PROJECT TITLE: Patient Activity Monitor for Holter Examination

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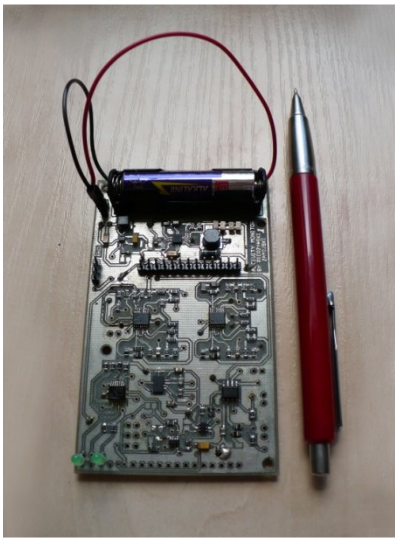
DATE: 20th June 2011

TI PARTS USED IN PROJECT:

- 1x TPS63700DRCT
- 1x TPS61221DCKT
- 2x OPA4347EA/250
- 1x OPA2349/250
- 1x TS5A3160DBVR
- 1x TLC555
- 1x SN74AHC74QPWRQ1



ABSTRACT

The main aim of this project was to design accelerometer-based detection circuitry for patient activity, which would be able to distinguish the following situations: patient is sitting/standing, patient is walking and patient is running. For this purpose authors decided to develop a pure analog circuit that could be further realized as a simple Integrated Circuit. The detector is supposed to be used together with a holter device to store patient activity data during 24h examination, helping a doctor to correlate physical effort with hearth activity. Thus, powering issues were also taken into consideration in the presented project.

1 Introduction

In this report the portable system able to monitor human activity is presented. Such device could be used together with a Holter device to supplement the overall diagnostic data from the 24h examination. The system can distinguish whether the patient is sitting/standing, the patient is lying, walking or running providing the feedback to a cardiologist. The main part of the system is accelerometer-based circuit with the pure analog detection system consisting of rectifiers, adders, charge pump and timer units. The other important part is power supply unit, which uses only one AAA accumulator. This allowed to significantly decrease the size of the device, which makes it quite comfortable for the patient being examined.

In the following chapters we would like to demonstrate how TI parts can be used for construction such a device.

2 Motivation for Project

As young students of electronics we are taking first steps in electrical and signal engineering. Problem of human body monitoring was presented during one of our seminars. Then our idea of a patient activity monitor for Holter examination have come up and after discussion with the cardiologist about usefulness of the additional data about patient’s effort, we decided to start the MoveWatcher project. Fortunately at the same time the TI Analog Design Contest was announced and we decided to take advantage of it and transform our idea into reality using wide range of TI products.

The whole process of the device development involved: simulations, PCB design, assembly and testing.

3 Theoretical Background

The most appropriate solution for move monitoring nowadays is using an accelerometer. There are many types of them that differ from each other, e.g., by sensitivities, interfacing, etc. Unfortunately the *TI* does not produce such an IC, thus we decided to use a product of one of the most valued motion sensors producer – *Freescale Semiconductor*. The MMA7331LC is a low power, low profile capacitive micromachined accelerometer with a 1-pole low pass filter embedded, temperature compensation and g-select allowing choice to be made between two sensitiveness: 4g and 12g. To check what kind of signals we will have to deal with, we assembled the small PCB board with the accelerometer. We examined output signals while staying, walking and running, keeping the device near a belt, where it is supposed to be attached during Holter examination. Results are shown in figures 1-3.

