# Ambulatory ECG Recording System based on ADS 1298 and STM32L431xx Microcontroller

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***Abstract*** **- In this paper a portable, low-coast wearable system for recording electrocardiogram (ECG) of a subject is developed. Two separate designs: single lead and 12 lead ECG have been implemented using ADS 1298 and STM32L431RCT6 microcontroller. ADS 1298 is an 8-channel, 24-bit analog front end for biopotential measurement by Texas Instruments, whereas STM32L431RCT6 is an ARM cortex-M4, 80MHz, LQFP-64 MCU from ST Microelectronics. The recorded ECG signal can be viewed both on the on-board OLED display as well as on the computer via Bluetooth. This portable and low-cost healthcare monitoring system would be advantageous to common people as it will be a convenient option for hospitalization for recording long term (ambulatory) ECG. The system could be significantly helpful to the physicians also for a first-hand monitoring of cardiac abnormalities of a subject.**

***Keywords - Wearable system, ambulatory, ECG, ADS 1298, STM32L431RCT6, Bluetooth***

## I. INTRODUCTION

In this era of fast pace and stress-filled lifestyles, cardiological disorders are becoming very common even in the people of early age groups. In order to detect the cardiac abnormalities, if any, earlier and get properly treated it is necessary to have routine body check-ups and even hospitalization at regular intervals. However, due to time and other constraints it may not be possible for everyone who is at potential cardiac risk and maintain regularity in this respect. An easy and convenient option to hospitalization is to use the *wearable devices (WD).* Many such WDs have been proposed by researchers [1] – [8]. The modern wearable electrocardiogram (W-ECG)/ ambulatory ECG (A-ECG) recorders not only record the ECG signals and related physiological parameters, but are also capable, due to advancements in telemedicine, of updating the physician whenever an abnormal cardiac event or arrhythmia occurs to the wearer. In [9], [10] authors have classified body movement activities (BMAs) captured in W-ECG/ A-ECG using various classification algorithms. In [11], authors have developed a wireless patient monitoring system. The designed system will record the physiological parameters - body temperature, oxygen saturation in blood (SpO2), heart rate, as well as two bioelectrical signals electrocardiogram (ECG) signals and electroencephalogram (EEG). The recorded parameters and signals have been transferred via Bluetooth communication protocol to an android based smartphone. In [12], authors have presented a wearable healthcare monitoring system for acquiring bioelectric signals and other health parameters- body temperature and blood oxygen saturation (SpO2). The system is based on ADS 1298 and STM32L431xx MCU.

The cardiac abnormalities like bradycardia, tachycardia, atrial and ventricular fibrillation/flutter are increasing even in the people of age group 35 to 50 years due to sedentary lifestyles. In this paper, we have implemented a low-cost, wearable system for recording the ECG of the subject in ambulatory conditions. It is a convenient option of hospitalization for the patients suffering from various cardiac abnormalities. The uniqueness of the implemented design is two-fold: firstly, it uses ADS 1298- an 8 channel, 24-bit analog front end (an analog to digital converter coupled with in-built signal conditioning blocks for better quality ECG recording. Thus, the design can easily be extended for recording other bioelectric signals like EEG, electromyogram (EMG), electrooculogram (EOG) etc. through other channels of ADS 1298. Secondly, the system consumes very low power as it is based on ST Microelectronics' STM32L431RCT6 microcontroller, which is an ultra-low power ARM cortex-M4 MCU suitable for long-term, ambulatory signal recording. This portable, low-cost healthcare monitoring system would not only be advantageous to common people but also could be significantly helpful to the physicians for a first-hand monitoring of cardiac abnormalities of a subject.

The organization of the paper is as follows: Section I provides the background information about the wearable systems; section II describes the system components as well as the block diagram; section III comprises the PCB design layouts; section IV presents results and discussion and in section V the conclusion and future work is presented.

