Intelligent Home Automation

Master Thesis

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Abstract

The aim of this master thesis is to develop a home automation concept by a concrete example of a one-family house which is currently in planning phase. The communication of the components is based on a Controller Area Network (CAN) bus. The control is realized with sensors and actuators which should be cost-efficient. It is central and has a fall-back mode, which means if the control fails or is turned off, only comfort functionality gets lost, but basic functions will still work. So the main objectives are to add comfort functionality, improve security and reduce energy costs.

The basic functionality of this specific intelligent home automation system consists of the control of light sources inside and outside the building, shutters as well as to provide information of temperature sensors, light intensity sensors and the present state of window and door contacts. Additional features, for example multi-room sound or energy consumption measurement might be implemented.

Zusammenfassung

Das Ziel dieser Masterarbeit ist es ein Hausautomatisierungskonzept anhand eines konkreten Beispiels eines Einfamilienhauses zu entwickeln, das sich gerade in der Planungsphase befindet. Die Kommunikation der Komponenten basiert auf einem Controller Area Network (CAN) Bus. Die Steuerung ist mit Sensoren und Aktuatoren realisiert, die kosteneffizient sein sollen. Die Steuerung ist zentral und besitzt einen Fall-Back-Mode, was bedeutet, dass wenn die Steuerung ausfällt oder abgeschaltet wird, nur Komfortfunktionen verloren gehen, jedoch die Basisfunktionen weiterhin funktionieren. Die Hauptziele sind also Komfort hinzuzufügen, die Sicherheit zu erhöhen und Energiekosten zu reduzieren.

Die Basisfunktionen dieser speziellen intelligenten Haussteuerung beinhaltet die Kontrolle der Lichtquellen innerhalb und außerhalb des Gebäudes, Beschattung sowie das zur Verfügung stellen von Temperatursensorwerten, Helligkeitssensoren und dem aktuellen Zustand von Fenster und Türkontakten. Weitere zusätzliche Funktionen wie Multi-Room-Sound oder Energie-Verbrauchsmessung, können implementiert werden.

Acknowledgment

This thesis would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First of all I would like to express my love and gratitude to my mum and my dad for their understanding and keeping me grounded, through the duration of my studies. They enabled me to realize my plans and supported me whatever I wanted to do. Especially, I would like to give my special thanks to my sisters Christine and Petra, who encouraged me to complete this thesis and their loving support.

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1 Introduction

"There is no reason for any individual
to have a computer in his home."
(Ken Olsen, founder and CEO of
Digital Equipment Corp., 1977)

1.1 Background

Nowadays, most technical devices in a home are controlled by microprocessors. Home automation keeps the handling and controlling of many devices simple for the user. Therefore, devices are connected together to a network and interact with each other to manage complex tasks. The user is able to control devices all over the house from a central location, for example a touch terminal or remotely via a smartphone. So far, automation of a building was mainly used for industrial and public buildings, but now it is getting more and more popular in private homes as well.

For me, home automation is an interesting area with a lot of potential. Currently I am involved in supporting a house planning in my personal surrounding. Therefore, I came up with the idea of developing a concept for the electricity installation using home automation.

1.2 Problem Statement

The project will investigate the requirements to implement a home automation system which is optimized to the residents' needs. This includes the development of modules and to put them together in a prototype system.

1.3 Purpose

The purpose of this project is to come up with a concept for a simple and cost-efficient home automation system which fulfills the following major objectives: comfort, flexibility, security, safety and low costs. Furthermore, the concept gives guidelines to plan and realize the electricity installation in the specific house.

1.4 Method

The master thesis is divided into two parts. In the first part, a pre-study is conducted to determine the basic topology and requirements of a home automation system. Therefore, an evaluation of possible bus interconnection technologies and an identification of the tasks are carried out. In the second part, a basic system structure is developed which leads to a system implementation and the development of different modules. Prototypes of these modules are built and tested within a demonstration system. The test results are used to plan the final electricity installation.

2 Home Automation

2.1 Overview and Benefits

Home automation is a subdomain of building automation where building automation is mainly used in industrial and public buildings with the goal to reduce energy costs and employees. In contrast to that home automation is used in residential buildings or simply called “homes” to control, monitor and optimize electric devices in households with the focus on special requirements. The main objectives are to add comfort, flexibility, improve security, safety and low costs. Comfort is added by automating tedious tasks and by a self-explaining and well-designed user interface. Improving security is done by using outdoor cameras and notification mechanisms like door or window contacts to immediately react in the case of an attempted burglary. Safety is addressed by sensors which detect danger to life, for example smoke detectors. The objective “low costs” has two meanings. First, expenses for purchasing and installing the system should be low. Second, reduce energy costs by smart energy management. [1]

Some typical tasks in a home automation system are for example controlling lights, shutters, heating as well as monitoring temperature sensors, smoke detectors or window contacts. The keyword “intelligent” in a home automation system indicates that there is an intelligent control behind the system which can trigger certain actions on upcoming events, for example turn on the light when somebody enters the room. [2]

The user interface or often called “visualization” of a home automation should be intuitive and easy to use. It allows the resident to access all devices via a common user interface such as a touch screen. There is also the possibility to control home functions remotely via the Internet, for example from the work place or a smartphone.

