# "SÍNTESIS DE FILTROS MODERNOS"
# "PARTE I - FILTROS PASIVOS

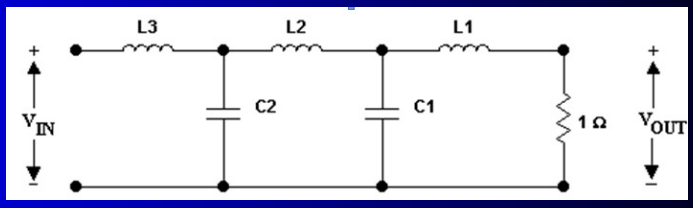
Ing. Juan José GARCIA ABAD

TEORÍA DE LOS CIRCUITOS II

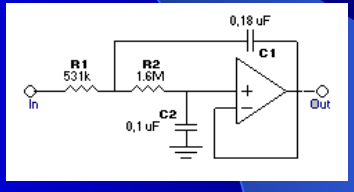


## SINTESIS :

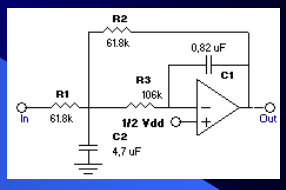
### CIRCUITOS PASIVOS




### CIRCUITOS ACTIVOS




SALLEN KEY




MFB

# RED ESCALERA CON ELEMENTOS PASIVOS

**Emplearemos un circuito basado en reactancias.**

**Partiremos de un circuito *NORMALIZADO* con $R_{OUT}$ = 1 [Ω ] y $\omega_C$ = 1 [rad/seg].**

**Supondremos en primer lugar que la impedancia del Generador es $R_{GEN}$ = 0 [Ω ].**



**El circuito propuesto se genera para un valor de Amax = 3 [dB].**

**Para desnormalizar a cualquier valor de Amax , de Ro y de pulsación de corte $\omega_C$ ó $\omega_p$ usaremos :**

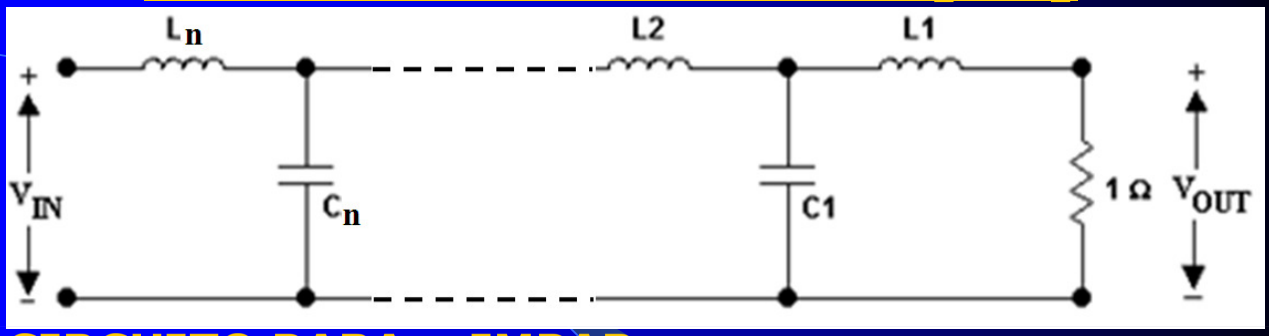
$$\varepsilon = \sqrt{10^{(0,1*Amax_{dB})} - 1}$$

$$R_X = R_{OUT}$$

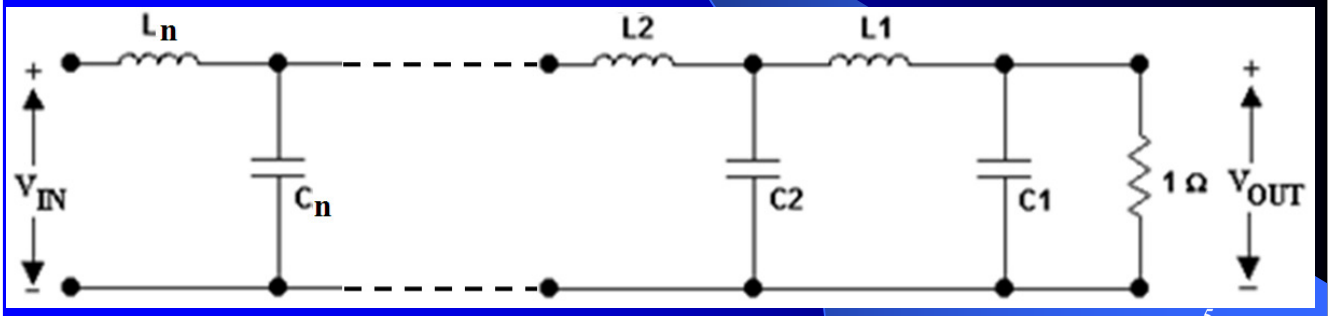
$$L_X = R_{OUT} * \varepsilon^{1/n} * \frac{1}{\omega_P} * L_N$$

