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Design of Signal Conditioning Circuit for Biomedical Sensors and Battery Monitoring Circuit for a Portable Communication System

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ABSTRACT: *A portable, battery operated communication system was developed with receiver and transmitter section. The system consists of necessary features to track the location and monitor health of a person and wirelessly transmit real time data at the base station. This paper presents a detailed design of biomedical sensors with the necessary signal conditioning circuit. Temperature sensor LM35 and heartbeat sensor TCRT1000 was used in this system. System uses Lithium Polymer battery of 2200 mAh. Battery monitoring circuit was designed to safeguard the battery and avoid abrupt shutdown of the system. This circuit also includes low voltage disconnect (LVD) which gives an additional feature of hysteresis to avoid false triggering. The designed system is useful for military applications. This system also identifies whether the person was accidently or forcefully disconnected from communication with the base station.*

Keywords: *Hysteresis, Multi-switching, Optocoupler, Oscillations, Photoplethysmography (PPG), Phototransistor.*

I. INTRODUCTION

The system was developed considering its varying applications. Foremost application is for military use. A robust, portable system is proposed which could either be wearable on a person's arm or beneath his suit or inside the back pack. This product is designed for military personal engaged in high-risk operations such as confronting heavily armed terrorists or performing hostage rescue operations in remote locations.

We have divided our system into two parts one of which is the personal unit and the other is the base unit. Personal unit is fully integrated with biomedical sensors, communication platform, emergency keypad, tracking system, display, battery, battery monitoring system etc. The information transmitted by the personal unit will be represented on a central desktop using a Real time Graphical User Interface. The GUI will provide access to the Real time information of the Health, Position, and Critical signals regarding battery status received from the person engaged in assigned mission. The proposed paper is a part of this system. The application can variably change according to the requirement and this system can thus be implemented.

It can also be used for patients whose biomedical parameters can be monitored wirelessly while tracking their exact location. In case of emergency, the person can either inform to the hospital through his keypad or in scenarios where the person becomes unconscious due to sudden change in his health condition, an important message can be triggered and thus the required help could be provided. We are monitoring temperature and pulse rate which is considered the most vital biomedical parameter for a human being. We have also included a wearable connection along the suit or arm. The reason for keeping such a provision was to alert the base unit in case of accident when the whole personal unit might get disconnected without manually removing it. A connection break will trigger this priority message. Proposed block diagram for this system is given in figure 1. This diagram represents all the blocks of the system.

This paper represents the detailed design of signal conditioning circuits for biomedical sensors along with battery monitoring circuit. Second part of this paper represents hardware design of signal conditioning circuit. Third part elaborates the design using simulation results. Fourth part includes experimental results of proposed design. And last part is conclusion.

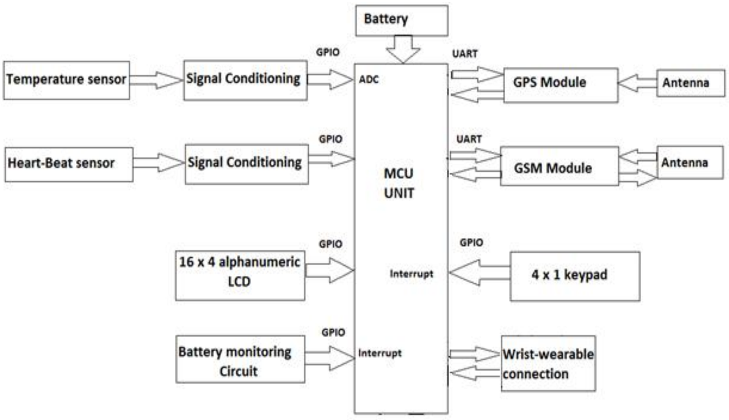


Figure1.a: Proposed block diagram (Personal unit)

Figure 1.b: Proposed block diagram (Base unit)