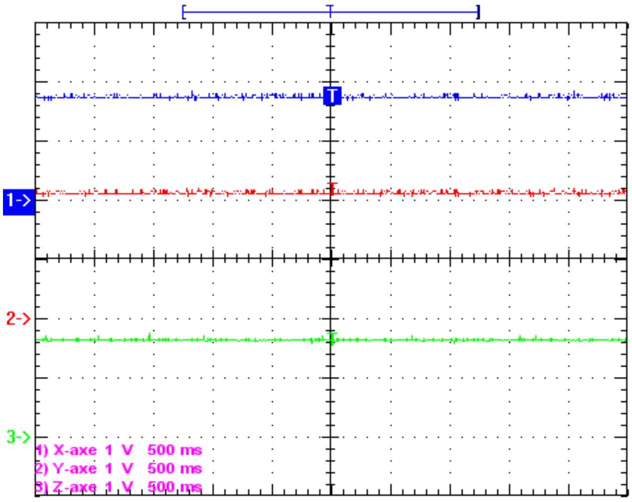


Figure 1: Accelerometer output (XYZ axes) – standing

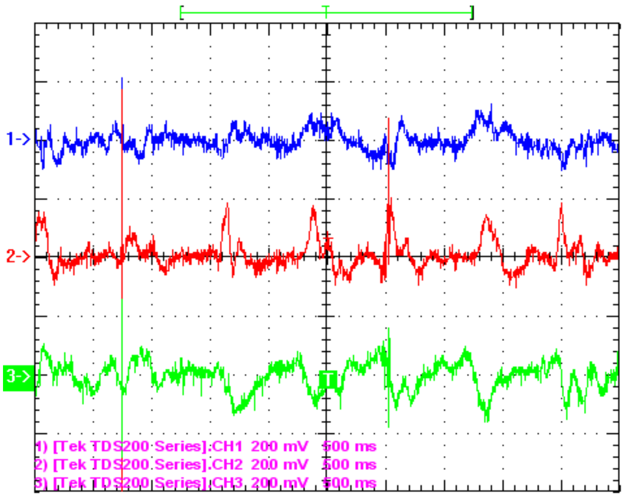


Figure 2: Accelerometer output (XYZ axes, AC) – walking

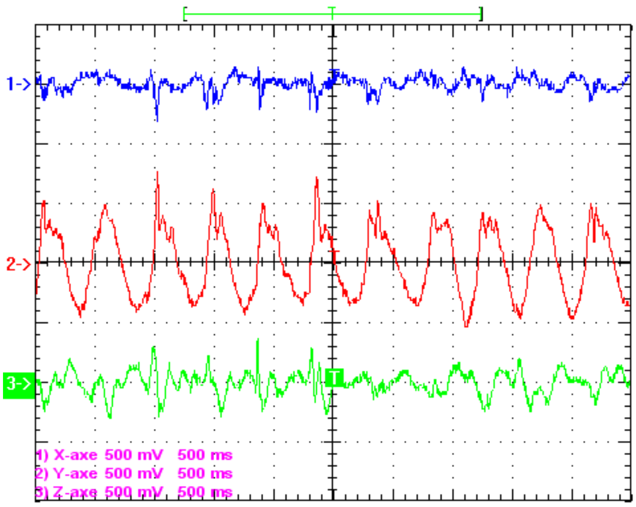


Figure 3: Accelerometer output (XYZ axes, AC) – running

While the move of a person keeping the device become more intensive, the output signal base frequency and the amplitude of the signals from XYZ axes are rising. The obtained results shown, that the proper analog signal processing can provide information about how intensely the patient is moving as significant differences are visible in the signals.

At a glance, it appeared that a typical digital signal processing could be applied for the detection purposes, e.g., the Fourier transform. However, does the same effect can be achieved using just a pure analog circuitry?

4 Implementation

A block diagram of the designed system is shown in figure 4.

