

Development of a quantitative smoke detector as a handheld device

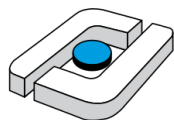
Project report

by

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1 Introduction

A smoke detector is a device that detects smoke, which is typically as an indicator of fire. These devices are often used in commercial, industrial, and residential environments. In general, the detectors issue a local audible or visual alarm from themselves. Most smoke detectors work either by optical detection or by physical process (e.g. ionization), while others use both methods to increase the sensitivity. In commercial and industrial buildings they are usually operated by a central fire alarm system, which is powered by the building power with a battery backup. Whereas in private housings the detectors are in most cases powered by a simple single battery. As already mentioned there are two different types of smoke detectors on the market, the optical and the physical system, of which the device with the optical principle is the more common one. Justified by a cheap prize (10 – 15 €) and a relatively easy construction principle. (USFA FEMA, 2013) (Prosser, 1970) (TheWFSF, 2006)

In general the whole device consists of a smoke chamber and a circuit, which evaluates the signals. In the smoke chamber there is an infrared LED (light emitting diode) and a photodiode as a detector (Figure 1). On the sides of the smoke chamber there are cascades attached to ensure that air can flow into the chamber, but no insects or larger particles, since this would lead to false alarms. The diode emits periodically a light pulse, but the detector normally does not receive a signal because of its placement in the chamber. In the case of fire, smoke particles flow into the smoke chamber. The emitted light gets reflected by the small particles and reaches the receiver. The photodiode shows a voltage increase, which processes the alarm and optionally triggers the signal. (Fischer, 2013)

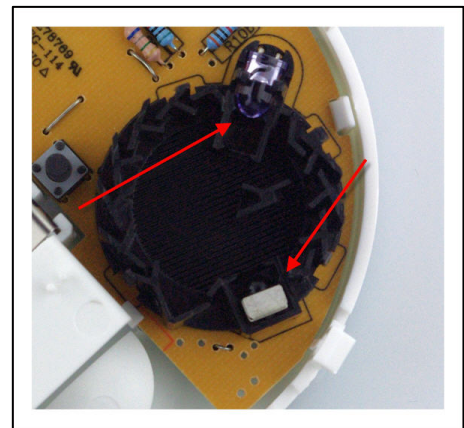


Figure 1: Smoke chamber with LED and photodiode

The outputted voltage by the photodiode can be used in different ways. One interesting example would be the application on display equipped handheld devices with a small screen. Furthermore the signal can be evaluated via large company networks as well.

2 Description of the Project

2.1 General information

Due to the scope of project, the project team was split into two groups. The following information (documentation, implementation etc.) regarding the project have been carried out exclusively by the persons named above.

2.2 Requirements

The requirement of the project was to build a portable smoke detector. This smoke detector has to exist in two versions. One version has to be small, portable and equipped with a small display to read the concentration of the air pollution directly. The other version has to be designed for accommodation in rooms or big industry halls in order to measure the concentration of smoke in the air for a long time. A computer reads out these values. Regarding the design the device has to be developed with consideration to ergonomy, usability and portability.

This project report deals with the second version of the smoke detector and the development and production of a new amplifier board.

2.3 Previous state

The starting point of the project was a 100 x 100 mm large circuit board (figure 2). This printed circuit board (PCB) is used to amplify the analog voltage, which is outputted by the photodiode in the smoke chamber. This chamber was directly mounted on the PCB. This means, if smoke is in the air, the components will be directly exposed to the dust. The distances between the different components are also very large, which leads to a relatively big sized PCB. The wiring of the component was made on the back of the board. These connections were not soldered, but realized with simple isolated wires. This has some significant drawbacks. For example, the tracking of the wiring is very difficult. Furthermore some wires could snap or just tear off, which can cause electrical shorts or even a break down of the board.

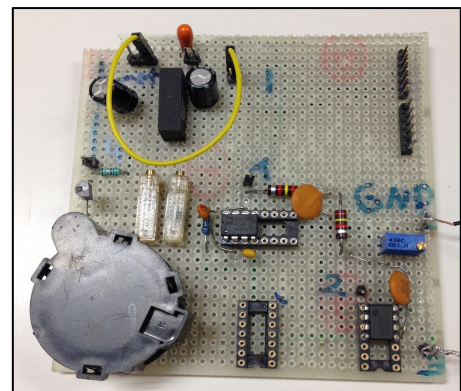


Figure 2: PCB of previous project

3 Experimental part

3.1 Construction scheme

A new, smaller board with the layout editor *EAGLE* has been redesigned. That should replace the old circuit board, which was build up in the Summer University project within last year. For this purpose, at first the old board was analyzed and checked for operation. In the next step the construction of the new board was planed. The result of this is a divided PCB into three sections.

