Application of Switched-Capacitive Filters in Anti-Aliasing Filtering

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***Abstract* – In this paper we introduce possible applications of switched-capacitive filters for anti-aliasing filtering. In order to avoid aliasing effects in the process of sampling an analog signal, it is necessary to use an analog anti-aliasing filter to eliminate noise of outside the useful signal band. Today we have the importance of implementation of integrated solutions that can be packed in small form of chip and aspiration to minimize the integration of number of electronic blocks in one electronic circuit. In addition switched-capacitive filters bring many advantages compared to active filters, require no external capacitors, precision, accuracy and limit the frequency up to ± 0.2%, and less sensitivity to temperature changes. A very important feature of switched-capacitive filter is their flexibility, because changing the frequency of overlap changes the cut-off frequency of the filter and thus avoids the need for changing the values of capacitors in the circuit filter.**

***Keywords* – Anti-aliasing, analog filters, switched-capacitive filters.**

I. Introduction

Aliasing effect emerged as a product of side effects or false signals outside the desired frequency band is a problem in many applications that use the A/D conversion. These signals, if not properly filtered, can seriously damage performance of the system for A/D conversion.

Components of the signal from outside the useful band, which for some reason, we have on input of the A/D converter, due to the aliasing effect will appear in the output samples with frequencies that fall into the desired frequency band. This imposes the need for the necessity of filtering the input signal of the A/D converter. Standard analog filters require a larger number of passive components, which becomes a problem especially in today's highly integrated electronic circuits. For these applications switched-capacitive filter becomes more significant considering the possibility of integration of higher order filters in a small area, but also all the other benefits that this technology brings.

This work will mainly illustrate the occurrence of aliasing effects in order to underscore the importance of removing, then the basis of realization of switched-aliasing filter with the implementation of an integrated solution switched-capacitive filter and simulation results of application EE-Sim for design and simulation of the filter, from the company Maxim Integrated Products, Inc..

II. Anti-aliasing Effect

A/D converters typically operate with a constant sampling frequency when digitalize an analog signal. Using a sampling frequency (f_s), which is usually called the Nyquist rate, all components of the input signal with frequencies below $f_s/2$ will be reliably digitalized. If the input signal has components over the frequency domain $f_s/2$, after A/D conversion that components will appear in a useful range of output signal with preserved values of the amplitude. This phenomenon leads to the fact that it is impossible to discern the difference between the signals from the useful range (below $f_s/2$) and components over the useful range (above $f_s/2$).

The appearance of aliasing effect is illustrated in the frequency domain in Fig 1.

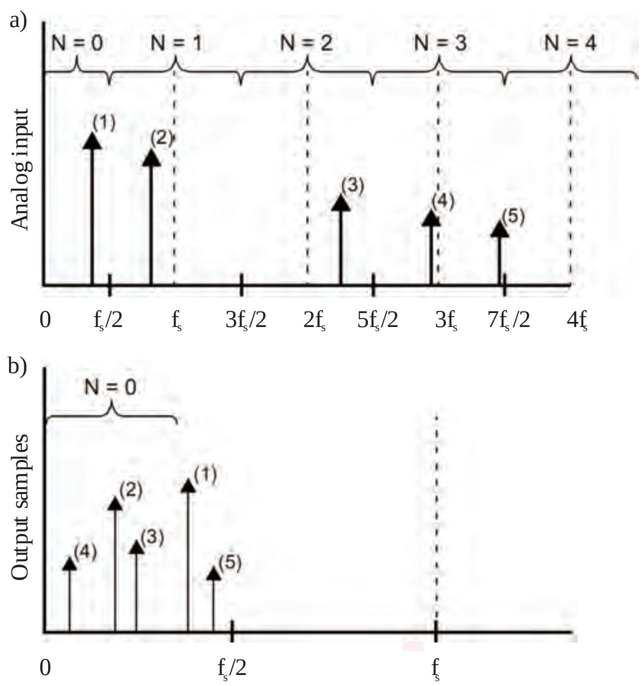

Fig 1. a) A system that sampled input signal with the frequency f_s identify signals with frequency $f_s/2$, and signals with higher frequency b) Signals with a frequency above $f_s/2$ will be represented as components of frequencies below $f_s/2$ in the digital output