$$C_X = \frac{1}{R_{OUT}} * \varepsilon^{1/n} * \frac{1}{\omega_P} * C_N$$

# RED ESCALERA CON ELEMENTOS PASIVOS CON Amax =3[dB]



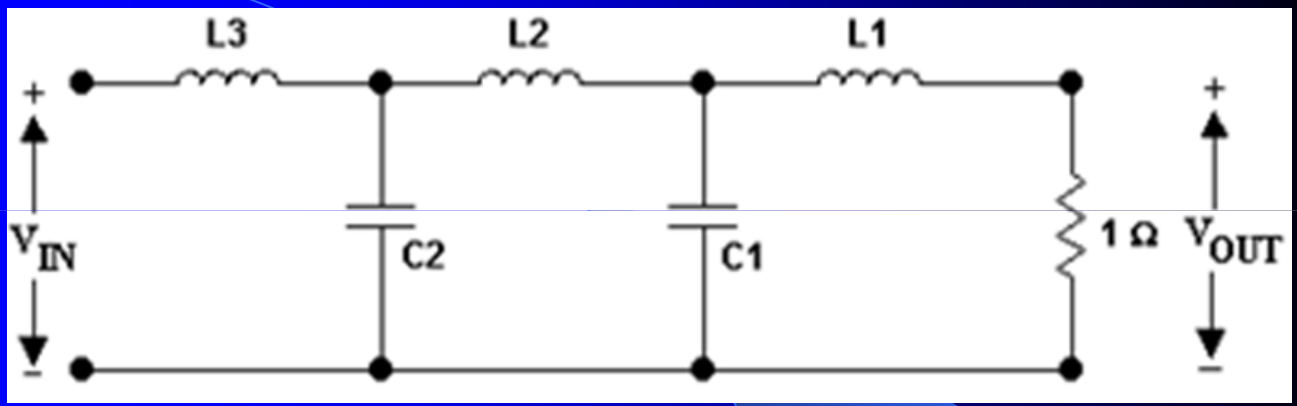

CIRCUITO PARA n IMPAR



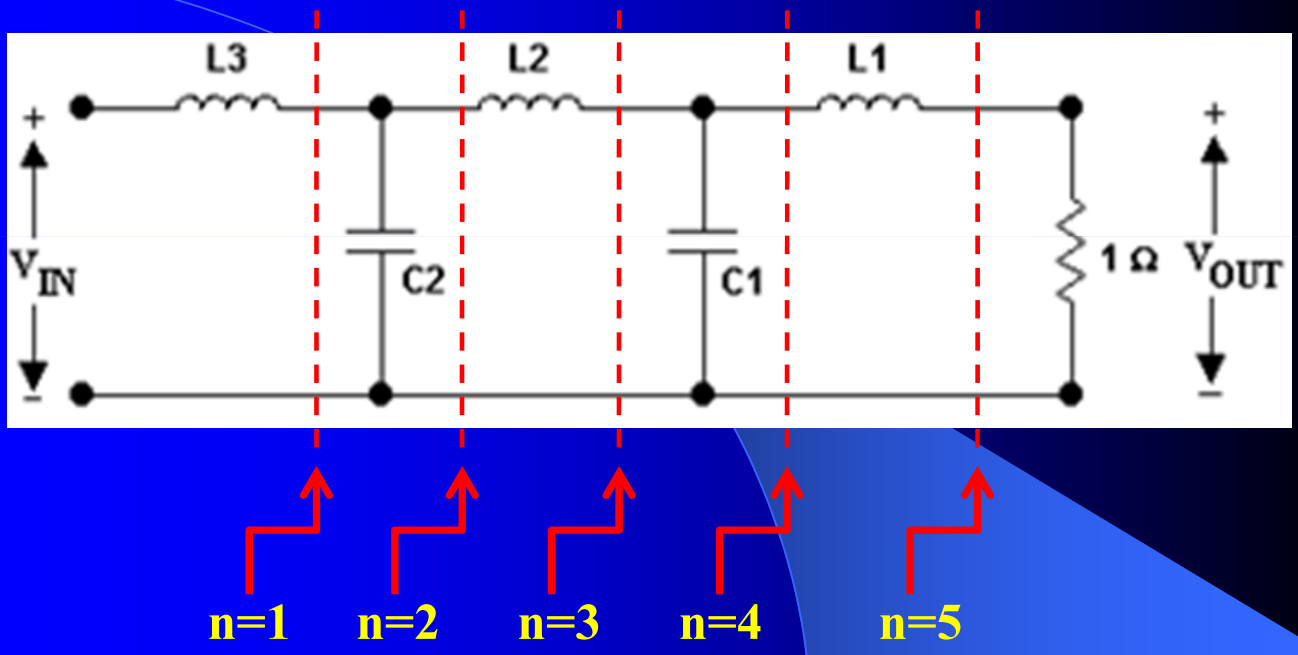

CIRCUITO PARA n PAR



# RED ESCALERA PASA-BAJOS PASIVA GENERALIZADA DE 5 ELEMENTOS



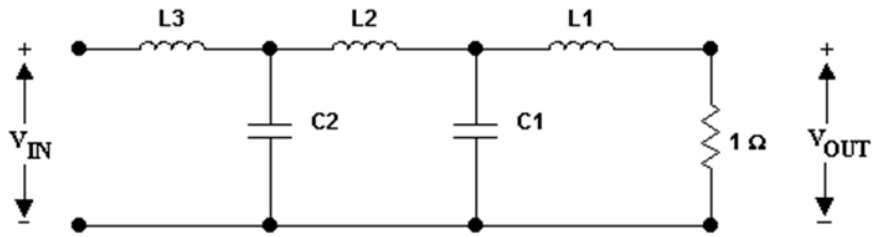
# RED ESCALERA PASA-BAJOS PASIVA GENERALIZADA DE 5 ELEMENTOS






# RED ESCALERA PASIVA PASA-BAJOS DE BUTTERWORTH CON Amax = 3 [dB] Y n =5

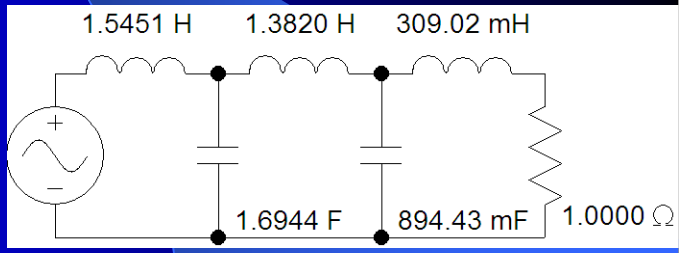
n = 5.




$$G_5(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^5.L_1.L_2.L_3.C_1.C_2 + S^4.L_2.L_3.C_1.C_2 + S^3[L_1.(L_2.C_1 + L_3.C_1 + L_3.C_2) + L_2.L_3.C_2] + S^2.[C_1.(L_2 + L_3) + L_3.C_2] + S.(L_1 + L_2 + L_3) + 1}$$

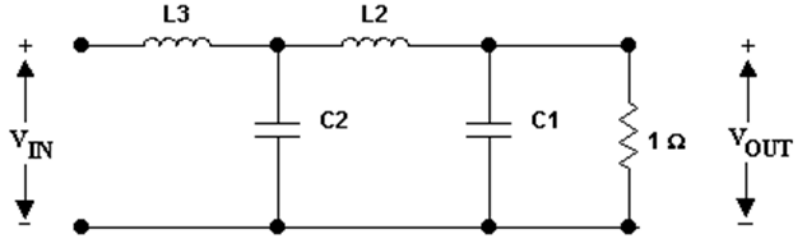
5th Order Low Pass Butterworth

$$\frac{1}{S^5 + 3.236*S^4 + 5.236*S^3 + 5.236*S^2 + 3.236*S + 1}$$



# RED ESCALERA PASIVA PASA-BAJOS DE BUTTERWORTH CON Amax = 3 [dB] Y n =4

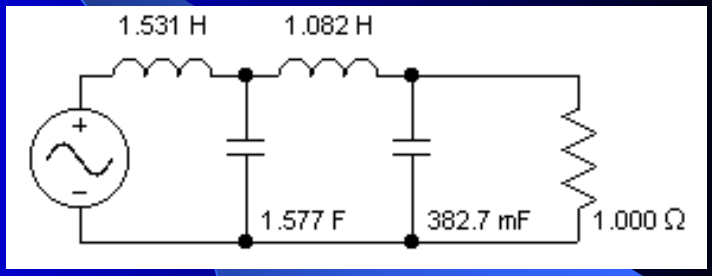
$n = 4.$




$$G_4(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^4.L_2.L_3.C_1.C_2 + S^3(L_2.L_3.C_2) + S^2.[C_1.(L_2 + L_3) + L_3.C_2] + S.(L_2 + L_3) + 1}$$