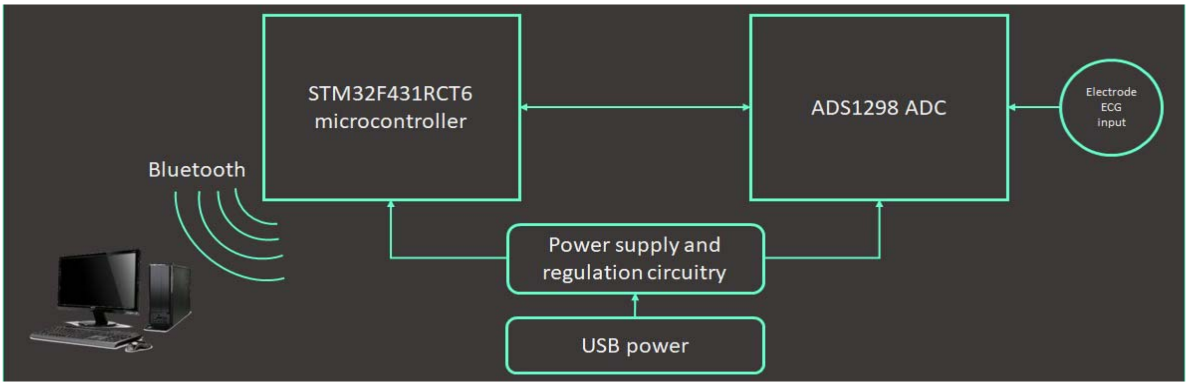



Figure 1. System Block diagram

## II. SYSTEM DESCRIPTION

In this section the description of the main system components- ADS 1298, STM32L431RCT6 microcontroller, OLED display module and the HC 05 Bluetooth module is presented. Figure 1 above shows the block diagram of the system implemented.

### *A. ADS 1298*

ADS 1298 is a low-power, 8-channel, 24-bit analog front end for biopotential measurement. With high levels of integration and exceptional performance, the ADS129x and ADS129xR enables the development of scalable medical instrumentation systems at significantly reduced size, power, and overall cost. Typical applications of ADS 1298 include measurement of ECG, EEG and electromyogram (EMG); event, stress and vital parameter monitoring; evoked audio potential (EAP) and sleep study monitoring. Following are the features of ADS 1298:

- Eight Low-Noise PGAs and Eight High-Resolution ADCs
- Low Power: 0.75 mW/channel
- Data Rate: 250 SPS to 32 kSPS
- CMRR: –115 dB
- Programmable Gain: 1, 2, 3, 4, 6, 8, or 12
- Built-In Right Leg Drive Amplifier, Lead-Off Detection, Wilson Center Terminal, Pace Detection, Test Signals
- Built-In Oscillator and Reference
- SPI Compatible Serial Interface

The ADS1298 has a highly-programmable multiplexer (mux) that allows for temperature, supply, input short, and RLD measurements. Additionally, the mux allows any of the input electrodes to be programmed as the patient reference drive. The PGA gain is chosen from one of seven settings: 1, 2, 3, 4, 6, 8, or 12. The ADCs in the device offer data rates from 250 SPS to 32 kSPS. Communicate with the device by using an SPI-compatible interface. The device provides four GPIO pins for general use.

### *B. STM32L431RCT6 Microcontroller*

The STM32L431xx devices are the ultra-low-power microcontrollers based on the high-performance ARM Cortex-M4 32-bit RISC core operating at a frequency of up to 80 MHz. The Cortex-M4 core features a Floating-point unit (FPU) single precision which supports all ARM single-precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security. The STM32L431xx devices embed high-speed memories (Flash memory up to 256 Kbyte, 64 Kbyte of SRAM), a Quad SPI flash memories interface (available on all packages) and an extensive range of enhanced I/Os and peripherals connected to two APB buses, two AHB buses and a 32-bit multi-AHB bus matrix. The STM32L431xx devices embed several protection mechanisms for embedded Flash memory and SRAM: readout protection, write protection, proprietary code readout protection and Firewall.

