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HEART RATE AND EKG MONITER USING MSP430FG439

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Abstract: This application report describes how to build a digital heart-rate monitor using a MSP430FG439 microcontroller (MCU). The heartbeat rate per minute is displayed on an LCD. In addition, the applicant on outputs a digital data stream via an RS232 serial port to allow EKG waveform display on a PC. The entire application runs using a CR2032 3-V lithium battery.

I. INTRODUCTION

Electrocardiography (ECG or EKG) is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the surface of the skin and recorded by a device external to the body. The recording produced by this noninvasive procedure is termed an electrocardiogram (also ECG or EKG). An ECG is used to measure the rate and regularity of heartbeats, as well as the size and position of the chambers, the presence of any damage to the heart, and the effects of drugs or devices used to regulate the heart, such as a pacemaker. Most ECGs are performed for diagnostic or research purposes on human hearts, but may also be performed on animals, usually for diagnosis of heart abnormalities or research.

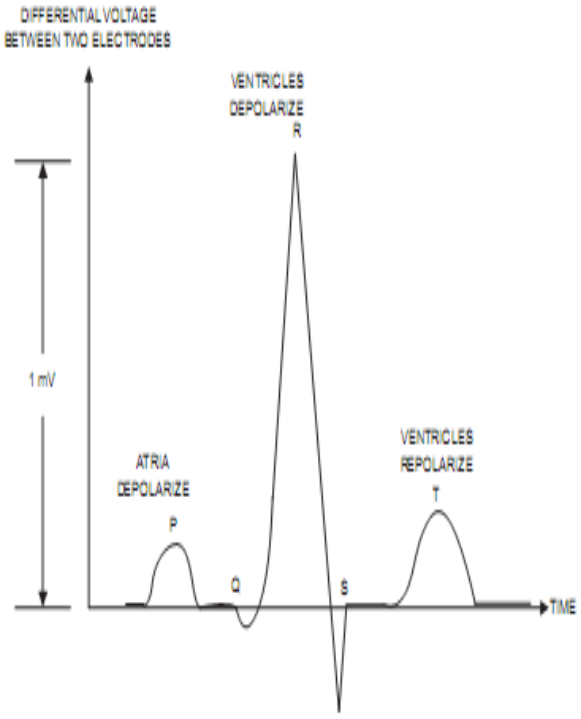
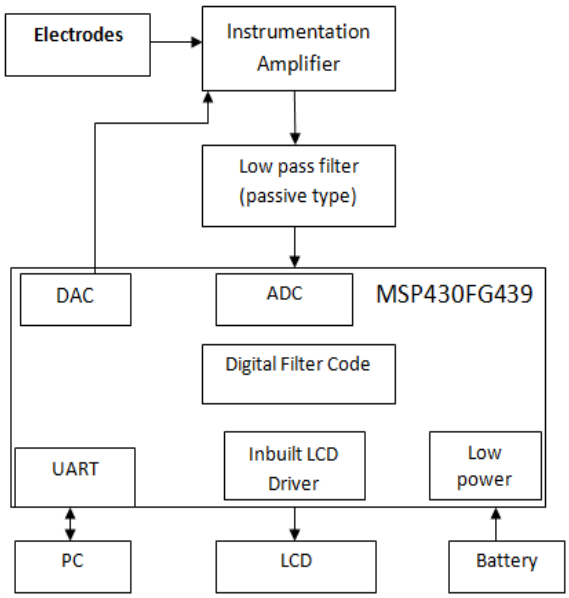


Figure 1. A Typical EKG Waveform

II. OBJECTIVES

- Designing of instrumentation amplifier
- Designing of microcontrollers circuit
- Microcontroller circuit
- Design of low pass filter
- Using of electrodes
- Implementation of hardware on PCB
- Interfacing with pc

III. BLOCK DIAGRAM



IV. ELECTRODES

The ECG signal is measured with the button type ECG electrodes and it is given to Instrumentation amplifier for the amplification. This Disposable ECG electrode uses an AG/AgCl sensor element and solid conductive & adhesive Hydro-gel for adhesion. The AG/AgCl sensor element has the best sensitivities and the solid conductive & adhesive hydro-gel has very low impedance and is non-irritating, non-sensitizing and non-cytotoxic to the skin.

