Application Note AN2250

ECG Meter using PSoC™

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Associated Project: Yes
Associated Part Family: CY8C27xxx
PSoC Designer Version: 4.2

Abstract
Lots of people know it and some even watch it: the daily soap opera about a hospital. Beautiful nurses, enthusiastic first-aid attendants and intelligent (good-looking) doctors strive for their patients' life and limb. If one does not pay exclusive attention to the attractive actors, one notices the expensive technical equipment. The appearance of the electrocardiogram, also known as the ECG or the EKG, is always impressive. Surely, some people have wondered how such a gadget works and what their own pulse rate looks like. This Application Note explains how an electrocardiogram can be created with a few circuits and some mental acrobatics. The expenditure is modest, but the result of displaying one's own pulse rate is interesting.

The PSoC™ mixed-signal array contains almost all of the components needed for simple ECG measurements. Excluding the preamplifier, filter, A/D and D/A-converter, the interface circuits and some computing capacity are available.

Introduction
The measurement of an ECG signal is (relatively) simple. The heart muscle produces electronic potential energy when it is pumping blood. Three electrodes (two of them pick up the biologic signal and the third provides the reference potential) connect the subject to the amplifier. As shown in Figure 1, the input signal to the amplifier consists of five components:

- Desired biopotentials
- Undesired biopotentials
- Power line interference signal of 60 Hz (50 Hz in Europe) and its harmonics
- Interference signals generated by the subject's body tissue and the electrode interface
- Noise

An instrumentation amplifier, also known as a differential amplifier, eliminates these problems by filtering out a large portion of the signal interference. Please refer to Figure 2 for a schematic of the amplifier.

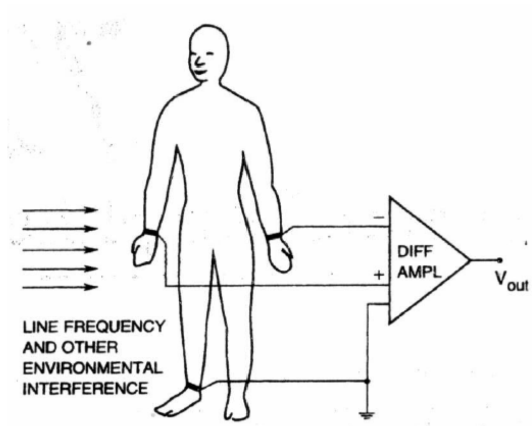

Figure 1. Measuring an ECG Signal

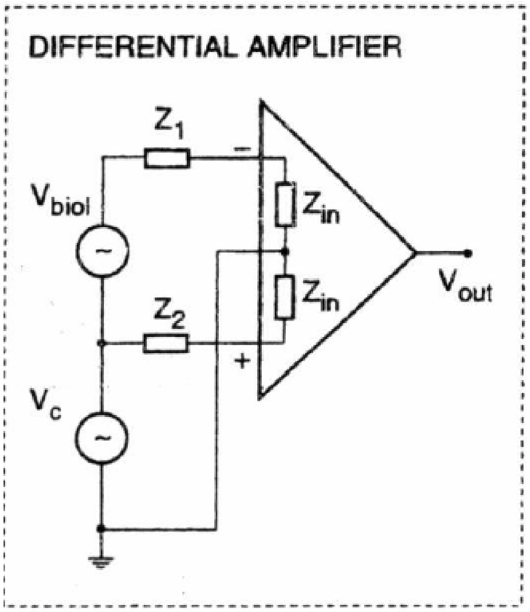

Figure 2. Amplifier Schematic

System Design

Our task is to take this concept of measured values and change it into something tangible. What do we have to do?

We have to build our own ECG monitor. We need an instrumentation amplifier, a low-pass filter, a D/A converter, a serial transmitter and an isolated output. That should be a simple task, but it is not. The PSoC mixed-signal array accomplishes this. With the exception of the amplifier, all of the equipment we need, such as configurable software blocks, is available directly on the PSoC device.

Because an extremely high input resistance is needed, an AD627 Micropower Instrumentation Amplifier should be used in lieu of the built-in amplifier in the PSoC device. The AD627 is often used in medical applications.

There is a high common mode rejection ratio (CMRR) in the AD627. Therefore, a two-pole, low-pass filter is necessary. If the user wants better accuracy, a second low-pass filter could be used.