The devices offer a fast 12-bit ADC (5 MSPS), two comparators, one operational amplifier, two DAC channels, an internal voltage reference buffer, a low-power RTC, one general-purpose 32-bit timer, one 16-bit PWM timer dedicated to motor control, four general-purpose 16-bit timers, and two 16-bit low-power timers. They also feature standard and advanced communication interfaces: Three I2Cs, Three SPIs, Three USARTs and one Low-Power UART, One SAI (Serial Audio Interfaces), One SDMMC, One CAN, One SWPMI (Single Wire Protocol Master Interface).

#### *B.1 Adaptive Real time memory (ART) Accelerator*

The ART Accelerator is a memory accelerator which is optimized for STM32 industry-standard ARM Cortex-M4 processors. It balances the inherent performance advantage of the ARM Cortex-M4 over Flash memory technologies,

DOI 10.5013/IJSSST.a.20.05.03

ISSN: 1473-804x online, 1473-8031 print

which normally requires the processor to wait for the Flash memory at higher frequencies.

To release the processor near 100 DMIPS performance at 80MHz, the accelerator implements an instruction prefetch queue and branch cache, which increases program execution speed from the 64-bit Flash memory. Based on CoreMark benchmark, the performance achieved thanks to the ART accelerator is equivalent to 0 wait state program execution from Flash memory at a CPU frequency up to 80 MHz.

### *B.2 Memory Protection Unit (MPU)*

The memory protection unit (MPU) is used to manage the CPU accesses to memory to prevent one task to accidentally corrupt the memory or resources used by any other active task. This memory area is organized into up to 8 protected areas that can in turn be divided up into 8 subareas. The protection area sizes are between 32 bytes and the whole 4 gigabytes of addressable memory.

The MPU is especially helpful for applications where some critical or certified code has to be protected against the misbehaviour of other tasks. It is usually managed by an RTOS (real-time operating system). If a program accesses a memory location that is prohibited by the MPU, the RTOS can detect it and take action. In an RTOS environment, the kernel can dynamically update the MPU area setting, based on the process to be executed. The MPU is optional and can be bypassed for applications that do not need it.

### *B.3 ST-Link/V2 In-circuit Debugger and Programmer*

The ST-LINK/V2 is an in-circuit debugger and programmer for the STM8 and STM32 microcontroller families. The single wire interface module (SWIM) and JTAG/serial wire debugging (SWD) interfaces are used to communicate with any STM8 or STM32 microcontroller located on an application board. In addition to provide the same functionalities as the ST-LINK/V2, the ST-LINK/V2-ISOL features digital isolation between the PC and the target application board. It also withstands voltages of up to 1000 Vrms. STM8 applications use the USB full-speed interface to communicate with the ST Visual Develop (STVD) or ST Visual Program (STVP) software. STM32 applications use the USB full-speed interface to communicate with Atollic, IAR, Keil or TASKING integrated development environments.

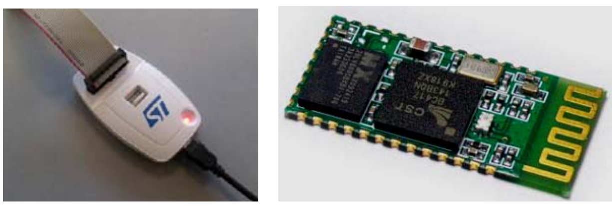


Figure 2. ST-Link/V2 In-circuit Debugger; HC 05 Bluetooth module

### *C. OLED Display Module*

The DD-160128FC-1A, an RGB colour OLED display module, from Densitron has been used. Following are the main features of this display module:

- Supply voltage is 2.8V
- Display format of 160 (RGB) x 128dots
- Overall dimension of 35.80mm x 30.80mm x 1.6mm
- Viewing area of 30.78mm x 25.02mm
- Passive matrix display
- 1/128 duty driving
- SEPS525F driver IC
- Operating temperature range from -20°C to 70°C

The SEPS525F display driver controller has three high-speed system interface: a 68-system, an 80-system 8/9/16/18 bit bus, and a clock synchronous serial (SPI: Serial Peripheral Interface). Among the interface modes, a specific mode is selected by the setting of PS pin and MEMORY_WRITE_MODE register (16h). The SEPS525 has 3-type registers: an index register (IR) 8-bits, a write data register (WDR), and a read data register (RDR). The IR stores index information for the control registers and the DDRAM. The WDR temporarily stores data to be written into control registers and the DDRAM, and the RDR temporarily stores data read from the DDRAM. Data written into the DDRAM from the MPU is first written into the WDR and then it is automatically written into the DDRAM by internal operation. Data is read through the RDR when reading from the DDRAM, and the first read data is invalid and the second and the following data are valid.

