

$$\left\{ \begin{aligned} Z_{RC}(s) &= K \frac{(\Delta+z_1)(\Delta+z_2) \dots (\Delta+z_m)}{(\Delta+p_1)(\Delta+p_2) \dots (\Delta+p_n)} = \frac{K_0}{s} + K_\infty + \sum_i \frac{K_i}{s-p_i} \\ Z_{LC}(s) &= \frac{K_0}{s} + K_\infty s + \sum_i \frac{2K_i s}{s^2 + \omega_{pi}^2} \end{aligned} \right.$$

$$D = - \frac{\partial \angle H(j\omega)}{\partial \omega}$$

Butterworth

$$\left\{ \begin{aligned} \|H(j\omega)\| &= \sqrt{1 + \epsilon^2 \left(\frac{\omega}{\omega_p}\right)^{2n}} \\ \Omega &= \epsilon^{1/n} \left(\frac{\omega}{\omega_p}\right) \end{aligned} \right.$$

n	H(s)
1	$s^2 + 1$
2	$s^2 + 1.414s + 1$
3	$(s+1)(s^2 + s + 1)$
4	$(s^2 + 0.76537s + 1)(s^2 + 1.84776s + 1)$
5	$(s^2 + 0.61803s + 1)(s^2 + 1.61803s + 1)(s+1)$

Chebyshev

$$\left\{ \begin{aligned} C_0(\Omega) &= 1 \\ C_1(\Omega) &= \Omega \\ C_{n+1}(\Omega) &= 2\Omega C_n(\Omega) - C_{n-1}(\Omega) \\ \|H(j\Omega)\| &= \sqrt{1 + \epsilon^2 C_n^2(\Omega)} \end{aligned} \right.$$

$$\Omega = \omega/\omega_p$$

Bessel

$$\left\{ \begin{aligned} B_0(s) &= 1 \\ B_1(s) &= s+1 \\ B_n(s) &= (2n-1)B_{n-1}(s) + s^2 B_{n-2}(s) \end{aligned} \right.$$

$$\left\{ \begin{aligned} \text{HPF} & S = \omega_p/s \\ \text{BPF} & S = \frac{s^2 + \omega_c^2}{Bs} \\ \text{BRF} & S = \frac{Bs}{s^2 + \omega_c^2} \end{aligned} \right.$$

$$\left\{ \begin{aligned} S_x^P &= \frac{x}{P} \frac{\partial P}{\partial x} \\ \gamma_{G(x)} &= \frac{\partial G(x)}{\partial x/x} \end{aligned} \right.$$

$$H(s) = \frac{-y_{21}}{Y_L + y_{22}} = - \frac{y_{21}/Y_L}{1 + y_{22}/Y_L} = \frac{V_o}{V_i} = \frac{Q(s)}{P(s)}$$

$$\left\{ \begin{aligned} \frac{V_o}{V_i} &= \frac{M_1}{M_2 + N_2} & (N_1=0) &= \frac{M_1/N_2}{1 + M_2/N_2} \\ \frac{V_o}{V_i} &= \frac{N_1}{M_2 + N_2} & (M_1=0) &= \frac{N_1/M_2}{1 + N_2/M_2} \end{aligned} \right.$$

$$\left\{ \begin{aligned} H(s) &= \frac{V_o}{V_i} = - \frac{H_{FF}}{H_{FB} + 1/A} \approx - \frac{T_{FF}}{T_{FB}} & (FB = \text{neg}) \\ H(s) &\approx \frac{k \cdot H_{FF}}{1 - k \cdot H_{FB}} = \frac{k \cdot T_{FF}}{N - k T_{FB}} & (FB = \text{pos}) \end{aligned} \right.$$

$$\Delta \leftrightarrow \frac{z-1}{z+1}$$

Table Elliptic Approximation Functions for  $A_{min} = 0.5$  dB

(a)  $\Omega_c = 1.5$

n	Denominator Constant K	Denominator of H(s)	Numerator of H(s)	$A_{min}$
2	0.38540	$s^2 + 3.92705$	$s^2 + 1.03153s + 1.60319$	8.3
3	0.31410	$s^2 + 2.80601$	$(s^2 + 0.45286s + 1.14917)(s + 0.766952)$	21.9
4	0.015397	$(s^2 + 2.53555)(s^2 + 12.09931)$	$(s^2 + 0.25496s + 1.06044)(s^2 + 0.92001s + 0.47183)$	36.3
5	0.019197	$(s^2 + 2.42551)(s^2 + 5.43764)$	$(s^2 + 0.16346s + 1.03189)(s^2 + 0.57023s + 0.57601)(s + 0.42597)$	50.6