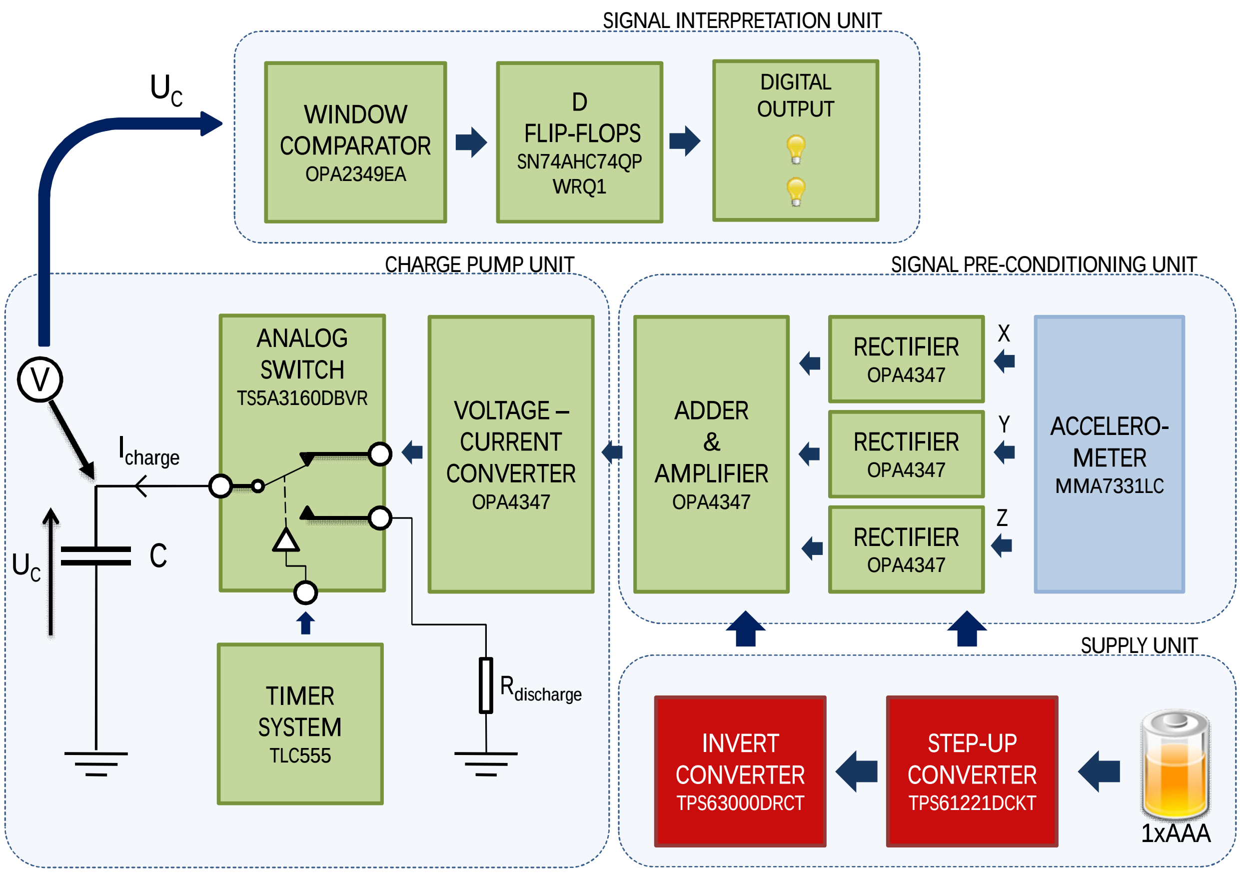


Figure 4: Block diagram

4.1 Supply unit

One of the requirements for the monitor was portability. Thus supply unit is based on battery power (1xAAA) and the set of converters (step-up and inverting) to provide proper voltage levels especially for operational amplifiers and small-signal rectifiers that must be supplied by a symmetrical voltage. Expected current consumption was assumed to be under 100 mA, therefore TPS61221DCKT is accurate for this purpose. Input voltage range from 0.7 V and efficiency at level of 96% allow to power the whole device using single-cell battery or accumulator. The 3.3V voltage for powering the most of the circuit is being reached without any additional voltage dividers, what also is advantage of this solution. Another reason for choice of this converter is small package, which is crucial issue in portable devices.

The choice for the voltage inverter wasn`t hard. TPS63000DRCT provides accurate negative voltage -3.3 V with output current up to 360mA for proper rectifiers powering.