4th Order Low Pass Butterworth

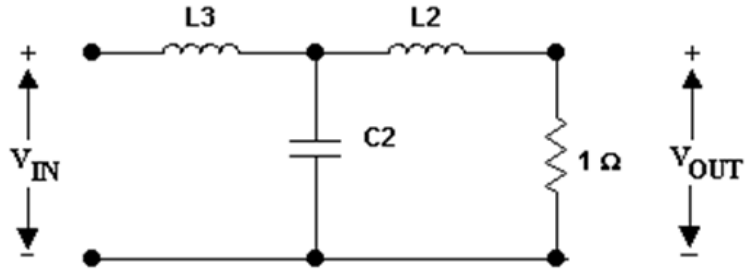
$$\frac{1}{S^4 + 2.613*S^3 + 3.414*S^2 + 2.613*S + 1}$$






# RED ESCALERA PASIVA PASA-BAJOS DE BUTTERWORTH CON Amax = 3 [dB] Y n =3

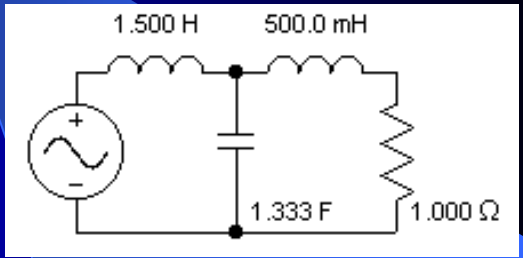
$n = 3.$




$$G_3(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^3(L_2.L_3.C_2) + S^2.L_3.C_2 + S.(L_2 + L_3) + 1}$$

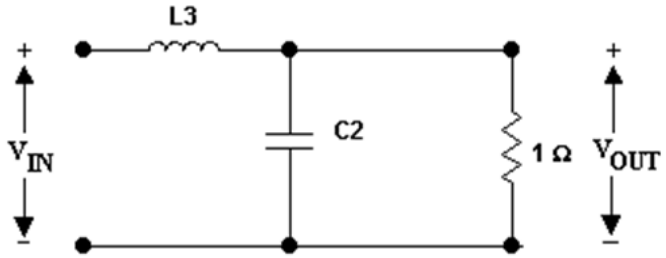
3rd Order Low Pass Butterworth

$$\frac{1}{S^3 + 2.000*S^2 + 2.000*S + 1}$$



# RED ESCALERA PASIVA PASA-BAJOS DE BUTTERWORTH CON Amax = 3 [dB] Y n =2

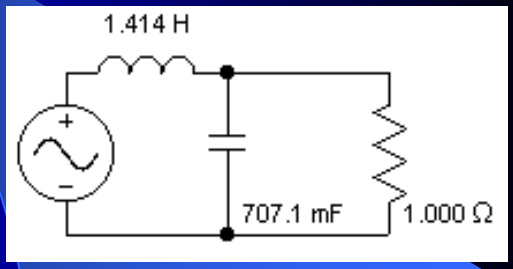
n = 2.




$$G_2(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^2.L_3.C_2 + S.L_3 + 1}$$

2nd Order Low Pass Butterworth

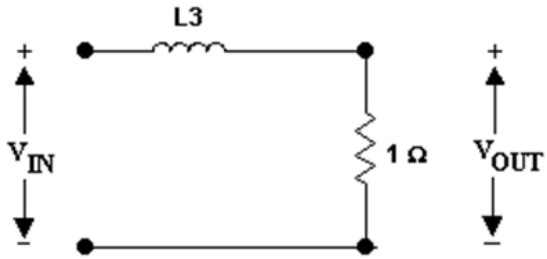
$$\frac{1}{S^2 + 1.414*S + 1}$$






# RED ESCALERA PASIVA PASA-BAJOS DE BUTTERWORTH CON Amax = 3 [dB] Y n =1

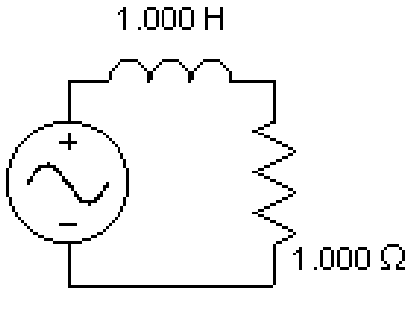
n = 1.



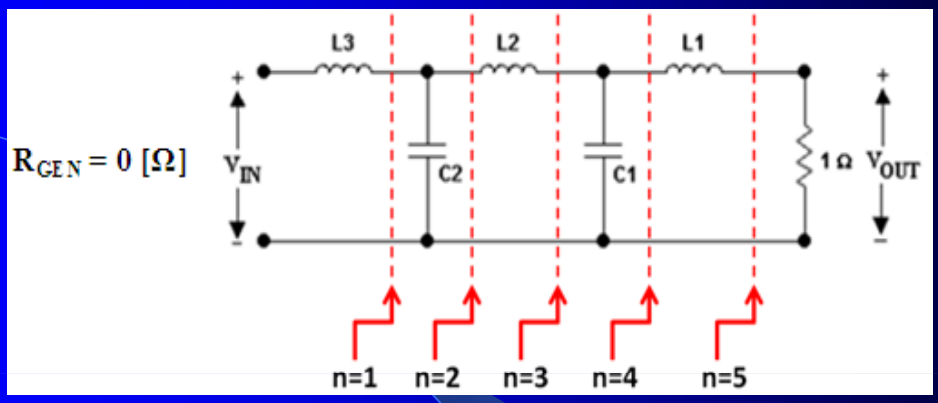

$$G_1(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S.L_3 + 1}$$

1st Order Low Pass Butterworth

$$\frac{1}{S + 1}$$



# RED ESCALERA CON 5 ELEMENTOS PASA-BAJOS DE BUTTERWORTH - GENERALIZADA




## VALORES DE COMPONENTES PARA Amax = 3 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | 1 |
| 2 | 1 | | | | 0,70710678 | 1,41421356 |
| 3 | 1 | | | 0,5 | 1,33333333 | 1,5 |
| 4 | 1 | | 0,382683 | 1,08239 | 1,57716 | 1,53073 |
| 5 | 1 | 0,309017 | 0,894427 | 1,38197 | 1,69443 | 1,54508 |