### *D. HC05 Bluetooth Module*

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup. Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). It has the footprint as small as 12.7mmx27mm.

Following features are incorporated with the HC 05 module:

- Typical -80dBm sensitivity
- Up to +4dBm RF transmit power
- Low Power 1.8V Operation ,1.8 to 3.6V I/O
- PIO control
- UART interface with programmable baud rate
- With integrated antenna
- With edge connector
- Default Baud rate: 38400, Data bits: 8, Stop bit: 1, Parity: No parity

- Supported baud rate: 9600, 19200, 38400, 57600, 115200, 230400, 460800.

## III. PCB DESIGN LAYOUTS

Two types of designs have been implemented for recording a single-lead and 12-lead ECG signals. ADS1298 has been interfaced with STM32L4 microcontroller for the acquisition of ECG signals. The schematic is designed for interfacing Bluetooth module HC-05 over UART terminals. The power supply requirement is met with mini USB port interfaced with personal computer. STM32L4 requires +3.3 Volts while the OLED requires +14 Volts. Buck and Boost switching regulators MP1584 and MT3608 respectively are used for generating +3.3 Volts and +14 Volts from available +5 Volts at USB port.

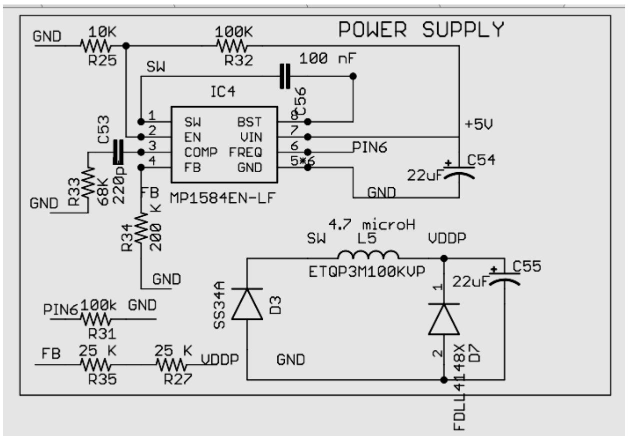



Figure 3. Switching Regulator for +3.3 Volts

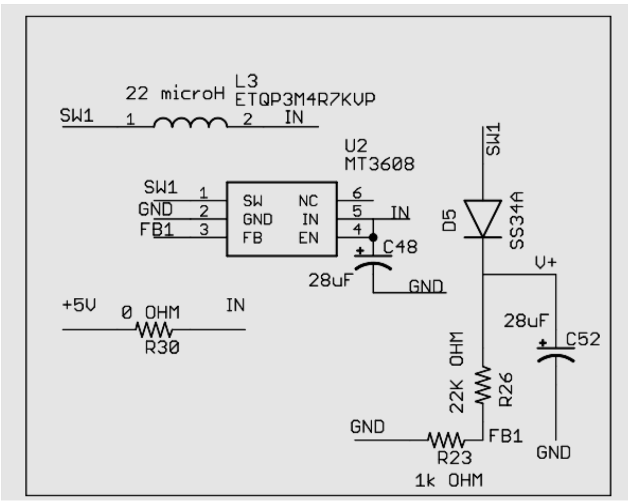



Figure 4. Switching Regulator for +14 Volts

Four keys for supporting menu operations are interfaced with GPIO port of microcontroller. SPI port of microcontroller is used to interface serial Flash memory of 8Mbytes. Figure 6 shows the double-sided PCB design of the system with dimension 55 mm x 85 mm. The Density of components is clearly visible from the figure. Pushbutton switches are laid on top of the board with 2.5mm audio jack at the bottom. STM32 