EE387 Signal Processing

Laboratory 04 – Filter Design using MATLAB

Introduction

The signal processing Toolbox in MATLAB includes a number of files to develop filters.

1. <u>Butterworth filter</u>

We can use the function ***butter(N, Wn,'s')*** to design an order ***N*** low pass transfer function with a prescribed 3-db cutoff frequency at ***Wn*** rad/sec. The output data of this function are the numerator and the denominator coefficient vectors, ***num*** and ***den*** respectively, in descending powers of s. If ***Wn*** is a two-element vector ***[W1, W2]*** with ***W1<W2***, the function generates an order ***2N*** bandpass transfer function with 3-dB band edge frequencies at ***W1*** and ***W2*** with both being non zero numbers. To design an order ***N*** highpass or an order ***2N*** bandstop filter, the function ***butter(N, Wn, 'filter type', 's')*** is employed where ***filter type = high*** for a high pass filter with a 3-dB cut off frequency at ***Wn*** or ***filter type = stop*** for a bandstop filter with a 3-dB stopband edges given by a two element vector of nonzero numbers ***Wn=[W1, W2]*** with ***W1<W2***.

The function ***buttord(Wp, Ws, Rp, Rs, 's')*** computes the lowest order ***N*** of a butterworth analog transfer function meeting the specifications given by the filter parameters, ***Wp, Ws, Rp, Rs,*** where ***Wp*** is the passband edge angular frequency in rad/sec, ***Ws*** is the stopband edge angular frequency in rad/sec, ***Rp*** is the maximum passband attenuation in dB, and ***Rs*** is the minimum passband attenuation in dB. ***Wn*** in rad/sec is the 3-dB cutoff angular frequency.

This function can also be used to calculate the order of any one of the four basic types of analog butterworth filters. For a lowpass design, ***Wp<Ws***, where as for highpass design, ***Wp>Ws***. For the other two types, ***Wp*** and ***Ws*** are two-element vectors specifying the passband and the stopband edge frequencies.

2. <u>Type 1 Chebyshev filter</u>

The M-file functions for the design of analog Type 1 Chebyshev filters are as follows:

[z, p, k] = cheplap(N, Rp)

[num, den] = chebyl(N, Rp, Wn, 's')

[num, den] = chebyl(M, Rp, Wn, 'filter-type', 's')

[N, Wn] = cheblord (Wp, Ws, Rp, Rs, 's')

Where ***Rp*** - passband ripple in dB; ***Rs*** - minimum stopband attenuation in dB; ***Wn***- passband edge angular frequency in rad/sec.

Type 2 Chebyshev filter

The M-file functions for the design of the analog Type- 2 Chebyshev filters are;

[s, p, k] = cheb2ap (N, Rs)

[num, den] = cheby2 (N, Rs, Wn, 's')

[num, den] = cheby2 (N, Rs, Wn, 'filter types', 's')

[N, Wn] = cheb2ord (Wp, Ws, Rp, Rs, 's')

Where ***Wn*** is the stopband edge angular frequency in rad/sec

The function ***cheb2ap (N, Rs)*** returns the zeros, poles and gain factor of a normalized analog Type 2 (Inverse) Chebyshev lowpass filter of order ***N*** with a minimum stopband attenuation of ***Rs*** in dB. The normalized stopband edge angular frequency is set to 1. The output files are the length-***N*** column vectors ***s*** and ***p***, providing the locations of the zeros and poles respectively, and the gain factor ***k***.

3. Bessel filters

For the design of a Bessel filter, the available M-file functions are:

[z, p, k] = besselap (N)

[num, den] = besself (N, Wn)

[num, den] = besself (N, Wn, 'filtertype')

The function ***besselap(N)*** is employed to compute the zeros, poles and gain factor ***k***.

Exercises:

Use the above functions to design the following filters. Plot their Bode plots to verify the designs.

1. Design the Butterworth filter with the following specifications: Fp = 1000 Hz; Fs = 5000 Hz;
2. Design the Butterworth filter with Fp = 1000 Hz, N = 4;
3. Design Chebyshev Type 1 filter with N = 4, Rp = 2 ; Fp = 1000.