DESIGN AND PERFORMANCE ANALYSIS OF IIR FILTER FOR RF APPLICATIONS

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Abstract: This paper presents design and simulation of IIR bandpass filter for RF applications. Three different techniques are used for design simulation namely Butterworth, Chebyshev and elliptic. The design has been analyzed and compared in terms of transition width and group delay. The hardware requirements are also computed in terms of multipliers and adders. It can be observed from the simulated result that the magnitude response and group delay of Butterworth and Chebyshev type 1 are almost same at higher order and better than Chebyshev type 2 and elliptic filter. Multiplier requirement of Chebyshev type 1 filter is 45% less than Chebyshev type 2 and elliptic filter and adder requirement of Butterworth and Chebyshev type 1 is 25% less than Chebyshev type 2 and elliptic filter.

Keywords: Butterworth, Chebyshev, DSP, Elliptic, IIR

I. INTRODUCTION

Digital Signal Processors (DSPs) take real-world signals like voice, audio, video, temperature, pressure, or position that have been digitized and then mathematically manipulate them. A DSP is designed for performing mathematical functions like “add”, “subtract”, “multiply” and “divide” very quickly. Digital signal processing is the regulation that studies the rules prevailing the behavior of discrete signals, as well as the systems used to route them. It also deals with the issues involved in processing continuous signals using digital techniques. Digital signal processing pervades modern life. In analog signal processing, we take a continuous signal, representing a continuously varying physical extent, and go by it through a system that modifies this signal for a certain purpose. This modification is, in general, incessantly variable by nature. On the other hand, in digital signal processing, we process sequences of numbers using some sort of digital hardware. We normally describe these sequences of numbers digital or discrete-time signals. The power of digital signal processing comes from the fact that, once a sequence of numbers is available to suitable digital hardware, we can carry out any form of arithmetical processing on it. As there are several tools available to implement very complex digital signal processing systems. In practice, a digital signal processing system is implemented either by software on a general purpose digital computer or DSP, or by using application-specific hardware, usually in the form of an integrated circuit.

The field of digital signal processing has developed so fast in recent decades. The structure blocks for digital signal processing systems considered are used to process signals which are discrete in time and in amplitude. The main tools are discrete-time signal representations, discrete transforms and their fast algorithm spectral estimation, design and implementation of digital filters and digital signal processing systems, multirate systems and filter banks, wavelets. Although the techniques we deal with are directly applicable to processing deterministic signals, many statistical signal processing methods employ similar building blocks. Digital signal processing is extremely useful in many areas like Image processing, Multimedia systems, Communication systems and Audio signal processing. Transforms, filters and correlation are the major parts of linear signal processing systems.

In Digital Signal Processing the filter is essentially required to process the signals. In digital signal processing applications, we consider only the digital filter. Filter specifically used to remove unwanted frequency components from the signal, to enhance wanted ones, or both. Digital Filters are of two types FIR and IIR. Finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. This is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying).

IIR filters are helpful for a high-speed design because they require a less number of multiplies compared to FIR filters. IIR filters can also be designed to have a frequency response that is a discrete version of the frequency response of an analog filter. Unfortunately, IIR filters do not have linear phase and they can be unstable if not designed properly. IIR filters also are very sensitive to filter coefficient quantization errors that occur due to using a finite number of bits to represent the filter coefficients. One way to reduce this sensitivity is to use a cascaded design.
II. IIR FILTER

Although almost all analog electronic filters are IIR, digital filters may be IIR or FIR. The presence of feedback in the topology of a discrete-time filter generally creates an IIR response. The transfer functions pertaining to IIR analog electronic filters have been extensively studied and optimized for their amplitude and phase characteristics. These continuous-time filter functions are described in the Laplace domain. Desired solutions can be transferred to the case of discrete-time filters whose transfer functions are Thus digital IIR filters can be based on well-known solutions for analog filters such as the Chebyshev filter, Butterworth filter, and Elliptic filter, inheriting the characteristics of those solutions expressed in the z domain, through the use of certain mathematical techniques such as the bilinear transform, impulse invariance, or pole–zero matching method. As the speed of digital signal processing technology continue to enhance, digital filters (IIR) are being applied to high frequency signals in the RF (radio frequency) domain.

Basic IIR filters are of four types. Butterworth Filter: The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the passband. It is also referred to as a maximally flat magnitude filter. Chebyshev type 1 Filter are analog or digital filters having a steeper rolloff and more passband ripple (type 1) than Butterworth filters. The Chebyshev Type 1 filter minimizes the absolute difference between the ideal and actual frequency response over the entire pass band by incorporating an equal ripple in the pass band.

