Simple Circuit for Implementation of an Analog Stack Filter

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Abstract

A simple design for implementing an analog stack filter is presented. The implementation of this design is very simple and economical as it needs only operational amplifiers, resistors and capacitors. The design, starting from the simple case of median filter, is extended to that of larger-point analog median, then to that of weighted analog median. Similarly, These design is then developed analog weighted order statistic filter, and then extended to that of an analog stack filter. The same structure was used for all of these extension, with very small modification and with few additional components. The experimental results for these different circuits, for different cases of inputs are included and these results demonstrate that the designs have performed as they were expected.

1: Introduction

With the aid of the threshold decomposition, *Coyle et al* [2] developed an optimal stack filtering theory which can be used to design a stack filter. The necessary and sufficient condition for a binary function to possess the stacking property is that it can be expressed as a Boolean expression which contains no complements of input variables, i.e. must be positive Boolean function (PBF). All stack filters for three variables are Weighted Order Statistic filters. Of the 7581 PBF's of five variables or less, there are 3287 WOS (Weighted Order Statistic) filters [7]. The WOS filters are composed of a large number of extensively used median type filters, such as, Order Statistic (OS), Weighted Median (WM), and Standard Median filters.

Stack filters can be implemented either using the threshold decomposition architecture in the binary domain or using a real domain architecture which is based on MAX/MIN operations. For example, the three-point median over three variables X_{-1}, X_0, X_1, which is a method of replacing each point by the median over itself and its two neighbours, is a stack filter defined by the PBF

$$f(x_{-1}, x_0, x_1) = x_{-1}x_0 + x_{-1}x_1 + x_0x_1 \quad (1)$$

corresponding to

$$MED[X_{-1}, X_0, X_{-1}] = MAX[MIN[X_{-1}, X_0], MIN[X_{-1}, X_1], MIN[X_0, X_1]] \quad (2)$$

In signal smoothing problems where sharp edges must be retained, median filters are often preferred over linear methods. Thus, these filters are getting many applications in signal processing including speech processing and image enhancement. So far, many designs for digital median filters have been proposed, their review is found in [6], but less work has been done on designing analog median filters, of which, most of them are relatively complicated or have many performance limiters, and for others number of inputs is restricted to three [3,4,5,8]. However, there are occasions when an analog median filter is preferred. Advantages of an analog median filter include the avoidance of expensive fast A/D and D/A converters, the simple implementation of nonlinearities and high processing speed.

This work starting from a simpler algorithm which has been proposed by Astola and Kuosmanen [1], expands and modifies the theoretical analysis to a practical design. The composition of the paper is as follows: first, the structure of the design of three-point median filter, of five-point WOS filter, and of a three variables stack filter are described, then the circuit needed for implementing the design is presented. At last, the experimental results for the different circuits for different cases of inputs are shown and summarized.

2: Description of the Design Approach

The structure of the three point median filter is shown in Fig. 1. It consists of comparators, an adder and an integrator. For any larger point median filter the structure remains the same, but only the number of inputs increases accordingly. The inputs can be from three different sources or

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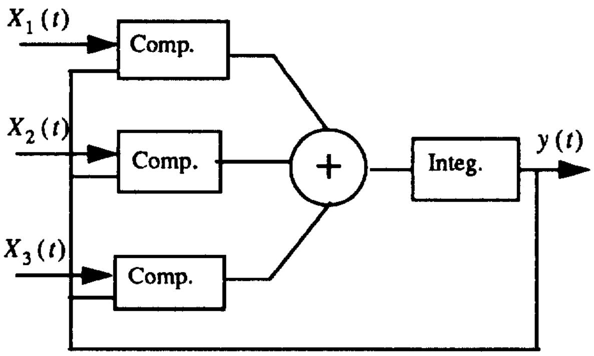


Fig. 1: **A 3-point median filter.**

from same source, where the second and the third inputs are delayed once and twice respectively.

The system takes in the inputs, compares each inputs with the instantaneous value of the output, sums up the comparison results, and integrates the consecutive outputs of the adder. It does this repeatedly until it finds the median of the inputs, i.e. the adder output reaches to zero or the overall output comes to steady state point. This same procedure of computing the median is followed for larger point median filter cases.

In some cases it may be necessary to give more emphasis to some of the inputs and thus we need a weighted median. The process of computing the weighted median is similar to the case of standard median. Weights are implemented by giving higher gain (> 1) to the adder inputs. The gains here act as multiplier of the comparison result and can have any positive real value.

Sometimes it is also necessary to output other rank than the median i.e. the first, the last etc. This can be implemented using the structure shown in Fig. 2, where an additional input is fed to the adder called 'Rank Selector'. The computation of the output is similar as the case of the median filter, but for non-median output the sum of the comparison results shouldn't be zero as the desired value is obtained.

