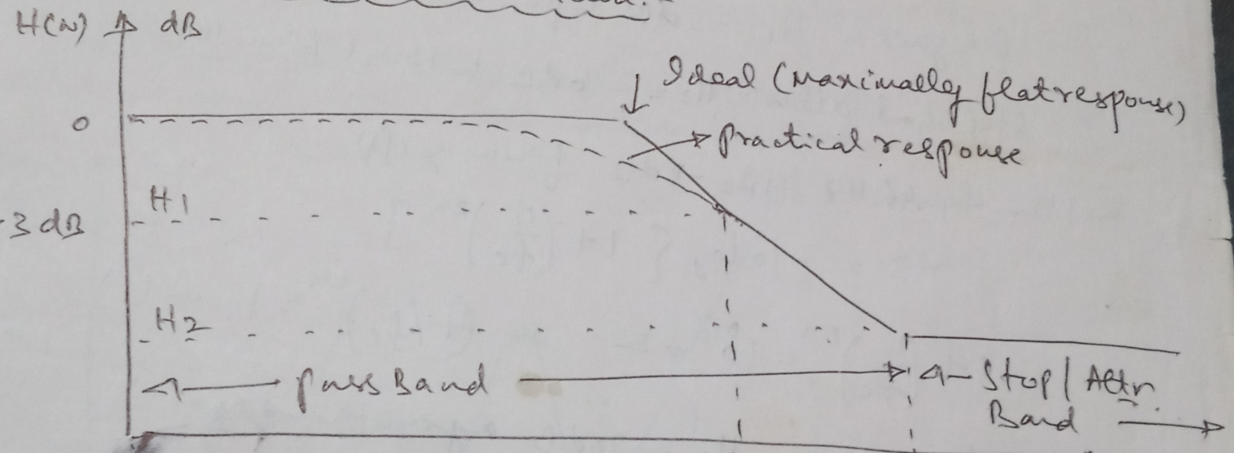


Capacitive Iris.

Steps involved in design of μwave filters by IL method 0: discrete components [MW 1-25] 23

1. To design any filter of a particular order, LP | HP | BP | BE filters first design Prototype LP filter using Butterworth | chebyshev transfer function at low freq. LP filter can be converted to other type of filters.
2. Use freq transformation to suit μwave freq.
3. Element Normalization
4. Simulate the elements by using μwave Txn lines | w.g | Strip lines | irises.

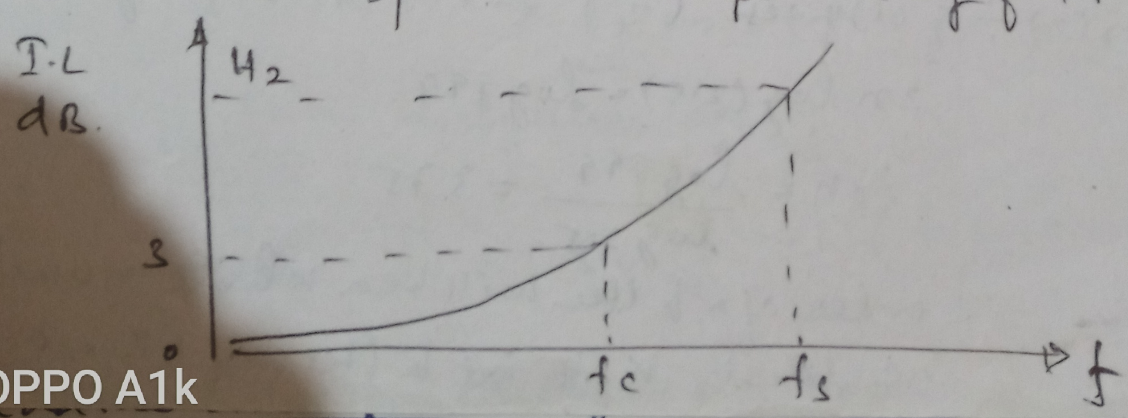
(a) Butterworth filter method:-



Butterworth Transfer function response $f_c = f_1$ $f_s = f_2$

f_c = cutoff freq, f_s = Freq at which stop band gain or attn is of desired value (i.e H_2)

Insertion loss response is the Complementary or Inversion of T.F. freq response



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Butterworth polynomial is given by

$$H(f_0) = 20 \log \left[\frac{1}{1+(f/f_c)^{2n}} \right]^{1/2} \text{ dB} \quad \text{— (A)}$$

MW1-22

f = any freq, f_c = cutoff fr, n = order of the filter

$$H(\omega) = -10 \log \left[1 + (f/f_c)^{2n} \right] \quad \text{— (B)}$$

From this order of the filter can be determined.