4.2 Signal pre-conditioning unit

Because of unpredictable orientation in space of the device the 3-axes accelerometer was used as a sensor. From the XYZ signals DC components are removed that could generate additional problems in the further part of the circuit, especially in the charge pump. The AC components of the signals are rectified by small-signal, OpAmp-based rectifier. These signals are summed and amplified to the required level. Thanks to this solution the user does not have to take care about the proper device orientation.

Signal pre-conditioning was carried out using precision amplifiers with input and output rail-to-rail feature (*OPA4347*). The mentioned property is necessary to avoid problems with amplifiers saturation. With 4 channels in one package, the OPA4347 is the ideal solution because of the low power consumption (34µA per channel) and *microSize* packages.

Adder and amplifier was realized using one OpAmp of the OPA4347 IC.

Schematics and the obtained results of SPICE simulation are shown in figures 5-7.

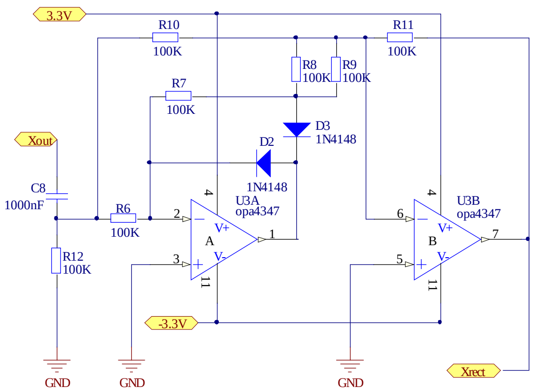


Figure 5: Small-signal rectifier for each axis

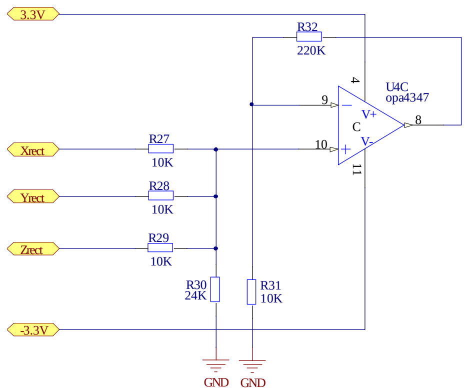


Figure 6: Adder with amplification circuit

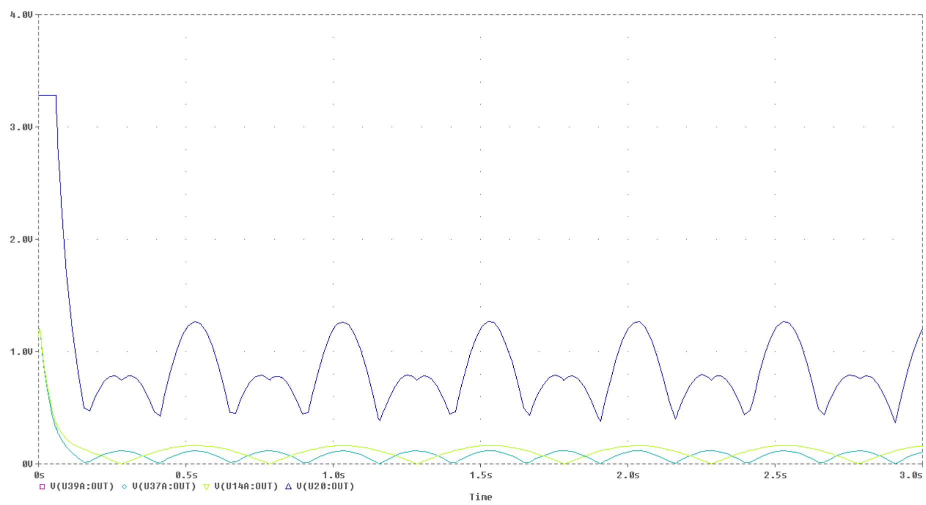


Figure 7: Signal pre-conditioning unit output (rectifiers, adder with amplification) - simulation results

4.3 Charge pump unit

The main component of the detection circuitry is a capacitor *C*. It is widely known that voltage on the capacitor U_C is proportional to the accumulated electric charge and inversely proportional to the capacity. When capacity is fixed, the voltage depends only from amount of accumulated electric charge. Moreover, the electric charge at the time *t* is integral of the current I_{charge} from *0* to the *t*. Thus, conversion of the accelerometer rectified voltage signal to the current charging the capacitor allows to obtain linear relationship between the move intensity (frequency and amplitude) and the capacitor voltage U_C. Additional assumption for the proper detection is that the capacitor must be periodically discharged.

