

## ECG DEVICE BASED ON ADS1298

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**Abstract.** *The aim of this paper is to describe a modern ECG device based on ADS1298, an embedded system and an analog Front-End unit. In the same chip there are the programmable gain amplifiers, delta-sigma ADC and SPI interface communication. It can achieve the standard 12-lead ECG on the computer by using a graphical interface (GUI) designed with the LabWindows CVI program.*

**Keywords:** ECG signal, ADS1298, SPI, LabWindows CVI

### 1. Introduction

Electrocardiography is a process of recording the electrical activity of the heart. The electrical variation from the body surface is generated by electrical events. [1]

The QRS complex is the most important component of the ECG recording. It corresponds to the process of a more extensive ventricular activation. An electrocardiograph has a system for signal processing, formed by electrodes, cables and an input block that contains electrical resistance required for the building various unipolar derivations. It also has a system of signal amplification and a system for signal display [2]. The electrodes are made from metal surfaces that are covered with a Ag/AgCl layer. Standard colors of the limbs electrodes are in the table below:

**Table 1.** Limbs electrodes

No.	Color	Limb
1.	yellow	left hand
2.	red	right hand
3.	green	left leg
4.	black	right leg

The electrocardiogram has a standard 12-lead to represent the heart's electrical activity recorded from electrodes. A lead is not the electrode contact, it represents the difference between 2 limb potential.

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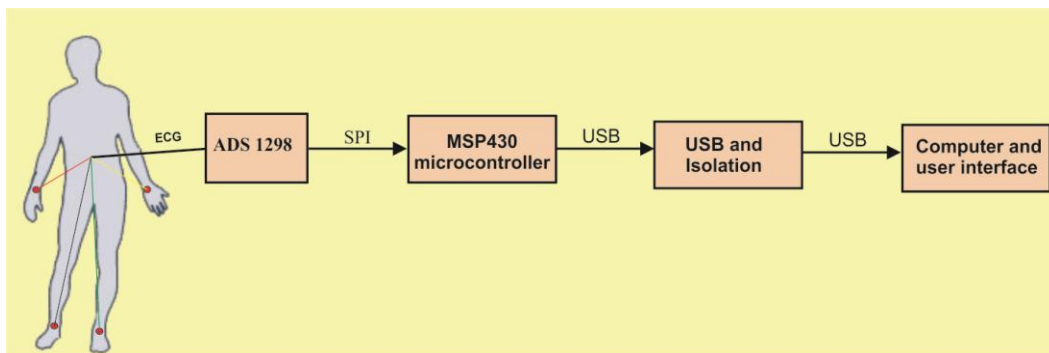
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In the table below, we have the standard limb configuration [3]:

**Table 2.** Standard limb configuration

<i>Lead</i>	<i>Definition</i>	<i>Comments</i>
<b>I</b>	<b>I=L-R</b>	<b>Bipolar extremity LEADS</b> <b>Einthoven limb LEADS</b>
<b>II</b>	<b>II=F-R</b>	
<b>III</b>	<b>III=F-L</b>	
<b>aVR</b>	<b>aVR=R-(L+F)/2</b>	<b>Goldberger augmented LEADS</b> <b>From one of the electrodes on the limbs to a reference point</b>
<b>aVL</b>	<b>aVL=L-(R+F)/2</b>	
<b>aVF</b>	<b>aVF=F-(L+R)/2</b>	
<b>V1</b>	<b>V1=C1-CT</b>	<b>Wilson Unipolar chest LEADS</b> <b>From one other the electrodes on the chest to the Central Terminal (CT=(L+R+F)/3)</b>
<b>V2</b>	<b>V2=C2-CT</b>	
<b>V3</b>	<b>V3=C3-VT</b>	
<b>V4</b>	<b>V4=C4-CT</b>	
<b>V5</b>	<b>V5=C5-CT</b>	
<b>V6</b>	<b>V6=C6-CT</b>	