Eg:- obtain the order of a B.W filter with

P.B gain = $H_1 = -3$ dB upto 4 GHz (f_1)

stop band attn = $H_2 = -30$ dB to start from 10 GHz

with $f_1 = 4$ GHz, $H_1 = -3$ dB from eq (B)

$$-3 = -10 \log \left[1 + \left(\frac{4}{f_c}\right)^{2n} \right]$$

$$1 + \left(\frac{4}{f_c}\right)^{2n} = 10^{0.3} = 2 \quad \text{or} \quad (4/f_c)^{2n} = 1 \quad \text{— (1)}$$

with $f_2 = 10$ GHz, $H_2 = -30$ dB again from eq (B)

$$-30 = -10 \log \left[1 + \left(\frac{10}{f_c}\right)^{2n} \right]$$

$$\therefore (10/f_c)^{2n} = 999 \quad \text{— (2)}$$

eq (2) $\div$ eq (1) gives $\left(\frac{10}{4}\right)^{2n} = 999$; Taking log on both sides

$$2n \log(2.5) = \log 999$$

$$\therefore n = \frac{\log 999}{\log 2.5} = 3.75$$

$\because$ order of a filter will be a whole number we select $n = 4$ i.e filter is of 4th order

$\left[\quad (\;\;/f_c) \right] \text{— (2)}$

Order of a Chebyshev filter:-

-tion of LPF using discrete components MW1-25

23

(b) chebyshev filter method:-

MW1-23

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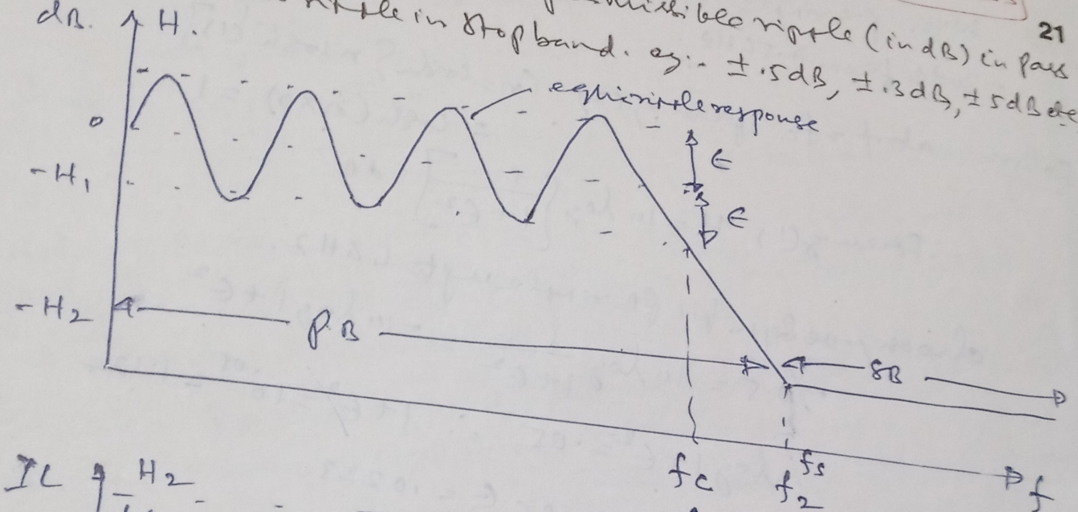
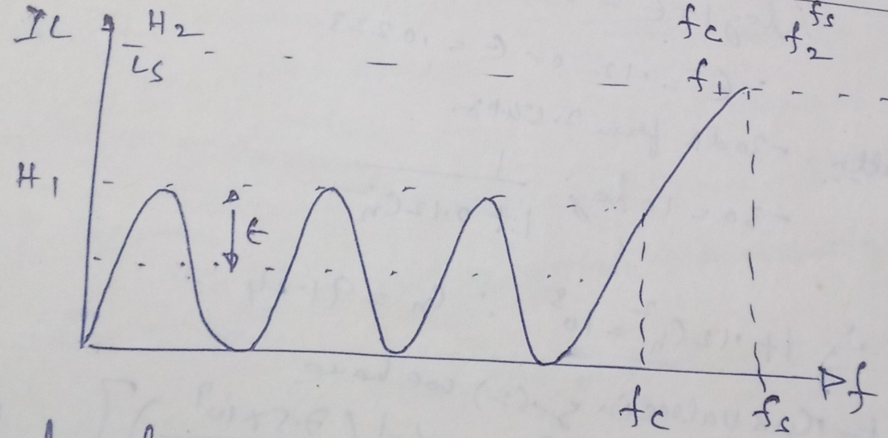
The response has some permissible ripple (in dB) in pass band & no ripple in stop band. eg:- ±.5dB, ±.3dB, ±5dB etc.





chebyschev polynomial is given by

$$H(\omega) = 10\log\left[\frac{1}{1+\epsilon^2 C_n^2}\right] dB \quad -(1)$$

C_n is chebyschev coeff.

where $C_n = \cosh\left\{n\cosh^{-1}(f/f_c)\right\} \quad -(2)$

To find the order of a chebyschev filter:-

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eg:- Find the order of a chebyshev filter with pass band ripple ± 0.5 dB upto 4 GHz, attn or I.L to be -30 dB from 7.5 GHz.