II. HARDWARE DESIGN

2.1 Signal Conditioning for Temperature Sensor LM35

In our system we are using LM35 temperature sensor. [6] LM 35 is a calibrated, readily available and low-priced sensor. Also it has accuracy of 0.5^{0}C. [5] As the LM35 draws only 60 µA from the supply, it has very low self-heating of less than 0.1°C in still air. In order to increase the resolution of the system we have restricted the temperature range of the sensor only up to 30^0 C to 40^0 C. LM 35 has resolution of 10mV/^{0}C which increases linearly with the temperature. And at 0^0 C its output is 0 V. That means at 30^0 C output of sensor is 300mV and at 40^0 C its output is 400mV. But in order to use internal ADC of microcontroller (LPC 2148) this voltage range is not suitable. So we mapped these voltages to 0 V – 3.3 V (as internal ADC of LPC requires these levels). First of all sensor output is amplified to 1V and then 1V is subtracted from it and again amplified to suitable level (between 0-3.3V) as given in fig 2. Purposefully 300mV offset voltage is not subtracted because the small offset error can cause large variation in the output when amplified. Following circuit gives the output of 0V-3.3V.

2.1.1 To amplify sensor output voltage

At 30^0 C the output of the sensor will be 300 mV which will be amplified to 1V. The output of LM 35 is connected to non-inverting pin of the op-amp. TLC-272 op-amp is a dual op-amp IC. It has highest rail to rail voltage, single supply operation; low offset voltage which is desirable for our system.

For, Vo= 1V Vin= 300 mV, we have to calculate Rf and R2, Rf= R3 + R4.

Assume, R2=1k Therefore,

Using, $Vo = (1 + \frac{Rf}{R2})\ Vin$

$Rf = (\frac{Vo}{Vin} - 1)\ R2$

$Rf = (\ \frac{1\ V}{300\ mV} - 1\ )\ 1k$

Rf= 2.3 k

But 2.3 k is not the standard value. Therefore we will use R3= 2.2 kΩ and R4=100Ω resistors.

2.1.2 Subtraction of 1V from amplified output

In order to generate on board reference voltage we used LM 385. This IC provides reference voltage of 1.2V. Using voltage divider, this 1.2V is converted to 1V. Using the equation,

$Vo = (\ \frac{R6}{R7+R6}\ )\ Vin$

Vo= 1V; Vin= 1.2V.

Assume R7= 1k, therefore, R6=4.7k. This reference voltage is subtracted from the previously amplified sensor voltage. This output is connected to unity gain amplifier for impedance matching and to avoid the loading effect of the next op-amp.

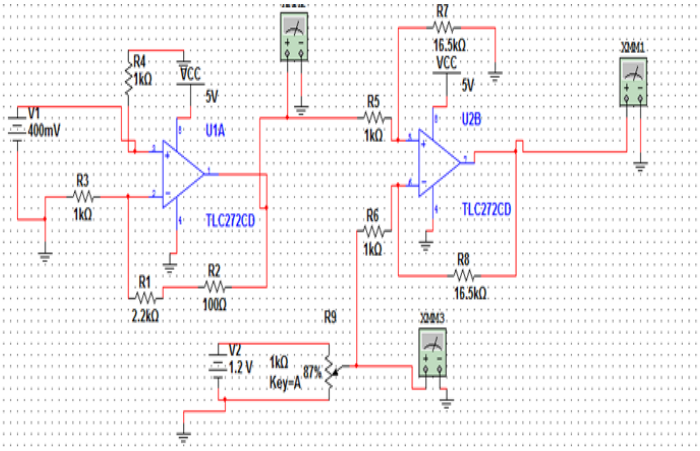


Figure 2: Signal Conditioning for LM35

For, 10 bit ADC, there are 2^10 =1024 levels. We are using internal ADC of LPC2148. Hence, a range of 30 deg to 40 deg can be achieved with 10 bit ADC as 30.01, 30.02, 30.03, 30.04, and 30.05 and so on up to 40.

2.2 Signal Conditioning for Heart-beat monitoring using TCRT1000

We are using optocoupler TCRT1000 as our pulse rate sensor. This sensor is used to implement the principle of ‘Photoplethysmography (PPG)’. [1] It is the science of measuring Blood parameters (heart-beats) using optics. The light source (IR LED) and the light detector (Phototransistor) is the part of TCRT1000.[2] It is placed on the same side of a body part. When light is transmitted into the tissue, some will be reflected directly by the skin surface, some will be distributed in the tissue by absorption or scattering, while the remaining photons will travel into the tissue either straight through or with a number of collisions. Low levels of infrared light are used by PPG to detect small changes in blood volume content in these regions. It provides a voltage signal, which is proportional to the amount of blood present in the blood vessels. The light is emitted into the tissue and the reflected light is measured by the light detector. This sensor can be applied to any part of human body.