microcontroller and ADS1298 are both supplied power the switching regulator circuit implemented in the bottom-center part of the PCB. All the interfacing connectors for Bluetooth, OLED, debugging, etc are provided on the left side of the PCB. There is power LED on board to indicate whether power is available to the circuits. Switches are debounced using capacitors, and capacitors and resistors are used extensively used in the circuit for various filtering and current limiting purposes. There is a 1MB SPI flash on board for intermediate storage of data on board. Complete implementation of the first prototype (design 1) is shown in Figure 6. The single-lead ECG is acquired by three electrodes placed at standard locations collected by a 2.5 mm audio jack shown in bottom left of figure 6. OLED display is seen on top right part of the figure.

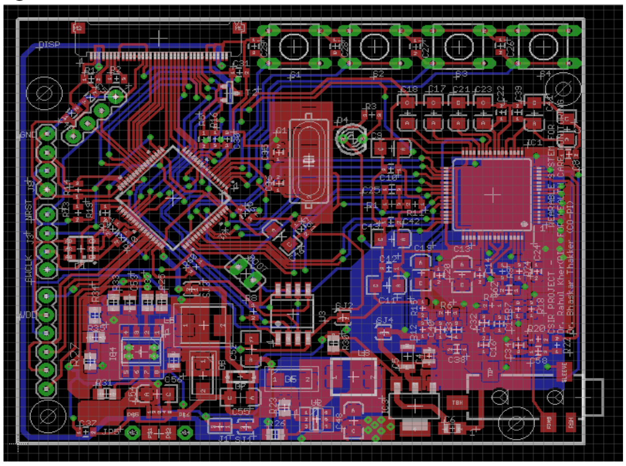


Figure 5. Double side PCB layout for Design 1

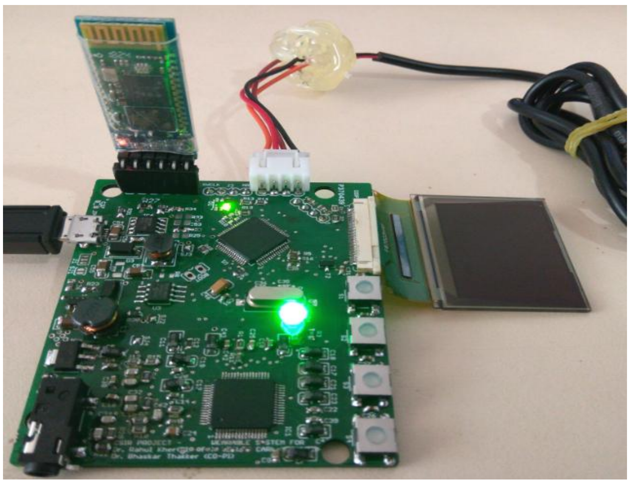


Figure 6. Prototype of Design 1

In the second design we have replaced many things. For example, 3 lead AUX (2.5mm jack) is replaced by a DB-15 connector, OLED display is replaced by SSD1306 module for OLED screen of resolution 128 x 64. Linear regulator ICs are used for power supply regulation and voltage conversion. ADS1298 is supplied with bipolar voltage range of +2.5 to -2.5 V. RC filters are externally provided at every electrode lead. Following are the features of the second design:

- 2 wire I2C communication OLED screen SSD1306 is used in the design.
- STM32L431RCT6 microcontroller and interfacing circuits
- ADS1298 Integrated circuit connected to host microcontroller over SPI interface.
- DB-15 connector for 12 Lead ECG.
- Second order Low Pass Filters at each electrode inputs.
- Bipolar power supply.