MW 1-24

Soln:- at $f = f_c$ from eq (2) $C_n = \cosh[n \cosh^{-1}(1)]$
$= \cosh(n \times 0) = 1$

$\therefore$ From eq (1) $H = 10 \log \left[\frac{1}{1+\epsilon^2}\right]$ dB

choosing -ve sign for pass band ripple upto 4 GHz.

$$-0.5 = 10 \log \frac{1}{1+\epsilon^2} = -10 \log 1+\epsilon^2$$

$$\log 1+\epsilon^2 = .05 \quad \therefore 1+\epsilon^2 = 10^{.05} = 1.12$$

$$\therefore \epsilon^2 = .12 \text{ or } \epsilon = .0233$$

with attn. -30 dB from 7.5 GHz.

$$-30 = 10 \log \frac{1}{1+0.12 C_n^2}$$

$$\therefore 1 + .12 C_n^2 = 10^3 \quad \therefore C_n = 91.24$$

substituting these values in eq (2) we have

$$91.24 = \cosh\left[n \cosh^{-1}\left(\frac{7.5 \times 10^9}{4 \times 10^9}\right)\right]$$

$$\cosh^{-1}(91.24) = n \cosh^{-1}(1.875)$$

$$\therefore n = \frac{\cosh^{-1}(91.24)}{\cosh^{-1}(1.875)} = \frac{5.207}{1.2416} = 4.19$$

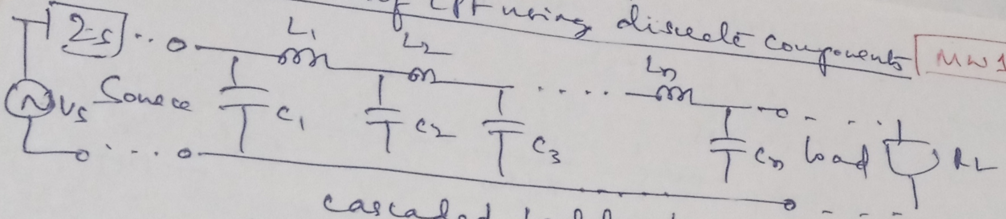
$\therefore$ we select a filter of order 5.

Procedure

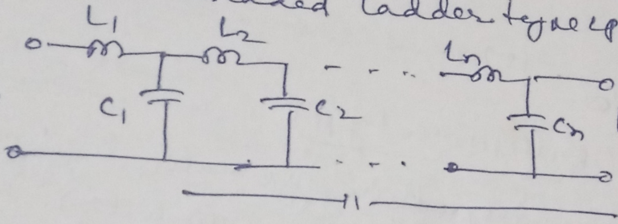
Implementation of LPF using discrete components

MW1-25

23



cascaded ladder type LPF. cap i/p type.



with Ind i/p type.

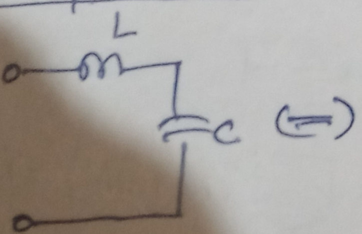
Each L-C section is a 2nd order LPF, hence two L-C sections give 4th order. In general $n/2$ sections (where n is even) are needed to construct an nth order filter.

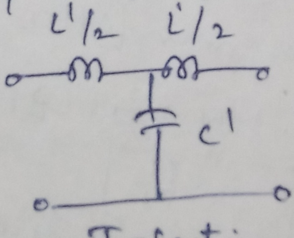
To construct an odd ordered filter we must cascade required no of 2nd order filters & a 1st order filter.

eg:- 3rd order — One 2nd order filter with a first order filter
5th " — two " & " etc.

In general $\left(\frac{n-1}{2}\right)$ sections (where n is odd) are required to cascade with a 1st order filter to construct odd ordered filter.

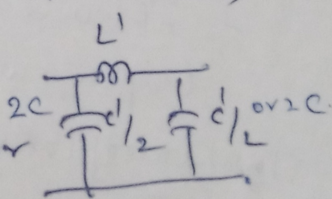
Filter design at LF:- (using lumped elements like L & C)





T-Section

or



π-section

If R_0 = char imped $= \sqrt{L'/C'}$ —(1)

f_c = cutoff freq of filter $= \frac{1}{\pi\sqrt{L'C'}}$ —(2)

It is common to split L & C as $L'/2$ & $C'/2$

MW 1-26

From eq (1) $L' = C' R_0^2$ — (3)

eq (3) in eq (2) gives

$$f_c = \frac{1}{\pi R_0 C'} \quad \text{or} \quad C' = \frac{1}{\pi f_c R_0} \quad \text{or} \quad \frac{C'}{2} = \frac{1}{2\pi f_c R_0} = \frac{1}{w_c R_0} \quad \text{— (4)}$$

$$\text{III}^{ly} \quad \frac{L'}{2} = \frac{R_0}{w_c} \quad \text{— (5)}$$

Practical LPF design (Butterworth type):-

Butterworth filters are designed using normalized polynomials for various values of n (n is the order of the filter).

eg:- $n=1$ $\quad s+1$

$n=2$ $\quad (s^2+1.414s+1)$

$n=3$ $\quad (s^2+s+1)(s+1)$ etc...

