A Dual-Slope Integration Based Analog-to-Digital Convertor

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Abstract: Problem statement: With the advent of the advanced technology and the need for more advanced equipment, the current progress and development of electronic instruments stimulate more interest and efforts for more innovative ideas and better designs. Many real world physical values, such as sounds, temperature, pressure and humidity, can be measured as analog or continuous signals. However, to process these signals by computers or digital equipments, we need first to convert these analog signals into digital or discreet signals. **Approach:** There are many types of Analog-to-Digital Converters (ADCs) which can be classified according to the concept on which they were designed. For example, there are charge-coupled A/D converter, digital-ramp A/D converter, successive approximation A/D converter, voltage-to-frequency A/D converter, Delta-Sigma A/D converter, Flash A/D converter and some of these converters require the use of Digital-to-Analog Converters (DACs) and/or analog comparators and some logic modules. In some other cases, many analog comparators are needed to perform the conversion. We are trying to use a different approach that reduce the design complexity and improve the measurement quality by using the double-slope integration concept. **Result:** The new design does not require the use of a DAC module, nor does it need to use many analog comparators to do the conversion. **Conclusion:** The advantage of the new design would contribute to the simplicity of the design, enhance its reliability and guarantee the linearity of the conversion process that leads into better quality instruments.

Key words: Analog-to-digital converters, analog signals, digital signals, quantization

INTRODUCTION

An Analog-to-Digital (A/D) converter is an electronic circuit, which converts continuous signals to discrete digital signals. An analog signal is continuous in time and it is necessary to convert it into a digital signal so it can be measured and processed using digital equipment[1,7]. Most processing equipment today are digital in nature and they work with signals which are represented as binary values. In a digital or binary representation, a signal is represented by a word, which is composed of a finite number of bits. The processing of signals is preferably carried out in the digital domain because digital processing is fast, accurate and reliable. A/D converters are widely used for converting analog signals to corresponding digital signals in many electronic devices. Analog to digital converters allow the use of sophisticated digital signal processing systems to process analog signals, which are common in the real world. Many modern electronic systems require conversion of signals from analog to digital or from digital to analog form. Circuits for performing these functions are now required in numerous common consumer devices such as digital cameras, cellular telephones, wireless data network equipment, audio devices such as MP3 players and video equipment such as Digital Video Disk (DVD) players, High definition Digital Television (HDTV) and numerous other products. ADCs form an essential link in the signal processing pathway at the interface between the analog and digital domains. Advances in ADC technology[2-6] have increased the speed, lowered the cost, reduced the power requirements of A/D converters and resulted in an increase in the ADC's applications.

Digital signals are often an approximation of the analog data (like voice or video) that is obtained through a process called quantization. The digital representation is never the exact signal, but its most closely approximated digital form. So its accuracy depends on the degree of approximation taken in quantization process. The first advantage of digital communication over analog one is its noise immunity. In any transmission path some unwanted voltage or noise is always exist which cannot be eliminated fully. When a signal is transmitted, this noise gets added to the original signal causing a distortion of the signal. However, in a digital communication at the receiving end this additive noise can be eliminated to a great

extent easily resulting in a better recovery of actual signal. In case of analog communication it's difficult to remove the noise once added to the signal. Digital communication provides better security to messages than the analog communication. It can be achieved through various coding techniques available in digital communication. Moreover, digital communication can be done over large distances through internet and other techniques. Digital signal provides facilities like video conferencing which save a lot of time, money and effort.

Analog signals suffer from some problems when there is a significant loss of data or slightly faulty equipment while broadcasting the signal. The important aspects of the analog data are that analog signals use simpler technology, signals are continuous, but are prone to noise & interference, so not exactly what is transmitted is received without being altered. When the analog signal gets weaker or the equipment are not perfect some reception can give some unexpected picture, sound, or value. The reason can be because of a signal interception by other parties with the same technology. For this reason, signals are converted from analogue to digital. However, in digital form, electronic pulses are transmitted in the form of High/Low, 0-5 v, signals. When these pulses are received, they can be added to or removed from the existing data, so a clearer picture can be created and/or a better sound quality can be produced. In addition, required values will be received correctly. It is also secure because data can be encrypted to stop interception from unwanted parties.