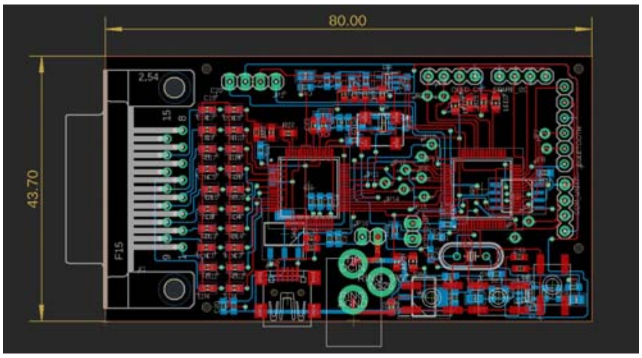



Figure 7. PCB layout for Design 2

The new design, shown in figure 7, is much cleaner and more composed. Figure 9 shows the complete prototype of design 2. 12V DC jack is provided for supplying power to the whole circuit. Power supply circuits are on the bottom plane which is visible as blue coloured tracks. The ADS and STM32 microcontroller are on the top plane visible in red. DB-15 connector is visible on the left for connecting electrodes followed by an array of resistors on bottom plane and an array of capacitors on the top plane used for second order Low Pass Filters. Pinheader connectors are provided for:

- Debugging
- OLED connector (I2C)
- Bluetooth module
- Rx-Tx communication port

## IV. RESULTS AND DISCUSSION

Figures 10-12 show the waveforms captured on DSO during the communication taking place between various ADS 1298 signals and the microcontroller. Figure 13 shows a single-lead ECG signal acquired by the design 1 (presented in figures 6-7) of subject 1. Figure 14 shows an ECG signal captured by second design (a 12-lead ECG acquisition system presented in figures 8-9) for the same subject. We were unable to display the acquired ECG signals on-board; however, they were successfully transmitted to PC/ laptop through Bluetooth.

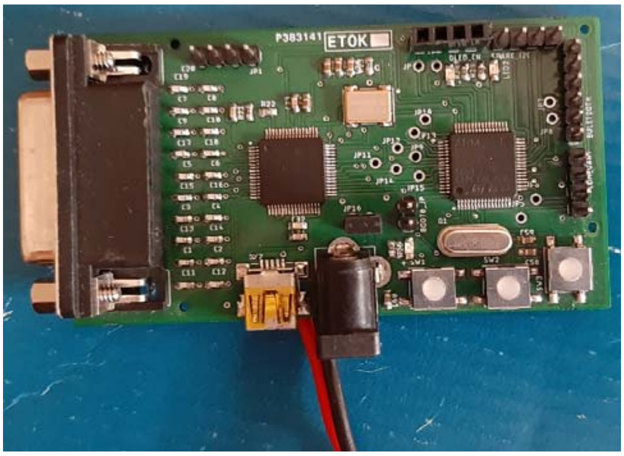



Figure 8. Prototype of Design 2

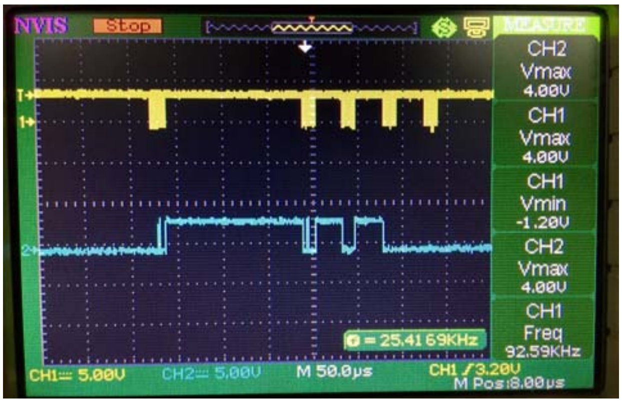



Figure 9. Image of all SPI signals transmitted

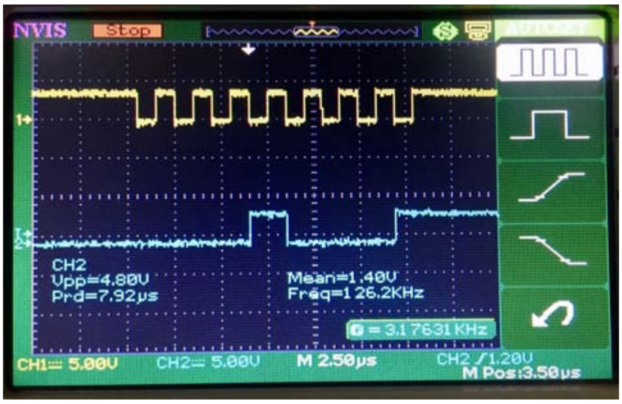



Figure 10. Image of transmission of SDATAC signal (0x11)