∴ Normalized TF for 2nd order filter is $H(s) = \dfrac{1}{s^2+1.414s+1}$

(Normalized means, f_c = unity).
or $w_c = 1$

But actual T.F is $H(s) = \dfrac{w_c^2}{s^2+1.414 w_c s + w_c^2}$

coefft. of s term in each of the 2nd order section are used to obtain respective values of components used to implement a given filter.

Two forms of ladder N/W type LPF are used

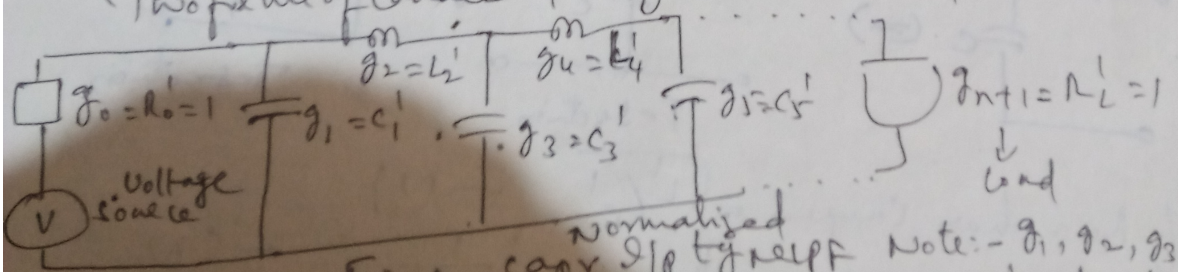
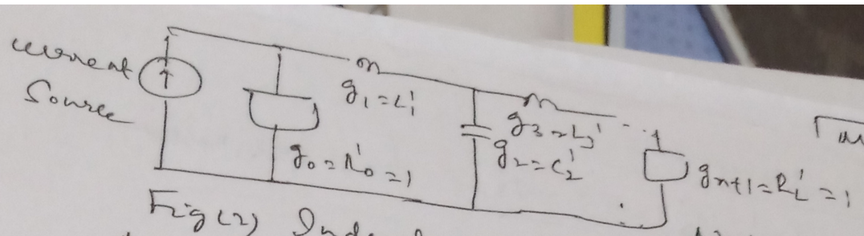


Fig 1 Normalized cap. I/P type LPF

Note:- $g_1, g_2, g_3 \ldots$ / $C_1', L_2', C_3', L_4' \ldots$ represent Normalized values of components

Normalized component values



Fig(2) Inductor i/p filter

Not unique...

Most of the time we use cap^r i/p filters.

<u>LP filter design</u> :- g_0 } → Normalized $R_0 = R_{in} = 1$
& g_{n+1} } → — " — $R_L = R_0 = 1$

Elements of the filter — $C_n = \frac{g_n (= C_n')}{\omega_c R_0}$ —(1) $L_n = \frac{g_n (= L_n') R_0}{\omega_c}$ —(2)

From fig 1 $g_1, g_3, g_5 \ldots$ are shunt elements (Capacitors)
$g_2, g_4, g_6 \ldots$ series — " — (Inductors)
i.e in eq(1) n is odd such that n = 1, 3, 5 ...
— " — (2) — " — even — " — = 2, 4, 6 ....

Q:- obtain the components of the 4th order Butterworth filter with $f_c = 4GHz$, $R_0 = 50\Omega$

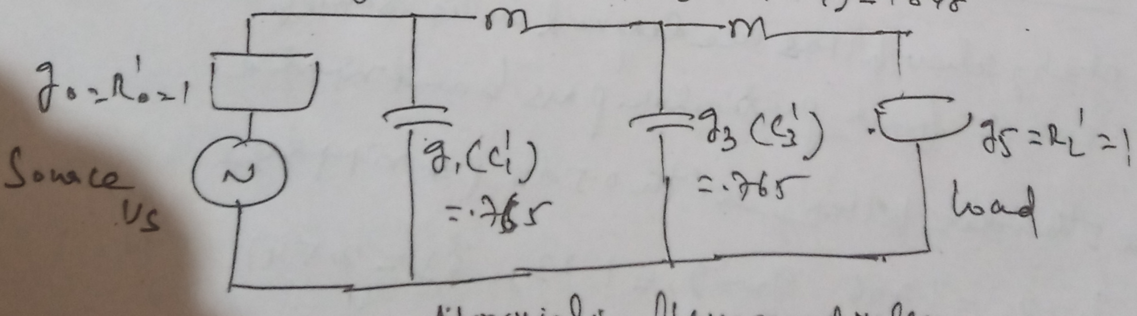
T.f. is $H(s) = (s^2 + .765s + 1)(s^2 + 1.848s + 1)$