Analog-to-Digital Converters (ADCs): There are different types of architectures available for A/D converters. These types vary in speed, accuracy and interface. Among the most common ones that are commercially available are:

- Digital-ramp ADC
- Successive approximation ADC
- Flash ADC

The basic idea of the conversion is the use a comparator to determine whether or not to set to 1 a particular bit of a binary number output. Most of the common ADCs use a DACs and an analog comparator to carry out the conversion[9]. Figure 1 shows a simple block diagram of an ADC.

The logic block can be one of many different designs. The conversion of an analog signal to a digital one is done by comparing the input analog signal with a predetermined value (a guess) and if this value does not exceed the unknown input value then the process will be repeated until the optimum guessed value is obtained. Different ADCs use different guess strategy or conversion algorithms.
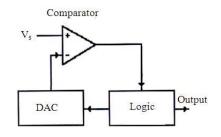

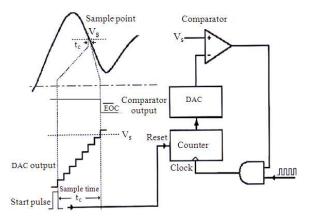Fig. 1: A basic block diagram of an analog-to-digital converter

Fig. 2: A basic block diagram for a digital-ramp ADC

Digital-ramp ADC: Figure 2 shows a simple block diagram of this type of ADCs[11]. The analog input signal is connected to the input terminal of a comparator that triggers a binary counter. The counter is connected to a DAC and the output of the DAC is connected to the other input terminal of the comparator. The output of the DAC will increase gradually as the counter is getting incremented. This process will continue until the output of the DAC exceeds the unknown analog input signal, then the comparator output will change and cause the counter to stop and its value at that moment will represent the value of the input analog voltage.

Successive approximation ADC: This type is used in most modern IC ADCs. It is much faster than the digital-ramp ADC because it uses a digital logic that converges on the closest value to the input analog voltage[8,11,12,14]. Figure 3 shows the block diagram of a Successive Approximation ADC. The successive approximation converter performs a binary search through all possible quantization levels before converging on the final digital value. The simplicity of the design allows for both high speed and high resolution while maintaining relatively small area.
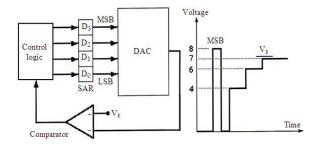
Fig. 3: A basic block diagram for a successive approximation ADC

The binary search starts with the Most Significant Bit (MSB) and works towards the Least Significant Bit (LSB). The control logic initializes the MSB to a value 1. Then the content of Successive Approximation Register (SAR) is fed into a DAC which outputs an equivalent analog voltage value needed to be compared with the unknown input voltage. If this value exceeds the input voltage then the comparator causes the control logic of the SAR to reset the MSB back to 0 and set the next bit to 1. If the output of the DAC is still lower than the input voltage then this bit will be kept at value 1 and the next lower bit will be set to 1. The binary search continues till every bit of the SAR is tested. The content of the SAR then will be the digital approximation value of the sampled input analog signal.

Flash ADC: Flash ADCs, also known as parallel ADCs, are among the most common ADCs and considered to be among the most efficient in terms of speed. They use a linear voltage ladder with different levels of comparison between input voltage values and successive reference voltage values.

Its circuit uses a series of comparators, each one comparing the input signal with a unique reference voltage. Although flash type analog-to-digital converter has some advantages, it suffers from a number of drawbacks due to massive parallelism and lack of front-end sampling circuit. These analog-to-digital converters require excessively large power and area for resolutions above 8 bits. Furthermore, the large number of comparators gives rise to problems such as dc and ac deviation of the reference voltages generated by the large nonlinear input capacitance and noise at the analog input.