In this paper we will describe a modern ECG device based on ADS1298, an embedded system and an analog Front-End unit which has in the same chip a lot of functional blocks, as the programmable gain amplifier, delta-sigma analog to digital converters (ADCs) and SPI interface communication. It can achieve the standard 12-lead ECG, on graphical user interface (GUI) designed with LabWindows CVI. This is represented in the diagram below:



**Fig. 1.** Block diagram of the acquisition hardware for the ECG unit.

## 2. THE HARD UNIT

The ADS1298 is a multichannel, simultaneous sampling, EMI protection, delta-sigma ( $\Delta\Sigma$ ) analog-to-digital converters (ADCs) with built-in programmable gain amplifiers, internal reference, and an onboard oscillator. The ADS1298 incorporates all of the features that are commonly required in medical ECG or EEG applications in a very small case and it is capable to develop a lot of medical instrumentations at low power supply, at about 0.75 mW/channel, and low cost. The communication with a microcontroller is made through the serial peripheral interface (SPI) port, and with a PC is made by SPI/USB converter.

ADS1298 can be used in various differential input and referencing configurations, as well as in passive ground mode or right leg drive (RLD) mode, figure 2 [4]:

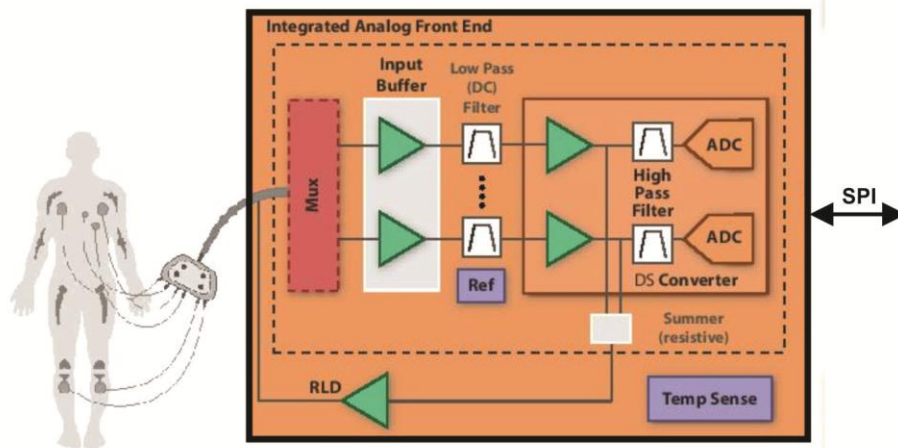


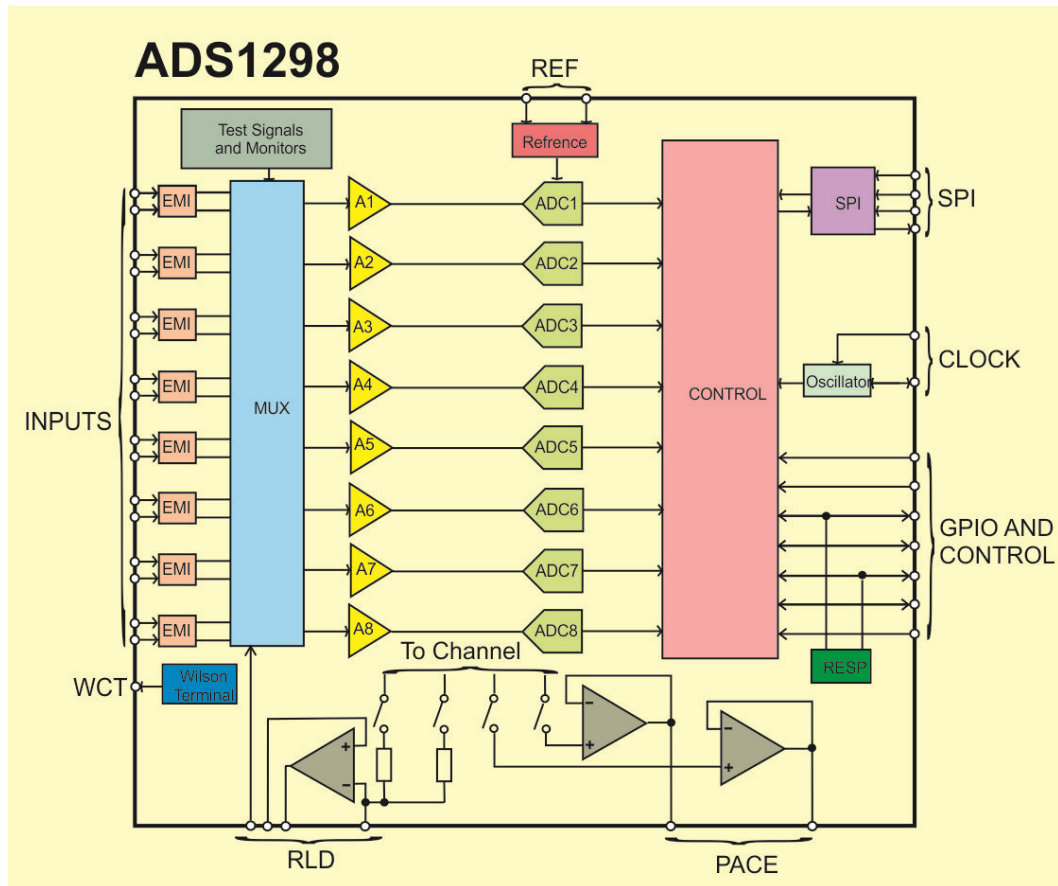
Fig. 2. Block diagram of ADS1298 converter.

The ADS1298 provides an EMI filter to protect from external interference created by electromagnetic field variation. The EMI filter consists of an RC filter type, which has a -3dB bandwidth of 3MHz across all channels.

