AD CONVERSION FOR AMBULATORY ECG RECORDING

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The ambulatory ECG digital recording is often impeded by high and asymmetrical QRS complexes when a small low-cost microcontroller (such as 68HC11) with an 8-bit incorporated AD converter is used. Therefore a low AD resolution is introduced inevitably in order to prevent the loss of signal beyond the ADC range. We found simple hardware and software solutions that allow: i) 10-bit or more AD conversion with an 8-bit converter and ii) optimal positioning of the recorded signal within the ADC range.

The amplifier connected to a 68HC11 controller is shown in Fig. 1. The first stage A1 is an instrumentation amplifier, followed by the second stage A2 with an output voltage that can be shifted by a DAC. The dividers of this voltage, as well as the resistor of the time-constant circuit and the artifact protection diodes have a common point fixed at the potential V_{RM} equal to the middle point of the used ADC range of 2,5 V [1]. Thus each of the ADC inputs AN0, AN1 and AN2 of the 68HC11 have one and the same signal baseline and the amplitudes are divided by 1, 2 and 4 respectively. The converted AN0 signal is used whenever no overflow occurs. In this case the two MSB of the 10-bit conversion are zeroed and the obtained high resolution of 10 μV/bit covers a range of ±1,28 mV around the middle point of the ADC. Beyond this range the converted without overflow AN1 signal is multiplied by 2 resulting in two symmetrical margins with resolution of 20μV/bit and MSB=0. The third way through AN2 gives the next two margins, 10-bit coded with 40 μV/bit resolution (the signal is multiplied by 4), quite sufficient for the highest and lowest parts of the QRS complexes.

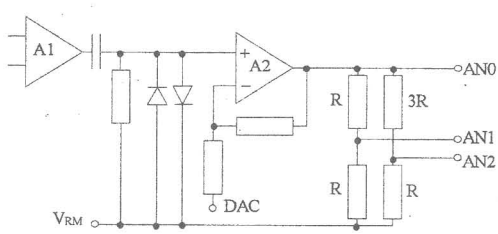

Fig. 1

The goals of an optimal positioning are: i) to center a signal non-exceeding the 10-bit range, ii) to cut the high or low part of one-sided QRS complexes exceeding the range and iii) to cut both parts of two-sided QRS exceeding this range. In our opinion these goals could be accomplished by a program in no more than 3 s in order