3.1.1 Voltage supply

Figure 3 is an excerpt of the *EAGLE* layout. The external power supply, which has a voltage of 5 V, has to be connected to the junction point 1 (JP1). Capacitor C1 is used for debugging the voltage. The external voltage is applied to a voltage regulator of the company *TRACO POWER*. This regulator converts an input voltage of +5 V to a voltage of +5 V, 0 V and -5 V. The voltage is required to further supply the ICs, and especially the operational amplifier. The two capacitors C2 and C3 are used for suppression or smoothing the voltage.

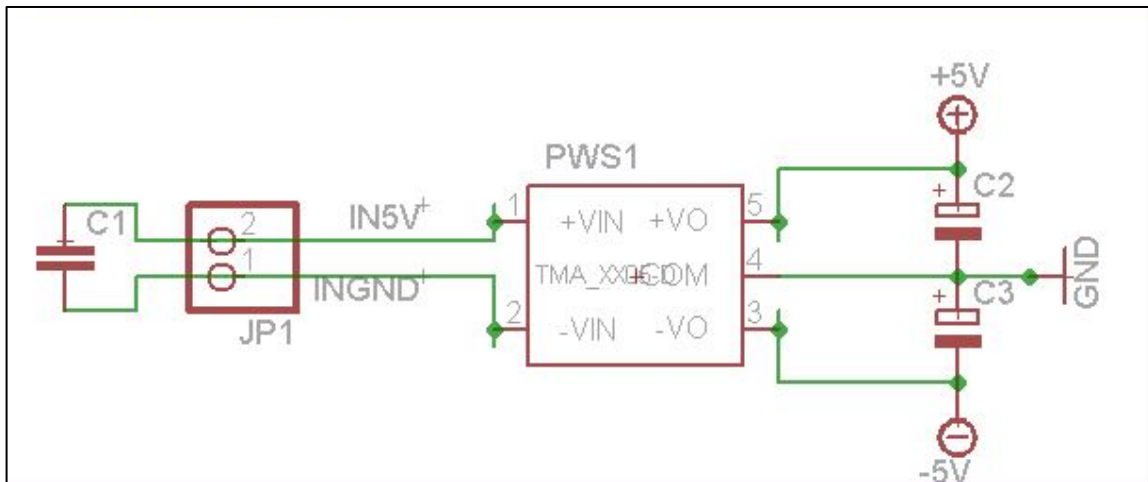


Figure 3: Voltage supply

3.1.2 Sensor control

In Figure 4 the controlling of the infrared LED is described. The IR-LED has to be connected to the junction point “LED”. By means of the JP2, the sensor can be switched on or off with the help of a microcontroller. If there is a voltage of about +5 V applied, the NPN transistor connects through. Thus, the cathode of the IR-LED is connected to GND and at the anode, a voltage of 5 V is applied. Consequently, the diode emits infrared light. The resistor R1 and the trimmer R2 serve to limit the current.

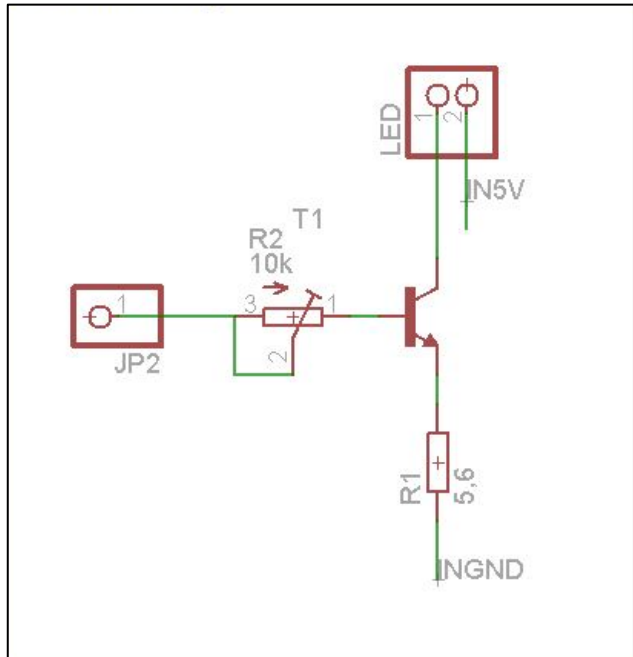


Figure 4: Sensor control

3.1.3 Analysis of the measured values

The evaluation of the analog output values of the photodiode consists of three amplifier stages, which were built using operational amplifiers. These stages amplify the very small analog output signal. Thus one can obtain at the output pin “analog out” a voltage value in the range of 0 V to +5 V.

