Digital Signal Processing for Protection and Control - Laboratory

Exercise 2*: <u>Synthesis and analysis of digital IIR and FIR filters (4 hours)</u>*

Exercise contents:

even group number: f_s=(900+(‘*group number’*)*100) Hz
odd group number: f_s=(1900+(‘*group number’*)*100) Hz

1. Design the IIR digital filter according to the following requirements:
   - employ ‘*group number*’ analogue filter prototype (see Appendix);
   - low-pass filter (even group number) or high-pass filter (odd group number);
   - cut-off frequency f_{cd}=(200+(‘*group number’*)*50) Hz.
2. Determine/draw the frequency response of the designed IIR filter, compare with the frequency response of the analogue prototype.
3. Analyse the filtering efficiency of the filter for the signals containing harmonic, inter-harmonic and decaying DC components (see Exercise 1).

4. Define the FIR digital filters having the impulse responses as specified in point A‘*group number’* and B1 (odd group number) or B2 (even group number) (see Appendix).
5. Determine/draw the frequency responses of the FIR filters.
6. Analyse the filtering efficiency of the filters for the signals containing harmonic, inter-harmonic and decaying DC components (see Exercise 1).
7. Analyse filters’ responses in time and frequency domains after their data window modification with selected smoothing filtering windows (e.g. Hamming, Blackman, …).

8. Compare operation efficiency of designed IIR and FIR digital filters.

APPENDIX

<u>IIR digital filter design formulae</u>:

$$LP: \quad G(z) = G(s)\Big|_{s \to A\frac{1-z^{-1}}{1+z^{-1}}} \quad , \quad A = \omega_{ca} ctg(\omega_{cd} T_s / 2)$$

$$HP: \quad G(z) = G(s)\Big|_{s \to B\frac{1+z^{-1}}{1-z^{-1}}} \quad , \quad B = \omega_{ca} tg(\omega_{cd} T_s / 2)$$

<u>Analogue filter transfer functions (standard approximations)</u>:

I. Butterworth 2nd order $\quad G(s) = \dfrac{1}{s^2 + \sqrt{2}s + 1}$

II. Bessel 2nd order $\quad G(s) = \dfrac{1}{s^2 + 1.73s + 1}$

III. Tschebyschev I, 2nd order $G(s) = \dfrac{1.43}{s^2 + 1.4256s + 1.5162}$

IV. Tschebyschev II, 2nd order $G(s) = \dfrac{0.056s^2 + 0.1125}{s^2 + 0.46s + 0.1125}$

V. Butterworth 2nd order $G(s) = \dfrac{1}{s^2 + \sqrt{2}s + 1}$

VI. Bessel 2nd order $G(s) = \dfrac{1}{s^2 + 1.73s + 1}$

VII. Tschebyschev I, 2nd order $G(s) = \dfrac{1.43}{s^2 + 1.4256s + 1.5162}$

VIII. Tschebyschev II, 2nd order $G(s) = \dfrac{0.056s^2 + 0.1125}{s^2 + 0.46s + 0.1125}$

A. Standard windows of non-recursive digital filters:

A1. Walsh function of zero order (full cycle).
A2. Walsh function of first order (full cycle).
A3. Walsh function of second order (full cycle).
A4. Sine window (full cycle).
A5. Sine window (half cycle).
A6. Cosine window (full cycle).
A7. Cosine window (half cycle).
A8. Sine window (double-cycle).
A9. Cosine window (double-cycle).

B. Non-standard windows of FIR filters:

B1. Triangle window (full cycle).
B2. Trapezoidal window (full cycle).

Useful functions/procedures in MATLAB:

- fft, ifft
- filter
- plot, bar, stairs, hist
- freqz, dbode
- hamming, hanning, blackman