Effect of All Pass Section on Group Delay in Phase Compensated Time Varying Chebyshev Filter

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Abstract— In the present paper a hypothetical technique for constant group delay and shortening of transients in response of phase compensated time varying chebyshev filters have been discussed. The concept is utilizing the phase compensated time varying chebyshev filter by adding all pass section to it and the effect of all pass sections on group delay and reduction of transient present in noisy rectangular signal have been studied. The paper contains the simulation results of the proposed filter and results confirming the effect of all pass sections on group delay and reduction of transient present in noisy rectangular signal.

Key words: All pass section, continuous time filtering, data acquisition, group delay, linear parameter varying (LPV) approach, phase compensated time varying Chebyshev filter, transient state

I. Introduction

As per the requirement of many measurement process in analog continues time filters is that designing a filter whose magnitude response is specific, group delay is as constant as possible and also the transients to be short as much as possible.

In order to get the constant group delay, the additional group delay is introduced by the all pass filter so that the total delay is nearly flat over the desired frequency band as explained in filter theory [1],[2],[3].

The signals which are distorted by noise causes problem in measurement and data acquisition process such as sensor response correction in weighing process [4], fast processing of the brainstem auditory evoked potential signal [5].

The improvement of transient behavior of system is an old problem which has been considered in many fields of engineering. There are several techniques used for this purpose in the field of circuit design such as operational amplifiers used in switched-capacitor circuits [6]-[9]. Sometimes commonly smoothing filters are used but in many cases they are insufficient due to long lasting transients

In traditional time invariant filters there are only small possibilities of shortening the transients state because the filter parameters are calculated based on the assumed method of the frequency response approximation[10]-[11],[2]. However significant changes in transient duration can be obtained by variation of filter passband [12],[10]-[13], the concept is to change the value of filter coefficients according to the theory of linear time varying continues time systems [14]-[18].

To meet the above requirement phase compensated time varying chebyshev filter is designed with the help linear parameter varying (LPV) approach [19], using second order differential equation.

In the present paper, the effect of all pass section on group delay and reduction of transient duration in the response of the phase compensated time varying chebyshev filter is studied. The rest of the paper is organized as follows: in section 2, the issues of the all pass section are explained. Design of the time varying filter with the help of linear parameter varying (LPV) approach with detailed examination of variation range of filter parameters [20] are examined in section 3 and 5. In section 5 noise signal is generated and section 6 displays the result of simulation. The conclusion is described in section 7.

II. Compensation Process

All pass section has the characteristic that they do not disturb the magnitude response and have same gain for all frequencies. As number of all pass section increases, the group delay of the filter approaches towards the constant group delay which has been widely described in filter theory [1],[2],[3].

III. Linear Parameter Varying (LPV) Approach

The dynamic properties of a filter are explained by damping variable (β), natural frequency (ω_o), and time constant (T) similiarly the all pass filter is explained by natural frequency (ω_{op}) and damping factor (βp). A time variation of these parameters can be helpful for the diminishment of the transient of the phase compensated time varying filter. With the help of second order differential equation the simulink model of phase compensated time varying chebyshev filter is designed and for nth order filter the model can be written as

$$T(t)y'_1(t) + y_1(t) = x(t) \quad (1a)$$

$$\omega_o^{-2}(t)\, y_2''(t) + 2\beta(t)\, \omega_o^{-1}(t)\, y_2'(t) + y_2(t) = y_1(t) \quad (1b)$$

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$$\omega_{op}^{-2}(t)\, y_n''(t) + 2\beta_p(t)\, \omega_{op}^{-1}(t)\, y_n'(t) + y_n(t)$$
$$= \omega_{op}^{-2}(t)\, y''_{n-1}(t) - 2\beta_p(t)\, \omega_{op}^{-1}(t)\, y'_{n-1}(t) + y_{n-1}(t) \quad (1c)$$

Where x(t) and $y_n(t)$ are the input and output of the filter respectively. Equation 1(a) describes the dynamics of the first order element. In the present paper the second order differential equation [(1b) and (1c)] is used to construct the model of the filter.