The three amplifier stages will be discussed in more detail below:

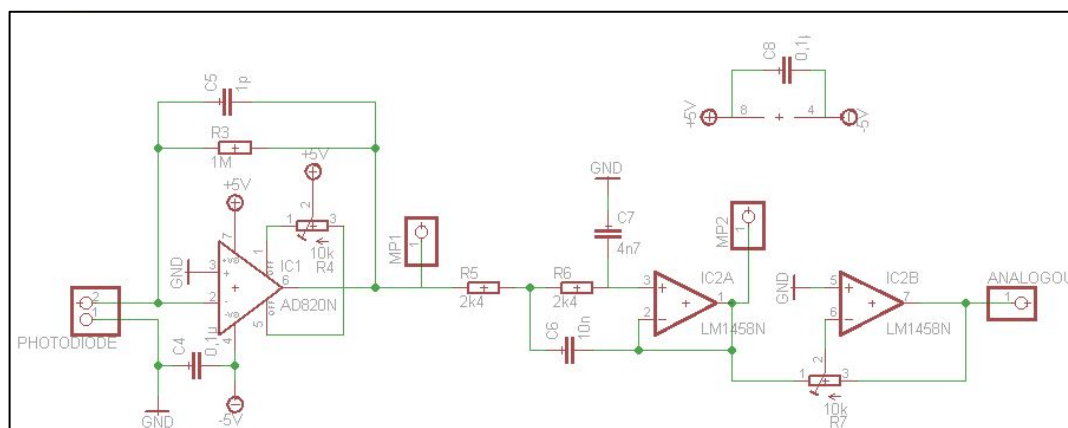
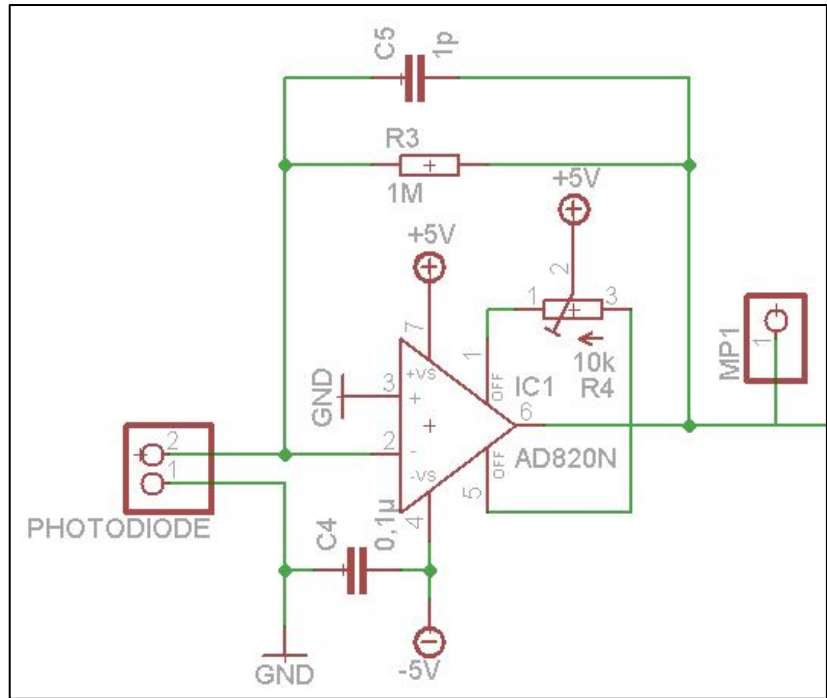


Figure 5: Schematic of the analysis unit

3.1.3.1 First amplifier stage

The first amplifier stage is located at the input of the entire circuit. Here, the photodiode of the smoke sensor is connected. The center part of this amplifier is the operational amplifier AD820N. It is connected as an inverting amplifier. Because of the very large resistance of R3 this circuit has an amplification of -10^6 . Therefore you get for example at a very low voltage of only 10^{-6} V, an output of -1 V at the measure point 1 (MP1).



MP1 represents the output of this circuit. Other

components of the circuit are the trimmer R4, which is used for offset compensation and the capacitor C4, which derived transients of the supply voltage.

