PROJECT TITLE: **Cool bag powered by a battery pack and charged with solar power**

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TI PARTS USED IN PROJECT:

- 1 TMP123, http://focus.ti.com/docs/prod/folders/print/tmp123.html
- 1 bq24105, http://focus.ti.com/docs/prod/folders/print/bq24105.html
- 1 MSP430F2013, http://focus.ti.com/docs/prod/folders/print/msp430f2013.html

Figure 1: Our Team

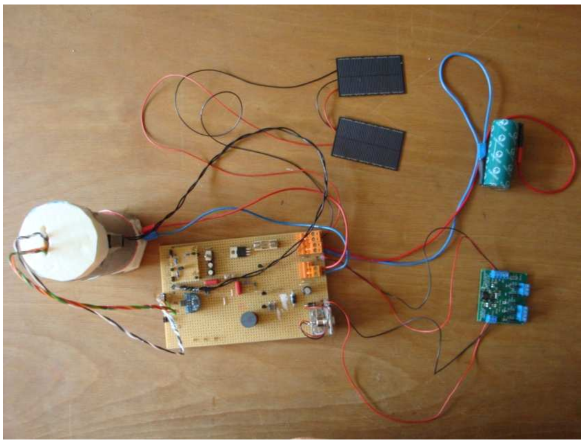


Figure 2: The hardware

PROJECT ABSTRACT:

A transportable cool bag for medical use is developed. A temperature sensitive medical drug is stored within a thermally isolated container. The cooling is done by a Peltier element. The energy is supplied by a battery which can be charged by line adapter or solar cells. A temperature sensor measures the temperature inside the container; an opening sensor measures the door position. A microcontroller gathers all the information, calculated the necessary cooling power and controls the Peltier element.

Introduction

Our team (Figure 1) consists of four students studying electrical engineering at the University of Applied Sciences in Regensburg, Germany. We are between 20 and 21 years old and are all native to Germany. We are all in our 4^{th} semester and are all participating in a dual study program, which allows students to study regularly and learn a profession simultaneously.

We started the project in January 2010 when Prof. Fuhrmann gave us the task to develop a cool bar for medical drugs. This project was started from scratch. We only had the specification from the Professor. Up to this point we only had theoretical lessons about electronics and no experience how to develop a complex electronic product.

Motivation for our Project

Our motivation to build this portable cooler for medical drugs was both the technological challenge and the possibility to create something useful from which other people can benefit.

Our cool bag was therefore designed to hold a single medication, an aerosol valve similar to those used for asthma therapy. This special medication needs to be kept cooled to a temperature of about 15℃, which makes it problematic to simply carry it around in a purse, for example. This is supposed to be made possible by our project.

Theoretical Background

Following general conditions were defined:

- The maximum supply voltage (from the battery pack) is 3.3V
- The cool bag has to be portable
- A Peltier element is used for the cooling process
- Temperature acquisition with a temperature sensor (TMP123)
- System is controlled by a microcontroller (MSP430F2013)
- A possibility to charge the battery with solar power or line adapter (bq24105)
- All components must have low power consumption

From these conditions, a number of challenges arose. How to control the current through the Peltier element was the first question for us. We decided to use a power MOSFET for this task. The MOSFET was supposed to be controlled by a PWM signal generated by the microcontroller. This was not possible, however, with a supply voltage of merely 3.3V. Therefore, we designed a voltage doubler and a voltage follower which also needed to be controlled by the microcontroller.

The battery pack was supposed to be charged by the solar cell as well as by a line adapter. For the charging process, a charge management device was required. This device was only compatible with the mains connection, but not with the solar cell, since the output current from the cell was too low. An alternative was needed here, as well. Thus, we implemented a circuit that charged the battery directly from the grid.

The communication of the temperature sensor with the microcontroller was put into practice through an SPI bus system connecting the two components.

In order to guarantee a most efficient use of power, an opening sensor was added, which turns the whole system off as soon as the thermally isolated lid is opened.