## VALORES DE COMPONENTES PARA Amax = 2 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 0,764783102 | | | | | 0,7647831 |
| 2 | 0,874518783 | | | | 0,61837816 | 1,23675632 |
| 3 | 0,914490983 | | | 0,45724549 | 1,21932131 | 1,37173647 |
| 4 | 0,93515709 | | 0,35786872 | 1,01220468 | 1,47489236 | 1,43147301 |
| 5 | 0,947780255 | 0,29288021 | 0,84772025 | 1,30980388 | 1,6059473 | 1,46439632 |

## VALORES DE COMPONENTES PARA Amax = 1 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 0,50884714 | | | | | 0,50884714 |
| 2 | 0,713335223 | | | | 0,50440417 | 1,00880835 |
| 3 | 0,798354503 | | | 0,39917725 | 1,06447267 | 1,19753175 |
| 4 | 0,844591749 | | 0,3232109 | 0,91417766 | 1,33205632 | 1,29284193 |
| 5 | 0,87360974 | 0,26996026 | 0,78138014 | 1,20730245 | 1,48027055 | 1,34979694 |

## VALORES DE COMPONENTES PARA Amax = 0,5 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 0,3493114 | | | | | 0,3493114 |
| 2 | 0,591025719 | | | | 0,41791829 | 0,83583659 |
| 3 | 0,704267401 | | | 0,3521337 | 0,9390232 | 1,0564011 |
| 4 | 0,768781971 | | 0,29419979 | 0,83212192 | 1,21249217 | 1,17679763 |
| 5 | 0,810293867 | 0,25039458 | 0,72474871 | 1,11980182 | 1,37298624 | 1,25196885 |

**PARA OBTENER LOS VALORES DE LOS COMPONENTES PARA CUALQUIER VALOR DE Amax, SE CALCULA ε MEDIANTE LA SIGUIENTE EXPRESIÓN :**

$$\varepsilon = \sqrt{10^{(0,1*Amax_{dB})} - 1}$$

**Y SE MULTIPLICA EL VALOR DE CADA UNO DE LOS COMPONENTES DE LA TABLA PARA Amax = 3[dB] POR $\varepsilon^{(1/n)}$**

VALORES DE COMPONENTES PARA Amax = 3 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | 1 |
| 2 | 1 | | | | 0,70710678 | 1,41421356 |
| 3 | 1 | | | 0,5 | 1,33333333 | 1,5 |
| 4 | 1 | | 0,382683 | 1,08239 | 1,57716 | 1,53073 |
| 5 | 1 | 0,309017 | 0,894427 | 1,38197 | 1,69443 | 1,54508 |

**EJEMPLO PARA Amax = 0,25 [dB] Y ε = 0,243420881**

VALORES DE COMPONENTES PARA Amax = 0,25 dB

| n | Epsilon^(1/n) | L1 | C1 | L2 | C2 | L3 |
|---|---|---|---|---|---|---|
| 1 | 0,243420881 | | | | | 0,24342088 |
| 2 | 0,493377017 | | | | 0,34887023 | 0,69774047 |
| 3 | 0,624385214 | | | 0,31219261 | 0,83251362 | 0,93657782 |
| 4 | 0,702408013 | | 0,26879961 | 0,76027941 | 1,10780982 | 1,07519702 |
| 5 | 0,753826787 | 0,23294529 | 0,67424303 | 1,041766 | 1,27730672 | 1,16472269 |



**CÁLCULO DE EPSILON A PARTIR DEL VALOR DE Amax [dB**

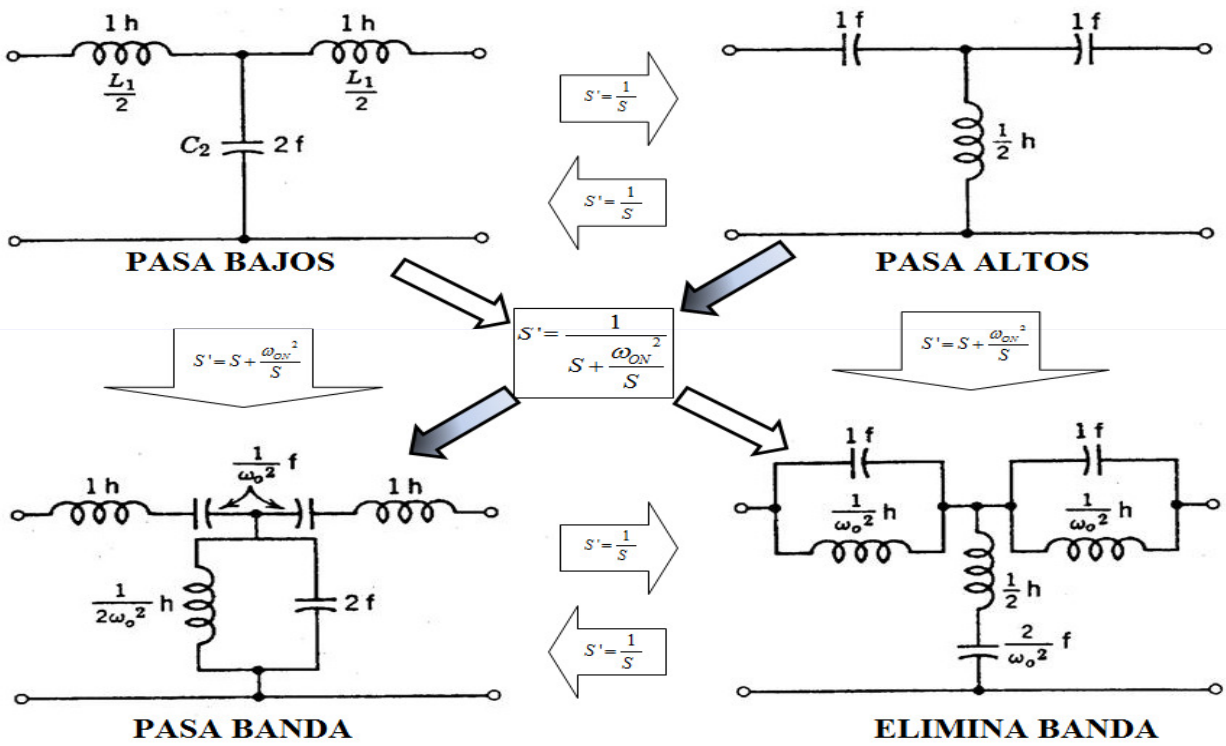
$$\varepsilon = \sqrt{10^{(0,1*Amax_{dB})} - 1}$$