∴ coeffts in the above equation are $g_1 = g_3 = 0.765$, $g_2 = g_4 = 1.848$

These are the normalized Component values

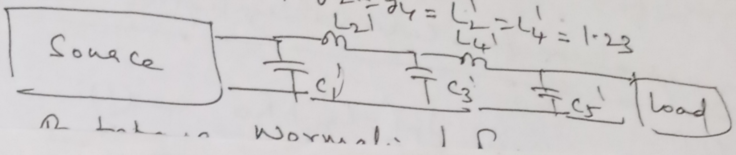
i.e $g_1 (C_1')$ & $g_3 (= C_3')$; $g_2 (L_2')$ & $g_4 (L_4')$

∴ Thevenin's form $g_2 (L_2') = 1.848$ $g_4 (L_4') = 1.848$



Normalized component values

$g_1 = g_3 = 2.541$, $g_2 = g_4 = L_2' = L_4' = 1.23$



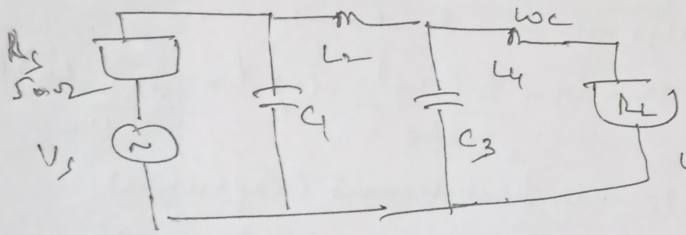
MW1 28

Denormalized Components:-

$$C_1 = C_3 = \frac{(C_1' \text{ or } C_3') \text{ or } (g_1 \text{ or } g_3)}{\omega_c R_0} \qquad f_c = 4\,GHz, R_0 = 50\Omega$$

$\therefore C_1 = C_3 = .609\,pF$

$|||^{ly}$ $L_2 = L_4 = \frac{(L_2' + L_4') \text{ or } (g_2 \text{ or } g_4) R_0}{\omega_c} = 3.68\,nH$



4th order denormalized filter

Note:- Instead of T.F we can use Normalized Component table available in log books.

order		g-values	
$n = 1$	$g_0 = 1$	$g_1 = 2$	$g_2 = 1.0$
$= 2$	-||-	$g_1 = g_2 = 1.414$	$g_3 = 1.0$
$= 3$	-||-	$g_1 = 1,\ g_2 = 2,\ g_3 = g_4 = 1$	
$= 4$	-||-	$g_1 = g_3 = .7654,\ g_2 = g_4 = 1.8478,\ g_5 = 1$	

Note:- Chebyschev filters are designed in the same fashion except for a particular pass band ripple.

H.W

eg:- For 5th order filter with 0.5 dB P.B. ripple

$g_1 = g_5 = 1.706$, $g_2 = g_4 = 1.23$, $g_3 = 2.541$

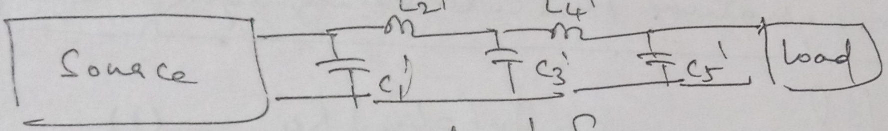
$$\frac{\quad}{2} \qquad \frac{\quad}{2\sqrt{1+12x}}$$

with $f_r = 5$, $x = 1.044$

Soln.

$g_1 = g_5 = C_1' = C_5' = 1.706$ $\boxed{MW1-29}$

$g_3 = C_3' = 2.541$, $g_2 = g_4 = L_2' = L_4' = 1.23$

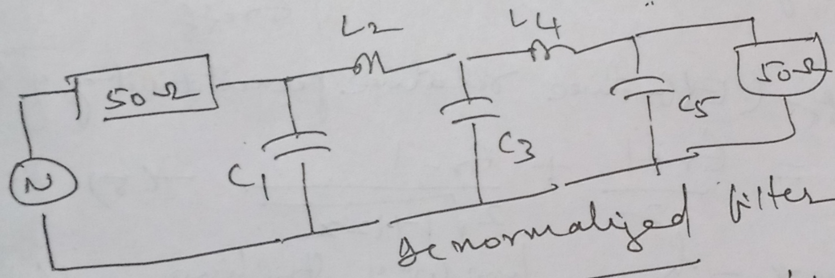


Prototype normalized form

At $f_c = 4GHz$, $R_0 = 50\Omega$, Denormalized Values are

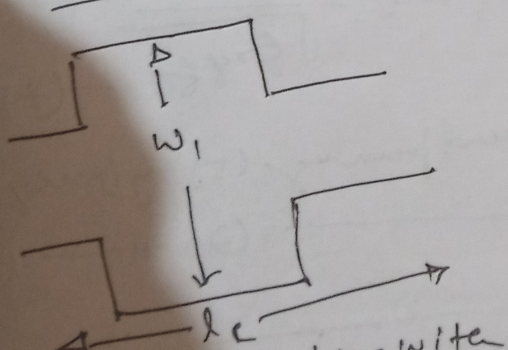
$$C_1 = C_5 = \frac{g_1 \text{ or } g_5}{\omega_c R_0} = 1.36 pF, \quad C_3 = \frac{g_3}{\omega_c R_0} = 2.02 pF$$