(b)  $\Omega_c = 2.0$

n	Denominator Constant K	Denominator of H(s)	Numerator of H(s)	$A_{min}$
2	0.20133	$s^2 + 7.4641$	$s^2 + 1.24504s + 1.59179$	13.9
3	0.15424	$s^2 + 5.15321$	$(s^2 + 0.53787s + 1.14849)(s + 0.69212)$	31.2
4	0.0036987	$(s^2 + 4.59326)(s^2 + 24.22720)$	$(s^2 + 0.30116s + 1.06258)(s^2 + 0.88456s + 0.41032)$	48.6
5	0.0046205	$(s^2 + 4.36495)(s^2 + 10.56773)$	$(s^2 + 0.19255s + 1.03402)(s^2 + 0.58054s + 0.52500)(s + 0.392612)$	66.1

(c)  $\Omega_c = 3.0$

n	Denominator Constant K	Denominator of H(s)	Numerator of H(s)	$A_{min}$
2	0.083974	$s^2 + 17.48528$	$s^2 + 1.35715s + 1.55532$	21.5
3	0.063211	$s^2 + 11.82781$	$(s^2 + 0.58942s + 1.14559)(s + 0.65263)$	42.8
4	0.00062046	$(s^2 + 10.4554)(s^2 + 58.471)$	$(s^2 + 0.32979s + 1.063281)(s^2 + 0.86258s + 0.37787)$	64.1
5	0.00077547	$(s^2 + 9.8955)(s^2 + 25.0769)$	$(s^2 + 0.21066s + 1.0351)(s^2 + 0.58441s + 0.496388)(s + 0.37452)$	85.5

Table Chebyshev Approximation Functions

(a)  $A_{\max} = 0.25$  dB

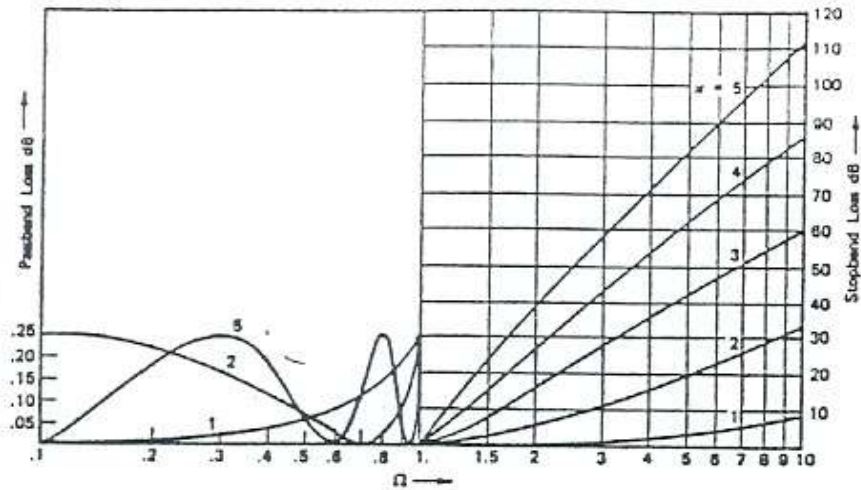
$n$	Numerator of $H(s)$	Denominator Constant $K$
1	$s + 4.10811$	4.10811
2	$s^2 + 1.79668s + 2.11403$	2.05405
3	$(s^2 + 0.76722s + 1.33863)(s + 0.76722)$	1.02702
4	$(s^2 + 0.42504s + 1.16195)(s^2 + 1.02613s + 0.45485)$	0.51352
5	$(s^2 + 0.27005s + 1.09543)(s^2 + 0.70700s + 0.53642)(s + 0.43695)$	0.25676