V. ANALOG SYSTEM

The electrical signal derived from the electrode is typically 1mv peak-peak. Amplification is required to render this signal usable for the heart rate detection. Realization of clean amplification of ECG signal is not easy task because noise is also amplified with the ECG signal. In certain situation the noise can completely override the ECG and render the

amplified signal useless. A better approach is to use a differential amplifier. A differential amplifier used here is INA 321 instrumentation amplifier that has perfectly matched and balanced integrated gain resistor. The device is operated on minimum 2.7v single power supply. The INA provides a fixed amplification of 5x for the ECG signal .With its CMRR specification of 94db extended up to 3 kHz the INA rejects the common-mode noise signals including the line frequency and its harmonics. The ECG signal at the output of INA 321 is further amplified by OA0 of MSP430FG439 the Texas instruments MSP 430 family of Ultra low power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. It is having five power saving modes which makes it suitable for the battery operated instrumentation.

The special features of this microcontroller that we are going to use are ADC, OP-AMPs, DAC; USART Chip Supply announces TI's MSP430 line of Ultra-Low Power Microcontrollers in die or Chip Scale Package form. For designers looking for either product in die form or a package format that is not offered by Texas Instruments, let Chip Supply provide a solution for you. Chip Supply offers several of the MSP430 line in Chip Scale Packages for applications that require reduction in size or weight. If the application requires further reduction in size, or additional functionality by adding other die to the package, speak to one of Chip Supply's sales representatives to begin finding a solution to meet your needs. The MSP430 family of 16-bit RISC mixed-signal processors provides the ultimate solution for battery-powered measurement applications. For low-power applications where both analog and digital signal processing are required, the MSP430 line provides a range of exceptional cost performance options. Using leadership in both mixed-signal and digital technologies, the MSP430 enables system designers to simultaneously interface to analog signals, sensors, and digital components while maintaining low power. The MSP430 family is suitable for applications such as: Utility Metering, Portable Measurement, & Intelligent Sensing.

VI. FILTER

The sampled ECG signal contains some amount of line frequency noise. This noise can be removed by low pass filtering the signal. The filtered signal can be output on the display unit by the DAC of MSP 430 or can be transmitted to the PC using UART of the MSP 430 or can be stored on the SD card. Here we are storing the ECG signal in the SD cards

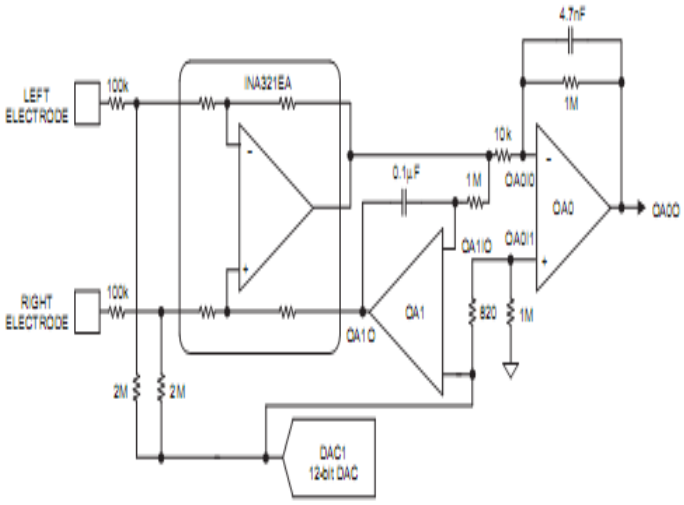
VII. HARDWARE DESIGN

A. FRONT END AMPLIFIER

The electrical signal derived from the electrodes is typically 1mV peak-peak. An amplification of about 1000´ is necessary to render this signal usable for heart rate detection. Realizing clean amplification of the EKG signal with such high gain is no easy task specifically with the given situation that the human body acts as a huge antenna that picks up a lot of noise including a dominant 50Hz/60Hz line frequency noise. This has to be filtered by a strong post filter after amplification. Unfortunately any amplification will amplify the noise voltages in addition to the desired EKG signal. In certain situations the noise can completely override the EKG and render the amplified signal useless. A better approach is to use a differential amplifier. Thanks to the identical common mode signals from the EKG pick up electrodes, the common mode noise is automatically cancelled out using an ideally matched differential amplifier. The differential amplifier used in the front end of this application is an INA321 instrumentation amplifier that has perfectly matched and balanced integrated gain resistors. This device is specified to operate with a minimum of 2.7V single rail power supply. The INA321 provides a fixed amplification of 5´ for the EKG signal. With its CMRR specification of 94dB extended up to 3 KHz the INA321 rejects the common mode noise signals including the line frequency and its harmonics. The quiescent current of the INA321 is 40mA and the shutdown mode current is less than 1Ma