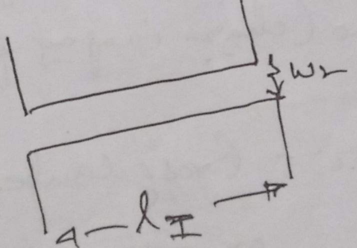
$$L_2 = L_4 = \frac{g_2 \text{ or } g_4 R_0}{\omega_c} = 2.447 nH$$



Prototype denormalized filter

Practical realization of lumped stripline filters





Wider stripline with low impedance acts as a capacitor

Narrow stripline having high impedance acts as an inductor

$2\sqrt{1+12(1.044)}$

Dimension in between C & L adj as an resistor. $\boxed{MW\ 1\text{-}30}$

Design equations for calculating length the Stripline

$$\beta l_{n\,(induct)} = \frac{g_n(=L_n') R_0}{Z_{high}} \quad -(1)$$

$$\beta l_{n\,(cap)} = \frac{g_n(=C_n') Z_{low}}{R_0} \quad -(2)$$

where β = phase constant $= 2\pi/\lambda_g$; radians —(3)

λ_g = Guide wavelength $= \frac{\lambda}{\sqrt{\epsilon_{reff}}}$ —(4)

ϵ_{reff} (Effective relative permittivity of Stripline)

$$= \frac{\epsilon_r+1}{2} + \frac{\epsilon_r - 1}{2\sqrt{1+12x}} \quad -(5)$$

where $x = \frac{h}{W} = \frac{\text{height of Stripline}}{\text{width} \text{ -- " --}}$ —(6)

typically $x \simeq 1.044$

R_0 (char. imped. of Strip line) $\simeq \frac{60}{\sqrt{\epsilon_{reff}}} \ln\left(8x + \frac{1}{4x}\right)$ —(7)

Note:- ϵ_{reff} can be found from eq (5) by giving ϵ_r & x

or —"— (7) —"— R_0 & x

Eg:- Implement the strip line LP Butterworth filter (4th order)

Data:- $R_0 = 50\Omega$, $Z_{high} = 150\Omega$, $Z_{low} = 10\Omega$,

$\epsilon_r = 5$, $h = .5mm$

Passband attn. → $H_1 = -3dB$ upto $4GHz$, $H_2 = -30dB$ from $10GHz$ → I.L

MW1-35

MW1-31

BSF: Procedure

Selection

* $\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{1+12x}}$

with $\epsilon_r = 5$, $x = 1.044$

$\epsilon_{reff} = \frac{5+1}{2} + \frac{5-1}{2\sqrt{1+12(1.044)}} = 3.54$

* $\lambda = \frac{c}{f} = \frac{3\times10^8}{4\times10^9} = .075m$

* $\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{reff}}} = \frac{.075}{\sqrt{3.54}} = 0.102m$

$\therefore$ * $\beta = 2\pi/\lambda_g = 61.625$ rads

For 4th order LP B.W filter, Coeffts are

$g_1 (=C_1') = g_3 (=C_3') = .765$ units

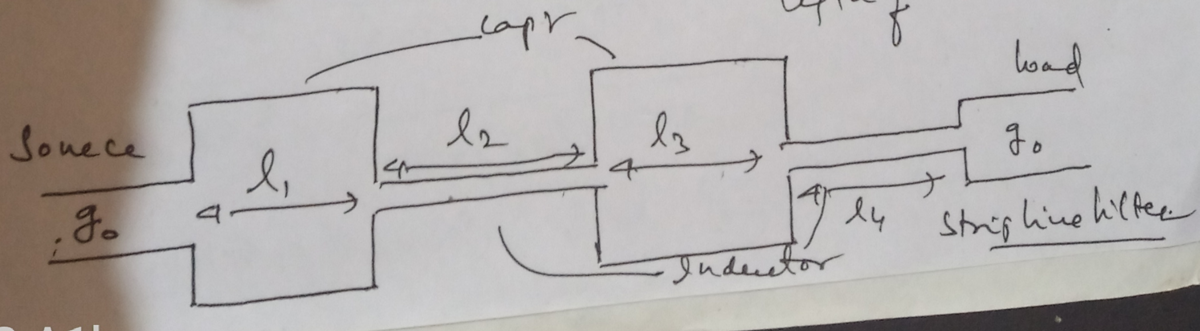
$g_2 (=L_2') = g_4 (=L_4') = 1.848$ units