A. Function of Filter Parameters

It is understood that the higher the value of natural frequency (ω_o) the shorter the transient of the filter so the value of natural frequency (ω_o) must be kept high. On the other hand the littler the value of damping factor (β) the littler the rise time of the filter and the bigger the overshoot so in order to make rise time minimum the value of damping factor (β) must be kept minimum. Taking into account the computer simulations and the previously stated principles, the function of the filter parameters was detailed in the following form:

$$F(t) = d.\bar{F}.[1 - \frac{d-1}{d}.\ h(t)],\ \text{where}\ d = \frac{F(0)}{\bar{F}} \quad (2)$$

Where F is the value of the filter parameters following the chebyshev approximation and all pass filter calculas, d is the variation range of function F(t). Assuming that the function f(t) is the necessity of settling during the transient of the original time invariant filter this condition is

$$\forall_{\ t} > t_{s\alpha}\ , \qquad F(t) = \bar{F} \pm \alpha$$

Where t_{sa} is the settling time of the time invariant filter with assumed accuracy α.

When the value of variation range (d) is greater than 1 the function F(t) diminishes to 1 in the variation interval as shown below in figure 1.

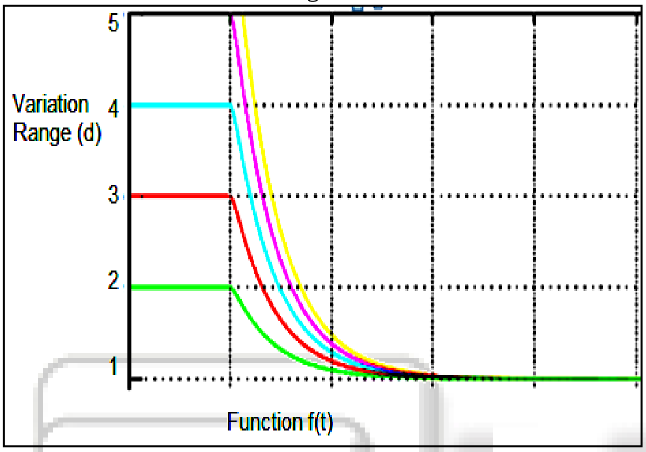

Fig. 1: Function f(t) diminishes to 1 for d > 1

and when the value of variation range(d) lies in between 0 and 1 then the function F(t) approaches to 1 in the variation interval as shown in figure 2 and for d = 1 the function is consistent F(t) = F.

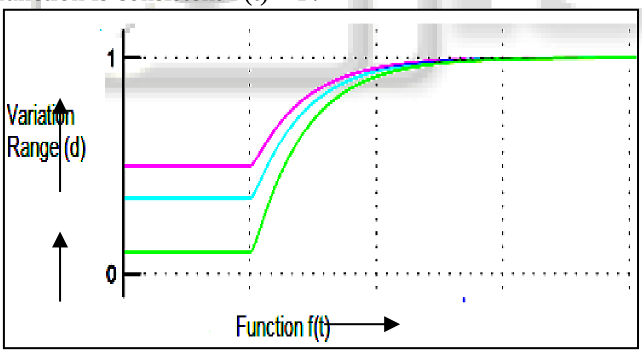

Fig. 2: Function f(t) increases to 1 for d ∈ (0, 1)

Function h(t) in (2) explains the step response of the second-order supportive system and $H_s(s)$ given by

$$H_S(s) = \frac{1}{\omega_{0f}^{-2} s^2 + 2\beta_f \omega_{0f}^{-1} s + 1} \qquad (3)$$

and has the following form: $h(t) = L^{-1}[s^{-1}\ HS(s)]$. L^{-1} is the inverse Laplace transform, ω_{of} determines the variation rate of function $F(t)$, and β_f determines the oscillations of function $F(t)$.