3.1.3.2 Second amplifier stage

The second amplifier stage represents an impedance converter. It is connected directly behind MP1. This amplifier circuit has an amplification of 1. Certainly it provides a high input resistance to disposal of the first amplifier circuit. The output of this circuit can be measured at MP2.

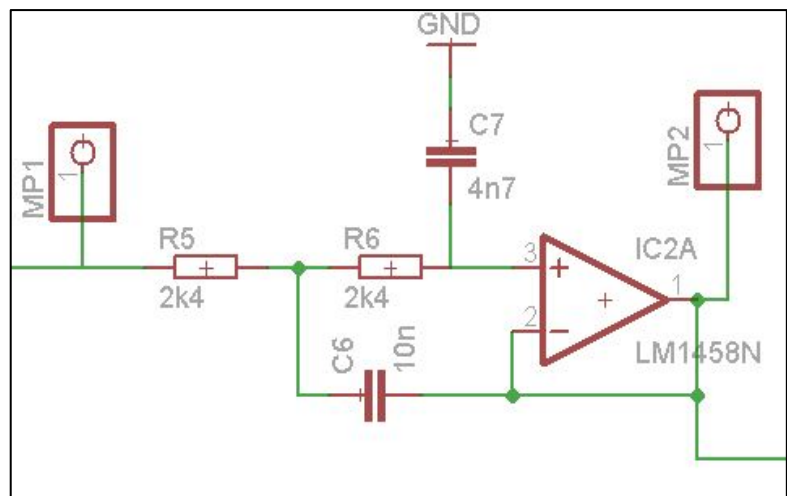


Figure 7: Second amplifier stage

3.1.3.3 Third amplifier stage

The third amplifier stage includes an adjustable inverting amplifier. With the help of the trimmer R7, the amplification can be adjusted, so that it is in the range of 0 V to +5 V, and can be evaluated by the microcontroller.

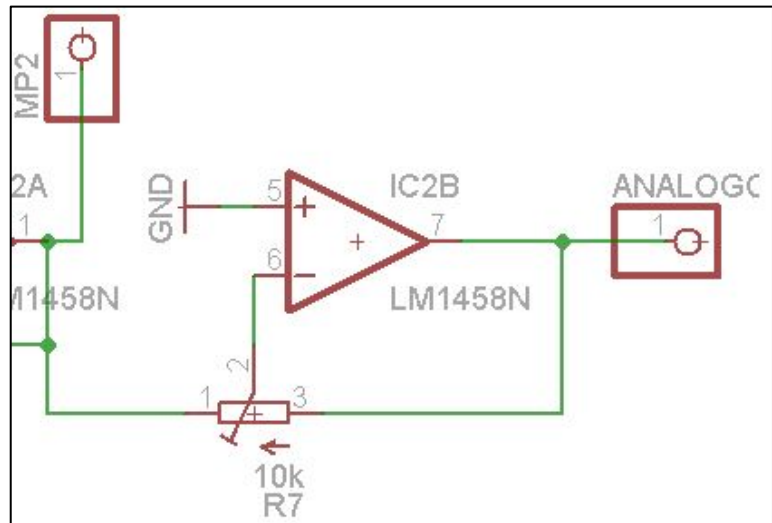


Figure 8: Third amplifier stage

3.2 Development of the layout

After the schematic drawing with EAGLE was completed, the development of the layout was started. The goal was to achieve the smallest possible version that fits into the given hard drive. After some consideration, the size of 5.5 cm x 4 cm was determined, as this provides ample space to accommodate all the components on the board and it still fits in the hard drive housing.