This unit has a multiplexer with 8 differential channels, amplifiers, 24 bit continuous delta-sigma analog to digital converters with data rates of 250 SPS to 32kSPS. It provides input multiplexers for configuring signal switching options easily. Each input of multiplexer can be independently connected to the internally generated signals for test, temperature and lead-off detection, that might be implemented into the device in 2 modes: with a pull-up/pull-down resistors or an excitation current sink/source.

The ADS1298 provides the options of normal electrode input, supply measurements, temperature sensor, test signals, right leg drive inputs (RLD), auxiliary differential input, lead-off excitation signals and auxiliary single ended inputs.

The setting for each channel can be changed by changing the CHnSET register and by writing the RLD MEAS bit in a particular configuration.



**Fig. 3.** Complete ADS1298 components.

Three integrated amplifiers generate the Wilson Central Terminal (WCT) and the Goldberger Central Terminal (GCT), which is required for a standard 12-lead ECG.

The common-mode interference generated by the power line, fluorescent lights, electric motor power in an ECG system is reduced by the right leg drive (RLD) circuitry. The RLD circuit creates a negative reaction, which drives a feedback loop on the body for an inverted common-mode signal on the right leg.

The reference voltage for the RLD can be generated internally as average supply voltages or generated externally with a resistive divider.

PACE detection can be provided in two modes: in software or by external hardware [5].

To operate the ADS1298 involves a set of sequential steps. First, the device must be powered by the power up sequencing. All digital and analog inputs must be 0. After connecting the power supply, the clock signal must be supplied at the CLK pin, if we wish to use external clock.

The advantage of this ADC in this architecture is the use of the digital interface (SPI). The SPI interface protocol has four signals: CS, SCLK, DIN, DOUT. SPI can read and write the registers content, controls of the operations and controls the conversion of data.