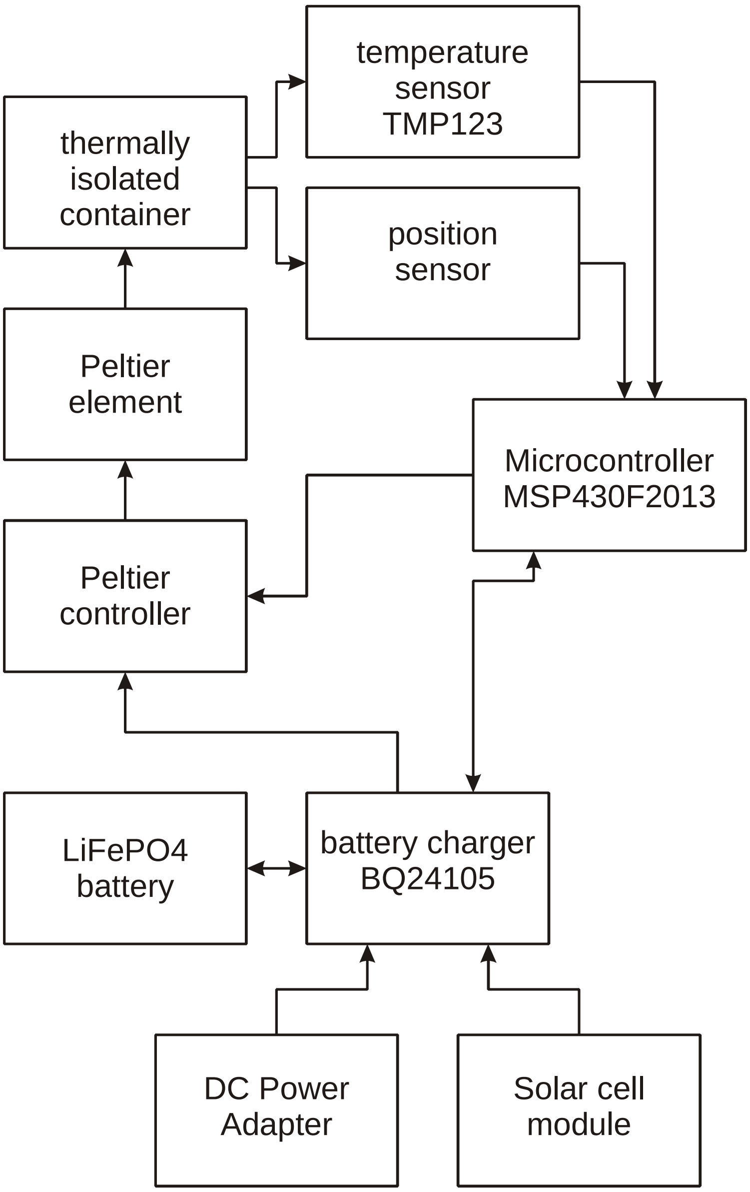


Figure 1: Block diagram of hardware

Implementation

Block diagram (Figure 3):

The microcontroller MSP430F2013 is the central unit in our system. It communicates with the battery charger and receives data from both the temperature and the position sensor. It further manages the Peltier controller, which controls the Peltier element. The Peltier element cools the thermally isolated container to an adequate temperature for the medication. The two sensors (temperature and position), placed inside the container, observe any condition changes within the container and send the data to the microcontroller.

The battery charger redirects the power supplied by the DC power adapter and solar cell module to the LiFePO4 battery pack. When the battery pack is discharged, the battery charger redirects the current from the battery to the Peltier controller. It can also communicate with the microcontroller, for example when the charge process is running or the battery is fully charged.

Single Components:

The TMP123 was our chosen temperature sensor. We decided to use this sensor in our project because of its size, its performance, power efficiency and its easy handling.

The TMP123 has a tiny SOT23-6 package size. This made it easy for us to fit it easily into the interior of our relatively small cool bag.

The TMP123 allows measuring of temperature within 2℃ accuracy over a wide temperature range. It is SPI-compatible, which makes it able to communicate with our central microcontroller. It is also a low-power device, needing only a maximum current of 50µA and a supply voltage between 2.7 and 5.5V, which makes it ideal for use in our battery-powered system.

We picked the MSP430F2013 as our microcontroller for operating our system because we required a small and economical, yet powerful processor. The MSP430F2013 supports I²C and SPI communication which makes it ideal for exchanging information with the peripherals in our cooler, such as the temperature sensor or the battery charger. With its small package size, but still 20 pins, it combined saving space with enough room for connecting peripherals. The MSP430F2013 provides 2kByte of flash memory and 256 Byte RAM, making it powerful enough to control our system. The MSP430F2013's timer also proved useful for certain algorithms.

The bq24105 was our charge management device of choice, mostly due to its compatibility with portable applications. The bq24105 designed for charging different types of Lithium batteries, making it the perfect choice for our LiFePO4 battery. It includes high-accuracy current and voltage regulation, charge preconditioning, charge status, and charge termination with power FETs for up to 2 A charge rate.