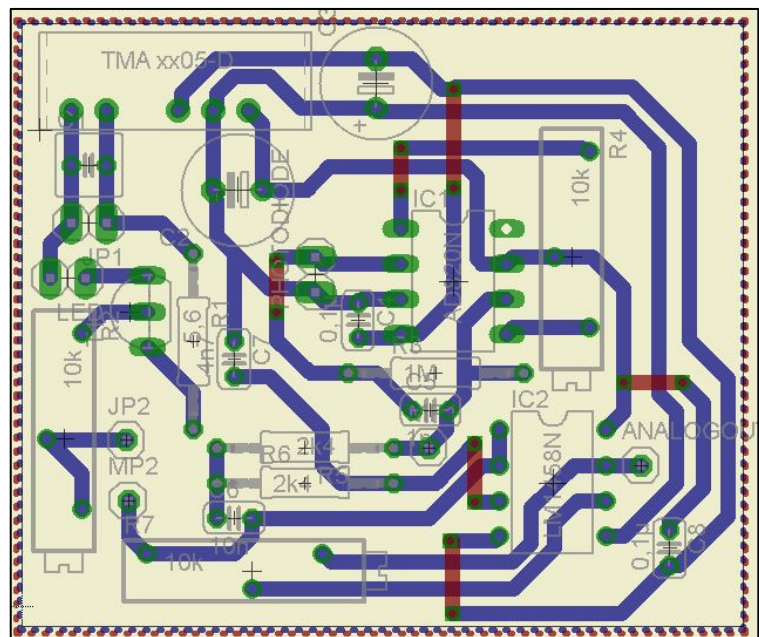


Figure 9: Finished routed layout of the circuit

3.3 Manufacturing the PCB

3.3.1 Milling the PCB

For the manufacturing of the PCB a milling machine was used. This method has some significant advantages like the advanced clean technique and the advantage of not needing any etching liquids like the traditionally etching machine.

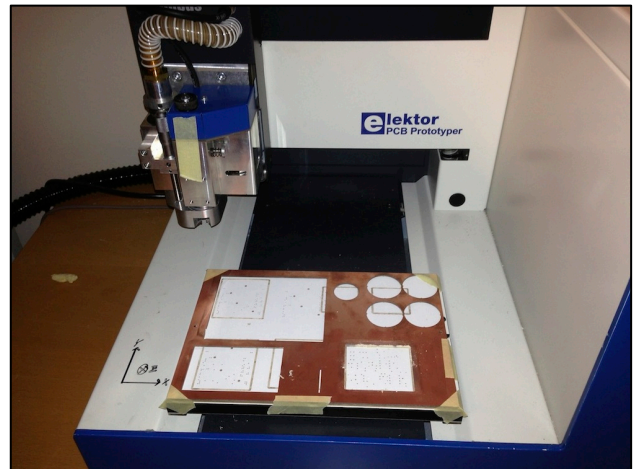


Figure 10: Milling the PCB

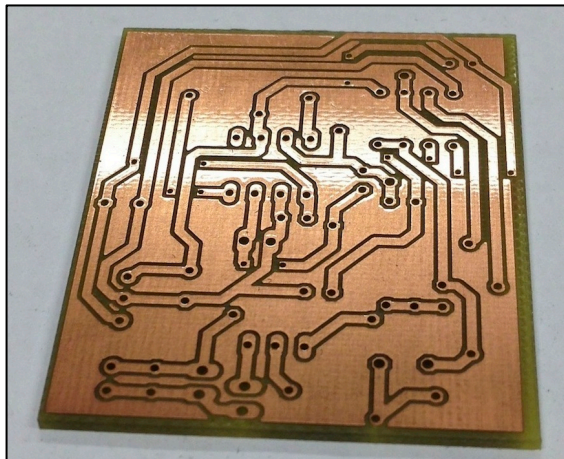


Figure 11: Finished milled PCB

However the EAGLE layout files cannot use directly by the machine. At first one has to create so-called “Gerber” files. With these files, the machine can perform the milling operation.

3.3.2 Equip the PCB

Thereafter, the milled PCB could be assembled. For this purpose, the EAGLE circuit layout was consulted to place the components in the correct order. Step by step the components were soldered onto the circuit board. After that, it has been checked for error regarding the solder joints and it was tested with an oscilloscope for functioning.

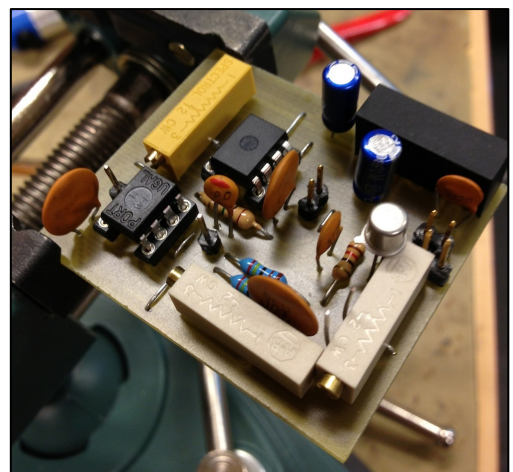


Figure 12: PCB with soldered components

4 Results and conclusions

The aim of this project was to build a small portable smoke detector. This detector should allow sending long-term measured data to a computer, or later via a connected network. Furthermore, the size of the smoke detector was crucial. For this purpose, the previous version of the amplifier board has been redesigned and thus a space saving of over 70% was achieved. In addition, now the smoke chamber can be placed outside the housing of the processing unit, because it is not necessary anymore to solder the chamber on the circuit board. This prevents contamination (dust, humidity, ...) of the boards, which can possibly lead to failure.