W.K.T $\beta l_{n(cap)} = \frac{g_n (=C_n') Z_{low}}{R_0}$ when n is odd

$\therefore l_1$ or $l_3 = \frac{.765\times10}{\times50} = .0025$ m length of capr striplines

IIly $\beta l_{n(ind)} = \frac{g_n (=L_n') R_0}{Z_{high}} = \frac{1.848\times50}{150}$

$\therefore l_2$ or $l_4 = .01$ m length of Inductor striplines

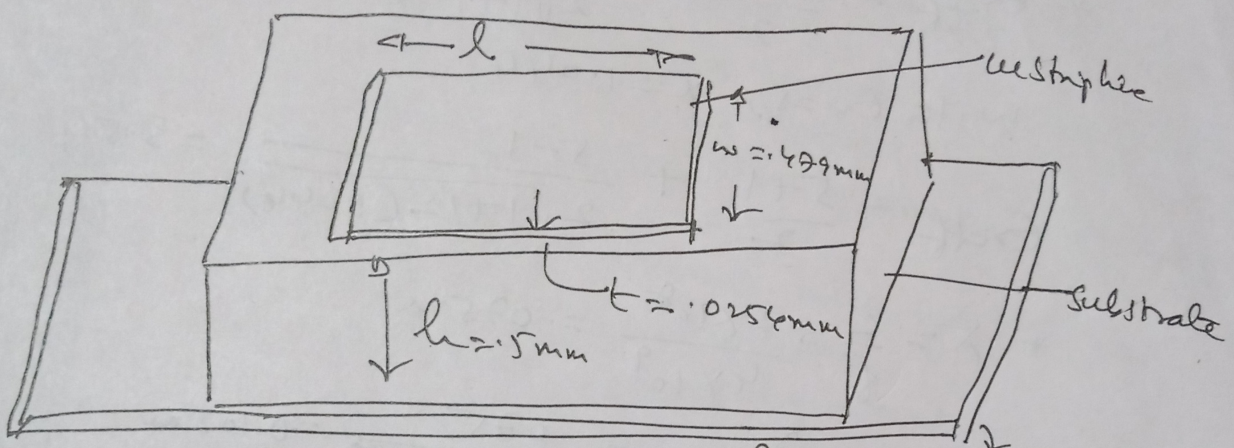


stripline filter

$w = \frac{h}{\pi} = .479mm$

Generally $t = 1mil = .0254mm$

MW1-32



Stripline Inductor

Summary of BP or chebyschev LP filter design

1). Find order of the filter

2). Realize a prototype Normalized filter

3). —"— de —"—

4). Find β & ε_{reff}, determine 'l' of cap. & Inductor strip lines.

LPF to BPF: Procedure

MW1- 35

LP Microwave filter design:-

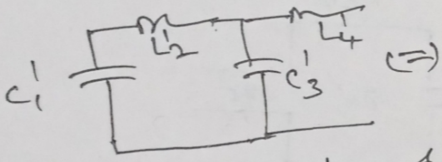
MW1-33

* Find order of filter from f_1, f_2, I.L in P.B & I.L in S.B using B.W or chebyschev T.F.
* Realize prototype normalized / de-normalized filter using filter co-effts from T.F or Table
* Realize Stripline filter by converting prototype filter

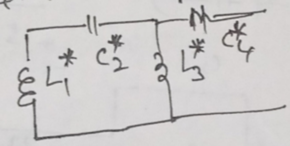
HP filter design:-

* Direct design not possible
* First realize LP as above
* Convert LP to HP using equations
* Realize using strip lines as in LPF.

eg:- 4th order LPF



4th order HPF



caps → to Inductances & vice-versa

Design equations:- $L_n^* = \frac{R_0}{\omega_c C_n'(=g_n')}$ — (1) n is odd 1,3,5...

$C_n^* = \frac{1}{\omega_c R_0 L_n'}(=g_n')$ n is even 2,4,6....

$R_0 = 50\Omega$, $f_c = 4\times10^9 Hz$

eg:- 4th order B.W HPF:-

$g_1(=c_1') = g_3(=c_3') = .765$

$g_2(=L_2') = g_4(=L_4') = 1.848$

Prototype-denormalized:

$L_1^* = L_3^* = \frac{50}{2\pi\times4\times10^9\times0.765} =$

$C_2^* = C_4^* = \frac{1}{2\pi\times4\times10^9\times1.848} =$

Strip line:- $R_0 = 50\Omega$, $Z_{high} = 150\Omega$, $Z_{low} = 10\Omega$, $\epsilon_r = 5$, $f_c = 4GHz$