Fig 3 gives the instrumentation circuit (see Part [1]) which describes the signal conditioning stages for the sensor output. Based on the circuit as shown in Fig 4, the output of the sensor passes through the passive RC high-pass filter (HPF) to remove the DC component and then passes through the active low-pass filter (LPF) which is Op-Amp circuit using MCP6004 to amplify the signal and to remove the high frequency noise.

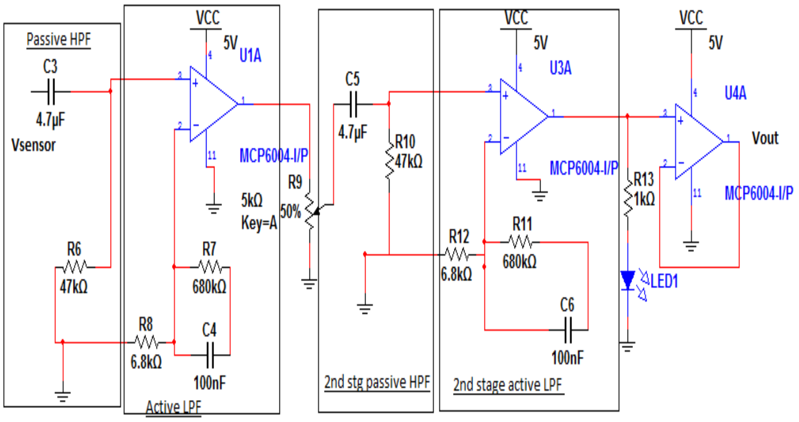


Figure 3: Signal conditioning circuit (TCRT1000)

The cut-off frequency for the HPF is 0.7Hz and the cut-off frequency for the LPF is 2.34Hz with 101 gain respectively. The output of the first stage of signal conditioning is further passed through the second stage signal conditioning of the same HPF and LPF combinations for further filtering and amplification. Thus, the total voltage gain for the cascaded stage is 10201dB. These two stages, converts the input PPG signal to near TTL pulses and they are synchronized with the heartbeat.

Part [1]: Calculations for cut-off frequency

1st and second stage passive LPF:

$$Fc = \frac{1}{2*\pi*Rf*Cf}$$

$$Fc = \frac{1}{2*\pi*47K*4.7uF}$$

Fc=0.7Hz

1st and second stage active LPF:

$$Fc = \frac{1}{2*\pi*Rf*Cf}$$

$$Fc = \frac{1}{2*\pi*680K*100nF}$$

Fc=2.34 Hz

2.3 Design of Battery monitoring circuit

In our system we are using rechargeable Lithium Polymer battery [7] consisting of 3 cells. Each cell has a voltage of 3.7V. Thus a battery of 3 cell, 2200 mAH, 7.4V, and 35C sufficed our system. Given below in Table 1, list of all the system components and their current requirements is mentioned.

Table1: Current consumption of the system

Component	Current required
LM 35	60 µA
TCRT 1000	25 mA
LPC 2148	79 mA
GSM	500 mA
GPS	100 mA
LCD	20 mA
LM 385	2.5 mA
TLC 272	10 mA
MCP 6004	0.5 mA
MIC 29302	40 mA
NE 555	10 mA
LED	7.4 mA
Total Current	794.46 ≈795 mA

$$\text{Duration of battery operation (T)} = \frac{\text{Battery capacity}}{\text{Total current drawn}}$$

$$T = \frac{2200mA}{795mA}$$

T = 2.77 hrs. ≈ 3 hrs

For the prototype system, our battery gives a continuous output for 3hrs. If the system ever commercializes, a more powerful battery can very well be replaced by it. [11]

While considering lithium polymer batteries there are certain safety factors which must be critically followed. Most important parameter is the upper threshold voltage and the lower threshold voltage. [8] Battery manufacturers provide us with these critical values. Battery voltage should not go beyond the upper threshold while charging and it should not discharge below a certain voltage. [9] We made use of a smart charger which gave us the solution for its upper threshold. But for the lower threshold we designed a low voltage disconnects (LVD) circuit, which is integrated with our system.