Figure 13 shows the final case with the amplifier board and the microcontroller, which demonstrates that the board, prepared within the project, fits well in the given case.

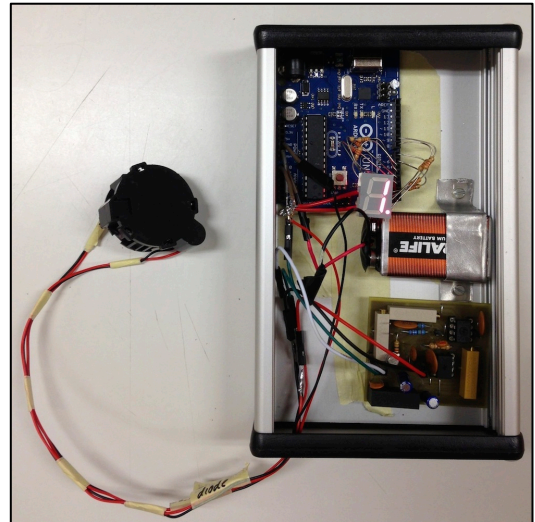


Figure 13: Final case

5 Future prospects

There are many extension possibilities for the smoke detector, which has emerged from this project. A coupling to a CANBUS or ISOBUS would be conceivable. This connection could for example determine the dust concentration in or behind agricultural machinery. These values could be passed on to the terminal of a tractor and displayed or even used in different applications.

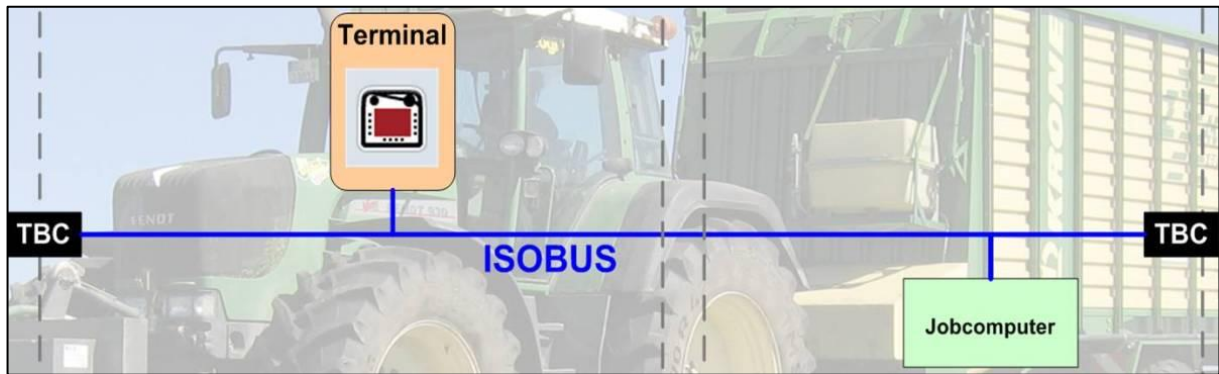


Figure 14: Schematic of ISOBUS (Competence Center ISOBUS, 2013)

Furthermore, an UMTS extension would be also conceivable. Smoke detectors, which have been installed in forests, could warn against any possible occurring forest fires. Even in large cities or at highly frequented roads, the use of these detectors would be possible to measure the pollution or particulate pollution in the air. However, this assumes that a sufficiently good UMTS coverage has to be guaranteed. This should not be a problem in cities but should be checked in remote areas.



Figure 15: A Forest fire in the USA (Steven, 2011)



Figure 16: Particulate pollution causes by cars (Bauchmüller, 2012)

Moreover, an operation of the smoke detector in the industry would be conceivable. With a wireless interface equipped, the current measured values could be sent to a processing computer. However, there could be used other protocols besides wireless, like the ZigBEE or MiWi. Also a Bluetooth connection would be conceivable. The relevant operating range should be noted, for example Bluetooth can be used just for small distances up to 10 m.

In the figure alongside a ZigBee and Bluetooth module is shown. This could be very well suited for the project because the module also can be set up very small.