| Amax [dB] | 0,1 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Epsilon | 0,152620 | 0,217091 | 0,267431 | 0,310609 | 0,349311 | 0,384907 | 0,418208 | 0,449738 | 0,479863 | 0,508847 |
| Epsilon^(1/2) | 0,390667 | 0,465930 | 0,517137 | 0,557323 | 0,591026 | 0,620409 | 0,646690 | 0,670625 | 0,692722 | 0,713335 |
| Epsilon^(1/3) | 0,534405 | 0,601009 | 0,644274 | 0,677233 | 0,704267 | 0,727420 | 0,747820 | 0,766161 | 0,782899 | 0,798355 |
| Epsilon^(1/4) | 0,625033 | 0,682591 | 0,719123 | 0,746541 | 0,768782 | 0,787660 | 0,804170 | 0,818917 | 0,832299 | 0,844592 |
| Epsilon^(1/5) | 0,686630 | 0,736764 | 0,768143 | 0,791485 | 0,810294 | 0,826173 | 0,839998 | 0,852299 | 0,863423 | 0,873610 |

| Amax [dB] | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 | 1,8 | 1,9 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Epsilon | 0,536889 | 0,564142 | 0,590731 | 0,616753 | 0,642291 | 0,667413 | 0,692177 | 0,716632 | 0,740822 | 0,764783 |
| Epsilon^(1/2) | 0,732727 | 0,751094 | 0,768590 | 0,785336 | 0,801431 | 0,816953 | 0,831971 | 0,846541 | 0,860710 | 0,874519 |
| Epsilon^(1/3) | 0,812758 | 0,826284 | 0,839067 | 0,851211 | 0,862801 | 0,873906 | 0,884584 | 0,894881 | 0,904839 | 0,914491 |
| Epsilon^(1/4) | 0,855995 | 0,866657 | 0,876693 | 0,886192 | 0,895227 | 0,903855 | 0,912125 | 0,920077 | 0,927745 | 0,935157 |
| Epsilon^(1/5) | 0,883033 | 0,891821 | 0,900073 | 0,907867 | 0,915264 | 0,922314 | 0,929059 | 0,935533 | 0,941765 | 0,947780 |

| Amax [dB] | 2,1 | 2,2 | 2,3 | 2,4 | 2,5 | 2,6 | 2,7 | 2,8 | 2,9 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Epsilon | 0,788549 | 0,812150 | 0,835610 | 0,858953 | 0,882201 | 0,905373 | 0,928486 | 0,951557 | 0,974600 | 0,997628 |
| Epsilon^(1/2) | 0,888003 | 0,901193 | 0,914117 | 0,926797 | 0,939256 | 0,951511 | 0,963580 | 0,975478 | 0,987218 | 0,998813 |
| Epsilon^(1/3) | 0,923867 | 0,932994 | 0,941892 | 0,950583 | 0,959082 | 0,967407 | 0,975570 | 0,983584 | 0,991461 | 0,999209 |
| Epsilon^(1/4) | 0,942339 | 0,949312 | 0,956095 | 0,962703 | 0,969152 | 0,975454 | 0,981621 | 0,987663 | 0,993589 | 0,999407 |
| Epsilon^(1/5) | 0,953599 | 0,959240 | 0,964719 | 0,970050 | 0,975245 | 0,980315 | 0,985270 | 0,990118 | 0,994868 | 0,999525 |

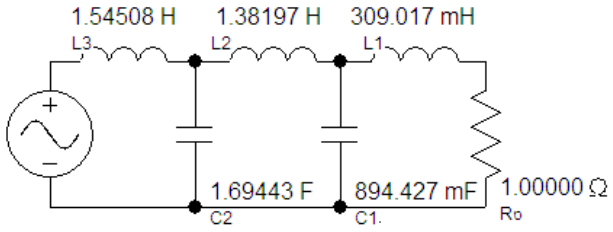
# TRANSFORMACIÓN DE FRECUENCIAS:





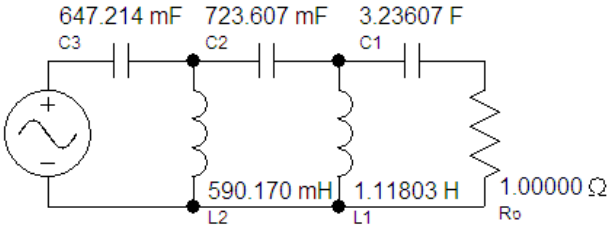

# TRANSFORMACIÓN PASA-BAJOS A PASA-ALTOS :

$$\frac{1}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$



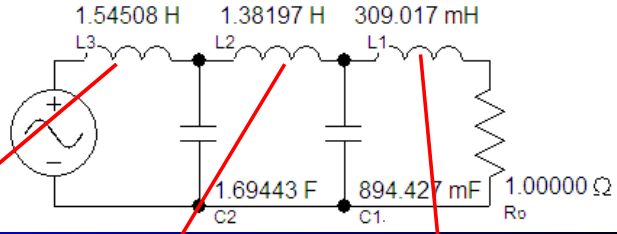

$$P \rightarrow \frac{1}{P}$$

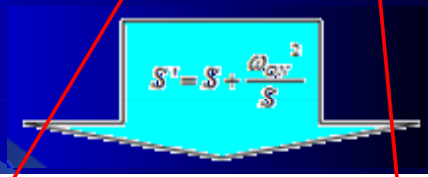
$$\frac{S^5}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$