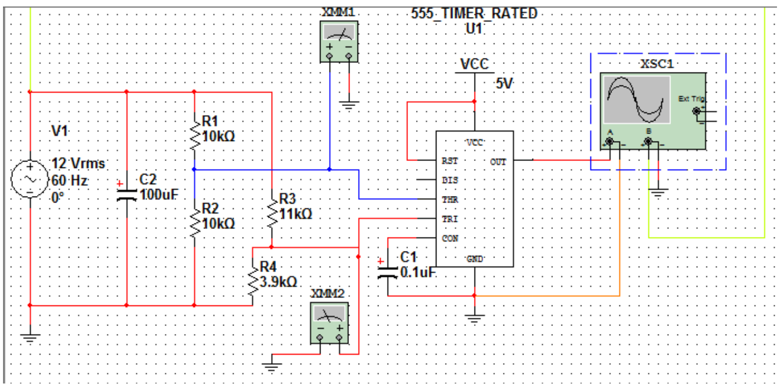


Figure 4: **Battery monitoring circuit**

The output of the battery is connected to the GPIO pin of the microcontroller, [10] and is programmed to generate an interrupt as soon as it detects a low level on the GPIO pin. This interrupt sends critical message to the base station. It displays a message of "Low Battery" on LCD. A switch is provided to manually disconnect the load from the battery.

The Low voltage disconnects (LVD) [14] circuit provides an additional feature of Hysteresis [13] in order to avoid on/off oscillations (multi-switching),
Lower Trigger Point (LTP): 6.2V
Upper Trigger Point (UTP): 6.5V

1. Calculating R1,R2

$$R2=\frac{R1*Vo}{Vin-Vo} \quad ; Vo = 2/3*Vcc$$

$$Vo = 3.33V \quad ; V_{in}=V_{UTP} = 6.5V$$

Let, R1= 10kΩ. Thus, R2= 10kΩ

2. Calculating R3, R4

$$R4=\frac{R3*Vo}{Vin-Vo} \quad ; Vo = 1/3*Vcc$$

$$Vo = 1.66V \quad ; Vin =V_{LTP} = 6.2V$$

Let, R3= 11kΩ. Thus, R4= 3.9kΩ

III. SIMULATION RESULTS

3.1 Signal Conditioning for Temperature Sensor LM35

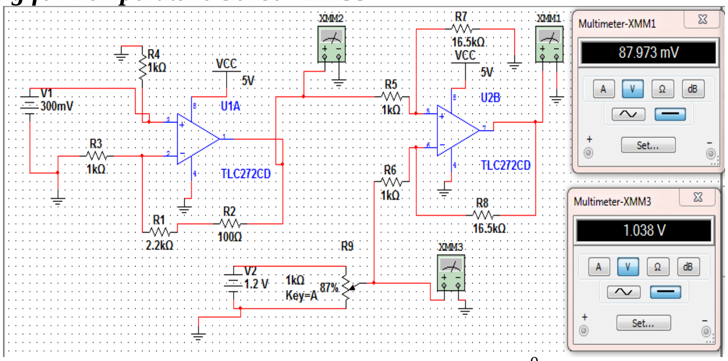


Figure 5: LM35 simulation (at 30^0C)

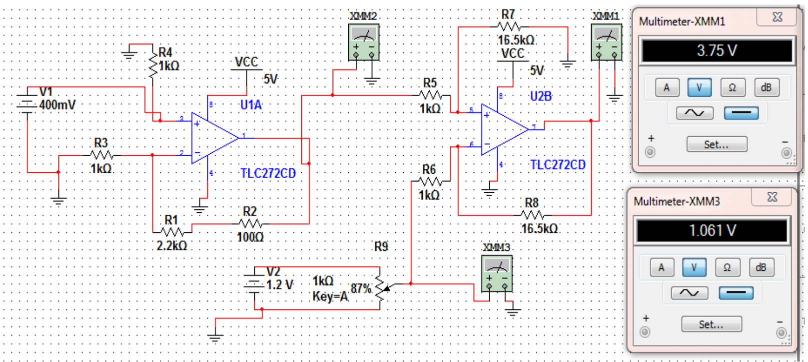


Figure 6: LM35 simulation (at 40^0C)

Ideally, at 30^0C, the output voltage should be 0V. From Fig.6 simulation result gives 87.973mV in virtual multi meter (XMM1). Ideally, at 40^0C, the output voltage should be 3.3V. From Fig.6 simulation result gives 3.75V in XMM1. XMM3 in both Fig.5 and Fig.6 is the reference voltage provided externally in simulation which is 1.061V. In actual hardware we are using LM385 to generate reference voltage. Multisim 11.0 is used as our simulation software.