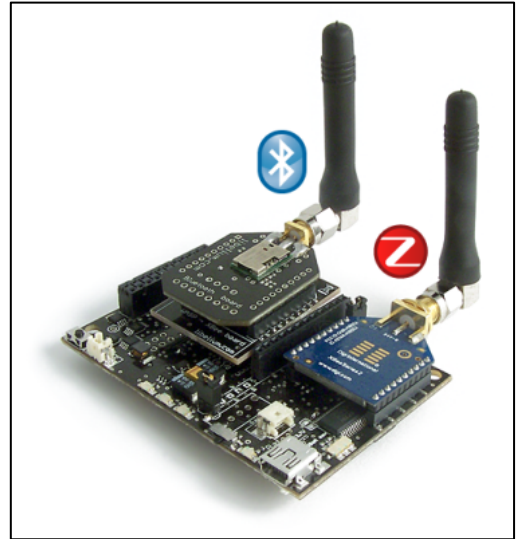


Figure 17: ZigBee and Bluetooth module (Bradley, 2011)

Also in industrial plants an alarm siren and a flashing light would be possible. These should warn workers at a too high smoke concentration in a machine room not to enter, or to leave the room. This could also used on a ventilation system, which reduces the smoke.



Figure 18: Alarm siren (Steubesandt, 2013)



Figure 19: Flashing light (Conrad Electronic SE, 2013)

6 Source materials

Bauchmüller, M. (2012). *Süddeutsche Zeitung*. Retrieved September 9, 2013, from <http://www.sueddeutsche.de/wissen/feinstaub-grenzwerte-dicke-luft-in-der-umweltzone-1.1277278>