After filtering, a delta-sigma A/D converter changes the analog input into digital values. Now, we have a little bit of digital signal processing. Because of the power-line interference, digital signals are damped. The simplest way to remove this measurement error is to compute the average of all values using Equation (1):

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (1)$$

However, this method requires a lot of memory space. In embedded control environments with limited resources, it is better to compute the floating mean, instead of the exact average. This is done using Equation (2):

$$\overline{y} = y_{(i-1)} + \frac{y_{(i-1)} + y_i}{d} \quad (2)$$

The software code is simple:

```
;    simple damping source code
;    new := old/2 + new/2
   mov A,[bTemp1]     ; A/D/ value
   asr A              ; value/2
   and A,~nBit7       ; bit 7=0
   asr [bAverage8]    ;old value/2
   And [bAverage8],~nbit7
   Add A,[bAverage8]  ; old + new
   mov [bAverage8],A  ; save new value
```

Code 1. Simple Damping Source Code

What other components do we need? There are four:

- Data transmission
- Negative power generation for the AD627
- Stabilization of the instrumentation amplifier
- Visualization of the measured values

For data transmission, we used the PSoC UART User Module. The optocoupler input drive circuit is for level converting and power down or on. With the help of two diodes, two capacitors and a rectangular signal from the PSoC device, a negative power supply is generated.

Undesired biopotentials cause large problems during ECG measurement. They are produced by muscle activity. Because the frequency of these signals is much lower than the frequency of the pulse rate, offset voltage values are added to the pulse rate signal.

The D/A converter, within the PSoC device's CY8C27xxx chip, functions as a regulator and compensates for the offset values. The average of multiple analog input allows the AD627's offset to shift into the best voltage window.

The last objective is to present data on the PC screen so it is readable. A simple PC program shows the sampled values.

Programming the CY8C27xxx

Microcontrollers can be controlled by such programming languages as assembly or C++. Most of the problems that occur while building in peripheral circuits can be avoided by using PSoC Designer. Please refer to Figure 3, which shows the ECG monitor user module configuration in PSoC Designer's Device Editor.

After assigning the different user modules, PSoC Designer generates a project. Every user module has its own application programming interface (API). The main task for the programmer now is to connect the hardware components with its software modules.

Using the ECG Display

To get ECG values, you need a heroic test person (before you begin your experiments, ask for their last will!).

Before you start, make sure the power down/on works. It is absolutely necessary that the power source be completely disconnected on your experimental board. If possible, use a battery-powered notebook for displaying values.

After verifying that the power is down, connect the three electrodes to the (heroic) test person. You can make the electrodes by yourself. A clean metal plate (1x1 inch) on wet skin will suffice. However, you will get better results using medical ECG electrodes. Figure 4 shows the PC output screen of the software that is included with the associated project. Figure 5 shows the electronic prototype. The DSO waveforms (Figure 6) show slightly more detail than the PC-captured waveforms (Figure 4). The .PLT schematic is included with the associated project. If you look at the source code, you will find that because of its simplicity, the resolution of the sigma delta A/D converter is reduced from 12 to 8 bits.