Figure 4 shows a 3 bit flash ADC with an input voltage and a reference voltage. If the reference voltage is lower than the input voltage for any comparator, then the output of that comparator will be set to 1.
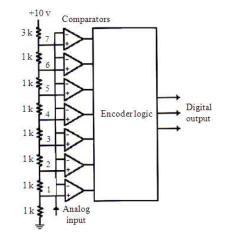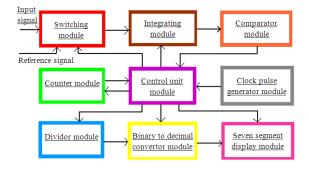

Fig. 4: A basic block diagram for a flash ADC

Fig. 5: A block diagram of the proposed design

Otherwise, it will stay at 0. An 8-to-3 priority encoder is used to convert the 8 bit code to 3 bit binary value that represents the input voltage value. The problem with this type of ADCs is that they require a large number of comparators[8,11,13,14].

Double-slope integration based ADC: Our proposed electronic measurement system, as shown in the following block diagram of Fig. 5, is based on the double-slope integration method.

MATERIALS AND METHODS

In our design, the converter receives two signals, the analog input signal and the other one is a reference signal. These signals are accessed by a switching module. Then the analog signal (continuous in time) is sampled and the sample is integrated via an integrator module and after a certain time window, the reference signal, with a negative polarity, will be integrated. The basic principle of this operation is that the comparator module will determine the time to stop the integration process as shown in Figure 6.
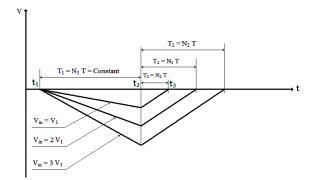
Fig. 6: A basic block diagram for a double-slope integration ADC

RESULTS

The time required for integrating the reference signal will be proportional to the value of the analog signal sample. Subsequently, the counter would contain binary digital representation of the input signal, which is converted into a decimal code. Finally, the decimal code representing the sample value is displayed on a seven-segment display.

DISCUSSION

We have designed, simulated and implemented our proposed ADC which is based on the double-slope integration concept without the need to use a DAC[1,7-10], as the case of the digital-ramp ADC and the successive approximation ADC, nor does it need a large number of comparators, as the case of the flash ADC. It takes only one integrator, one comparator, a timer block, a control block and a 7-segment display. Figure 7 shows the simple block diagram of our proposed ADC design.

We assumed that $V_{in\ Max} < V_{ref}$ so that $T_{2\ Max} < T_1$:

$$T_1 = N_1 T = \text{Constant} \tag{1}$$

$$T_2 = N_2 T \tag{2}$$

where, T is the clock pulse cycle time and N_1 and N_2 are clock pulse counts during time periods T_1 and T_2, respectively.

Since $V_{out} = -\dfrac{1}{RC}\int_0^t V_{in} dt$ for an integrator circuit, we can write:

$$V_{out} = -\frac{1}{RC}\int_{t_1}^{t_2} V_{in}\, dt + \frac{1}{RC}\int_{t_2}^{t_3} V_{ref}\, dt = 0$$

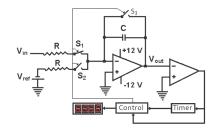$$\frac{V_{in}}{RC}(t_2 - t_1) = \frac{V_R}{RC}(t_3 - t_2)$$

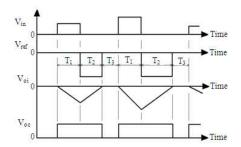Fig. 7: A basic block diagram for a double-slope integration ADC
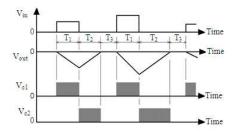