One of the most important part of the MoveWatcher is charge pump unit, which is responsible for effort (move) intensity recognition. The unit consist of the voltage current converter (carried out using *OPA4347*), analog switch (*TS5A3160DBVR*), capacitor and timer unit (*TLC555*) needed for triggering voltage cancelling.

The designed voltage-current converter is based on a simple current source in the Howland topology. One of advantage of this circuit is that the load can be connected to the ground. Another one is that this circuit does not require additional transistor and output current is proportional to input voltage and inversely proportional to the R35 resistor (according to the schematic in figure 8). Main aim of this circuit is to convert rectified, summed and amplified voltage to the proportional current I_{charge} which charges the capacitor.

As it was previously stated the capacitor *C* must be discharged in a fixed period. For this purpose one-chancel analog switch (TS5A3160DBVR) was used. This IC switches capacitor “hot” pin between the converter current output and discharge resistor $R_{discharge}$ connecter to the ground. The switch is controlled by rectangular signal generated by tlc555 timer. Rectangular signal generator was modified by adding additional diodes, in order to obtain the fill factor lower than 0.5. Capacitor is discharging during a high state of the timer.

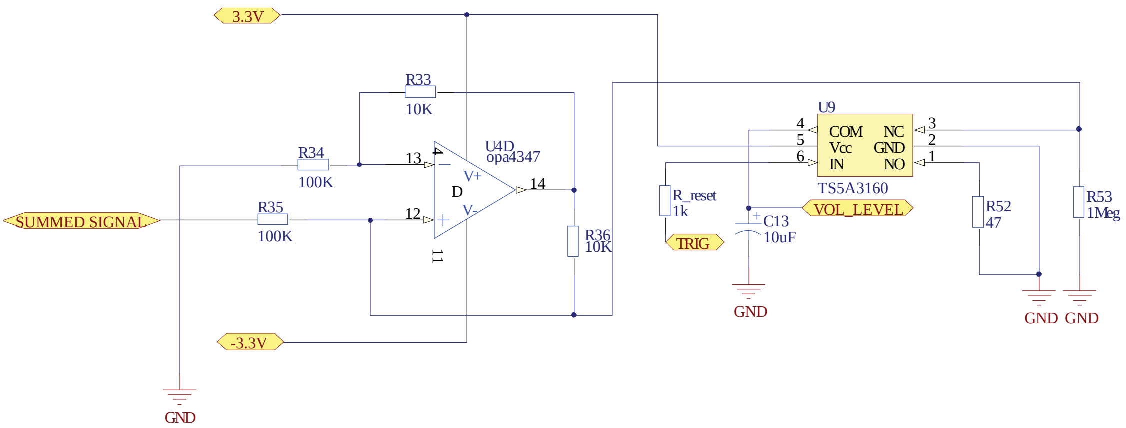


Figure 8: Voltage current converter with analog switch