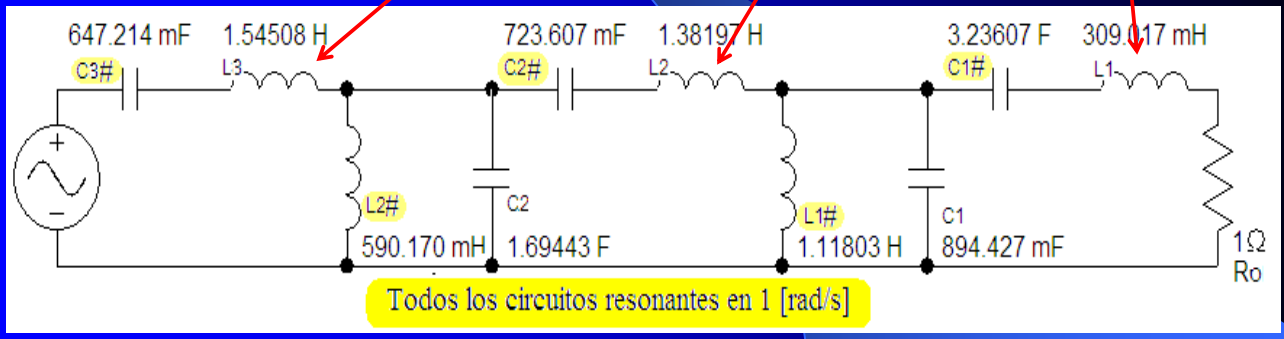


# TRANSFORMACIÓN PASA-BAJOS A PASA-BANDA :

$$\frac{1}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$



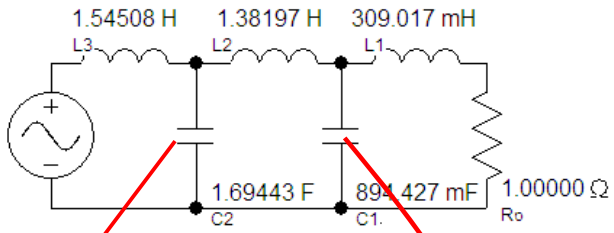



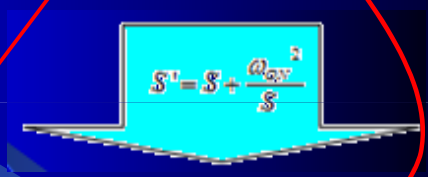



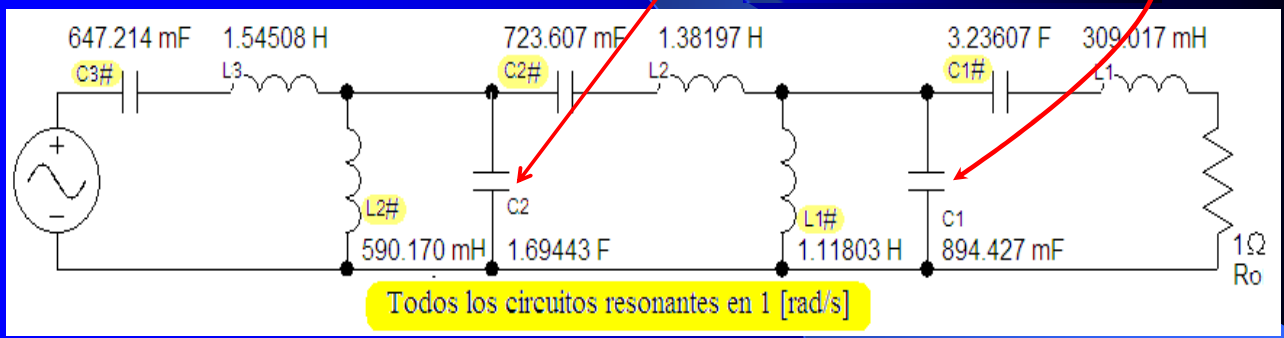

$$\frac{S^5}{S^{10} + 3.23607*S^9 + 10.2361*S^8 + 18.1803*S^7 + 28.9443*S^6 + 30.8885*S^5 + 28.9443*S^4 + 18.1803*S^3 + 10.2361*S^2 + 3.23607*S + 1}$$


# TRANSFORMACIÓN PASA-BAJOS A PASA-BANDA :

$$\frac{1}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$



$$\frac{S^5}{S^{10} + 3.23607*S^9 + 10.2361*S^8 + 18.1803*S^7 + 28.9443*S^6 + 30.8885*S^5 + 28.9443*S^4 + 18.1803*S^3 + 10.2361*S^2 + 3.23607*S + 1}$$

## PARA DESNORMALIZAR A LOS VALORES REQUERIDOS APLICAMOS LAS SIGUIENTES TRANSFORMACIONES , PARA LOS COMPONENTES ORIGINALES DEL FILTRO PASA BAJOS:

$$R_X = R_O \qquad L_X = L_N \frac{Ro * \varepsilon^{1/n}}{\omega_p} \qquad C_X = C_N \frac{\varepsilon^{1/n}}{\omega_p * Ro}$$

## MIENTRAS QUE PARA LOS ELEMENTOS QUE COMPLETARON LOS CIRCUITOS RESONANTES Y ESTAN MARCADOS CON # UTILIZAMOS :

$$L_X\# = L_N \frac{Ro}{\omega_{on}^{\ 2} * BW} \qquad C_X\# = C_N \frac{1}{\omega_{on}^{\ 2} * BW * Ro}$$

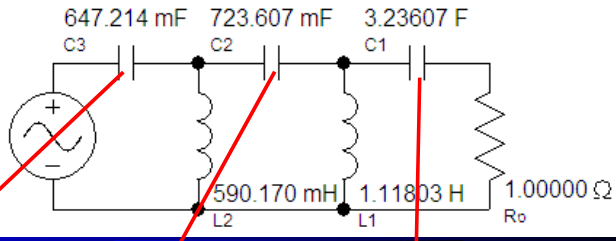
**RECORDANDO QUE :**

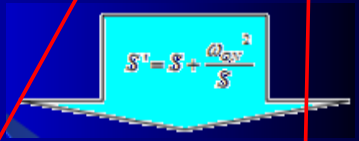
$$\omega_{ON}^{\ 2} = \frac{\omega_O^{\ 2}}{BW^2} = \frac{\left(\omega_{C2} \times \omega_{C1}\right)}{\left(\omega_{C2} - \omega_{C1}\right)^2}$$