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On the both graphics a) and b) on Fig 1. the x-axis shows the sampling frequency f_s. On the graphic a) can be seen five frequency segments. Segment n = 0 includes components from DC to half the sampling frequency. In this range, the sampling system will accurately display the frequency content of the analog input signal. Sampling high frequency signal components from segments N > 0 is also done by a system for the components segment N = 0, ie the frequency of fs/2. Mathematically, the high frequency components projected into a useful signal band will generate unwanted components which can be described by the following formula:

$$f_{ALIASED} = |f_{IN} - Nf_s| \qquad (1)$$

For example, if we have the sampling rate (f_s) 100kHz and have a frequency content:

$$f_{IN}(1) = 41kHz$$
$$f_{IN}(2) = 82kHz$$
$$f_{IN}(3) = 219kHz$$
$$f_{IN}(4) = 294kHz$$
$$f_{IN}(5) = 353kHz$$

Digital output after sampling will contain the true values of the amplitudes of all five components of the signal, but the four of them lie outside the range of the signal DC to $f_s/2$ or in this case the DC to 50kHz. Using the formula $f_{OUT} = |f_{IN} - Nf_s|$, frequency input signals are transformed into:

$$f_{OUT}(1) = |41kHz - 0x100kHz| = 41kHz$$
$$f_{OUT}(2) = |82kHz - 1x100kHz| = 18kHz$$
$$f_{OUT}(3) = |219kHz - 2x100kHz| = 19kHz$$
$$f_{OUT}(4) = |294kHz - 3x100kHz| = 6kHz$$
$$f_{OUT}(5) = |353kHz - 4x100kHz| = 47kHz$$

This frequency phenomenon can be eliminated or reduced by using low-pass filter in front of the A/D converter. This situation is shown in Fig 2, where we see that the filter passed only components of the signal to the fs/2, in this case only the first component f_{IN} (1), while all other components will be suppressed.

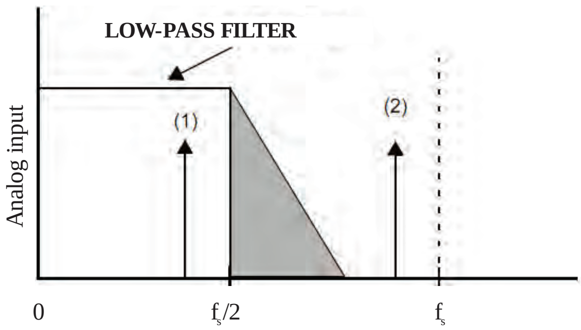

Fig 2. If the A/D system has a low pass filter ahead of the sampling mechanism, high frequency signals will be weakened and will not be sampled

For example, a 12-bit A/D conversion characteristics of the designed filter should be such as to provide at least that the SNR of the system for sampling 74dBA. For the purposes of design of anti-aliasing filters different realisations are used from an ordinary RC cell through standard filters, such as architectures Bessel, Chebyshev, Butterworth, Eliptic.

Important role here plays switched-capacitive filter for the realization of anti-aliasing filter.

III. REALIZATION OF SWITCHED-CAPACITIVE FILTER

Many designers have an aversion to analog filters because they are difficult to design, have a great tolerance and are difficult to produce, especially with the strong requirements. The rule that should be taken in the design is that the tolerances of discrete components accumulate. So with standard tolerances of resistors and capacitors, we can expect an error in relation to the estimated frequency. A good alternative to solves this problem is to use integrated solution filters.

There are two types of integrated filters, continuous time and switched-capacitive filters. Continuous time filters usually have a need for some external components to adjust the cutoff frequency, which makes them limited in the layer of flexibility. Switched-capacitive filters can, because of its architecture to be very flexible. If used properly can be an excellent alternative to discrete and continuous time integrated filters.

Switched-capacitive technology has long been known architecture that can be reliably and multiplicative implemented on silicon. How it works and some mathematical foundations are given in Fig 3.

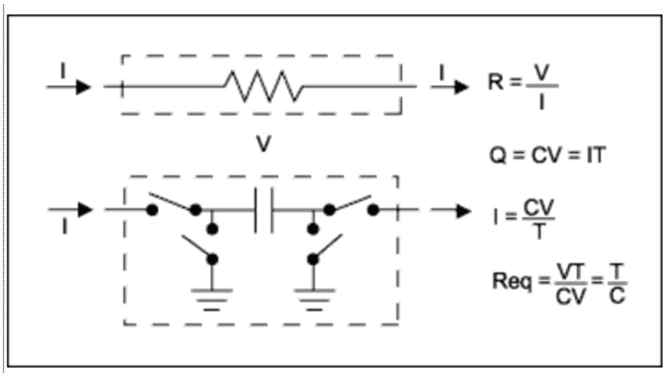

Fig 3. Switched-capacitive schematic

The operation is as follows: capacitor charged and discharged periodically depends to the switches on both sides. This causes the charge transfer, leading to the appearance of a pulsating current. The mean current can be calculated, and if the frequency of switching is large enough, this current will be equal to the current through the resistor. In basic terms, this means that the resistor is replaced by a capacitor. The value of current or indirect resistor values depend on two variables: the size of capacitors, and frequency of the switching. If the filter is created using this architecture, frequency behavior of the filter can be changed by changing the value of the capacitor or switching frequency. In the integrated solutions, the value of capacitor is fixed, so the frequency characteristics of the filter should be changed by changing the switching frequency. The principle scheme of such a filter is shown in Fig 4.