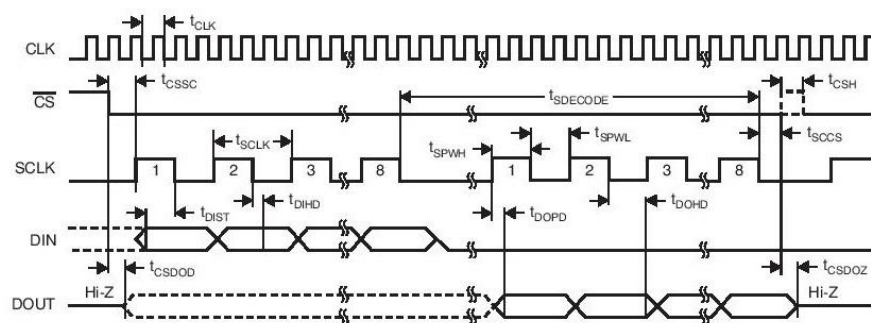
The DRDY output, 47-pin, indicates when data is ready and its digital status indicate the operation. When the DRDY level is 0, the new data is available.

$\overline{CS}$  (Chip Select), pin 39, can select the device for SPI communication mode. The  $\overline{CS}$  level is low for the entire duration of the serial communication. After the period of communication is finished, there is a delay of four time cycle before  $\overline{CS}$  becomes high. When  $\overline{CS}$  level is high, the serial interface is reset and DIN and SCLK signals are ignored, and DOUT has a high-impedance level. DRDY shows that the data conversion is ready, ignoring the  $\overline{CS}$  status.

The ADS1298 can go to a known state when  $\overline{CS}$  crosses from high to low.

SCLK (Serial Clock), pin 40, is the serial clock signal for SPI. It is used in commands and data out synchronization, specified in the Serial Interface Timing figure 4.

#### TIMING CHARACTERISTICS



NOTE: SPI settings are CPOL = 0 and CPHA = 1.

**Fig. 4.** ADS1298 timing characteristics [5].

DIN (Data Input), pin 34, together with SCLK, ensures communication with the unit (commands and data).

DOUT (Data Output), pin 43, is used together SCLK signal to read the conversion and register data. DOUT is active on rising edge front of SCLK. DOUT goes to the third state when  $\overline{CS}$  is high. DOUT shows when new data is available. These signals can be used at a minimum connection between ADS1298 and microcontroller.

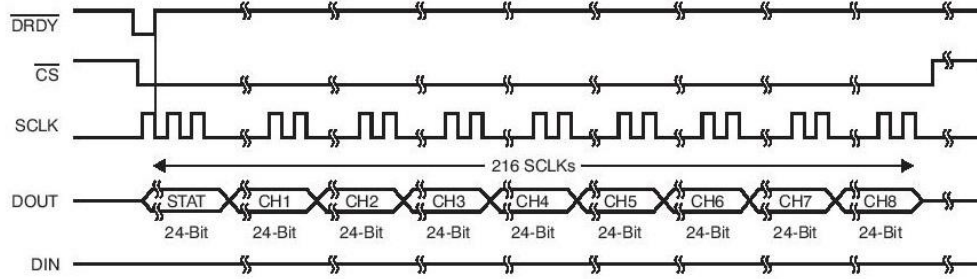


Fig. 5. SPI Bus Data Output (Eight Channels) [5].

The communication between ADS1298 and MSP microcontroller can be done with the SPI interface and between the microcontroller and PC, through the USB interface.

### 3. SOFTWARE AND RESULTS

Data is saved in a text file, which will be read in the User Interface designed in the National Instrument's C-based program, Labwindows/CVI 9.0 [6], figure 6.

In this interface, we have read the results from a text file and represent the 12 LEADS on 2 panels, one representing the I-III and aVL, aVR and aVF leads, and the other the V1-V6 leads.

To calculate all of these leads, we have used the information given in Table 2.

In the interface, we have introduced the Heart Beat Rate (HBR). For this we have created a QRS detection algorithm, introduced in the C-program. This detection is based on the first derivative of Lead II ECG signal and threshold.

Once we detect 5 consecutive QRS complexes, the HBR is calculated by taking the average of the five RR intervals.