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7 Appendix

7.1 Entire circuit layout of the amplifier board

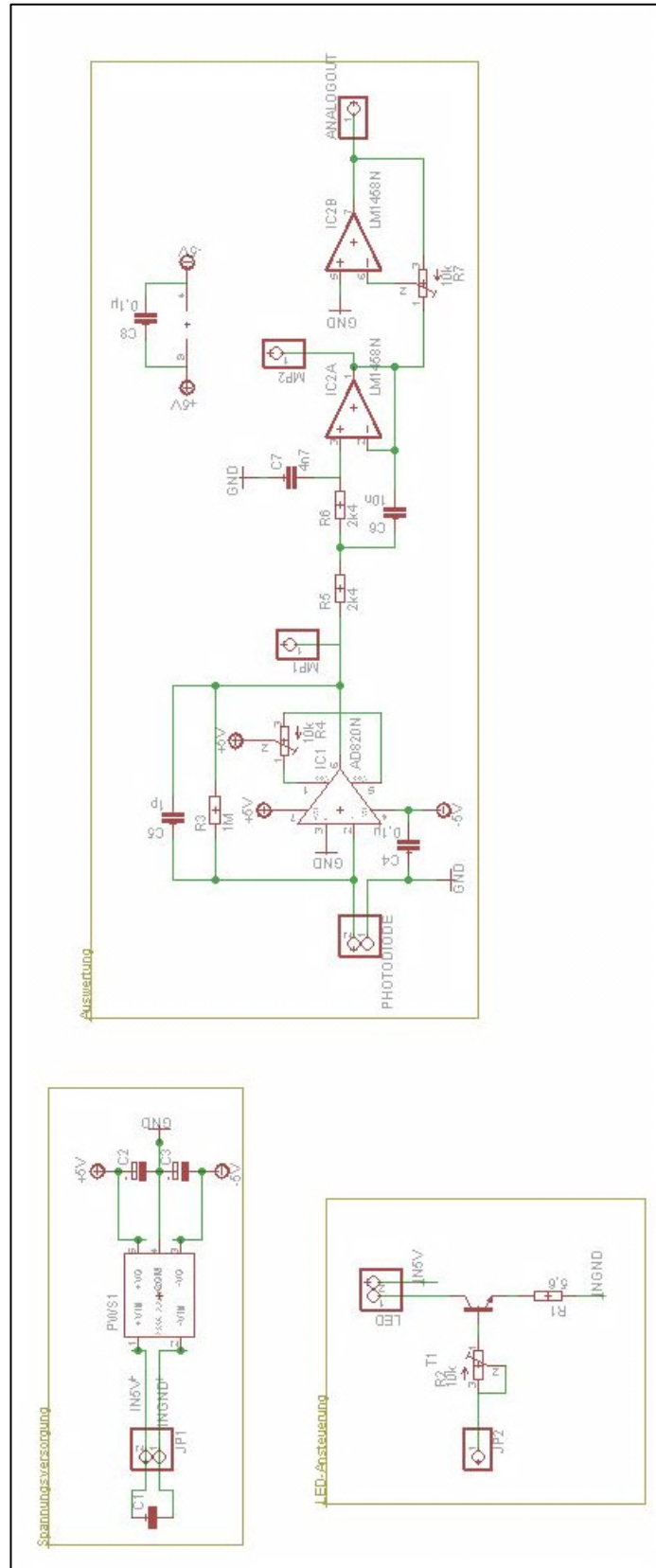


Figure 20: Entire circuit layout of the amplifier board

7.2 Finished routed layout of the circuit

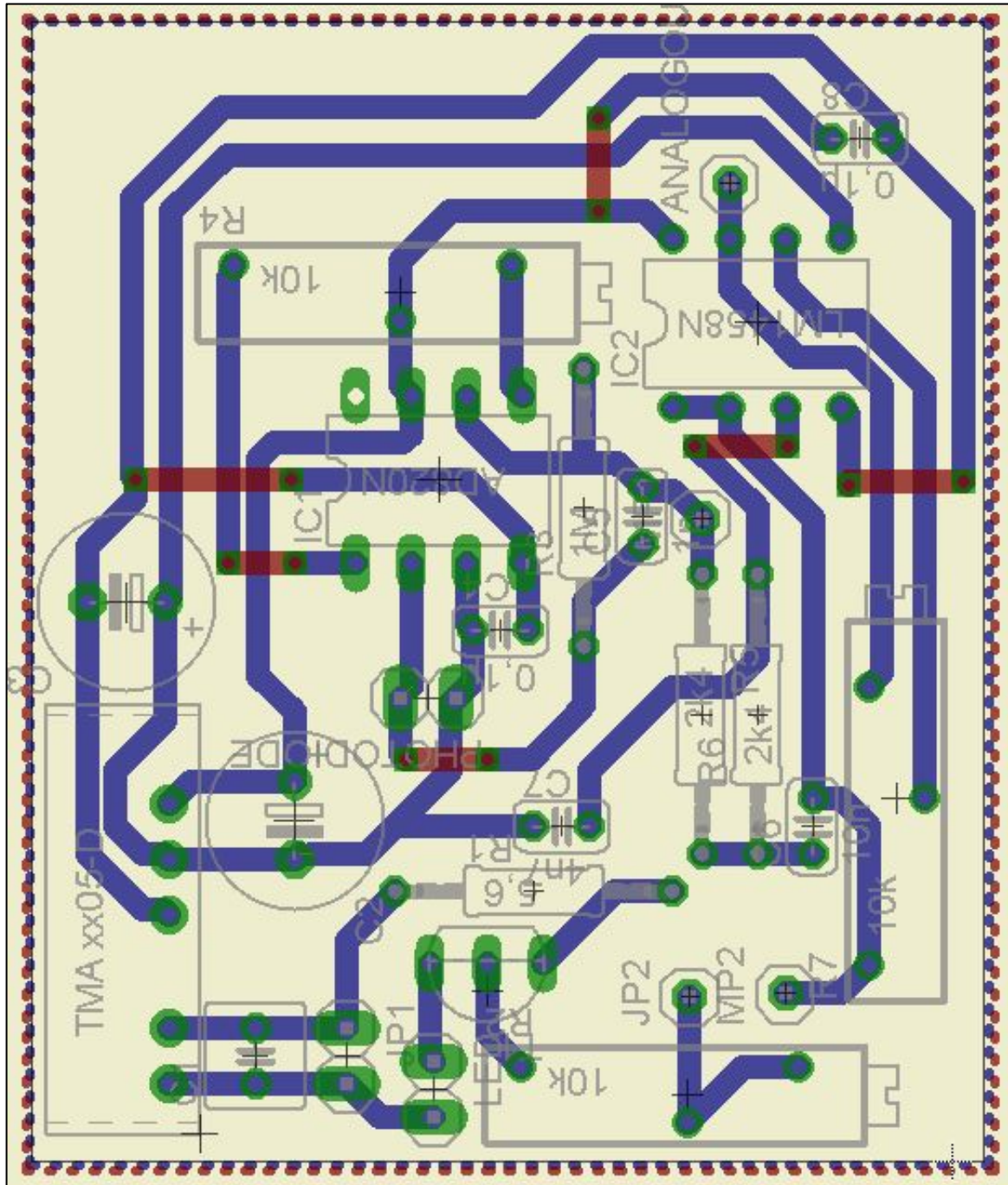


Figure 21: Finished routed layout of the circuit