B. EKG AMPLIFIER

The INA321 family is a series of rail-to-rail output, micro power CMOS instrumentation amplifiers that offer wide range, single-supply, as well as bipolar-supply operation. The INA321 family provides low-cost, low-noise amplification of differential signals with micro power current consumption of 40 A. When shutdown, the INA321 has a quiescent current of less than 1A.Returning to normal operations within microseconds, the shutdown feature makes the INA321 optimal for low-power battery or multiplexing applications. Configured internally for 5V/V gain, the INA321 offers exceptional flexibility with user programmable external gain resistors. The INA321 reduces common-mode error over frequency and with CMRR remaining high up to 3 kHz, line noise and line harmonics are rejected. The low-power design does not compromise on bandwidth or slew rate, making the INA321 ideal for driving sample Analog-to-Digital (A/D) converters as well as general-purpose applications. With high precision, low cost, and small packaging, the INA321 outperforms discrete designs, while offering reliability and performance.



VIII. SIGNAL PROCESSING AND HEART BEAT DETECTION

A. EKG Sampling

The amplified EKG signal is internally fed to the on chip analog to digital converter ADC12 input channel A1. The ADC12 samples the EKG signal with a sampling frequency sample of 512 Hz. Precise sampling period is achieved by triggering the ADC12 conversions with the Timer A pulses. The Timer A is clocked by the ACLK generated from the 32.768 kHz low frequency crystal oscillator.

The fastest deflection in the EKG is in the 20ms range and happens at the QRS complex. It is important to capture the QRS complex in its entirety for useful medical evaluation of the EKG waveform. Having a sampling frequency of 512 Hz or sampling period of approximately 2ms captures at least 10 samples at the QRS complex and ensures that the QRS complex is fully digitized. The QRS complex also serves as a Definite indicator for every heart beat hence it is necessary to have it captured for heart beat rate calculation. The heart beat rate itself is typically in the 60 to 200 beats per minute or about 3 to 4Hz.

B. Filtering the Line Frequency Noise

The sampled EKG waveform contains some amount of super imposed line frequency content. This line frequency noise is removed by digitally filtering the samples. A 17-tap low pass FIR filter with pass band upper frequency of 6 Hz and stop band lower frequency of 30Hz is implemented in this application. The filter coefficients are scaled to compensate the filter attenuation and provide additional gain for the EKG signal at the filter output. This adds up to a total amplification factor of greater than 1000´ for the EKG signal.

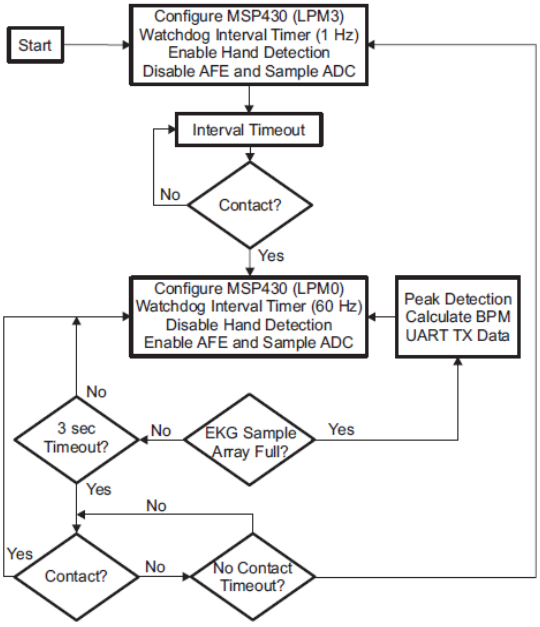
C. Calculating the Heart Beat Rate

The number of heart beats per minute is calculated using a three beat average. Two variables in the C main function, counter and pulse period accurately track the time scale. Each output sample from the QRS discriminator is compared against a set threshold to detect the presence of a beat. Pulse period is incremented by one during every sample period. Because each sample occurs every 1/512 seconds it is easy to track the time scale based on the number of counts in the pulse period variable. A 128-sampletime window is used as a de-bounce time using counter.