MW1- 35

- 15: Procedure

MW1-34

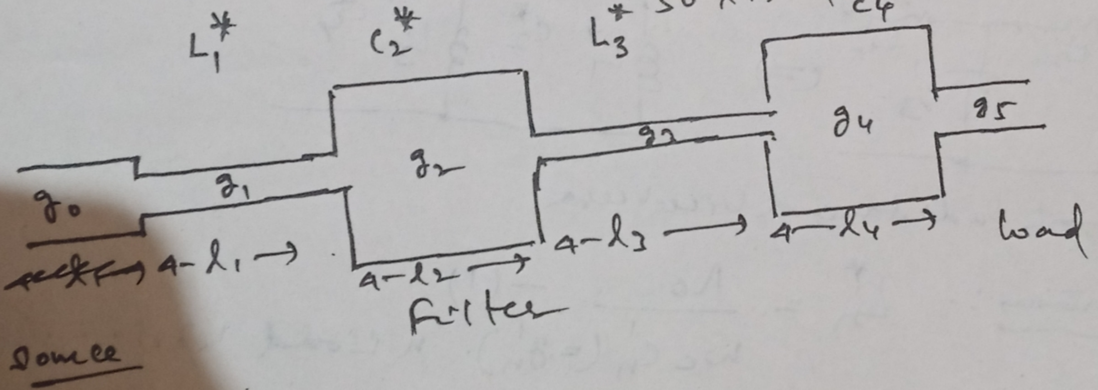
$$\beta l_{n\,(induct)} = \frac{g_n\,(=C_n')\,R_0}{Z_{high}}$$ n is odd 1,3,5....

$$\beta l_{n\,(cap)} = \frac{g_n\,(=L_n')\,Z_{low}}{R_0}$$ n is even 2,4,6...

$\epsilon_{reff} = 3.54$, $\lambda = .75m$, $\lambda_g = 0.04m$, $\beta = 157.1$ rad/s

$$\therefore\ l_1 = l_3 \text{ (Induct strip line length)} = \frac{0.765 \times 50}{157.1 \times 150} = \quad mm$$

$$l_2 = l_4 \text{ (cap —11—)} = \frac{1.848 \times 10}{50 \times 157.1}$$

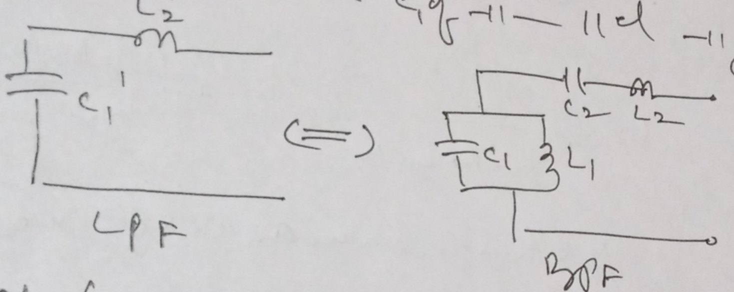


LPF to BPF: Procedure

- Realize LPF (prototype)
- convert Series L_2' of LPF to Series L-C Ckt of BPF (C_2-L_2)
- —||— Shunt C_1' of —||— ||el —||— (C_1-L_1)

$\boxed{\text{MW1- 35}}$

eg:-



- If f_{c1} is cutoff freq of LPF, f_{c2} is cutoff freq of HPF

For BPF $f_{c2} > f_{c1}$

Design equations:-

- components of ||el resonant ckt

$$C_n = \frac{C_n'}{\omega_r R_0 \Delta}, \quad L_n = \frac{\Delta R_0}{\omega_r C_n'} \quad \boxed{n \text{ is odd}}$$

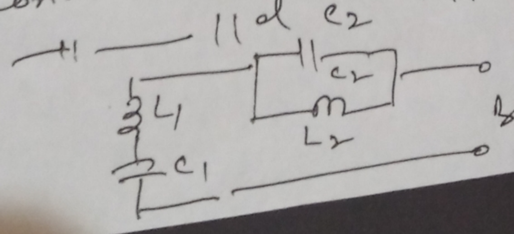
- components of series resonant ckt are

$$C_n = \frac{\Delta}{\omega_r R_0 L_n'}, \quad L_n = \frac{L_n' R_0}{\omega_r \Delta} \quad \boxed{n \text{ is even}}$$

where Δ = fractional b/w $= \frac{f_{c2} - f_{c1}}{f_r}$ & $f_r = \sqrt{f_{c1} f_{c2}}$

LPF to BEF Procedure

- Realize LPF (prototype)
- convert Series L_2' of LPF to ||el L-C ckt (L_2-C_2)
- —||— ||el C_2' —||— Series —||— (L_1-C_1)



Design equations

$$C_n = \frac{\Delta C_n'}{\omega_r R_o}, \quad L_n = \frac{R_o}{\omega_r C_n' \Delta}$$ for series elements

$\boxed{n \text{ is odd}}$

$$C_n = \frac{1}{\omega_r R_o L_n' \Delta}, \quad L_n = \frac{L_n' R_o \Delta}{\omega_r}$$ — " — ||el elements

$\boxed{n \text{ is even}}$

Δ & f_r are same as in BPF except $f_{c1} > f_{c2}$

where f_{c1} is cutoff freq of HPF

& f_{c2} — " — LPF $\quad \Delta = \frac{f_{c1} - f_{c2}}{f_r}$