First step is to calculate the first derivative of the Lead II:

$$b_0(x) = |a(x+1) - a(x-1)| \quad (1)$$

where,  $b_0(x)$  represents the first derivative,  $a(x+1)$  represents the sample value for  $(x+1)$  sample and  $a(x-1)$  is the sample value of  $(n-1)$  sample.

We store the maximum value ( $M$ ) in a matrix.

Next, we calculate the threshold:

$$F = 0.8 * M \quad (2)$$

In the next step, we compare each of the first derivative values calculated with the calculated threshold. We mark the ECG sample index (S1) of that sample whenever a derivative crosses the threshold.

After this, we detect the QRS peak by scanning the next 40 derivatives and obtain the maximum value (T), which is stored in another buffer.

Skip the next 50 samples to take care of the minimum RR interval that can occur in case of maximum detectable HBR, after detecting a QRS peak.

We detect the next four QRS peaks by repeating the steps above.

We calculate the RR interval as the number of samples between two consecutive QRS peaks.

The equation used to calculate the HBR is:

$$HBR = \frac{(60 * SamplingRate)}{(AverageRRfor5int)} \quad (3)$$

This value is represented on the User Interface, HBR.

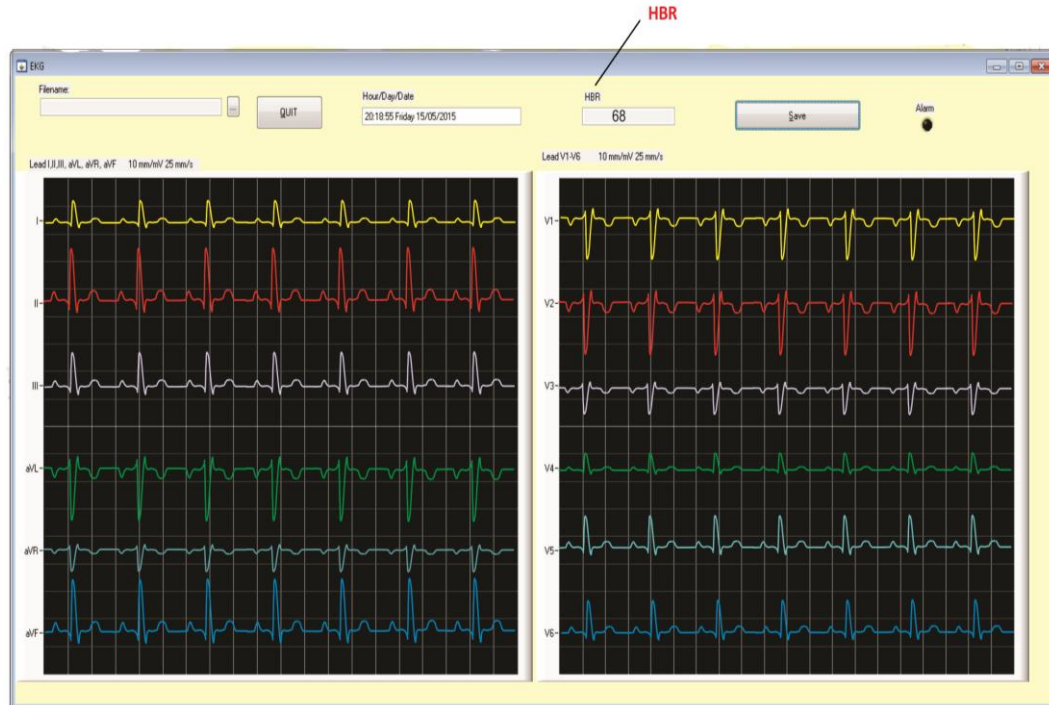


Fig. 6. LabWindowsCVI user interface of the ECG 12-lead representation.



#### 4. Conclusions

In this paper we have describe a modern ECG device based on ADS1298 and we have designed the user interface in LabWindows/CVI. For the reading of the results in the interface, we have used results from a database saved in a text file.

For our future work, we plan to improve the ECG recordings and to modify the user interface, by introducing some digital filters. All the results will be saved on a hard-drive, in a database

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