Every time a beat is detected counter is reset and the LCD icon with four arrows is turned on to represent the heartbeat. If a beat is not detected for128 consecutive samples then a separation between successive beats is identified and the LCD icon with four arrows is turned off. The Pulse period is accumulated for three consecutive beats. On the third beat Pulse period is used for the calculation of heart rate per minute and reset. Heart beat rate per minute = 1/ (Pulse period/ (3´512´60)) = 92160/Pulse period

IX. SOFTWARE

The software for this application is written in C using IAR Embedded Workbench Kick start edition available for free download from the MSP430 web page. The source code for reproducing this application is provided in a zip file available for download along with this application report. The software uses a dedicated 16x16 bits signed multiply routine written in assembly language for faster execution of the FIR Filter calculations compared to the native C math library multiplication function. This function is called from the main C program using the syntax long mul16 (register int x, register int y). Three C source files Heart rate.c, Heart rate with DAC output.c, and Heart rate with EKG Demo.c are provided in the zip file. The names of these files signify their functionality.



The project must include the C source file as per the required functionality and the mul.s43 assembler source file for proper compilation. The memory usage for the complete heart rate with EKG project is 1168 bytes of CODE memory, 225 bytes of DATA memory and 64 bytes of CONST memory. This is only about 1/4th of the 4 Kbytes limit of the free C compiler in the IAR Embedded Workbench Kick start edition. The CPU runs at 2.097152 MHz using the FLL to source MCLK. The entire EKG program including the FIR filters, QRS detection and heart rate calculation takes about 1 MIPS of the CPU bandwidth.

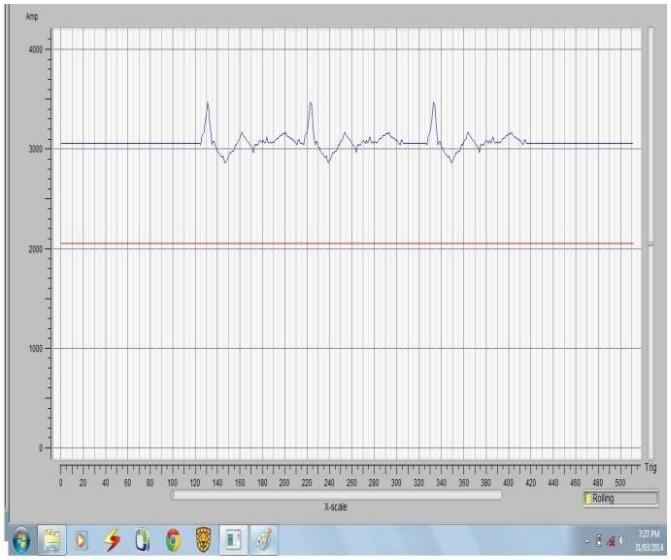
A. Testing the Application

Two square pads one on the top layer and the other on the bottom layer of the double sided PCB are provided on either side of the LCD to serve as right and left hands contact electrodes. When in use the power jumper PWR must be installed and the board must be held using both hands by placing the thumb and index fingers of each hand on the square pads. Care must be taken not to touch any other electrical areas of the PCB. A good way is to keep the hold towards the edges of the board. The contact resistance between the fingers and the square pads must be low for

good signal quality. A little bit of moisturizer spread and rubbed over the fingers helps users with dry skin.

B. PC Scope EKG Display

When using the Heart rate with EKG Demo. C program, a RS-232 level shifter is required between the EKG board and a PC. Only the TX line, P2.4/UTXD0 is required because no hand shake is used for the serial communication. The baud rate of the serial communication to the PC is 115.2 kbps. For displaying EKG the PC must run scope.exe using command line option of the windows. Thescope.exe is an open source PC application program. For convenience this application program is provided in the oscilloscope.zip file under the source files along with this application report.



X. APPLICATIONS

- To measure heart rate
- To see EKG waveform on pc

XI. ADVANTAGES

- Low power consumptions
- Low cost
- Portable
- Less component used
- Easy to use.

XII. CONCLUSION

All in all, this project achieved a lot of its goals. The project implemented a low cost, low power heart rate monitoring and alarm system using microcontroller technology. Lists of accomplishments include:

- Adequately acquiring biological signal
- Adequately amplifying biological signal
- ADC conversion of analog signal
- LCD heart rate display
- Use of low power components for battery operation

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BIBLIOGRAPHY

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