Table2: Comparison of Theoretical and Simulated Values

Temp ^{0}C	**voltage (mV)**	**Stage 1 Gain (V)**	**Ref voltage (+1V) (V)**	**Output Gain (8.5) (Theoretical) (V)**	**Output (Simulate) (V)**
30	300	-1	0	0	0
31	310	-1.03	0.03	0.255	0.27
32	320	-1.07	0.07	0.595	0.56
33	330	-1.10	0.10	0.85	0.84
34	340	-1.13	0.13	1.105	1.12
35	350	-1.16	0.16	1.36	1.41
36	360	-1.20	0.20	1.7	1.69
37	370	-1.23	0.23	1.955	1.97
38	380	-1.27	0.26	2.21	2.22
39	390	-1.30	0.30	2.55	2.54
40	400	-1.33	0.33	2.805	2.82
41	410	-1.37	0.36	3.06	3.10
42	420	-1.40	0.40	3.4	3.36

3.2 Signal Conditioning for Heart-beat monitoring using TCRT1000

Fig.7 gives the simulation circuit for heartbeat monitoring. The primary aim of the simulation is to convert a distorted (In this case pure) sine wave into square wave which is given to the microcontroller.

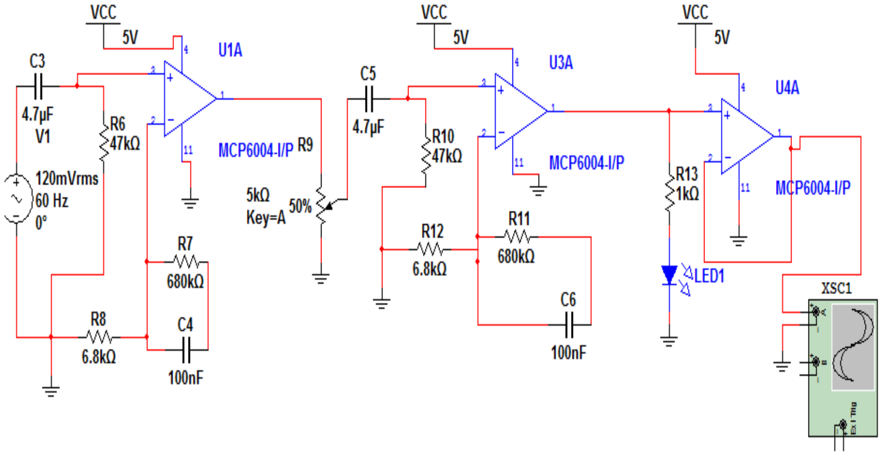
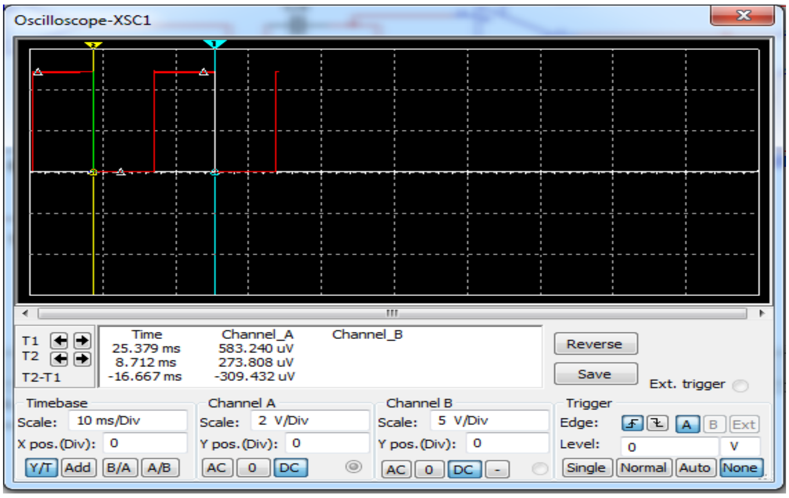


Figure 7: TCRT 1000 simulation circuit



	Time	Channel_A	Channel_B
T1	25.379 ms	583.240 uV	
T2	8.712 ms	273.808 uV	
T2-T1	-16.667 ms	-309.432 uV	