DOI 10.5013/IJSSST.a.20.05.03

ISSN: 1473-804x online, 1473-8031 print

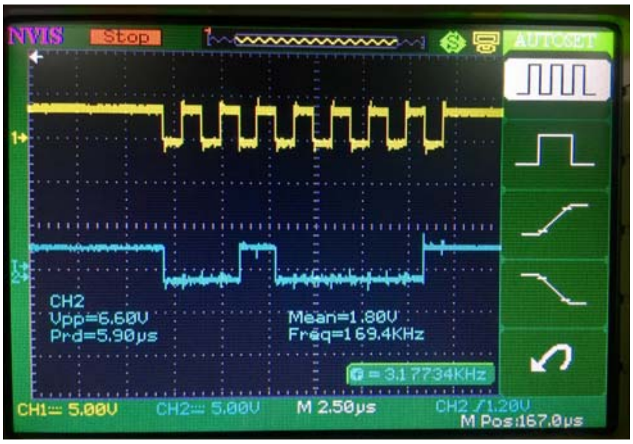
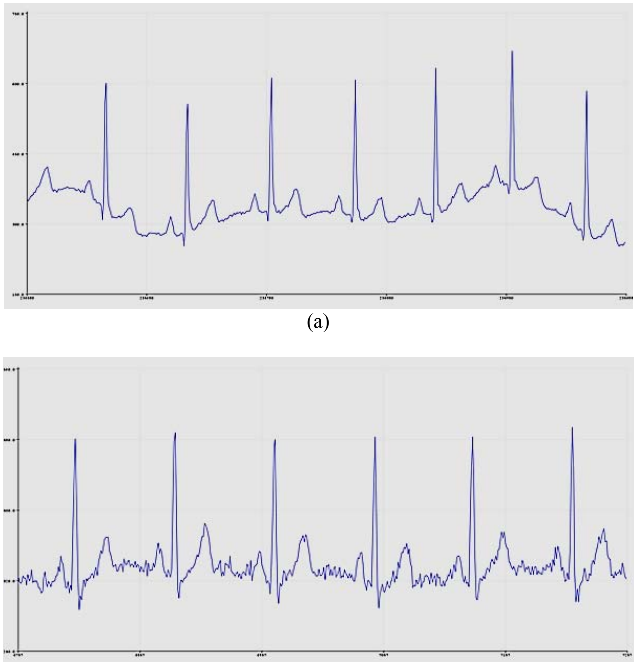



Figure 11. Transmission of RREG signal byte 1 (0x21)



(a)

(b)

Figure 12. (a) ECG signal acquired by design 1 for subject 1 (top); (b) ECG signal acquired by design 2 for subject 1 (bottom)

## V. CONCLUSION AND FUTURE SCOPE

A portable, low-coast wearable system for recording long-term/ ambulatory ECG of a subject has been developed. Two separate designs- single lead and 12 lead ECG have been implemented using Texas Instruments' ADS 1298 and ST Microelectronics' STM32L431RCT6 MUC. The acquired ECG signals were successfully transmitted to the computer via Bluetooth. This portable, low-cost healthcare monitoring system would not only be advantageous to the common people but also could be significantly helpful to the physicians for a first-hand monitoring of cardiac abnormalities of a subject. The systems can further be utilized for acquiring other important biopotentials like EEG, EMG, EOG etc.

## ACKNOWLEDGMENT

This project is funded by Council of Scientific and Industrial Research (CSIR), New Delhi via scheme no. 22(0727)/17/EMR-II. Hence, authors are extremely thankful to CSIR for providing the funding for this work.

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