MINIMUM PHASE FILTER DESIGN FOR RECONSTRUCTION FILTER COMPENSATION

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Abstract—This paper proposes minimum phase filter design and its applications. Which the properties of the minimum phase filter have the poles and zeros inside unit circle. The design step of the minimum phase filter, design the analog low-pass filter as reconstructions filter or output filter for digital signal processing system. The reconstruction filter is used as smoothing function for the output signal utilizing approximate derivative method and inverse transformation. The results show that the proposed method can be used to compensate attenuation of the output amplitude obtained from the reconstruction filter (for high frequency of digital signal processing system).

Keywords: Minimum phase filter, Digital filter, Approximate derivative

I. INTRODUCTION

In general, the signal processing systems include the input filter, analog to digital converter: A/D, digital processor, digital to analog: D/A and output filter or reconstruction filter. The reconstruction filter is used as smoothing for the output signal, which the reconstruction filter had implemented by analog low pass filter.[3,5,6,7] The later the reconstruction filter has developed to implement by switch capacitor filter. The important properties of the reconstruction filter, the cutoff frequencies are fs/2 and magnitude response is ideal low pass filter. In practical the reconstruction filter will affect the amplitude of output signal, by the amplitude of output signal at high frequencies is attenuate. The reason for this is the reconstruction filter has non ideal low pass filter property, by the magnitude response is low sharp cutoff frequency or the slop of transition band. In solving the problem of attenuate the amplitude at higher frequencies may be done by increase the order of reconstruction filter or disable the reconstruction filter and connect the output system at D/A.

For the increase order of reconstruction filter are difficult work because it requires a lot of analog hardware.

To disable the reconstruction filter, the high frequency signal is not reduced but the output signal is non smooth or the description of output signal is step.

In order to solve the problem, this research proposes the new method for amplitude compensation of the digital signal processing at high frequency using by the minimum phase filter. The minimum phase filter is ensure the stable system, the minimum phase system function have all pole-zero inside unit circle. Therefore, the minimum phase filter is suitable for implementation to compensate for output signal of reconstruction filter. Because the minimum phase filter can be designed to inverse function of reconstruction filter which will refute the effects of attenuation of reconstruction filter at high frequency.

II. CONVENTIONAL PRINCIPLE

The complete digital signal processing system is shown in figure 1. In figure 1 the output signal y(n) from digital signal processor is converted to analog signal by D/A circuit and through to the reconstruction filter for signal smooth. However at high frequencies, the amplitude of analog signal from reconstruction filter is attenuate. For implementing, the high pass filter, notch filter and all-pass filter will be affected by reconstruction filter, because the property of reconstruction filter is low-pass filter. For example, the digital notch filter operating at a notch frequency of 1 kHz and sampling frequency of 4 kHz and to see the effect clearly the reconstruction filter has been implemented by the first order low pass filter with operating at a cutoff frequency of 1.6 kHz. The magnitude response of digital notch filter with attenuate at high frequency by reconstruction filter is shown in figure 2.

From figure 2 the magnitude of digital notch filter has error at high frequencies especially, but it similar the magnitude response of first order low pass filter.
III. PROPOSED PRINCIPLE

The diagram of minimum phase filter for reconstruction filter compensation is shown in figure 3 and the minimum phase filter [4] will implement by software.

The reconstruction filter has implemented by first order low pass filter is shown in figure 4.

For design step of minimum phase digital filter system function, the system functions of analog reconstruction filter $H(s)$ is shown in (1).

$$H(s) = \frac{1}{RC} \frac{1}{s + \frac{1}{RC}}$$  \hspace{1cm} (1)

Using the approximate derivative principle define $s = \frac{1 - z^{-1}}{T}$, convert the analog system $H(s)$ to digital system $H(z)$ is shown in (2).

$$H(z) = \frac{aT}{1 + aT - z^{-1}}$$  \hspace{1cm} (2)

Where $a = \frac{1}{RC}$ and $T$ is sampling rate.