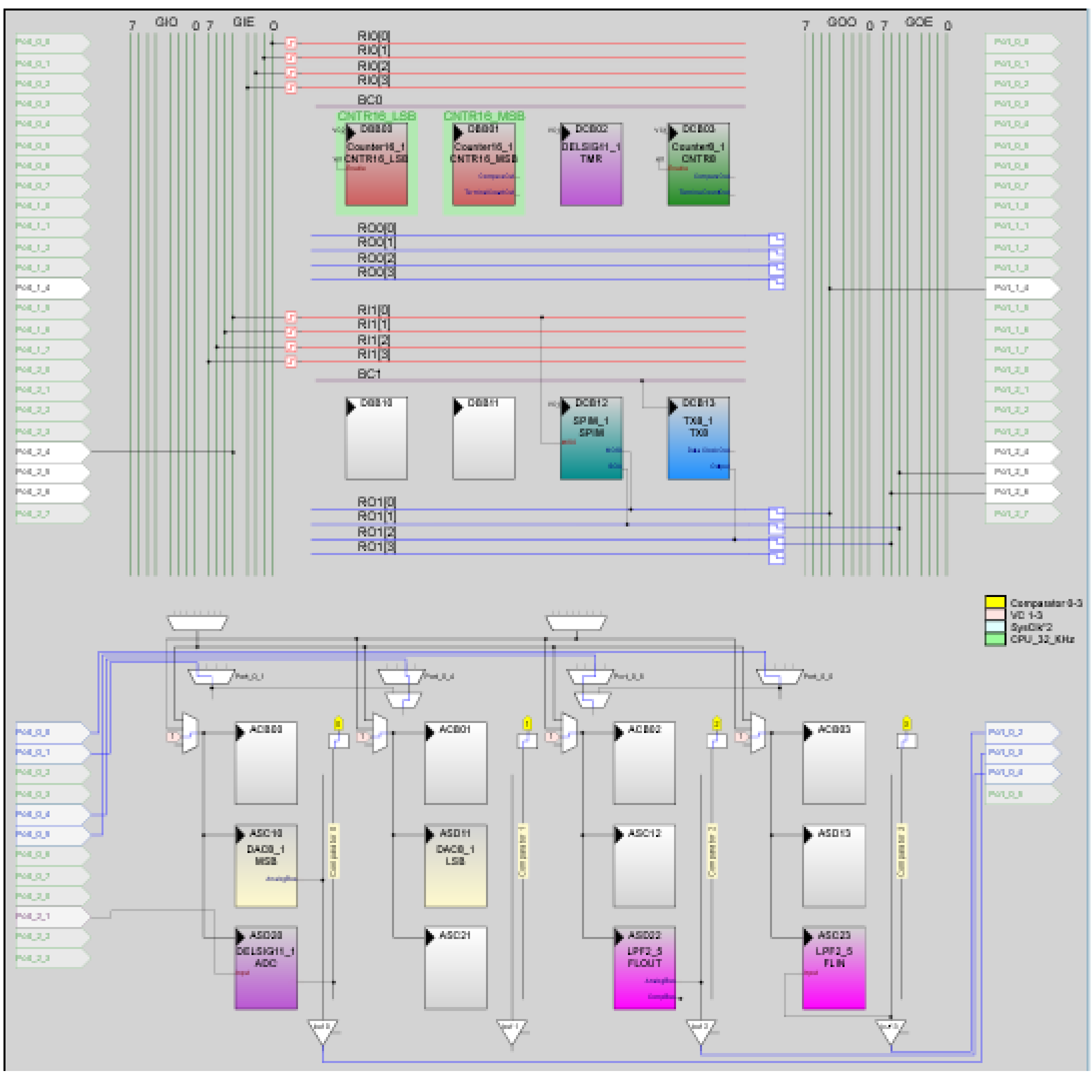

Figure 3. ECG Monitor User Module Configuration

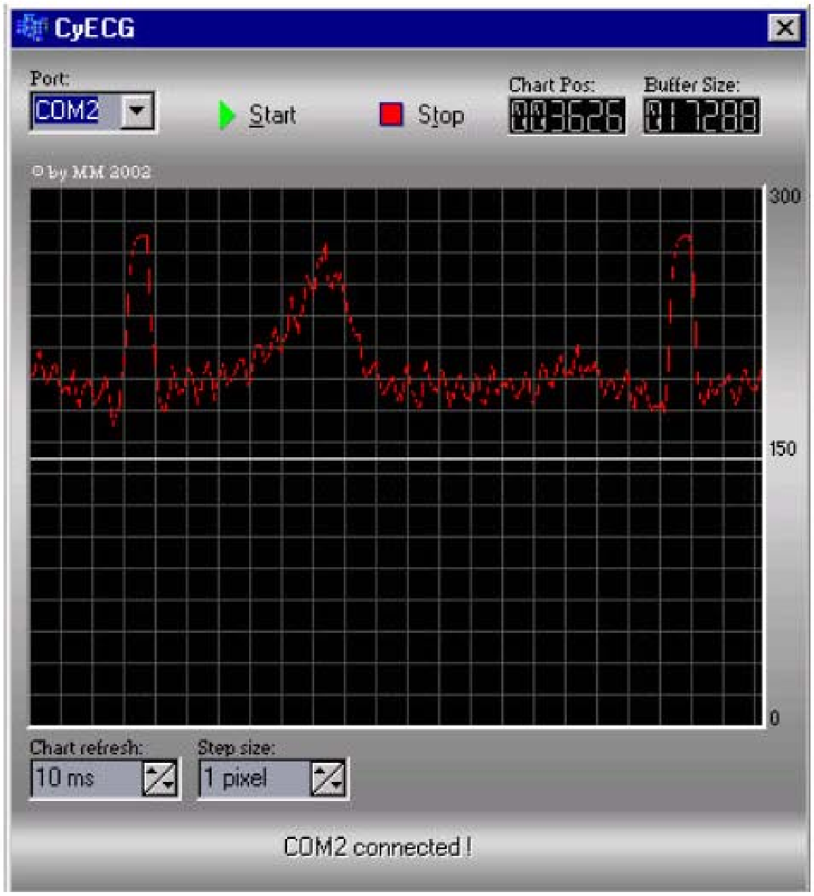

Figure 4. ECG Results on the PC Screen

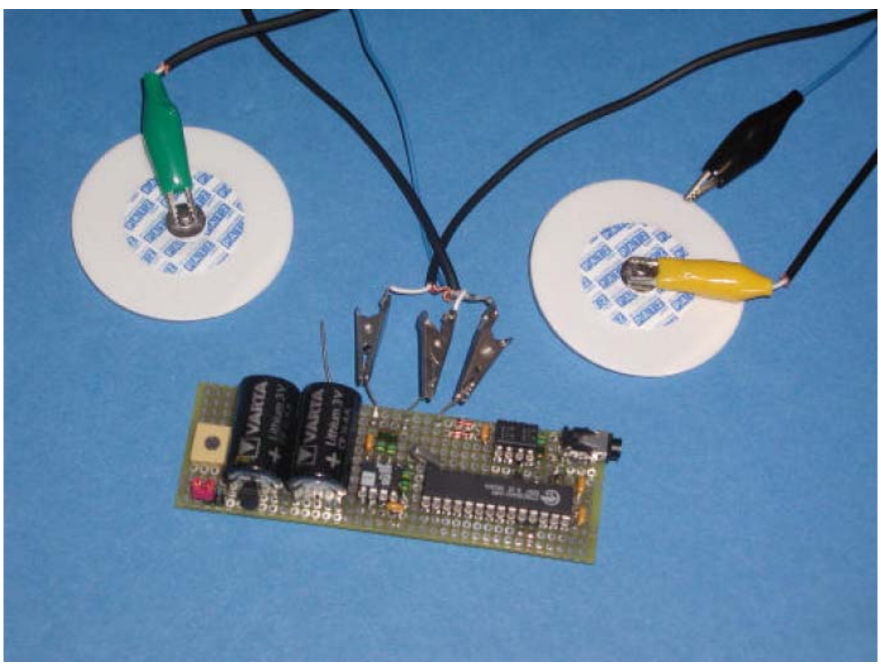

Figure 5. Electronic Prototype

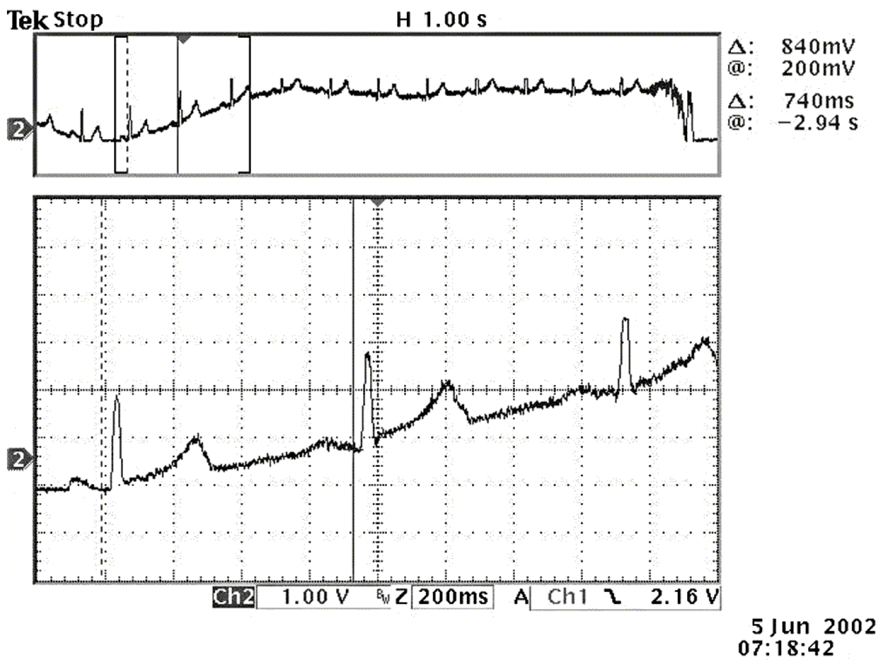

Figure 6. Typical ECG Measurement Configuration

Conclusion and Future Work

The examples in this Application Note emphasize the simplicity and the huge design potential of the PSoC device. Nine of the twelve analog blocks and seven of the eight digital blocks in the PSoC device are used.

To record the input, an EEPROM could be installed. There is enough computing capacity to implement better algorithms for noise shaping and signal adaptation.

Interesting information about important biopotentials is given with a few external components and a little bit of mental acrobatics.

References

Bronzino, Joseph D. (Editor). The Biomedical Engineering Handbook. Boca Raton: CRC Press, Inc., 1995.

About the Author

Name: Dr. Jens Altenburg

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Background: Jens earned his Informatics diploma in 1990 from Technical University, Ilmenau, Germany, PhD degree in Robotics in 2004, and is presently working as a developing engineer. He is especially interested in embedded control applications.

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