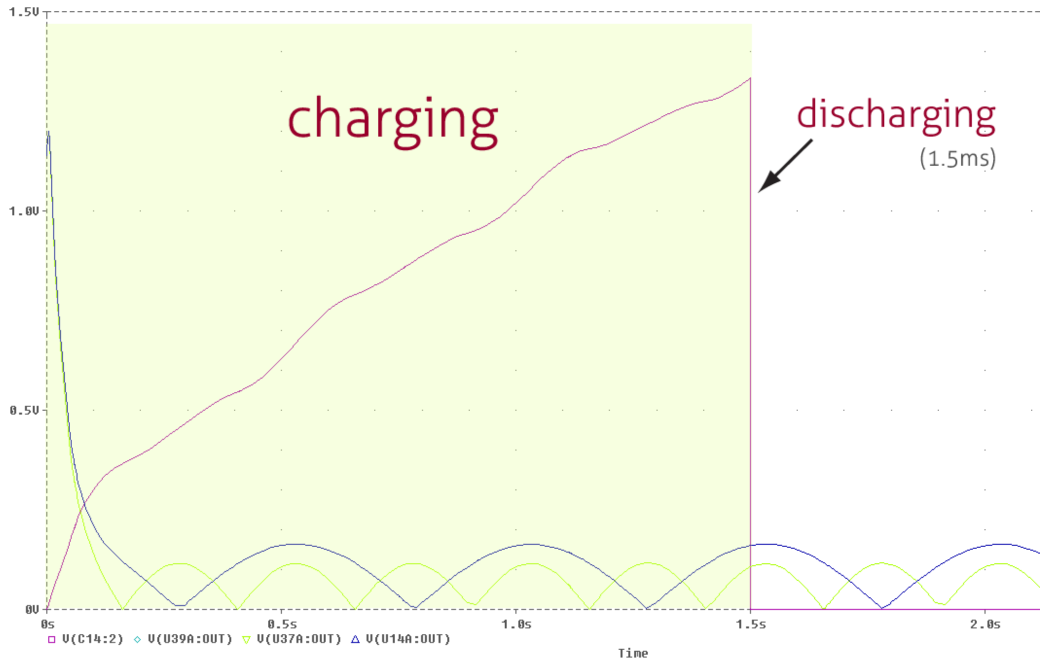


Figure 9: Charging and discharging simulation

4.4 Signal Interpretation Unit

The main part of this unit is the window comparator. Advantage of this solution is possibility of distinguishing voltage U_C level on the capacitor among 3 levels related to the user activity. The result is sampled and held using D-latch for the next 1.5 sec (chosen experimentally), which allow to better interpret and present the current patient's state. Important issue for choosing the proper IC`s for this purpose was that the operational amplifiers forming a window comparator should not introduce any error to the capacitor voltage measurement, e.g., by uncontrollable discharging. Therefore, we chose an OPAMP with FET inputs. The other aspect was providing proper CMOS logic at the output and wide range of input voltages. Thus rail-to-rail feature was necessary at the input and the output, and finally the OPA2349 IC was chosen, which is perfect for this purpose.

Result of simulation was shown in figure 10 (output signals are inverted by means of inverting output of latch).

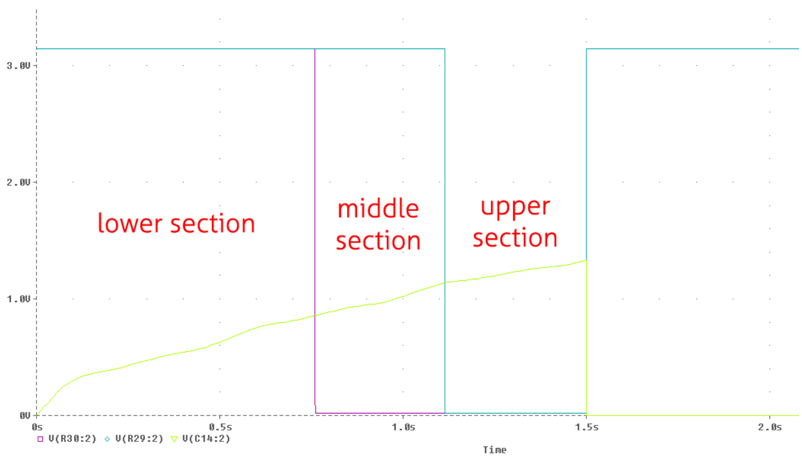


Figure 10: Charge pump with window comparator- simulation

5 Experimental Results

Figure 11 shows adder and amplifier output signal in the real circuit. Thanks to the capacitors at the each rectifier input, only AC component is amplified, which reduces the problem of DC component in charge pump. Depending on the shock strength and its frequency, the signal shape is changing.