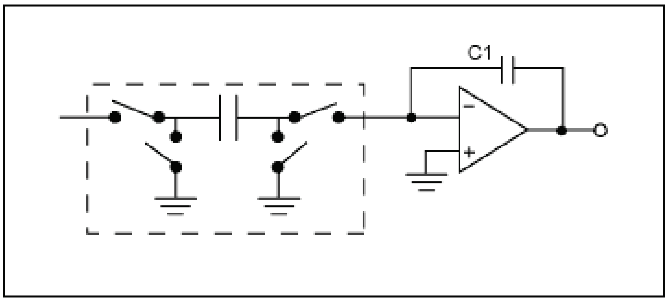

Fig 4. Simple filter implemented using Swiched-capacitive technology

In the case of a discrete filter, we can only use the unmatched components, while the integrated solutions matching these components can go in the range of 0.1%. So, we can expect good control characteristics of the filter. For example, round firm Maxim, MAX7490 has a precision of the cut-off frequency of about 0.2%, which is impossible to achieve discrete components. Also, the temperature drift is a great 10ppm /° C.

It can be said to switch capacitive filter is actually the same sampled signal. It actually converts the time-continuous signal at discrete time signal.

IV. RESULTS

Below is displayed the realization of a low-pass filter using the MAX7426 integrated circuit that can be used as anti-aliasing filter. MAX7426 integrated circuit is a switched-capacitive low-pass filter 5-th order with architecturez, making it suitable for the realization of doing anti-aliasing filter. Circuit is equipped with tuning of cut-off frequency from 1Hz to 12kHz. It is envisaged that the clock frequency 100 times greater than the desired cut-off frekvencije. Most of the switched-capacitive filters are achieved via biquadratic sections, each with two pairs of zeros and sections can be cascaded to tie in order to obtain higher order filter. The advantage of this approach is a simpler design. On the scheme of implementation, shown in Fig 5, we can see that the chip has no external passive components, except that two capacitors are used for decoupling of the power circuits.

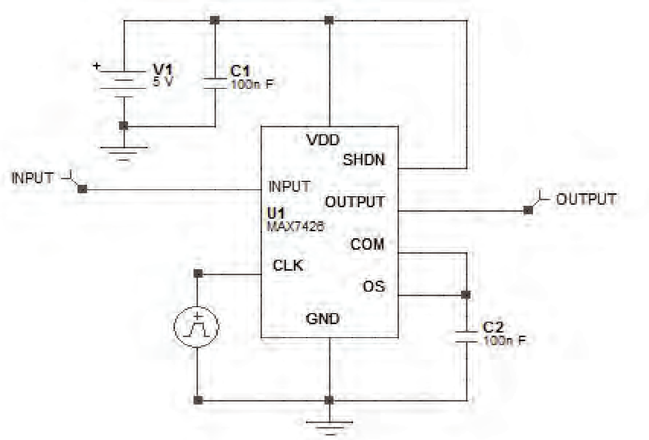

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Fig 5. Implementation scheme of the switched-capacitive filter with integrated solution Maxim, MAX7426 circuit

In figures below are shown the transmission characteristics of filters, as well as the launch-response functions, and a squared sinus function of the input filter.