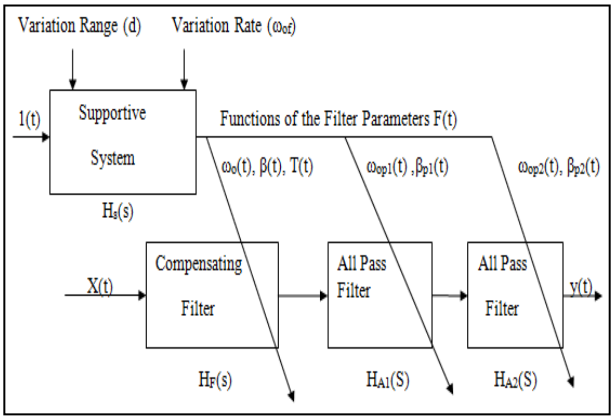

Fig. 3: Block diagram of proposed filter

Figure 3 shows the layout of designed phase compensated time varying chebyshev filter and explains how the supportive system influences the dynamics of the Chebyshev and all pass filters

IV. Selection of Variation Range of Different Parameters for the Proposed Filter

It has been proved [20] that the best result in reduction of transient duration is achieved when natural frequency of compensating filter (ω_{oi}),natural frequency of all pass section (ω_{op}) and inverse time constant (T^{-1}) is varied according to same variation range ($d\omega$).

On the other hand damping factor of compensating filter (β_i) and damping factor of all pass section (β_p) is varied according to different variation range denoted by $d_{\beta i}$ and $d_{\beta p}$ respectively.

Variation range for function $\omega_{oi}(t)$,$\omega_{op}(t)$ and $T^{-1}(t)$ denoted by $d\omega$ starts from greater value than 1 ($d\omega > 1$) and decreases in variation interval t ϵ (0,$t_{s\alpha}$) and the variation range for function $\beta_i(t)$ and $\beta_p(t)$ should be selected which satisfies the condition: $d_\beta > 1$ and [$d_{\beta p}$ ϵ (0,1)].

Function $\beta_i(t)$ is responsible for suppression of undesirable overshoot in the step response and $\beta_p(t)$ is responsible for undershoot elimination from step response.

Table 1 shows the values of variation range for different parameters taken for designing phase compensated delay equalized chebyshev filter in order to get best results in reduction of transient duration.

Filter Order (n)	Variation Range of the Functions $\omega_{oi}(t)$, $\omega_{op}(t)$ and $\frac{1}{T}(t)$ [dω]	Variation Range of the Function $\beta_i(t)$ [$d_{\beta i}$]	Variation Range of the Function $\beta_p(t)$ [$d_{\beta p}$]
3	6	2	.5
	5	2	.5
	4	2.05	.35
	3	2.05	.1
	2	2	.1

Table 1: Variation range for different parameters of proposed filter

Figure 4 shows detailed model of the phase compensated time varying Chebyshev filter which has been designed with the help of linear parameter varying (LPV) approach using second order differential equation and compensated with the help of the second order all pass filter.

For making the supportive system requires the utilization of multipliers, adders, and integrators which are available in simulink library.

As it can be noticed from the model that the complexity of the system has increased but in situations where transients should be as minimum as possible, the complexity of the system can be afforded.

