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Generalized Chebyshev Lowpass Filter (Closed Form): LPFCG

Symbol

Summary

LPFCG models represent lumped-element Generalized Chebyshev (or "Quasi-Elliptic") lowpass filters. The insertion loss ripples between zero and a specified maximum in the passband. The stopband attenuation is defined by arbitrarily specified transmission zeros. Real-frequency finite transmission zeros can be specified to improve selectivity at the expense of ultimate stopband attenuation and passband group delay, while complex-plane finite transmission zeros can be specified to provide passband group delay equalization at the expense of selectivity and ultimate stopband attenuation. Generalized Chebyshev filters represents a compromise between the simplicity of Chebyshev filters, the optimum amplitude response of more complicated Elliptic filters, and the phase linearity of Bessel and Gaussian filters. Because this type of filter allows one to make explicit design trade-offs between complexity, selectivity, and group delay equalization, it is often used to meet the demanding requirements of modern communications systems.

Parameters

Name	Description	Unit Type	Default
ID	Element ID	Text	LPFCG1
N	Order of the filter		3
FP	Passband corner frequency (when Qu is infinite).	Frequency	1 GHz
*PPD	Passband parameter description:- Maximum Insertion Loss,- Minimum Return Loss, or- VSWR.	Enumerated	Maximum Insertion Loss
PPV	Passband parameter value (when Qu is infinite)	dB or Scalar	0.1 dB
TZF	Real frequency, finite transmission zeros	(Real) Frequency	{2} GHz

Name	Description	Unit Type	Default
*TZR	Real parts of complex finite transmission zeros	(Imaginary) Frequency	{0} GHz
*RS	Source resistance	Resistance	50 ohm
*RL	Load resistance	Resistance	50 ohm
*QU	Average unloaded Q of reactive element in the filter.		0

`* indicates a secondary parameter`

Parameter Details

N. In mathematical terms, N is defined as the highest exponent of the complex frequency variable s in the transfer function, $S_{21}(s)$, of the filter's normalized lowpass prototype, or, equivalently, the highest exponent of s in the transfer function of the lowpass filter. And, in terms of a measurable electrical characteristic, the number of positive-frequency passband reflection ($S|_{11}|$) zeros corresponds to N/2 for N even and (N+1)/2 for N odd.

PPD & PPV. Parameters PPD and PPV work together to specify the characteristic of the filter's passband. PPD is used to indicate what the value of PPV represents. The flexibility these parameters provide eliminates the need to manually convert from the passband specification parameter of one's preference into whatever specific parameter the software was written to accept.

PTZF & TZR. List parameters TZF and TZR are used to specify the complex transmission zeros, Z, of the highpass filter response. Up to (N-1)/2 complex transmission zeros, $Z_i = TZR_i + jTZF_i$, can be specified. Each consists of a real part, TZR_i, and an imaginary part, the real frequency TZF_i. If TZR_i is not specified, it is assumed to be zero. And, each unspecified transmission zero is mapped to a normalized lowpass prototype frequency of infinity.

Parameter Restrictions and Recommendations

1. 32 > N > 1.
2. FP > 0.
3. If PPD = "Maximum Insertion Loss", then PPV > 0.

   If PPD = "Minimum Return Loss", then PPV > 0.

   If PPD = "Maximum VSWR", then PPV > 1.
4. $TZF_i > 0$.

   If TZR_i is specified, then TZF_i must be specified.

   If TZR_i is zero, then FP <TZF_i .

   If $TZR_i \neq 0$, there must be a $TZR_k = -TZR_i$ and a $TZF_k = TZF_i$.
5. RS > 0.

   RL > 0.
6. QU > 0 specifies a finite unloaded Q (recommend QU<$1e^{12}$).

   QU = 0 specifies an infinite unloaded Q.

Implementation Details

The model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent normalized lowpass prototype transfer function, $S_{21}(s)$, is[1, 2]:

$$s_{21}^2(s) = \frac{P_N^2(s)}{P_N^2(s) + \varepsilon^2 F_N^2(s)} = \frac{P_N^2(s)}{P_N(s) + j\varepsilon F_N(s))(P_N(s) - j\varepsilon F_N(s))} = \frac{P_N^2(s)}{\varepsilon^2 E_N^2(s)}$$

where F_N and E_N are polynomials of order N, and

$$\exp\left(-s^2\right) \approx \sum_{i=0}^{N} \frac{(-1)^i s^{2i}}{i!} = |g(s)|^2 = 1 + |h(s)|^2$$

