Assignment 4

ECE 615 − Mixed Signal IC Design

Problem 1 Maximum stable amplitude (MSA) Estimation:

1. Create and add a new MATLAB function to your personal $\Delta\Sigma$ toolbox titled **estimateMSA**, similar to the toolbox function **simulateSNR**. Use the MSA estimation algorithm suggested by Lars Risbo using the slow input ramp as discussed in class. The function should return the MSA and the peak SNR. The script should also optionally produce the $log\,|y[n]|$ vs normalized input amplitude (u/FS) curve for your future design reports.

2. Write a script using these functions to characterize a given modulator resulting in a plot containing SNR and SNDR (in dB) vs the input amplitude (in dBFS) (See Assignment 2 for an example plot). The plot should also clearly mark the peak-SNR, peak-SNDR, SFDR, input amplitude for peak SNR and the Dynamic Range. Use this script for all your designs henceforth.

3. Demonstrate your function **estimateMSA** for second- and third-order NTFs of your choice.

4. Write a script to generate a plot for MSA vs OBG (i.e. out of band gain) for a third-order NTF with 3-bit, 4-bit and 5-bit quantizer. See the example plot in Figure 1. You may use the *synthesizeNTF* function for this problem. Explain your observations in the generated plot and save this script for your future use.
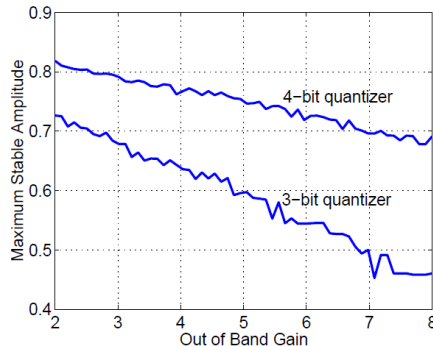

Figure 1: MSA vs OBG plot for a third-order NTF.

Problem 2 Butterworth NTF Design: Using a Butterworth highpass filter response,

1. Determine the NTF of a fourth-order $\Delta\Sigma$ modulator with an out of band gain (OBG) equal to 3. For the Butterworth response, all the NTF zeros are at DC (i.e. $z = 1$).

2. Plot the impulse response, $h(n)$ of the NTF and show that the NTF is realizable (i.e. there are no zero-delay loops). Also show the pole-zero plot for the designed NTF.

3. Assuming a 5-bit (32-level) quantizer and an OSR=16, write a MATLAB code to simulate the $\Delta\Sigma$ modulator with the NTF designed in part (1).

4. Using your **estimateMSA** function created in problem 1, estimate the maximum stable amplitude (MSA) for the design in part (1) of this problem. Determine the peak in-band SQNR in dB. Show the relevant spectrum plots with an appropriately sized Hann window.

Hint: For help on scripting the iteration on ω_N of the Butterworth high-pass NTF, to achieve a specified OBG, you may want to look at the code of the toolbox function **synthesizeNTF0**.

Problem 3 Chebyshev NTF Design: This problem explores the use of inverse-Chebyshev high-pass response for NTF design.

1. Explore the MATLAB function for generating an inverse-chebyshev high-pass response.

   ```
   [b,a] = cheby2(order,R,Wst, 'high')
   The inverse-chebyshev transfer function uses three parameters, viz,
   filter order, stop-band attenuation R and the stop-band
   edge-frequency ωst.
   ```

1. Using an inverse-Chebyshev highpass filter response, determine the NTF of a fifth-order $\Delta\Sigma$ modulator with OSR=16, and OBG=3. You can achieve this by using any of the following design approaches:

   (a) Use a fixed $\omega_{st} = \frac{\pi}{OSR}$, and then iterate upon R to get the desired OBG.
   (b) Use a fixed R (say equal to 60 dB), and then iterate upon ω_{st} to achieve the desired OBG.

2. Plot the impulse response, $h(n)$ of the NTFs and show that the designed NTF is realizable (i.e. there are no zero-delay loops). Also show the pole-zero plots for the NTF.

3. Assuming a 4-bit (16-level) quantizer and an OSR=16, write a MATLAB code to simulate the $\Delta\Sigma$ modulator with the NTFs designed in part (a).

4. Using your **estimateMSA** function created in problem 1, estimate the maximum stable amplitude (MSA) for the design in part (a) of this problem. Determine the peak in-band SQNR in dB. Show the relevant spectrum plots with an appropriately sized Hann window.

Problem 4 Complex NTF Zeros: This problem explores the NTF synthesis algorithm using NTF zero optimization and maximally flat poles.

1. Design a fifth-order (i.e. $L = 5$) NTF with optimized zero locations for minimizing the in-band quantization noise for a OSR=16. Let the all-zero NTF be given by

$$NTF_0 = \prod_{i=1}^{L} \left(1 - z_i z^{-1}\right) \tag{1}$$

where z_i's are the optimized NTF zero locations while ensuring that $NTF_0(\infty) = 1$. Plot the frequency response of NTF_0. What is the OBG ? Will this NTF lead to a stable $\Delta\Sigma$ modulator with a reasonable MSA?

(a) In order to reduce the OBG of the NTF to an acceptable value of OBG=3, we now introduce poles into the signal band. For a simple synthesis procedure, the poles can be added independently to the zero locations, given that the resulting response is maximally-flat in the signal band. Design a maximally-flat, all-pole, low-pass transfer function $\frac{1}{P(z)}$ (i.e. $P(z)$ is the denominator with the poles as its roots) such that the resulting NTF given by

$$NTF(z) = \frac{NTF_0(z)}{P(z)} \tag{2}$$

has an OBG=3. Ensure that your NTF is realizable, i.e. $NTF(\infty) = 1$. Plot the frequency response of $NTF(z)$ superimposed with that of $\frac{1}{P(z)}$ and $NTF_0(z)$. Also show the pole-zero plots for these transfer functions.

Hint: Use the following MATLAB function for generating an all-pole, maximally-flat, low-pass response :

```
[b,a] = maxflat(0,order,Wn)
```

(b) Plot the impulse response, $h(n)$ of the NTF and show that the NTF is realizable (i.e. $h[0] = 1$).

(c) Assuming a 4-bit (16-level) quantizer and an OSR=16, simulate the $\Delta\Sigma$ modulator with the NTF designed in part (2).

(d) Using your **estimateMSA** function created in problem 1, estimate the maximum stable amplitude (MSA) for this design. Determine the peak in-band SQNR in dB. How much improvement is this over a design with all zeros at $z = 1$? Show the relevant spectrum plots with an appropriately sized Hann window.

2. Repeat part (2) for an OSR=4. Is the frequency response of $\frac{1}{P(z)}$ maximally-flat in the signal band ? Will this design yield minimum in-band quantization noise (IBN) with the pre-selected optimal NTF zeros ?