The bq24105 manages charging automatically in three phases: conditioning, constant current and constant voltage. It automatically terminates charge if current falls below a certain value, and automatically restarts the charge cycle if the battery voltage falls below a certain level. The bq24105 even enters sleep mode automatically with removal of supply voltage for low power consumption.

Functionality:

The microcontroller receives the converted temperature from the TMP123 as a 16 bit word by pulling the $\overline{CS}$ signal low. The data word is then clocked out on the falling edge. The *SCK* signal is generated by the microcontroller. The temperature value is analyzed and sorted into 1 of 5 categories (Table 1). According to the category, the PWM signal is configured. This is done by setting the TACCR0 timer register. With the PWM signal, a power MOSFET is controlled, which adjusts the current through the Peltier element and thus influences the cooling process.

Temperature	**Status in MC**	**Cooling process**
< 15°	0	None (0A)
15°- 18°	1	Weak (up to 200mA)
18°- 20°	2	Medium (up to 500mA)
20°- 25°	3	Intense (up to 800mA)
> 25°	4	Maximum (from 1A up to 1.4A)

Table 1 Operational Modes of the Microcontroller

After the measurement of the temperature is complete, the $\overline{CS}$ signal is pulled high, which causes the temperature sensor to go into standby in order to save power. In standby mode, the temperature sensor continually converts data and then switches to an idle mode for the equal amount of time required for the conversion process. The $\overline{CS}$ signal is also generated by the timer overflow.

For better energy efficiency, a magnetic sensor was attached to the lid of the cooler. By opening the cool bag, the microcontroller receives a signal from the magnetic sensor, causing it to stop the cooling process. Also, the MSP430F2013 then powers down into a semi-standby state.

There are two possible ways to charge the battery. Either directly using a power supply, or by using the two solar cells included in the cooler. Both power sources are connected to the battery pack by a charge management device, which controls the current charging the battery, thus preventing the battery from damage. The solar cells are connected in parallel in order to achieve a maximum charge current.

The Peltier element is placed at the bottom of the cooler, while the temperature sensor is placed at the top. This prevents the temperature sensor from reacting too quickly to changes in temperature, although at its current position, it recognizes the change in temperature more slowly. The electronic components are all placed outside the cooler, since all electronic parts dissipate heat, especially the microcontroller and the large discrete components (resistors and the power FET).

The insulation is made from a Styrofoam cylinder coated with tin foil on the inside ensuring very good thermal insulation.

The circuit board has been assembled with discrete devices as a prototype. Designing a circuit board in SMD technology was too costly at the current state (see future plans). The power FET is triggered by a PWM signal, which makes the FET conductive for a certain period of time before pulling the gate low again (see experimental results). Before the PWM signal can be led to the gate, the voltage had to be raised from 3.3V to about 6V for the power FET. This was made possible by the voltage doubler, followed by the voltage follower to correctly control the power FET.

Experimental Results

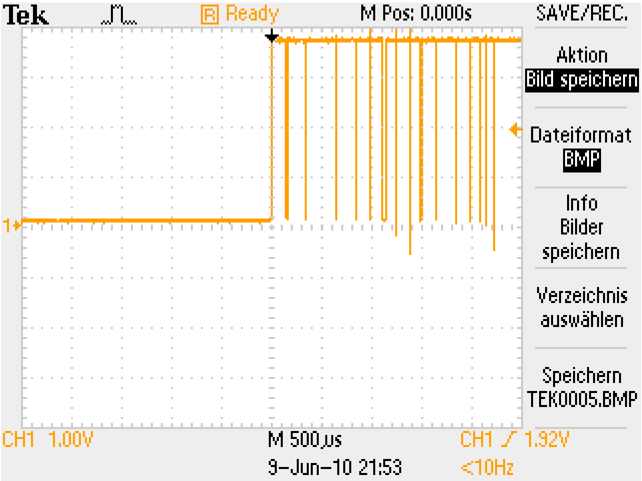
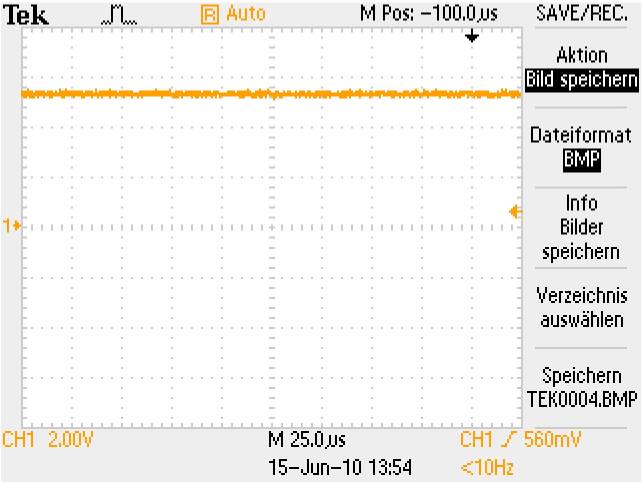