Fig. 8 Input/output signals

Fig. 9: Timing signals of the double-slope integration ADC

$$V_{in} T_1 = V_{ref} T_2 \tag{3}$$

If we replace T_1 and T_2 in (3) by their values from (1) and (2) and simplify both sides, we get:
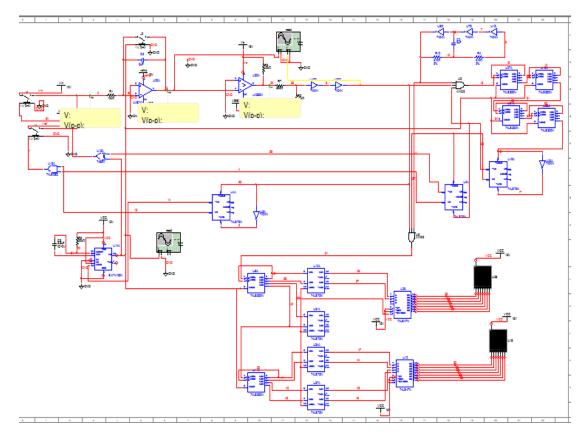
$$V_{in} N_1 T = V_{ref} N_2 T$$

$$V_{in} N_1 = V_{ref} N_2$$

$$V_{in} = \frac{V_{ref}}{N_1} N_2 = \text{Cons}\tan t\, N_2$$

$$V_{in} \approx N_2$$

The input and output signals are shown in Fig. 8.

Initially, switch S_1 is on and S_2 and S_3 are off. The integrator will integrate a sample of the input voltage, V_{in}, for a fixed period of time T_1 during which the comparator output will be 1 as shown in Fig. 8.

Fig. 10: Multisim simulation circuit
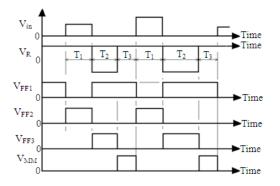

Fig. 11: Control timing signals

Fig. 12: First phase signals

Then at the end of T_1, switch S_1 will be off and switch S_2 will be on and the integrator will integrate a negative fixed reference voltage, V_{ref}, for a period of time T_2 at the end of which the output of the integrator go back to zero and similarly the comparator output changes back to zero too. Then the system will relax for a period of time T_3 during which the result will be displayed, switch S_3 will be on to discharge the capacitor and the system will go back to the initial state to start the process again, Fig. 9.
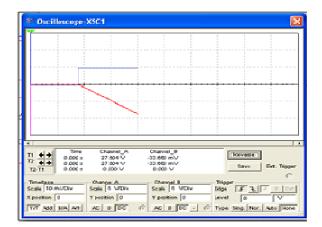
The simulation circuit using, Multisim software package is shown in Fig. 10 and the control timing signals are shown in Fig. 11.

The following Fig. 12-14 show the simulation output signals during the three different phases of the measuring process.
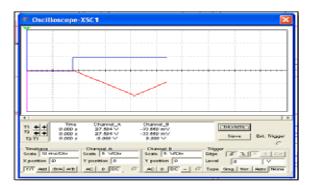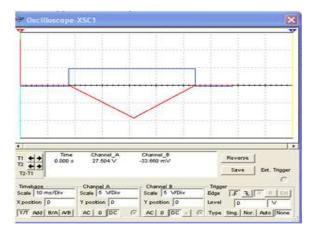
Fig. 13: Second phase signals

Fig. 14: Third phase signals

The period of times T_1 and T_3 are fixes. However, the period of time T_2 is proportional to the input voltage value. The system measures T_2 in terms of binary number to determine the value of the input voltage.

CONCLUSION

Different types of analog-to-digital converters are introduced. They either require digital-to-analog converters or a large number of comparators. We have discussed a new design of an analog-to-digital converter based on the double-slope integration concept. Our ADC design requires only one integrator, one comparator, a timer and a control logic circuit. It does not need a digital-to-analog converter nor does it need a large number of comparators, like the cases of other ADCs. This contributes to the simplicity of the design.

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