Timebase
Scale: 10 ms/Div
X pos.(Div): 0

Channel A
Scale: 2 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

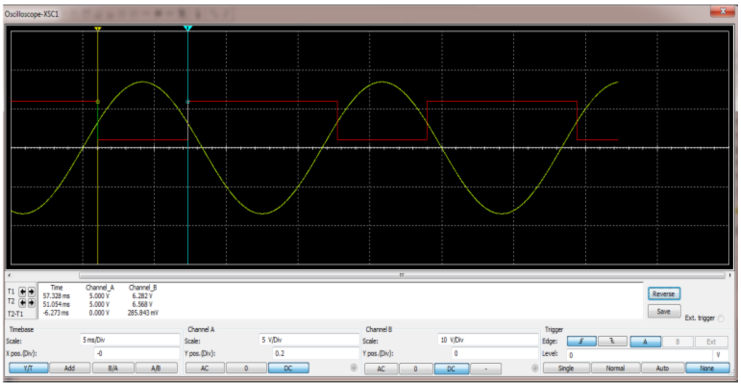
Trigger
Edge: A
Level: 0 V

Figure 8: TCRT 1000 simulation results

Fig.9. shows square wave using the virtual Oscilloscope-XSC1 which is the final output. The result of the simulation is as expected ideally.

3.3 Simulation for battery monitoring circuit

Referring to Fig. 4, Battery monitoring circuit shown in Fig. 9 gives the corresponding waveforms for it. [12] To test the battery voltage, Sine wave is given which is equivalent to charging and discharging of battery voltage. Square wave in the Fig.9 represents the transition from UTP to LTP and vice versa.



	Time	Channel_A	Channel_B
T1	57.328 ms	5.000 V	6.282 V
T2	51.054 ms	5.000 V	6.568 V
T2-T1	-6.273 ms	0.000 V	285.843 mV

Timebase
Scale: 5 ms/Div
X pos.(Div): -0

Channel A
Scale: 5 V/Div
Y pos.(Div): 0.2

Channel B
Scale: 10 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Figure 9: Output waveform of Battery Monitoring

IV. EXPERIMENTAL RESULTS

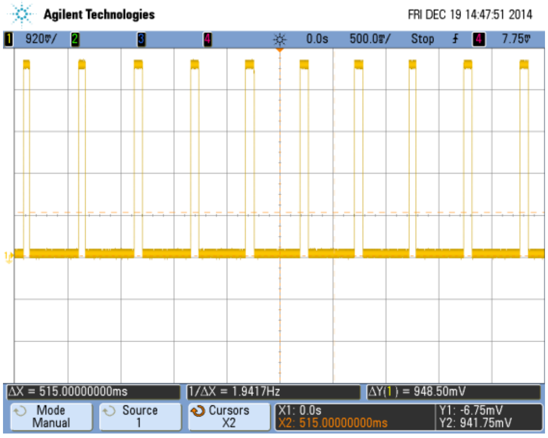
4.1 Signal Conditioning for Temperature Sensor LM35

Signal conditioning circuit built on breadboard was tested at room temperature which was measured at 32^0C using thermometer (Fig.10). The voltage came to be around 0.58V which is very close to the simulated value of 0.56V and theoretical value of 0.595.

Figure 10: Voltage measurement at room Temperature

4.2 Signal Conditioning for Heart-beat monitoring using TCRT1000

Fig.11 shows the square waveform measured for the signal conditioning circuit that was built on general purpose board. We measured the waveforms on Digital Oscilloscope (DSO) by ‘Agilent Technologies’. [4] The measured frequency was 1.9417Hz which clearly lies between the 0.7Hz to 2.34Hz band as designed earlier. [3]



ΔX = 515.00000000ms
1/ΔX = 1.9417Hz
ΔY(1) = 948.50mV
X1: 0.0s
X2: 515.00000000ms
Y1: -6.75mV
Y2: 941.75mV

Figure 11: TCRT 1000 Actual result (Tested on DSO)

V. CONCLUSION

This paper thoroughly represents the designing of signal conditioning circuit for temperature sensor LM35 and optocoupler TCRT1000 which is used as a heartbeat sensor. Battery monitoring circuit is also designed and implemented using low voltage disconnects circuit (LVD) with an additional feature of hysteresis. Similarity between the simulation results, theoretical results and practical results successfully shows the implementation of this system.

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