(b)  $A_{\max} = 0.5$  dB

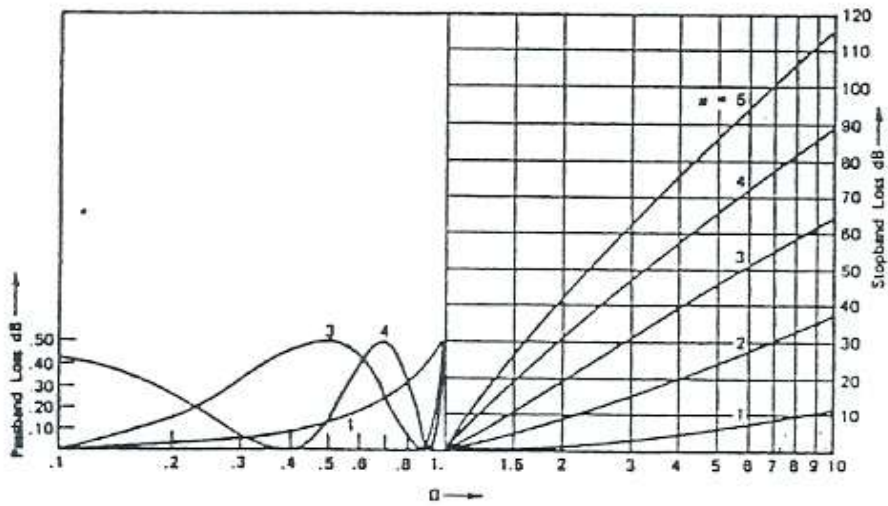
$n$	Numerator of $H(s)$	Denominator Constant $K$
1	$s + 2.86278$	2.86278
2	$s^2 + 1.42562s + 1.51620$	1.43138
3	$(s^2 + 0.62646s + 1.14245)(s + 0.62646)$	0.71570
4	$(s^2 + 0.35071s + 1.06352)(s^2 + 0.84668s + 0.356412)$	0.35785
5	$(s^2 + 0.22393s + 1.03578)(s^2 + 0.58625s + 0.47677)(s + 0.362332)$	0.17892

(c)  $A_{\max} = 1$  dB

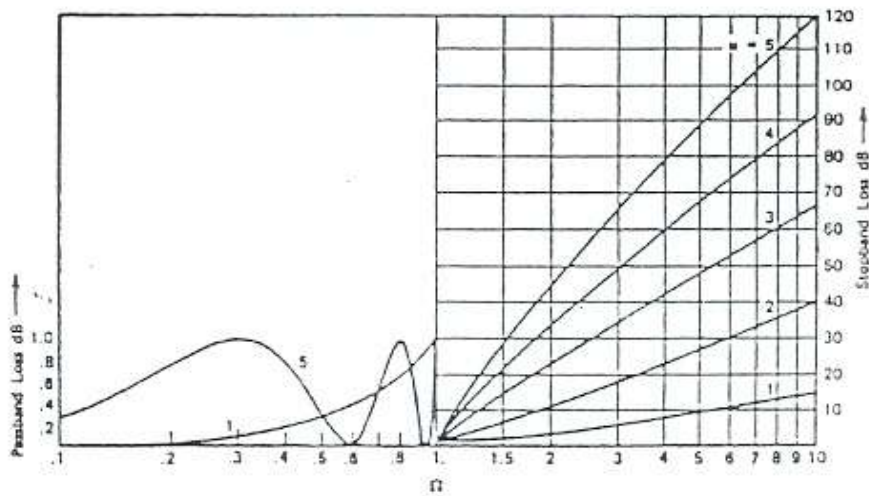
$n$	Numerator of $H(s)$	Denominator Constant $K$
1	$s + 1.96523$	1.96523
2	$s^2 + 1.09773s + 1.10251$	0.98261
3	$(s^2 + 0.49417s + 0.99420)(s + 0.49417)$	0.49130
4	$(s^2 + 0.27907s + 0.98650)(s^2 + 0.67374s + 0.27940)$	0.24565
5	$(s^2 + 0.17892s + 0.98831)(s^2 + 0.46841s + 0.42930)(s + 0.28949)$	0.12283