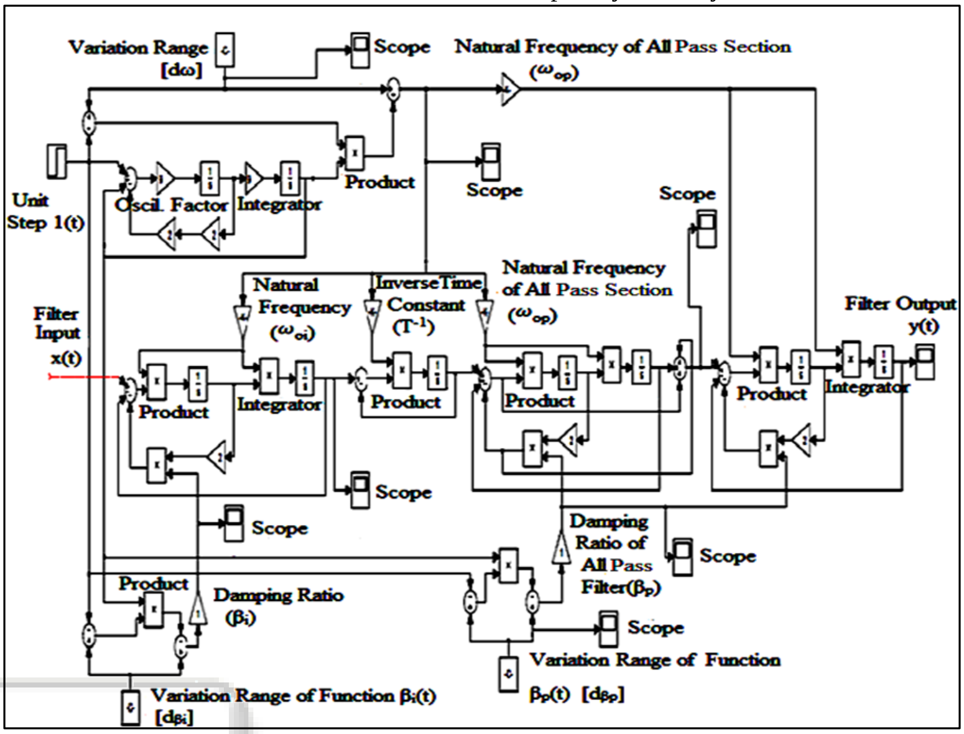

Fig. 4: Model of third order phase compensated time varying chebyshev filter

V. GENERATION OF NOISE SIGNAL

To test the effect of all pass section on phase compensated time varying chebyshev filter it is necessary to design a special system which can generate noisy rectangular signal with large transients. To get the required noisy signal a rectangular signal is generated with the help of signal builder and noise is generated with the help of band limited white noise block in simulink as shown in figure 5, then both these signals are passed through minmax running resettable block and then the output of it is passed through chebyshev low pass filter so that more transient can be obtained in the noisy signal. Chebyshev low pass filter is designed with the help of FDA Tool in MATLAB whose specifications are shown in figure 6.

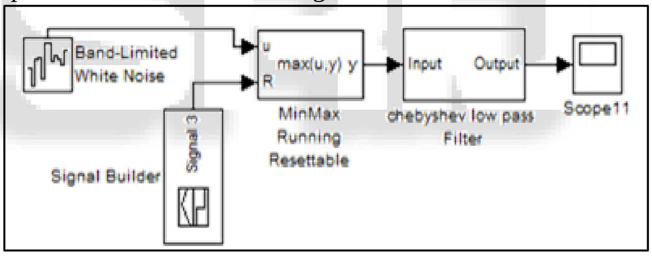

Fig. 5: Block diagram to generate noisy signal

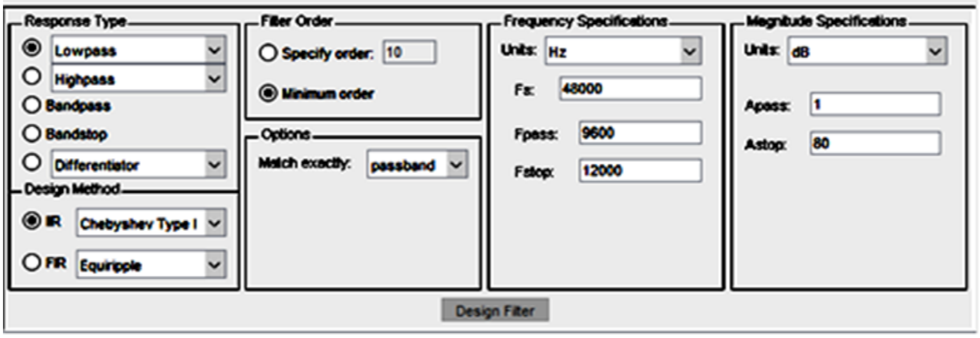

Fig. 6: Specification taken for designing low pass chebyshev filter using FDA Tool

Fig 7 shows the rectangular signal with transients which is obtained from above block diagram. The signal is used as input for phase compensated time varying chebyshev filter in order to study the effect of all pass section on reduction of transients.