Stop band response is maximally flat. Chebyshev type 2 Filter having a steeper roll-off and more stop band ripple (type 2) than Butterworth filters. The chebyshev Type 2 filter minimizes the absolute difference between the ideal and actual frequency response over the entire stop band by incorporating an equal ripple of Rs dB in the stop band. Pass band response is maximally flat. Elliptic filters is a signal processing filter with equalized ripple (equiripple) behavior in both the passband and the stopband [5].

III. DESIGN SIMULATIONS

Designing of Bandpass IIR filter for RF applications is done on basis of parameters magnitude response, group delay and hardware requirements. In this proposed work IIR filter has been designed and simulated using MATLAB by taking filter order 8,16,24 and 32 along with cutoff frequency range from 2.41 MHz to 28.7MHz, sampling frequency is 60 MHz, pass band attenuation is 0.5 and stop band attenuation is 75. For analysis of performance of IIR filter for RF applications four filters Butterworth, Chebyshev type I, Chebyshev type II and elliptical filters are taken. Different filters are compared with the help of transition width, group delay and hardware requirements. Simulated result for magnitude response is shown in figure 1,2,3,4.
Figure 1, 2, 3 and 4 shows the magnitude response of Butterworth, Chebyshev type 1, Chebyshev type 2 and elliptic filter for order N= 8, 16, 24, 32. Transition band is specified between the passband and the stopband to permit the magnitude to drop off smoothly. Figure shows that as order changes causes the transition band variation [9]. Magnitude response and group delay are related to each other. In general if magnitude response is good than group delay is worse. Group delay is a measure of phase distortion. Group delay is the actual transit time of a signal through a device under test as a function of frequency. The simulated result of Group delay are as follows:

Figure 5, 6, 7, and 8 shows the group delay response of all four filters. It can be seen from figures at lower order group delay of Chebyshev type 2 is better but when order is increasing from N= 8, 16, 24 and 32 group delay of Butterworth, Chebyshev type 1 and Chebyshev type 2 is improving but group delay of elliptic become worse.

IV. RESULT DISCUSSIONS

As can be seen from the design simulations the Butterworth filter has the widest transition bandwidth. Chebyshev type 1 filter has a transition band width that is smaller than the Butterworth filter but greater than the elliptical filter and Chebyshev type 2. Chebyshev type 2 has smaller transition width. On the other hand group delay of Chebyshev type 2 is better than Butterworth, Chebyshev type 1 and elliptic filter at N = 8. When order is increasing group delay of Butterworth filter and Chebyshev type 1 is standing towards ideal as shown in fig. 5, 6, 7, 8. Another way of performance analysis of IIR filter for RF frequencies would be to compare hardware requirement for all four filters.
Multiplier requirement of all four filters are shown above. From this it is clear that when order is increasing multiplier requirement is increasing. Chebyshev type 2 requires highest number of multipliers. Elliptic filter require almost same number of multiplier as chebyshev type 2. Chebyshev type 1 requires less multiplier among all four. Number of multiplier requirement for Chebyshev type 1 is reduced 45% from elliptic and Chebyshev type 2. While for Butterworth filter multiplier requirement is reduced 37% from elliptic and Chebyshev type 2 filters. So Chebyshev type filter require less multiplier among all.

### Table 2. Adder Requirement of Filters

<table>
<thead>
<tr>
<th>Order</th>
<th>Butterworth</th>
<th>Chebyshev type 1</th>
<th>Chebyshev type 2</th>
<th>Elliptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>16</td>
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<td>24</td>
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<td>32</td>
<td>48</td>
<td>48</td>
<td>64</td>
<td>64</td>
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</tbody>
</table>

Figure 10 shows the adder requirement of all four filters. It is clear that Elliptic and Chebyshev type 2 require same number of adder. Chebyshev type 1 and Butterworth require same number of adder which is less than Chebyshev type 2 and elliptic filter.

### CONCLUSIONS

This paper includes the method of designing bandpass IIR filter for RF application according to the specification. Performance analysis also done by using three different techniques namely Butterworth, Chebyshev and elliptic. From the result it is clear that magnitude response and group delay of Butterworth filter and Chebyshev type 1 is standing toward the ideal response. Butterworth and Chebyshev type 1 has almost same hardware requirement for lower order. But as the order is increasing the Chebyshev type 1 filter required 45% less multiplier than Chebyshev type 2 and Butterworth filter required 37% less multiplier than Chebyshev type 2. So the multiplier requirement for Chebyshev type 1 is less than the Butterworth filter. Adder requirement for Butterworth and Chebyshev type 1 are same i.e. 25% less than the Chebyshev type 2 and elliptic filter.

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### REFERENCES