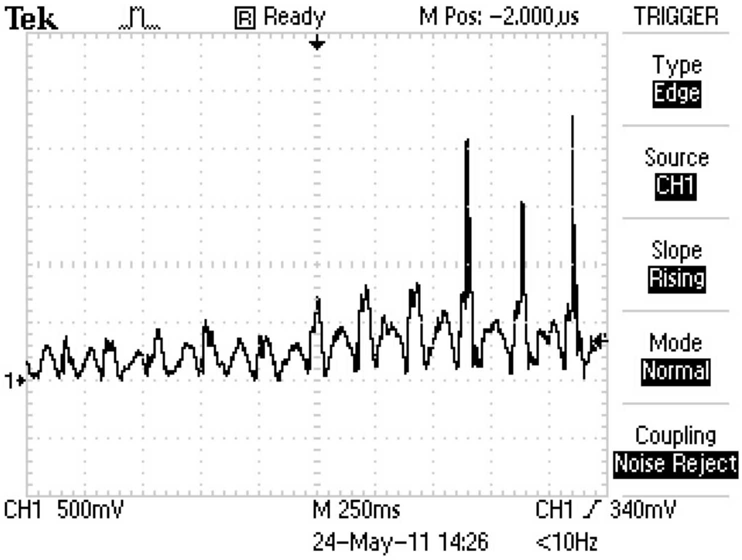


Figure 11: Adder with amplification output

Experiments proved simulation and the overall idea. The larger and the “thicker” adder signal is, the higher voltage level at the capacitor is obtained (at the end of the charging period). Based on this the system is able to distinguish intensity of the body activity – the patient effort.

The authors faced the problem of noise generated by the power converters, which causes some offset at the charge pump that additionally introduce the voltage error. The problem doesn’t exist using external supplier. Despite many attempts to resolve the problem by using, e.g., passive low-pass filter (RC) we did not managed to avoid it. The only solution, because of the lack of time for PCB board redesign and implementing LC filter, was to slightly increase thresholds of the window comparator.

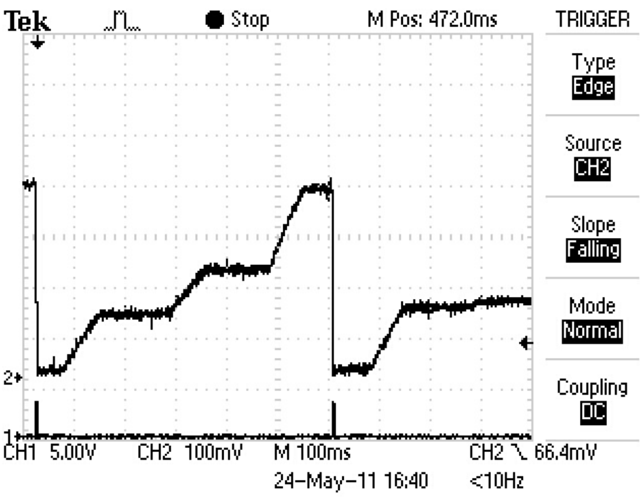


Figure 12: A voltage on the detection capacitor - slow walk

It is also worth noting, that using simple voltage-current converter, good quality capacitor and FET input-based OpAmp as a detector it is possible to store charge during specific period of time (stable voltage levels on Figure 12: A voltage on the detection capacitor - slow walk).

Figure shown below shows a process of discharging the detection capacitor.