Figure 2: SCK signal from the microcontroller

The communication with the TMP123 worked well, the *SCK* and $\overline{CS}$ signals were triggered by the microcontroller (see Figure 4).

As specified before, the PWM signal controls the power FET. Before this is possible, the voltage doubler amplifies the voltage.



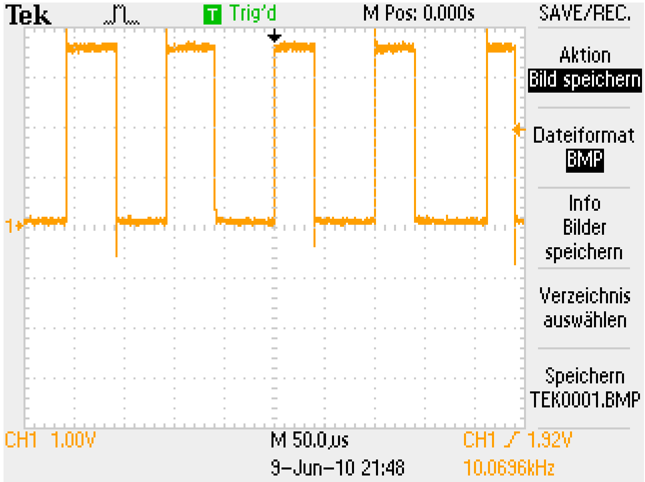
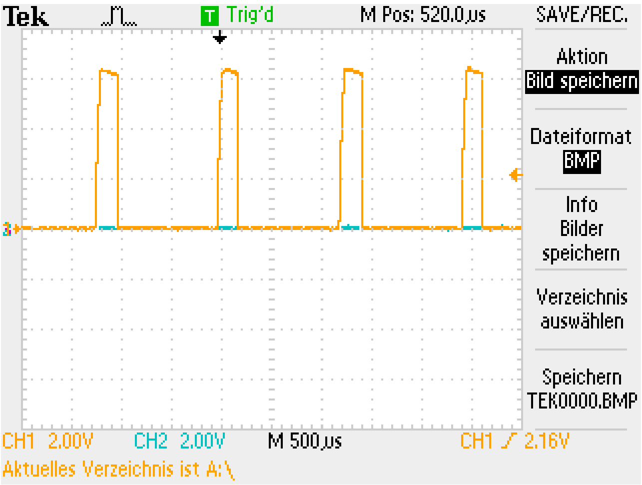


Figure 3: Voltage doubler output

Figure 4: Voltage doubler input

The output (see Figure 5) is nearly constant due to an output capacitor which stores the voltage long enough for it to appear constant. As you can see, input voltage level is about 3.5V. Output is around 5.5V.

The voltage doubler can be seen in Figure 9 Part A. In this circuit simulation, V1 represents the voltage doubler input coming from the microprocessor. V4 stands for the supply voltage from the battery pack. C1 is the capacitor storing the output voltage of nearly 6V.



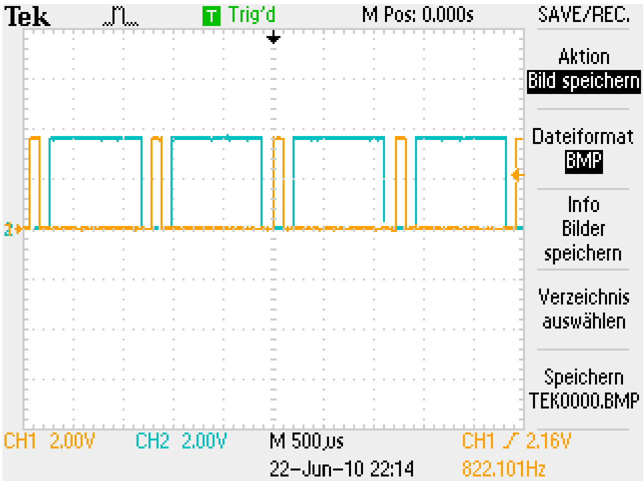


Figure 5: Power FET gate voltage

Figure 6: PWM signal

This voltage is sufficient for controlling the power FET. Now, the PWM signal can be led to the FET's gate.