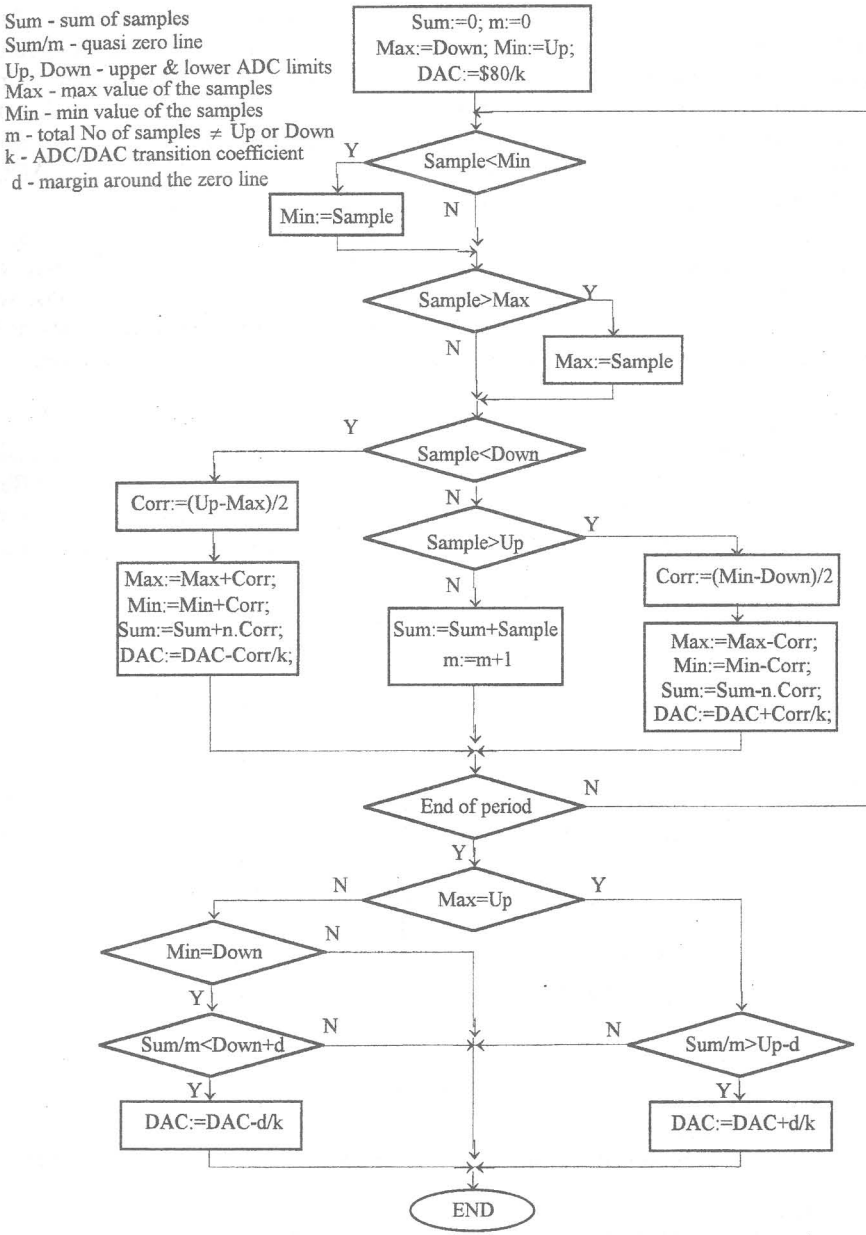
Sum - sum of samples
Sum/m - quasi zero line
Up, Down - upper & lower ADC limits
Max - max value of the samples
Min - min value of the samples
m - total No of samples ≠ Up or Down
k - ADC/DAC transition coefficient
d - margin around the zero line
Sum:=0; m:=0
Max:=Down; Min:=Up;
DAC:=$80/k
Sample<Min
Y
N
Min:=Sample
Sample>Max
Y
N
Max:=Sample
Sample<Down
Y
N
Corr:=(Up-Max)/2
Max:=Max+Corr;
Min:=Min+Corr;
Sum:=Sum+n.Corr;
DAC:=DAC-Corr/k;
Sample>Up
Y
N
Sum:=Sum+Sample
m:=m+1
Corr:=(Min-Down)/2
Max:=Max-Corr;
Min:=Min-Corr;
Sum:=Sum-n.Corr;
DAC:=DAC+Corr/k;
End of period
N
Y
Max=Up
N
Y
Min=Down
N
Y
Sum/m<Down+d
N
Y
DAC:=DAC-d/k
N
Sum/m>Up-d
Y
DAC:=DAC+d/k
END

Fig. 2

to acquire ECG amplitudes shortly after the recording is started. The algorithm of such a program is shown in Fig. 2. Within a period of 3 s the maximum and the minimum values are measured and the sum of the current values in the ADC range (Down-Up) is calculated. Every time the sample from the AN2 input comes out of range, the DAC code is corrected with the half of the opposite non-used part of the range, then new maximum, minimum and sum are recalculated (taking in consideration the ADC to DAC transition coefficient). Thus the convergence of the process is ensured. At the end of the period the sum is divided by the sample number m and Sum/m is assumed as a quasi zero line. Its position may be considered as an indication whether important parts of the ECG signal closely above and bellow the real zero line are lost when reaching some of the ADC range limits. If Sum/m is offset from these limits at less than a distance d, then the DAC code is corrected by d in the opposite direction.

Conclusions:

The AD conversion described provides for an optimal ambulatory ECG acquisition with a small portable instrument. Highest possible resolution through the different margins of the extended range is obtained. An optimal centered ECG with very large QRS complexes is shown in the Fig. 3, where a part of the positive QRS peaks is cut.

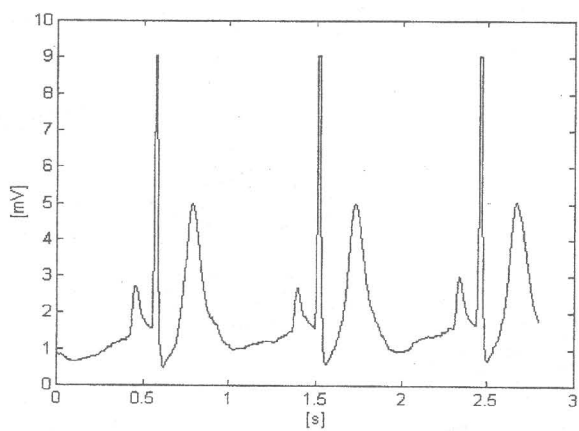

Fig. 3

Acknowledgments:

This study is supported by National Fund "Scientific Reasurch", Grant No TK-5-3/95

References:

[1] MC 68HC11F1. HCMOS Microcontroller unit. MOTOROLA INC., 1989.