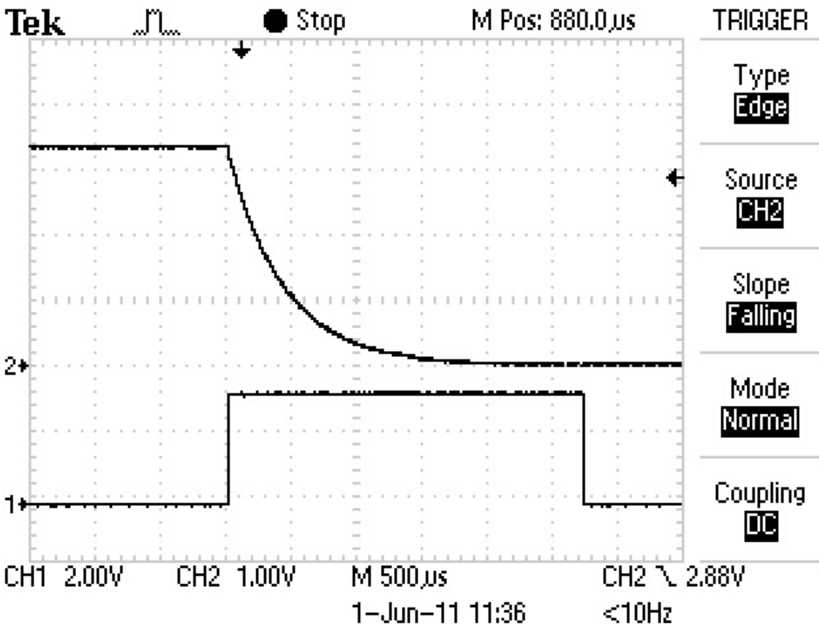


Figure 13: The detection capacitor discharge

Using analog key proved great solution. In a very short period the capacitor voltage can be discharged to almost zero, keeping safe work conditions for the analog key, capacitor and resistor as well.

6 Conclusions

- Charge pump was proved as a great solution for processing signals from accelerometer for the presented purpose; no digital signal processor or any other processor is needed for an activity monitor;
- Experimental results shown meaning of supply unit proper design – noise and distortions affect charge pump and window comparator; however, the circuit appeared to be quite proof against noise – some correction can be introduced by changing thresholds of the window comparator;
- Measured power consumption is at 50 mA (LED's are used), and 40mA (without LED's) – using 1xAAA battery at the input;
- The circuit is realized using pure analog techniques, thus it can be further realized as a simple IC chip;
- The designed analog circuit consumes less power than microprocessor system with the same functionality;

7 Summary

The main advantage of the presented device is its simplicity. We successfully built up an electronic device, which detects patient activity on the basis of analog accelerometer signals. The problem of activity detection based on move intensity was reduced to the specific integration operation which can be realized using only analog circuitry.

Experiments shown, that the device is able to give reasonable result, which can be further saved (see 8 *Future plans*) and then correlated with Holter examination data giving a feedback about patient activity.

Figure 14: Circuit mounted on the prototyped bar around the hips

8 Future plans

The presented board converts analog signals from the accelerometer circuit into digital, presented using two bits only. The first developing step is to equip the detector with simple microprocessor system being responsible for acquisition and storage the data about activity on some non-volatile memory, e.g., SD, EEPROM, etc. Such board was designed but not manufactured because of the exams time **J**. This circuit is based on MSP430 microcontroller family with CC430 RF wireless transmitter/receiver, real time clock and EEPROM memory. Furthermore, we would like to design simple USB stick with CC430 RF receiver/transmitter that could extend possibilities and allow communication of the monitor with a PC computer in the real-time.

Additional functionality, especially in the aspect of Holter examination, could be additional analog system providing information about the body position – staying or lying. For this purpose, taking into account DC component of signals from accelerometer, the best solution could be average value converter with comparator at the output.

Another important issue is the device miniaturization. The presented two-sided printed board (100x60 mm) contains passive components in the 0805 package. In the future, device can be redesigned into a size, which allows a patient putting it into his pocket, making the device presence almost imperceptible. Moreover, the device functionality realized as an IC could be used for integration with Holter devices.

Accelerometers are integrated in the most of modern mobile systems, e.g., smart phones. Thus, our idea to realize a ready-to-use Integrated Circuit for the user's activity detection seems to be worthy of further exploring also in the context of applications in this area.