EE212A Project: Digital Decimation Filter Design

Introduction

The goal of this project is to design a digital decimation filter which has an input sample rate F_1 1024KHZ, an output sample rate F_2 8KHZ, passband edge 2KHZ, stopband edge 3KHZ, minimum stopband attenuation 60db, maximum passband ripple 1db, passband phase linear and minimum output SNR 90db.

Note: All the figures generated by MATLAB are attached at the Appendix section.

Filter Design

The digital decimation filter is designed by using "cascaded Integrator comb" method (CIC filter). The transfer function is $H_{cic}(Z) = \left(\sum_{i=0}^{R*M} Z^{-i}\right)^N$ [1], where R is the oversample ratio 128, and M is the differential delay (chosen to 1 in this project). When the order N chosen is 8, the stop attenuation meets the requirement according to the test. Because a high order CIC filter will make the stopband attenuation higher, but the passband edge will droop quickly, an extra FIR compensator filter is cascaded after down-sampling to fix the droop at passband edge. The compensator filter is designed by using inverse $sinc$ function, $G(f) = \left|MR\left(\frac{\sin(piF/R)}{\sin(piMf)}\right)\right|^N$ [2] and it should run at single-rate 8KHZ with passband 2.1KHZ and stopband 3KHZ. The reason to set the passband edge a little bigger than the project specification is because it can make sure the combine filter can have a passband ripple less than 1 dB [3]. The CIC compensator is designed by using fir2 function in MATLAB with order 30 [4]. A high order of the compensator filter will consume more power but will make the passband ripple within the specification.

Figure 1 shows the structure of the architecture of the filter design and Figure 2 shows the magnitude response of CIC filter and CIC compensator filter.

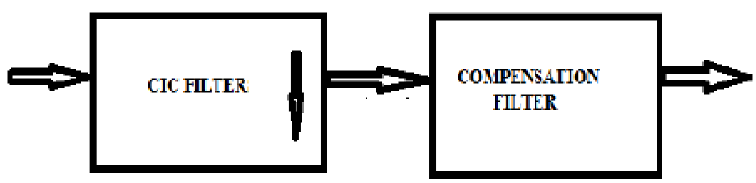

Figure 1 Cascaded structure of CIC and Compensation filter [5]

Magnitude Response and Impulse Response

According to the function $B_{max} = \lceil N * \log_2 RM + B_{in} - 1\rceil$ [6], the B_{max} should be 56 bits. When the CIC filter uses 56 bits, there is no quantization effect caused by CIC filter. For the CIC compensator filter, the number of bits used is 17 bits. When using 17 bits, the quantization effect will not violate the project specification in the combine filter and the SNR in output is also qualified (will be discussed in SNR at output section). Figure 3 and figure 4 shows the magnitude response and phase response for the designed filter with and without filter and figure 5 shows the zoom view at the passband. The passband ripple is 0.62dB and the stopband attenuation is 62 db.

The impulse response of the designed filter with and without quantization is shown in Figure 6. It shows that the quantization effect will only has a slightly influence on impulse response.

Poles and Zero

Since the filter is FIR type, it is always BIBO stable. All the zeros are around the unit circle in Z domain. Figure 7 show the pole-zero plane for the designed filter with and without quantization.

Output SNR

The noise of the designed filter is mainly come from two parts. One is from the transition from CIC filter to CIC compensation filter and the noise from CIC compensation filter. There is no noise from CIC filter because the B_{max} is used. The testing procedure is the following.

For the noise caused by transition, a random sequence is generated with the variance $\frac{\frac{1}{(2^{B max})}-\frac{1}{2^{Bq}})\text{^}2}{12}$ and let it pass through the CIC compensator filter to get the noise at the output. For the noise caused by CIC compensator filter, a random sequence is generated with variance $50 * \frac{\left(\frac{1}{2^{Bq}}\right)^2}{12}$ at the output, because the CIC compensator filter is in order 50. The input signal used is $sin(2 * pi * 1e3 * t)$ and let is pass the entire filter to get the output signal. Then, the output SNR is calculated by the output signal and the addition of the noise signals through snr function in MATLAB,

Table 1 shows the Output SNR with different bits used for CIC compensation filter. When using 17 bits, the output SNR qualify the project specification.

Bits Used for CIC Compensator Filter	Output SNR (dB)
11	59.000463
12	65.073360
13	71.048111
14	77.089478
15	83.104563
16	89.118864
17	95.171025

Power Consumption

For the CIC filter, it contains 8 integrator section running at high frequency and 8 comb section running at low frequency. Each section contains one adder and one register both having 56 bits. For the CIC compensator filter, it is running at low frequency and its order is 30, which means it contains 30 adders, 31 multipliers and 30 registers all with 17 bits. So, the final power should be the following:

$$Power = 8 * 56 * p * \left(4 * \frac{1024}{8} + 5 * \frac{1024}{8} + 4 + 5\right) + 30 * p * (4 * 17 + 5 * 17) + 31 * 2 * 17^2 * p = 542636p$$

In conclusion, the total power consumption for the designed filter is about 542636p.