$$\varepsilon^2 = \frac{1}{10^{PPV/10} - 1} \text{when PPD = " Minimum Return Loss "}$$

$$\varepsilon^2 = \frac{0.25(\text{PPV} - 1)^2}{\text{PPV}} \text{ when PPD="Maximum VSWR"}$$

$$P_N(s) = \prod_{i=1}^{N}\left(1 - \frac{s}{z_i}\right)$$

$$s = \frac{1}{q_u} + j\omega$$

$$j = \sqrt{-1}$$

A specified lowpass transmission zero, Z[i] = TZR[i] + jTZF[i] is mapped to a normalized lowpass prototype transmission zero, z[i], using [5]:

$$z[i] = \frac{Z[i]}{\text{FP}}$$

And, _FREQ (the variable that represents the project frequency) is mapped to the normalized lowpass prototype radian frequency, ω, using [5]:

$$\omega = \frac{\text{\_FREQ}}{\text{FP}}$$

Polynomial

$$F_N(s) = F_i|_{i=N}$$

is constructed using a doubly recursive algorithm [1][3]:

$$G_0 = b_1$$

$$F_1 = a_1$$

$$G_{(i-1)} = a_i G_{(i-2)} + b_i F_{(i-1)}$$

$$F_i = a_i F_{(i-1)} + c_i G_{(i-2)}$$

where i = 2 to N and, employing the normalized lowpass prototype transmission zero, z_k, for k = 1 to N:

$$a_k = -j\left(s + \frac{1}{z_k}\right)$$

$$b_k = \sqrt{1 + \left(\frac{1}{z_k}\right)^2}$$

$$c_k = -b_k\left(s^2 + 1\right)$$

Polynomial $E_s(s)$ is found by applying the "alternating singularity principle" [1][2][4] to the roots of

$$\left(\frac{P_N(s)}{\varepsilon} + \mathrm{j}\mathrm{F}_N(s)\right)$$

. Then, E_N and F_N are split into complex-even and complex-odd polynomials [2] such that E_N= E_e+$E_0$and F_N= F_e+F_0, where

$$E_e = \mathrm{Re}(e_0) + j \quad \mathrm{Im}(e_1)s + \mathrm{Re}(e_2)s^2 + \;\cdots, E_o = j \quad \mathrm{Im}(e_o) + \mathrm{Re}(e_1) + j \quad \mathrm{Im}(e_2)s^2 + \;\cdots$$

$$F_e = \mathrm{Re}(f_0) + j\,\mathrm{Im}(f_1)s + \mathrm{Re}(f_2)s^2 + \;\cdots, F_o = j\,\mathrm{Im}(f_o) + \mathrm{Re}(f_1) + j\,\mathrm{Im}(f_2)s^2\;\cdots$$

and and e_1 and f_1 (i = 0 to N) are the complex coefficients of E_N and F_N. Finally [3]:

$$y_{11} = \left(\frac{1}{\mathrm{RS}}\right)\left(\frac{E_e - F_e}{E_o + F_o}\right)$$

$$y_{22} = \left(\frac{1}{\mathrm{RL}}\right)\left(\frac{E_e + F_e}{E_o + F_o}\right)$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{\mathrm{RS} \times \mathrm{RL}}}\right)\left(\frac{-P_N/\varepsilon}{E_o + F_o}\right)$$

Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

Recommendations for Use

The transmission zeros can be tuned or optimized by assigning variables to the elements of the TZF and/or TZR lists and then tuning or optimizing these variables.

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not have any special relationship to RL for ideal transmission (as would normally be the case).

References

[1] Richard J. Cameron, "Fast generation of Chebyshev filter prototypes with asymmetrically-prescribed transmission zeros," ESA J., vol. 6, pp. 83-95, 1982.

[2] Richard J. Cameron, "General coupling matrix synthesis methods for Chebyshev filtering functions," IEEE Trans. Microwave Theory Tech., vol. 47, no. 4, pp. 433-442, April 1999.

[3] Douglas R. Jachowski, unpublished notes, 1995 and 2002.

[4] J. D. Rhodes and A. S. Alseyab, "The generalized Chebyshev low pass prototype filter," Int. J. Circuit Theory Applicat., vol. 8, pp. 113-125, 1980.

[5] H. J. Blinchikoff and A. I. Zverev, Filtering in the Time and Frequency Domains, (Robert E. Krieger Publishing Co., 1987), pp. 154-155