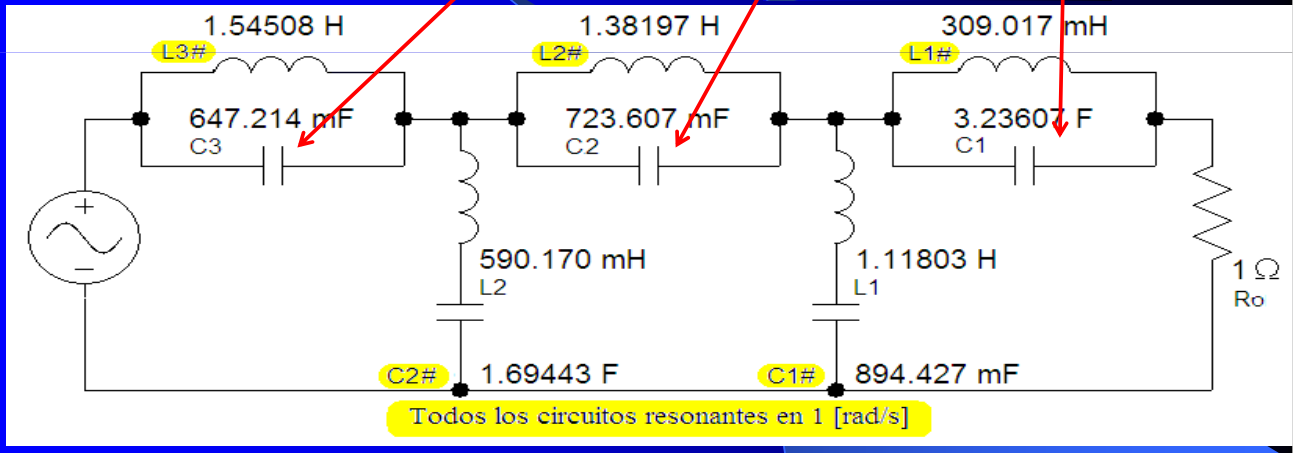


## TRANSFORMACIÓN PASA-ALTOS A ELIMINA-BANDA :

$$\frac{S^5}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$



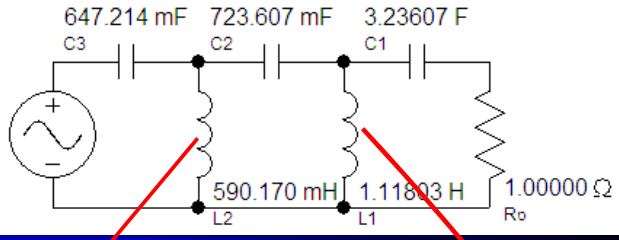



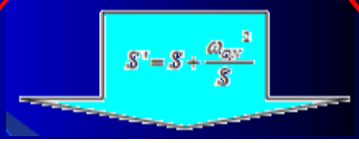



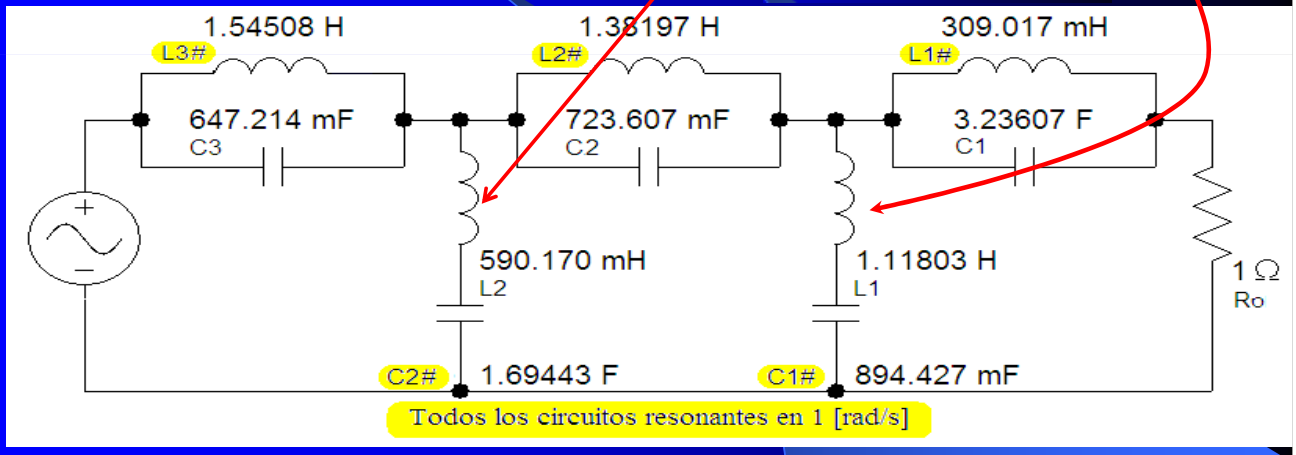

$$\frac{S^{10} + 5.*S^8 + 10.*S^6 + 10.*S^4 + 5.*S^2 + 1}{S^{10} + 3.23607*S^9 + 10.2361*S^8 + 18.1803*S^7 + 28.9443*S^6 + 30.8885*S^5 + 28.9443*S^4 + 18.1803*S^3 + 10.2361*S^2 + 3.23607*S + 1}$$

# TRANSFORMACIÓN PASA-ALTOS A ELIMINA-BANDA :

$$\frac{S^5}{S^5 + 3.23607*S^4 + 5.23607*S^3 + 5.23607*S^2 + 3.23607*S + 1}$$




$$\frac{S^{10} + 5.*S^8 + 10.*S^6 + 10.*S^4 + 5.*S^2 + 1}{S^{10} + 3.23607*S^9 + 10.2361*S^8 + 18.1803*S^7 + 28.9443*S^6 + 30.8885*S^5 + 28.9443*S^4 + 18.1803*S^3 + 10.2361*S^2 + 3.23607*S + 1}$$

# PARA DESNORMALIZAR A LOS VALORES REQUERIDOS APLICAMOS LAS SIGUIENTES TRANSFORMACIONES , PARA LOS COMPONENTES ORIGINALES DEL FILTRO PASA BAJOS:

$$R_X = R_O \qquad L_X = L_N \frac{Ro * \varepsilon^{1/n}}{\omega_p} \qquad C_X = C_N \frac{\varepsilon^{1/n}}{\omega_p * Ro}$$

# MIENTRAS QUE PARA LOS ELEMENTOS QUE COMPLETARON LOS CIRCUITOS RESONANTES Y ESTAN MARCADOS CON # UTILIZAMOS :

$$L_X\# = L_N \frac{Ro}{\omega_{on}^{\,2} * BW} \qquad C_X\# = C_N \frac{1}{\omega_{on}^{\,2} * BW * Ro}$$

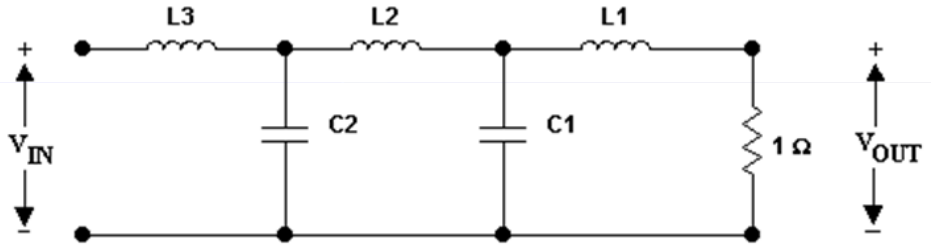
**RECORDANDO QUE :**

$$\omega_{ON}^{\,2} = \frac{\omega_O^{\,2}}{BW^2} = \frac{(\omega_{C2} \times \omega_{C1})}{(\omega_{C2} - \omega_{C1})^2}$$

## APLICACIÓN A OTROS TIPOS DE APROXIMACIONES:

**A PARTIR DEL TIPO DE APROXIMACIÓN Y DEL GRADO DEL FILTRO DESEADO, SE OBTIENE LA ECUACIÓN CARACTERÍSTICA Y LUEGO LOS VALORES DE LOS COMPONENTES A PARTIR DEL CIRCUITO BÁSICO DE CINCO REACTANCIAS PASA BAJOS :**

$n = 5.$




$$G_5(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^5.L_1.L_2.L_3.C_1.C_2 + S^4.L_2.L_3.C_1.C_2 + S^3[L_1.(L_2.C_1 + L_3.C_1 + L_3.C_2) + L_2.L_3.C_2] + S^2.[C_1.(L_2 + L_3) + L_3.C_2] + S.(L_1 + L_2 + L_3) + 1}$$