Reference

- [1], [6] Eugene B, Hogenuer,1981 “An economical class of digital filter for decimation & interpolation” IEEE Transaction on Acoustics, speech & signal processing (April 1981) 155-162.
- [2], [3], [5] Rich, R.K.Singh, 2012 “Polynomial based Design of CIC Compensation Filter used in Software Defined Radio for Multirate Signal Processing” International Journal of Computer Applications (0975 – 8887) Volume 39– No.17, February 2012
- [4] Altera’s application notes 455 April 2007, “Understanding CIC compensation filter” ver. 1.0.

Appendix

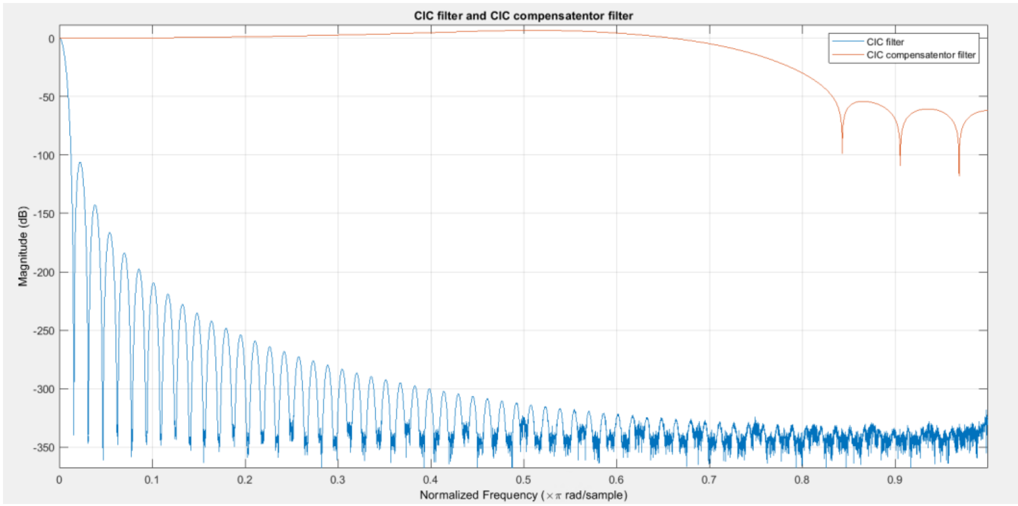

Figure 2 Magnitude Response for CIC filter and CIC compensator filter

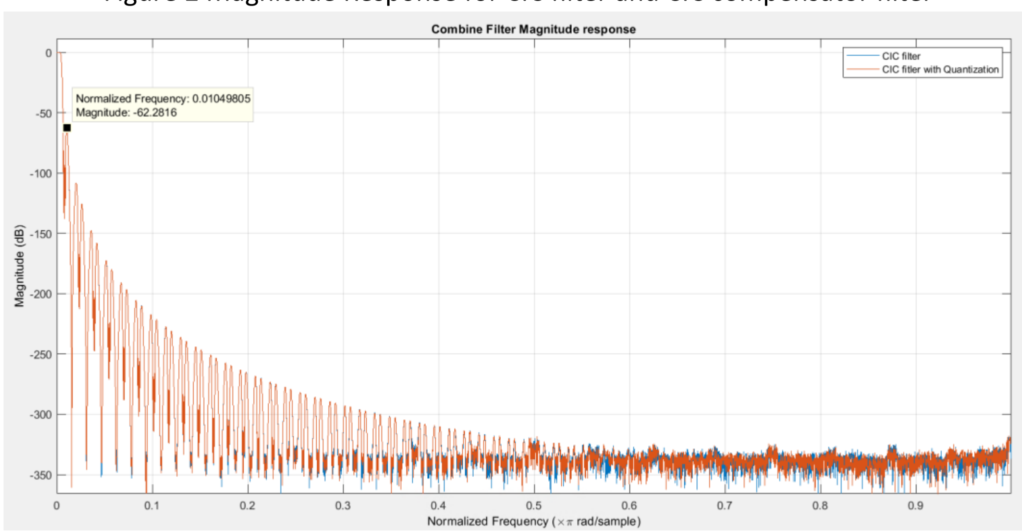

Figure 3 Combine Filter Magnitude Response

Figure 4 Combine Filter Phase Response

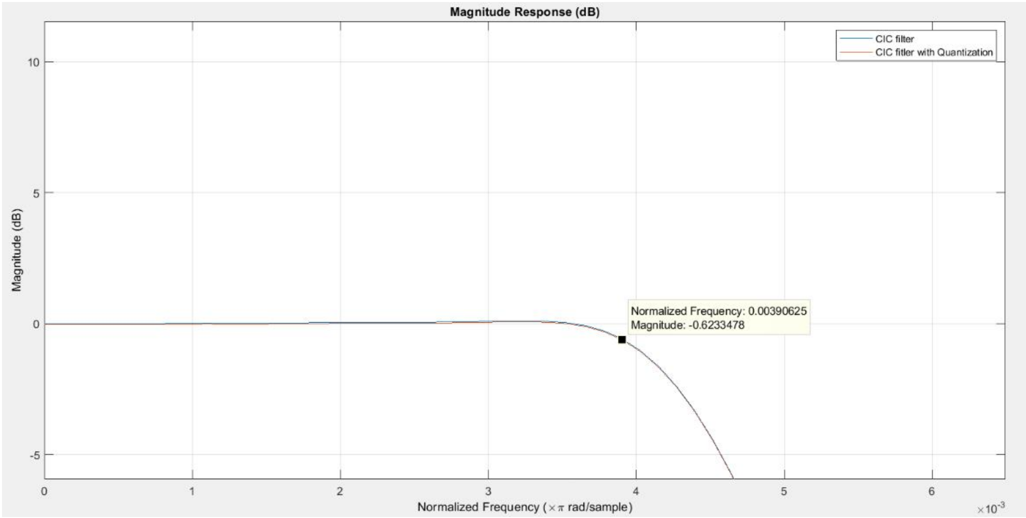

Figure 5 Combine Filter Magnitude Response (Zoom View at passband)

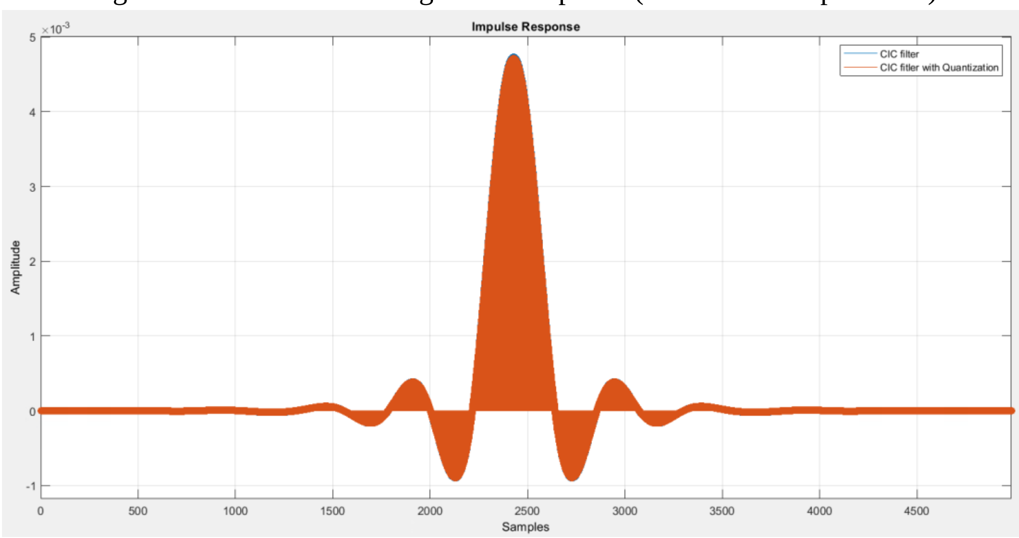

Figure 6 Combine filter Impulse Response

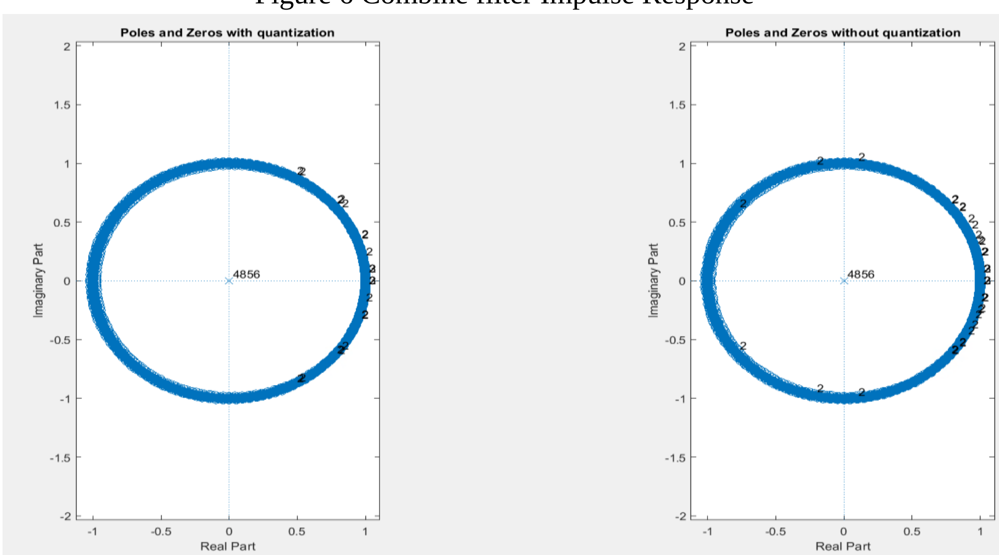

Figure 7 Poles and Zeros with quantization and without quantization