In the PWM signal picture (see figure 8), the orange oscillograph curve displays the high level gate voltage, while the blue curve demonstrates the low level. In this time period, the gate is pulled low by a bipolar junction transistor. As you can see, the FET voltage (see figure 7) follows the high PWM signal.

The voltage follower circuit is seen in Figure 9 Part B. Here, the output voltage from the microcontroller is converted into the PWM signal for controlling the gate of the power FET. Again, V2 and V3 represent the output pins of the microcontroller, respectively the high (V2) and low (V3) signal. The output voltage for the gate of the power FET is the voltage a Q2.

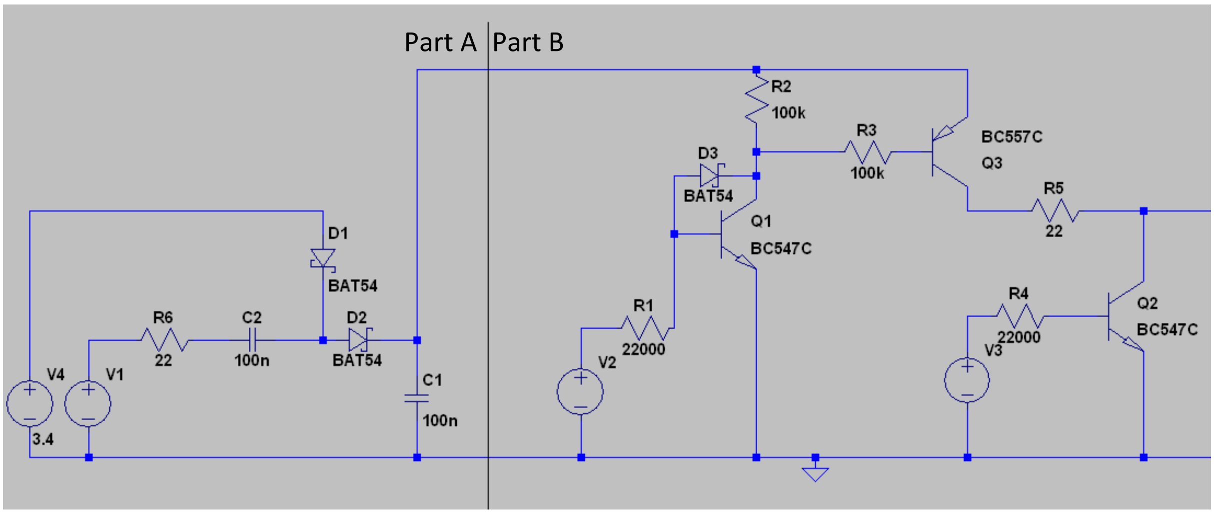


Figure 9: Voltage doubler and voltage follower

Conclusions

During our TI design contest project we developed a first version of a cool bag. First the individual components of this system were built and tested. Then these components were assembled and the whole system was tested. After we solved some problems with the microcontroller and the communication between the components the whole system worked as expected.

In the end we built a first working version of the cool bag.

Nonetheless, the project was astonishingly complex given the fact that designing a cool bag doesn't sound very sophisticated. During this project we saw the big difference between completing a thought-out task at university and to actually shape out an idea as a project, with all the obstacles which have to be overcome.

The one aspect that was not considered in the project was the actual visual design, how to make the cooler optically aesthetic. This and other points will be illustrated under "future plans".

Future plans

As already mentioned under "conclusions", the project does not end here. It will be further optimized.

At this stage, the cooler is still quite bulky and unwieldy, making it difficult to carry around. One future task will be to shrink the whole frame, most of all the circuit board. The circuit board is designated to be redesigned in SMD-technology, making it more compact. The other parts (solar cell, charge management device, battery pack) will be made as small as possible as well. In the final stage, all parts should fit together in one small case.

The cool bag will also be even further improved in saving energy. For example, a charge level indicator for the battery pack would allow exact monitoring of the battery's charge, enabling the microcontroller to adjust the power consumption of the other components.

Furthermore, to improve user friendliness, a display is planned to be installed, on which charge level, inside temperature and the remaining cooling time can be checked at a glance.