Fig.3 shows the design structure for a three variables stack filter, which is a 3-point median filter. The system composed of four Order Statistic filters. The first three have got two inputs from which the minimum values are selected and fed to the three point OS filter, from which the maximum is selected as a final output.

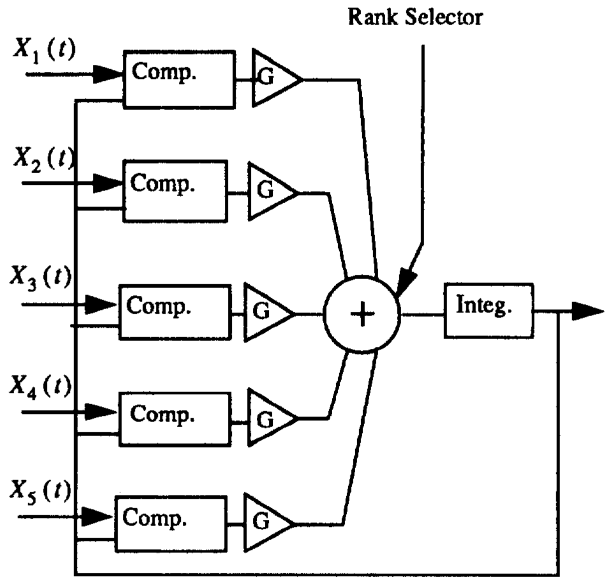


Fig. 2: **A 5-point WOS filter.**

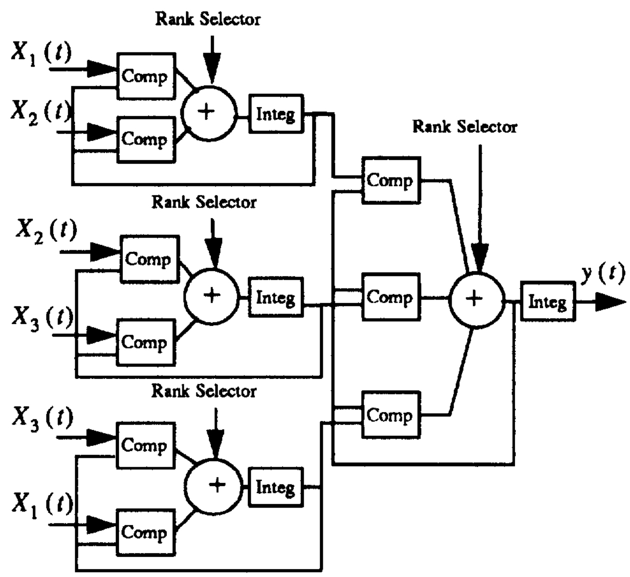


Fig.3: **A three variables stack filter.**

The circuit used to implement a 5-point WOS filter is shown in Fig. 4. As the name implies, the rank to be output depends on the value of the 'Rank Selector'. The 'Rank Selector' is a simple voltage input, and when its value is zero the output of the circuit is the median of the inputs. By increasing or decreasing the voltage of the 'Rank Selector', we can change the rank of the output to the next nearest lower or upper step respectively. This voltage adjustment has a linear relationship with the rank selection.

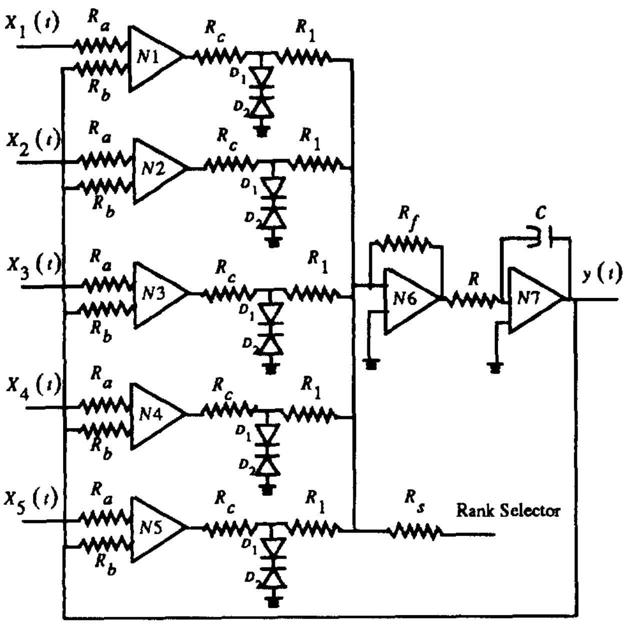


Fig. 4: **The circuit used to implement a 5-point WOS filter.**

The components needed to implement such filter are resistors, capacitors and operational amplifiers. R_a, R_b, R_c are $10\,K\Omega$ resistors, D_1, D_2 are Germanium diodes, $R_1, R_2, \ldots, R_n, R_f$ are $1\ M\Omega$ resistors and $N1, N2, \ldots, N7$ are general purpose operational amplifiers. A variable resistor of $100\,k\Omega$ is used for R and C is a $1\ \mu F$ capacitor. By changing the values of R and C, the gain of the integrator can be changed. Different weights can be obtained by adjusting the adders gain, that is the value of R_f / R_n.