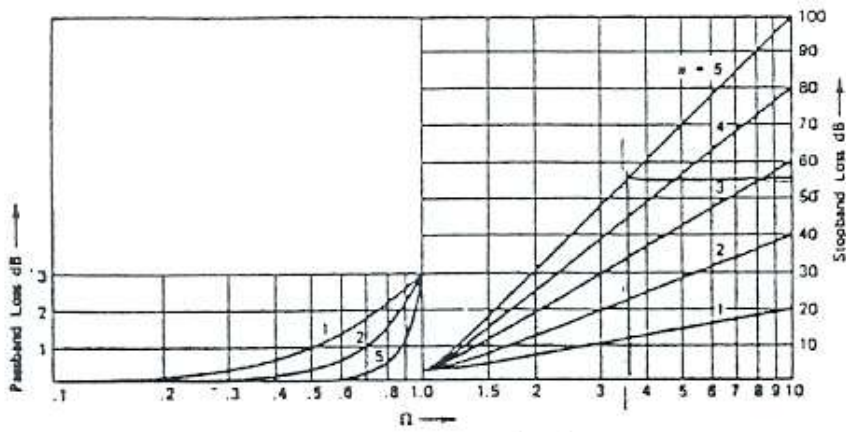
Loss of LP Chebyshev approximation for  $A_{max} = 0.25$  dB.



Loss of LP Chebyshev approximation for  $A_{max} = 0.50$  dB.

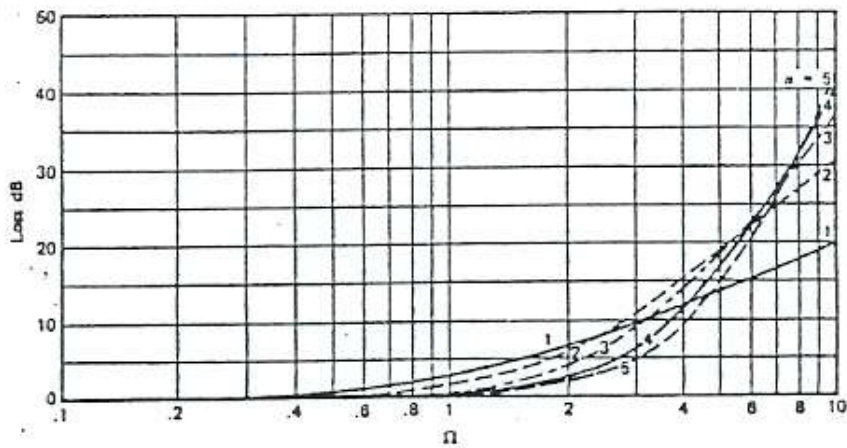


Loss of LP Chebyshev approximation for  $A_{max} = 1$  dB.

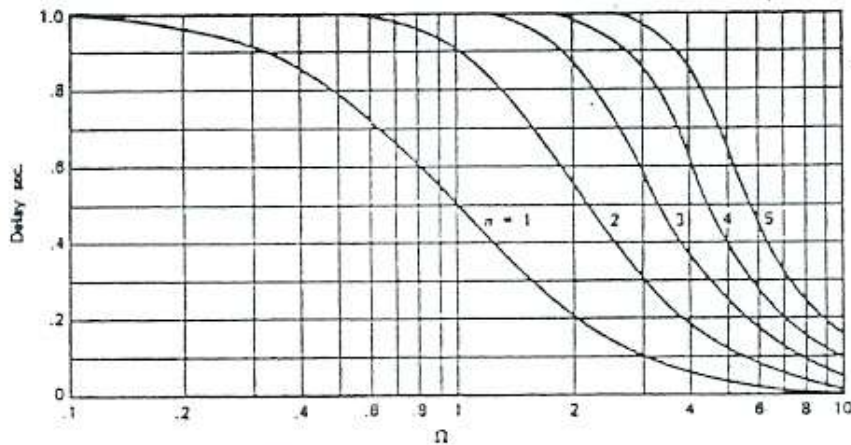


Loss of LP normalized Butterworth approximations.

SV108



Loss of LP Bessel approximations.



Delay of LP Bessel approximations.