The process of minimum phase is opposite with the process of reconstruction filter. Thus the system function property of minimum phase filter must be correspondingly the inverse system of reconstruction filter is shown equation 3.

$$H_m(z) = \frac{1 + aT - z^{-1}}{aT}$$  \hspace{1cm} (3)

From figure 5, Define $y_1(n)$ is output of application software and $y_2(n)$ is output of application software with compensating by minimum phase filter software.

The system function of minimum phase in equation 4 has been converse to difference equation as shown in equation 5.

$$y_2(n) = (1 + \frac{1}{aT})y_1(n) - \frac{1}{aT}y_1(n-1)$$  \hspace{1cm} (5)
The equation 5 is complete difference equation of minimum phase filter for compensation effect of reconstruction filter and can be implemented by software and executed by digital processor.

V. DESIGN EXAMPLE

From figure 4, Select C=0.1uF and R=1000 ohms the actual cutoff frequency of the reconstruction filter is 1.59 kHz and the sampling frequency of system is 4 kHz. From equation 1-2 the digital system functions as shown in equation 6 and pole-zero plot as shown in figure 6

\[ H(z) = \frac{2.5}{3.5 - z^{-1}} \]  \hspace{1cm} (6)

The pole-zero plot in figure 6 illustrate the digital system function of reconstruction filter has minimum phase system property. Because, the system has all pole-zero inside unit circle. And the system can be converted to minimum phase system using inverse transformation. From equation 3-5 the system function of minimum phase filter and equation for compensation as show in equation 7 and 8 and pole-zero plot as shown in figure 7. And equation 8 has been converse to software into digital signal processor and executed for amplitude compensate.

\[ H_m(z) = \frac{3.5 - z^{-1}}{2.5} \]  \hspace{1cm} (7)

\[ y_2(n) = 1.4y_1(n) - 0.4y_1(n-1) \]  \hspace{1cm} (8)

VI. EXPERIMENT AND RESULT

The diagram of experiment is shown in figure 8.

From figure 8 the input signal x(t), output signal from D/A without the reconstruction filter and output signal with the reconstruction filter are connect to oscilloscope channel 1, 2 and 3. The experiment was divided into two parts. The first part, the application software is signal amplify without/reconstruction compensation. The second part, the application software is digital notch filter with notch frequency is 1 kHz. The all experiment using the TMS320C31[8-10] floating point digital signal processing with operating at sampling frequency of 4 kHz, the reconstruction is a passive low pass filter operating at cutoff frequency of 1.59 kHz and the minimum phase filter for compensation signal used the difference equation in equation 8.

A. The magnitude response without/with the reconstruction compensation

In the experiment, define \( y(t) = 2x(t) \) the frequency of input signal start from 100 Hz to 3 kHz. The result of output signal as shown in figure 9 -11 and the magnitude response as shown in figure 12.
Figure 9 The output signal at input signal frequency of 1 kHz

Figure 10 The output signal at input signal frequency of 2 kHz

Figure 11 The output signal at input signal frequency of 3 kHz
B. The application with the digital notch filter

In the experiment, the digital notch filter with operating at notch frequency 1 kHz and sampling frequency 4 kHz [1-2]. The magnitude response of notch filter without/with the reconstruction filters compensation by dynamic signal analyzer 35670A as shown in figure 13 and figure 14.

IV. CONCLUSION

The results of the experiment showed that the minimum phase filter with proposed design can work properly based on principle. The experiments can be seen that the output signal of D/A without the reconstruction filter, the amplitude in operating frequencies \((0 - \frac{\pi}{2})\) is constant, but the signal are non smooth (step) and it is clear that at high frequency as shown in figure 9-11. For the case of the reconstruction filter, the output signals are smooth or non step. However, the amplitude of the output signal was attenuated at high frequency. For the case of the compensation, the output signals are smooth and the amplitude in operating frequencies is constant. And the applications for amplitude compensation of notch filter. The magnitude response of notch filter at high frequency will be free to amplitude attenuated. In addition, the results also showed that the reconstruction filter that is applied is not high order required.

REFERENCES