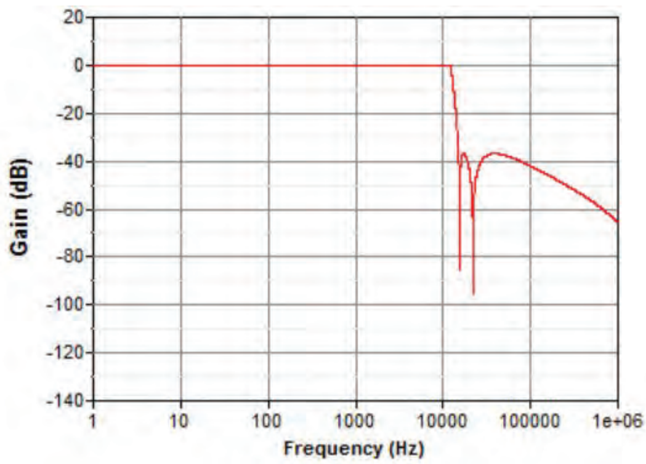

Fig 6. AC transmission characteristics of filter

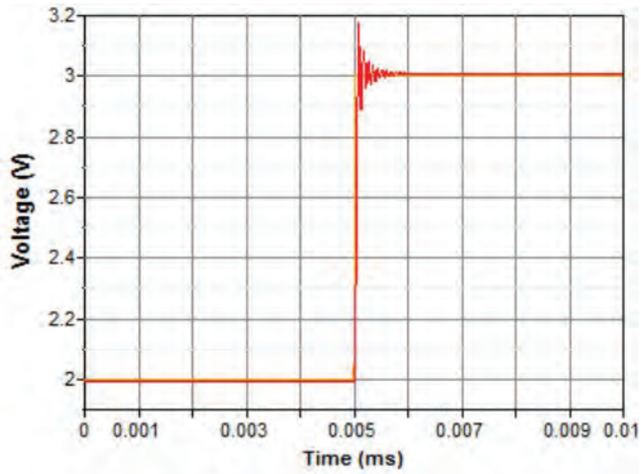

Fig 7. Response to a step function (input signal - orange, the output signal - red)

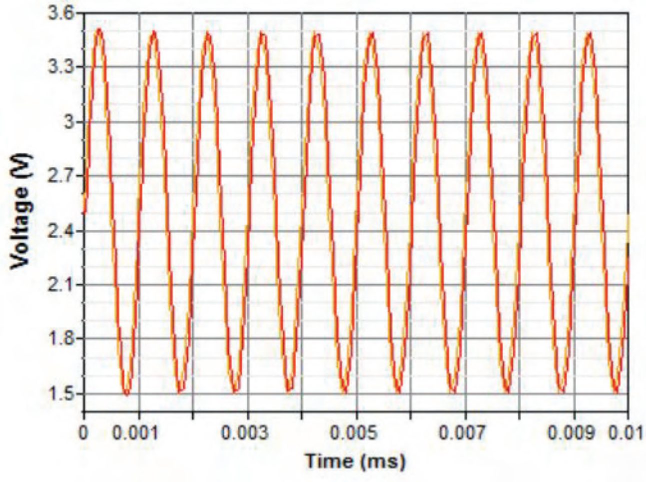

Fig 8. The response of the sinus function (input signal - orange, the output signal - red)

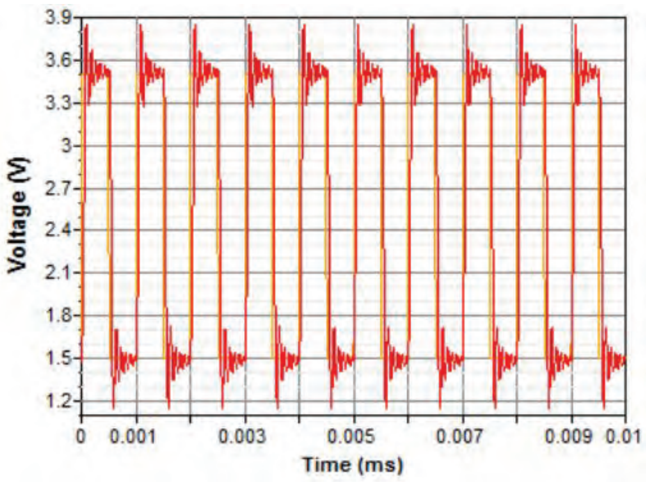

Fig 9. Response to a rectangular function (input signal - orange, the output signal - red)

IV. CONCLUSION

As a conclusion we have all the advantages of switched-capacitive technology that are mentioned. First of all we should mention the little area that offers a solution especially in the realization of higher order filters. In addition this filters allow a simple implementation, without external passive components that contribute to the instability of the filter due to tolerance, temperature drift, etc.

Of course we should be aware that this technology is like any other has its drawbacks and limitations. Possible problem is the appearance of jitter in clock time distribution in the circuit, which leads to distortion. Since in circuit where they would use such a filter we have some A/D converter, uC or DSP, which all use a clock, it is necessary to solve the problem of synchronization of all clocks. Therefore, the commonly way is to use single oscillator whose signal causes the circuits to work as a clock generator, and that generates a clock for each component in the circuit, with the lowest jitter of order 10^{-10}s.

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