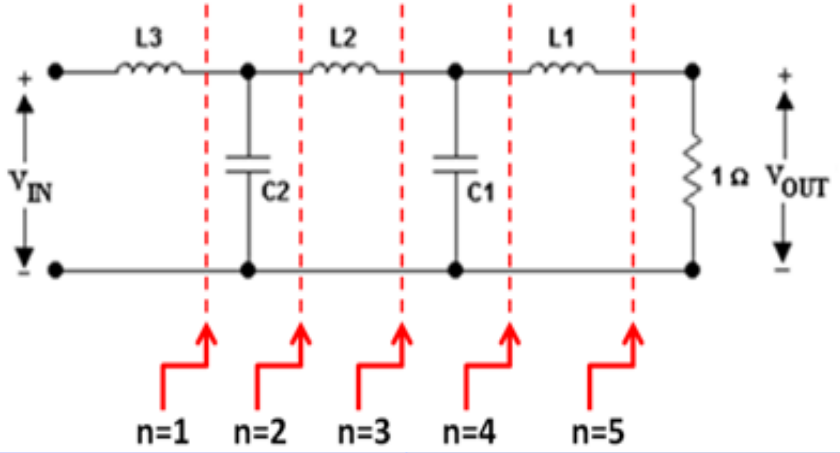


## APLICACIÓN A OTROS TIPOS DE APROXIMACIONES:

**ELIMINAR DE LA FUNCIÓN DE TRANSFERENCIA ORIGINAL LOS COMPONENTES QUE CORRESPONDAN DE ACUERDO AL GRADO DEL FILTRO REQUERIDO :**

$$G_5(S) = \frac{V_{OUT}}{V_{IN}} = \frac{1}{S^5.L_1.L_2.L_3.C_1.C_2 + S^4.L_2.L_3.C_1.C_2 + S^3[L_1.(L_2.C_1 + L_3.C_1 + L_3.C_2) + L_2.L_3.C_2] + S^2.[C_1.(L_2 + L_3) + L_3.C_2] + S.(L_1 + L_2 + L_3) + 1}$$

$R_{GEN} = 0\ [\Omega]$



# POLINOMIOS DE CHEBYSHEV CON Amax= 0,5 y 1 [dB]

Coeficientes de los polinomios de Chebychev ($\alpha_p = 0.5dB$).
($\varepsilon = 0.3493$ y $a_n = 1$)

| n | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ |
|---|---|---|---|---|---|
| 1 | 2.8627752 | | | | |
| 2 | 1.5162026 | 1.4256245 | | | |
| 3 | 0.7156938 | 1.5348954 | 1.2529130 | | |
| 4 | 0.3790506 | 1.0254553 | 1.7168662 | 1.1973856 | |
| 5 | 0.1789234 | 0.7525181 | 1.3095747 | 1.9373675 | 1.1724909 |

Coeficientes de los polinomios de Chebychev ($\alpha_p = 1dB$)
($\varepsilon = 0.5089$)

| n | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ |
|---|---|---|---|---|---|
| 1 | 1.9652267 | | | | |
| 2 | 1.1025103 | 1.0977343 | | | |
| 3 | 0.4913067 | 1.2384092 | 0.9883412 | | |
| 4 | 0.2756276 | 0.7426194 | 1.4539248 | 0.9527114 | |
| 5 | 0.1228267 | 0.5805342 | 0.9743961 | 1.6888160 | 0.9368201 |

## Polinomios de Bessel y ecuación de recurrencia

$B_0(p) = 1$

$B_1(p) = p + 1$ ➡ **Amax = 3 [dB]**

$B_2(p) = p^2 + 3p + 3$ ➡ **Amax = 1,597 [dB]**

$B_3(p) = p^3 + 6p^2 + 15p + 15$ ➡ **Amax = 0,903 [dB]**

$B_4(p) = p^4 + 10p^3 + 45p^2 + 105p + 105$ ➡ **Amax = 0,63 [dB]**

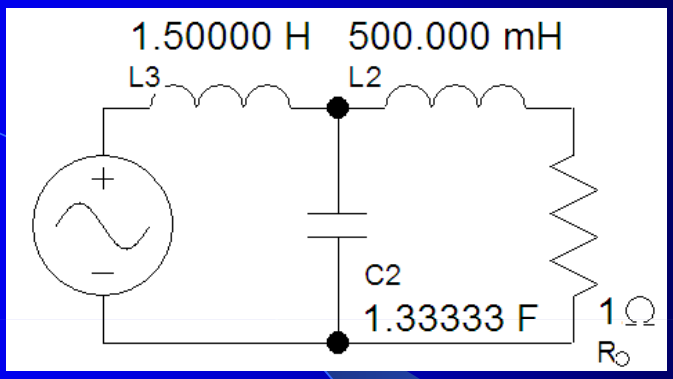
$B_5(p) = p^5 + 15p^4 + 105p^3 + 420p^2 + 945p + 945$ ➡ **Amax=0,4865 [dB]**

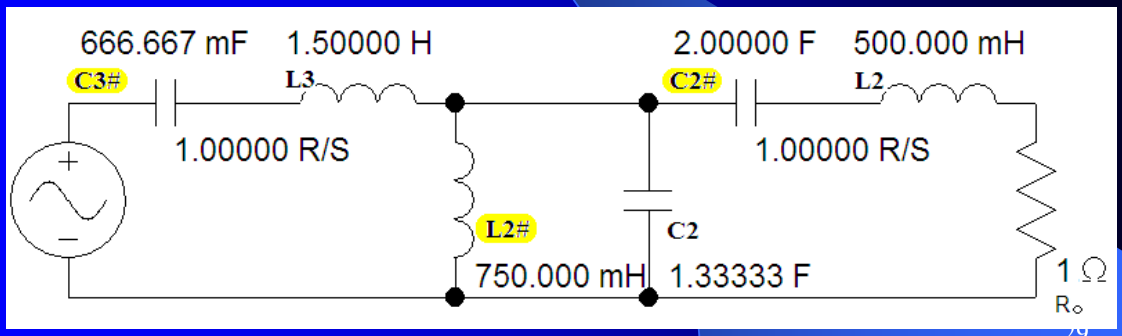
$B_6(p) = p^6 + 210p^4 + 1260p^3 + 4725p^2 + 10395p + 10395$

⋮

$B_{N+1}(p) = (2N+1)B_N(p) + p^2 B_{N-1}(p)$

# Ejemplo pasa bajos a Pasa Banda N=3 Y Amax = 3 [dB]



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**RECORDANDO QUE :**

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# FIN DE LA PRESENTACIÓN

# GRACIAS !