4. Quantization Characteristics and Coefficient Quantization Effects

4.1 Quantization Characteristics

Given the function ***twosquant*** for the quantization of the 2's complement number x in the range [-1,1) with wordlength w. You can select two round modes and two overflow modes, see function header below.

```
function xq = twosquant(x,w,rmode,omode)
% 2's complement quantizer for numbers in the range [-1,1)
% with two round modes and two overflow modes
%
% ### This function requires the Fixed-Point Toolbox !!! ###
% Arguments:
% x     : input sequence
% w     : wordlength
% rmode : roundmode
%  - 'r' for rounding (= convergent, i.e. to nearest level)
%  - 't' for 2's complement truncation
% omode : overflow mode
%  - 's' for saturation (clipping)
%  - 'o' for 2's complement overflow (wrap)
```

Write a script to use the function and to plot different quantization characteristics. To this end, create a sequence x = `n` for `n = -1.5:0.00001:1.5`. Set w = 5 (4 fraction bits).

Quantize the input in all 4 cases. Plot the input sequence, the output sequences of the quantizer and the error signals to see the differences in the 4 quantization characteristics.

4.2 Coefficient quantization effect on the magnitude response and stability

Design an elliptic highpass filter and realize the filter in direct form II structure.

The specification is given below.

```
Fp = 510;          % Passband Frequency in Hz
Fs = 500;          % Stopband Frequency in Hz
Ft = 2000;         % Sampling Frequency in Hz
Rp = 1.0;          % Passband Ripple in dB
Rs = 60;           % Stopband Attenuation in dB
```

Hint: You can use either the functions ***ellipord*** and ***ellip*** and the dfilt-object ***dfilt.df2***, or the fdesign-object ***fdesign.highpass*** and the methods ***design*** and **convert** to design the filter and to realize the filter in direct form II structure.

Quantize the coefficients with wordlengths of 14, 16, 18, 20, 22, 26 and 28 bits and analyze the magnitude responses of the quantized filters.

Check the compliance of the tolerance scheme and the stability of the quantized filters, e.g. using the Filter Visualization Tool (***fvtool***). You can also use the method ***isstable*** to check the stability of the filters.

4.3 Pole distributions of a second-order transfer function

Write a script to plot the pole distributions of a second-order transfer function in direct form and in coupled form, respectively.

Verify the coefficient sensitivity of these structures from the pole distribution plots.

4.4 Design and Analysis of a quantized linear-phase FIR Bandpass Filter

Design a linear-phase FIR bandpass filter and realize this filter in direct form.

Hint: You can use the functions ***firpmord*** and ***firpm*** and the dfilt-object ***dfilt.dffir***.

The specification is given below.

```
Ft     = 48000;           % Sampling Frequency in Hz
Fstop1 = 7200;            % First Stopband Frequency in Hz
Fpass1 = 9600;            % First Passband Frequency in Hz
Fpass2 = 12000;           % Second Passband Frequency in Hz
Fstop2 = 14400;           % Second Stopband Frequency in Hz
Dstop1 = 0.001;           % First Stopband Attenuation
Dpass  = 0.01;            % Passband Ripple
Dstop2 = 0.0001;          % Second Stopband Attenuation
dens   = 20;              % Density Factor
```

Set the fixed-point properties as given below.

```
set(Hd,'Arithmetic', 'fixed', ...
       'CoeffWordLength', 12, ...
       'CoeffAutoScale', true, ...
       'Signed',         true, ...
       'InputWordLength', 12, ...
       'InputFracLength', 11, ...
       'FilterInternals',  'SpecifyPrecision', ...
       'OutputWordLength',  26, ...
       'OutputFracLength',  24, ...
       'ProductWordLength', 24, ...
       'ProductFracLength', 24, ...
       'AccumWordLength',   26, ...
       'AccumFracLength',   24, ...
       'RoundMode',         'convergent', ...
       OverflowMode',       'Wrap');
```

Analyze the effects on the magnitude response of the filter.

4.5 Simulation of a fixed-point filter with Simulink

Open the Simulink model ***iir_bp_quantization_errors.slx*** and simulate the model. Observe the fixed-point settings in the block for the fixed-point filter.

Analyze the power spectral density of the difference between the outputs of the reference filter and the fixed-point filter.

Observe the messages in the command window of MATLAB.