3: Experimental Results

In this section, experimental result for different cases of inputs and circuits are presented. The results, the oscilloscope traces which are shown in the photographs and oscilloscope print out, are obtained from breadboarded circuits. For all cases the upper curves represent the inputs, the lower curves represent the output and the voltage scale is 1volt/-division. Fig. 5 shows the output of the 3-point median filter for one sine wave input, and for two sine wave inputs delayed by 25 and 50 milliseconds. As can be seen from the oscilloscope trace, the output follows the middle wave but at the sine waves junction it has a sort of notch as it follows the median at each instant.

The first rank output of the WOS filter is shown in Fig. 6. Here, the inputs are two sine waves, where the larger has weight 5 and the smaller has weight one, one sawtooth input with weight one, and two constant inputs of 1.1 volt and -0.9 volt with weight two. For the first rank selection the "Rank Selector" voltage was set at 25 volts. As can seen from the lower trace, the output curve follows the largest value at each instant. As the 1.1 volt input is the largest value at most instants, the output curve is constant in most of it parts.

The output of the stack filter which represents the 3-point median filter is shown in Fig. 7. Fig. 7(a), (b), and (c) show the first stage outputs, i.e. outputs of the three 2-point OS filters where the inputs are the square and the sine wave, the sawtooth and the sine wave, and the square and the sawtooth respectively. For all cases the minimum values are selected. Fig. 7(d) shows the second stage output, i.e. output of the 3-point OS filter where the inputs are the outputs of the first stage OS filters and the maximum of these inputs is selected out as a final output.

Fig. 5: **The 3-point median filter output.**

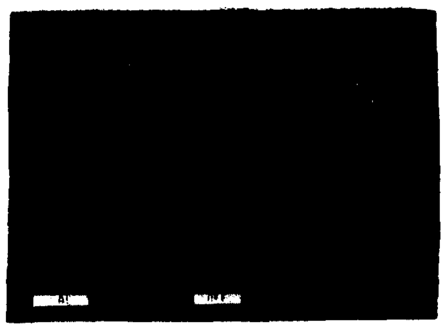
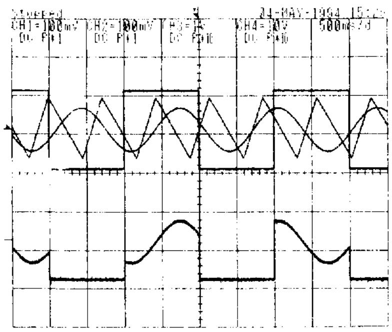
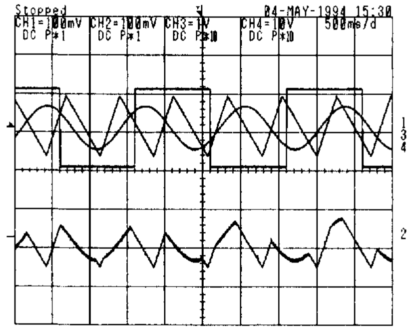


Fig.6: **The 1^{st} rank output of the 5-point WOS filter.**

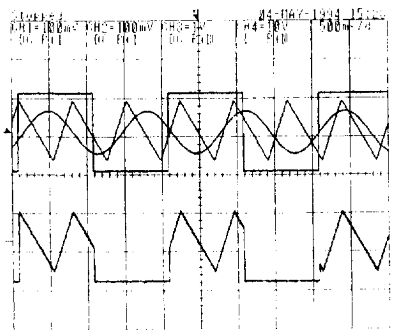
(a)



(b)



(c)



(d)

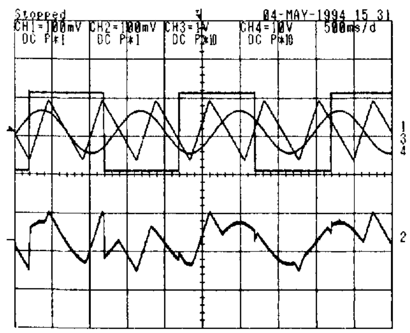


Fig.7: **Output of the three variable stack filter (a), (b) and (c) are outputs of the 1^{st} stage OS filters (d) is the final output.**

4: Conclusions

A simple implementation of an analog stack filter has been presented. The circuits needed to implement this design are very simple and they are constructed with operational amplifiers, resistors, and capacitors only. The design has another good feature in that, it can be easily extended to any stack filter with small change on the basic structure and very few additional components. As can be seen from the experimental results, the circuits are proved to perform very well.

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