Fig. 7: Rectangular input signal with transients

VI. Result of Simulation

Figure 8 presents the response of filtering by using the time varying filter before passing through all pass section. It is easy to notice that the processing of rectangular signal distorted by additive noise gives much better results with time varying filter having all pass section in reductions of transients as shown in figure 9.It is also observed that as the number of all pass section increases in the time varying filter the transients in the response of the filter will decreases and simultaneously the delay in time domain of the filter response occurs.

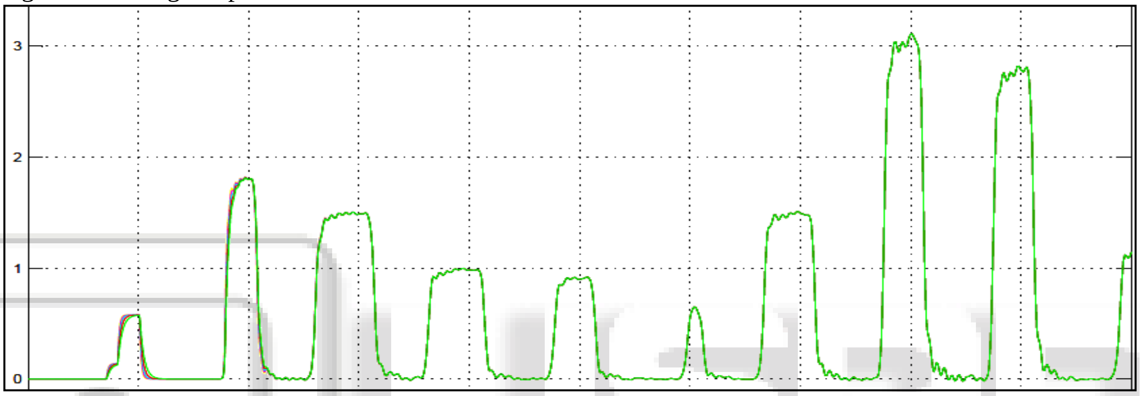

Fig. 8: Response of time varying filter before passing through all pass section

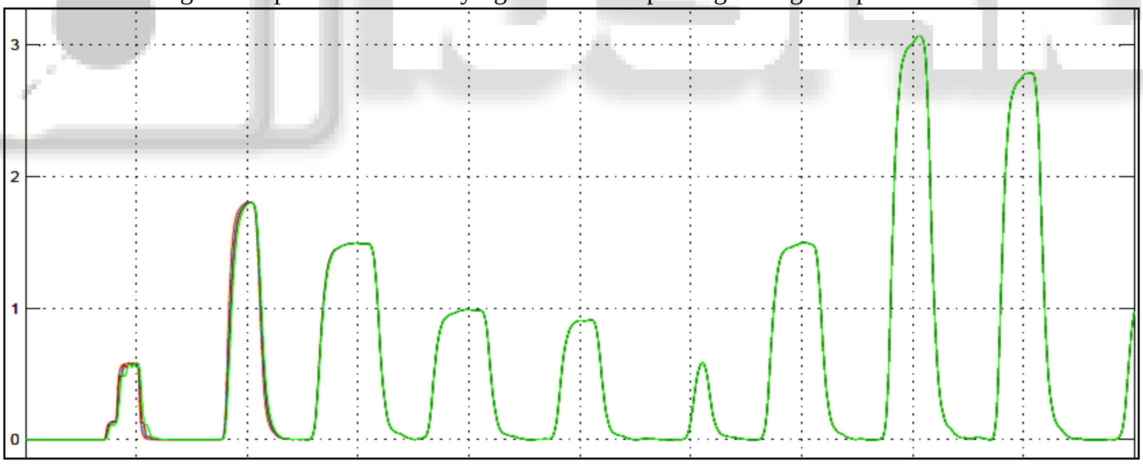

Fig. 9: Response of time varying filter after passing through all pass section

VII. Conclusion

It is verified from above observations that as the number of all pass section in phase compensated time varying chebyshev filter increases, the group delay of the filter approaches towards the constant group delay and transients in the rectangular signal distorted by additive noise will decrease but the complexity of the filter will increase so the number of all pass section in the filter should be selected as per the requirement and convenience.

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