

## ECE 417 Lab Exercise # 5

### IIR Lowpass Digital Filter Design and Coefficient Quantization

In this lab, you will design IIR digital filters for obtaining Butterworth, Chebyshev Type I, and Elliptic filter responses. You will also examine the effect of quantization of filter coefficients on the frequency response. You will again need the last three non-zero digits of your UIC ID # (UIN), say  $i, j, k$ . You will use the number  $N_{ID} = ijk = 100 * i + 10 * j + k$  in this lab exercise.

You will design filters to meet the following lowpass filter specifications:

- passband deviation  $\delta_p = 0.01$
- stopband deviation  $\delta_s = 0.01$
- passband edge frequency  $= f_p = 0.375 - N_{ID} * 10^{-4}$ .
- stopband edge frequency  $= f_s = 0.475 + N_{ID} * 10^{-4}$ .
- sampling frequency  $= 2.0$

Sample code is provided for a different set of specifications given below. The specifications (“specs”) should be modified according to your  $N_{ID}$  as shown in the blue text. You should label axes in plots, put title, etc.

#### 1 FIR filter design for comparison of filter order with IIR filters

In this part you will design a reference FIR filter for the specs given in blue and not what’s shown in the sample code below.

```
close all
dp=0.01;
ds=0.01;
fp=0.45; % modify as specified
fs=0.55; % modify as specified
Fsampl=2;
[nfir_ord,fr_edge,des_mag,wt] =
firlmord( [fp fs], [1 0], [dp ds], Fsampl);
```

```

hfir= firpm(nfir_ord,fr_edge,des_mag,wt);
[Hfir,w]=freqz(hfir,1,201);
plot(w/pi,abs(Hfir));
nfir_ord
%label axes in plot, put title, etc.

```

Q5.1 Plot the FIR filter magnitude response you obtain. Give the value of the estimated filter order. Find the maximum magnitude deviation in the passband and the stopband obtained in the design.

## 2 Butterworth lowpass filter Design

In this part you will design a Butterworth IIR digital filter for the specs given in blue. Sample code is given below.

```

[nbut_ord, wn] = buttord(2*fp/Fsampl, 2*fs/Fsampl,
-20*log10(1-dp), -20*log10(ds));% Filter order & parameter wn are computed.
[b_but,a_but] = butter(nbut_ord, wn);% Filter coefficients are computed.
[Hbut,w]=freqz(b_but,a_but,501);% Frequency response is computed.
figure
plot(w/pi,abs(Hbut));% Magnitude response vs. omega/pi
%label axes in plot, put title, etc.

```

Q5.2 Plot the Butterworth lowpass filter magnitude response. What is the estimate of the Butterworth filter order? Find the maximum magnitude deviation in the passband and the stopband obtained in the design.

## 3 Chebyshev Type I lowpass filter Design

In this part you will design a Chebyshev Type I IIR digital filter for the specs given in blue.

### 3.1 Chebyshev Type I lowpass filter design with unquantized coefficients

You will first plot the magnitude response using the unquantized filter coefficients. Sample code is given below.

```

[nch1_ord, wn] = cheb1ord(2*fp/Fsampl, 2*fs/Fsampl,
-20*log10(1-dp), -20*log10(ds));% Filter order & parameter wn are computed.

```

```

[b_ch1,a_ch1] = cheby1(nch1_ord, -20*log10(1-dp), wn);% Filter coefficients
[Hch1,w]=freqz(b_ch1,a_ch1,501);% Frequency response is computed.
figure
plot(w/pi,abs(Hch1));
nch1_ord
%label axes in plot, put title, etc.

```

Q5.3 Plot the Chebyshev Type I filter magnitude response. What is the estimate of the Chebyshev Type I filter order? Find the maximum magnitude deviation in the passband and the stopband obtained in the design.

## 4 Elliptic lowpass filter Design

In this part you will design an Elliptic lowpass IIR digital filter for the specs given in blue.

### 4.1 Elliptic filter lowpass design with unquantized coefficients

You will first plot the magnitude response of the filter with unquantized filter coefficients. Sample code is given below.

```

[nell_ord, wn] = ellipord(2*fp/Fsampl, 2*fs/Fsampl,
-20*log10(1-dp), -20*log10(ds));% Filter order & parameter wn are computed.
[b_ell,a_ell] = ellip(nell_ord, -20*log10(1-dp), -20*log10(ds), wn);% Filter
[Hell,w]=freqz(b_ell,a_ell,501);% Frequency response is computed.
figure
plot(w/pi,abs(Hell));
nell_ord
%label axes in plot, put title, etc.

```

Q5.4 Plot the filter magnitude response. Find the maximum magnitude deviation in the passband and the stopband.

Q5.5 Compare the order required for the four filters (FIR, Butterworth, Chebyshev Type I, and Elliptic) to meet the same specs.

### 4.2 Elliptic lowpass filter Design with quantized coefficients

You will now plot the passband response detail using the quantized filter coefficients. Sample code is given below.

```

bq_ell=quant(b_ell, 1/64);
aq_ell=quant(a_ell, 1/64);
Hqell=freqz(bq_ell,aq_ell,501);
figure
plot(abs(Hell))
nell_ord
figure
plot(abs(Hell(1:201)))
figure
plot(abs(Hqell(1:201)))
%label axes in plot, put title, etc.

```

Q5.6 Plot the magnitude response and the passband magnitude detail of the filter with quantized coefficients. Use 6-bit quantization as in the sample code. beyond the decimal. Note the change in passband magnitude deviation. Are the specs met?

Q5.7 Increase the number of bits used for coefficient representation to 10 (use 1/1024 in “quant”), and comment on the changes in passband magnitude deviation.

Q5.8 The poles of the filter transfer function should all be inside the unit circle. Using the command “roots(a\_ell)” determine the largest radius  $r_{max}$  of the poles of the filter with *unquantized* coefficients. Determine its “peak contribution”  $1/(1 - r_{max})$  to the magnitude response. Using the command “roots(aq\_ell)” determine the largest radius  $r_{qmax}$  of the poles of the filter with *quantized* coefficients. Determine its “peak contribution”  $1/(1 - r_{qmax})$  to the magnitude response. Comment on the change in the contribution due to quantization. Explain how this is manifested in the change in the magnitude response after quantization.

**Submit a hardcopy of your code along with the report.**

(Written by R. Ansari. Updated Fall 2023)