2.2 System and Control

A typical home automation system consists of sensors, actuators and hardware controllers. Basically there are two different ways of controlling a home automation system, the centralized and the decentralized control but also some mixture is possible. The structure of the system determines where the intelligence is located which means if the main part of the controlling software is housed in one component or in all components. In the following section the different structures are compared to each other and advantages and disadvantages are discussed. [2]

2.2.1 Centralized Control

In a centralized system, only one component contains the intelligence and generates actions. The signals from the sensors (switch, brightness sensor, motion sensor, temperature sensor, etc.) are sent to the central component and then it decides which actions have to be done by certain actuators (shutter, relay switch, dimmer, etc.). The master component is essential for the system and if it breaks or is removed, nothing will work anymore. An advantage of this system is that the sensors and actuators do not need much intelligence and are built simple. On configuration changes, only the software in the master component needs to be changed. Expansion costs are lower than with a decentralized system because the sensor and actuator modules contain less intelligence, but initial costs are higher because of the master controller. [2]

In general the master component asks the sensors for new data in regular time intervals which is also called polling. In that case the system would be a single master system. The more slaves are on the bus the more time is needed to request every slave. The other possibility is that sensors are able to send data automatically on a change. This would be then a multi-master system with the advantage that there is less traffic on the bus. [2]

2.2.2 Decentralized Control

In a decentralized system every component contains intelligence and sends out commands directly on the bus. The actuators listen on the bus for commands and decide if a particular command is interesting for them in order to execute an action. Such a system consists of a power supply and input and output devices. So the price for a small system is low, but expansions are generally more expansive than with a centralized system. If a component fails, it will not affect the operation of the other components. The bus activity depends on the number of events and not the number of sensors on the bus. [2]

2.2.3 Semi-centralized Control

A semi-centralized system consists of a few modules (e.g. light switching module, dimming module, shutter module, various sensor modules, etc.) which are standalone and the intelligence is housed there. So if these modules are connected together via the bus, the intelligence is distributed among the various output modules and each output module has only the intelligence to control its own actions. The system consists of subsystems with their own controller. So if one module fails, the other modules can still work. [2]

2.3 Topology

In every home automation system, there is a certain way of wiring between the units. In practice that means where wires need to be installed. To guarantee proper operation, rules have to be followed strictly according to the chosen topology.

2.3.1 Star Topology

In a star topology every module has its own wire to a central connection point. One advantage is that if a wire is broken the certain module will not work but the other modules will. A disadvantage is that a lot of wiring is required and that there are a lot of connections at the central point. [2]

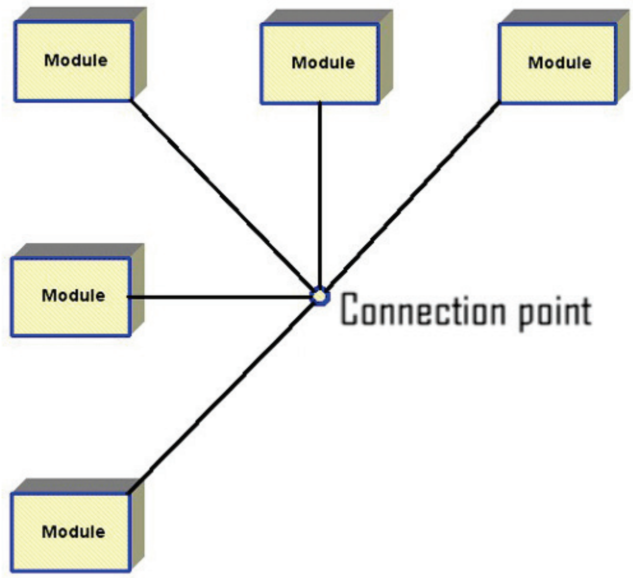

Figure 2.1: Star Topology [2]

2.3.2 Bus Topology

In a bus topology the wire leads from one module to the other where a branch to more than one module is not allowed. In practice often a terminating resistor is required at the ends of the bus to avoid reflections. There is less wire needed compared to star topology but if the bus breaks, more than one module would not work anymore. [2]

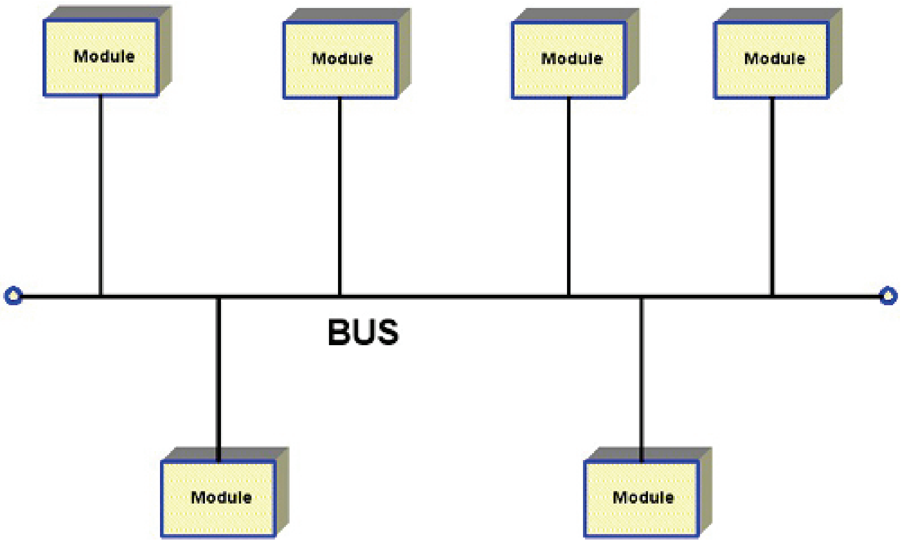

Figure 2.2: Bus Topology [2]

2.3.3 Tree Topology

The tree topology is a combination of star and bus topologies. The installer is free to make any kind of branches, except loops. This topology results in a high flexibility but if a wire breaks more than one module would not work anymore. [2]

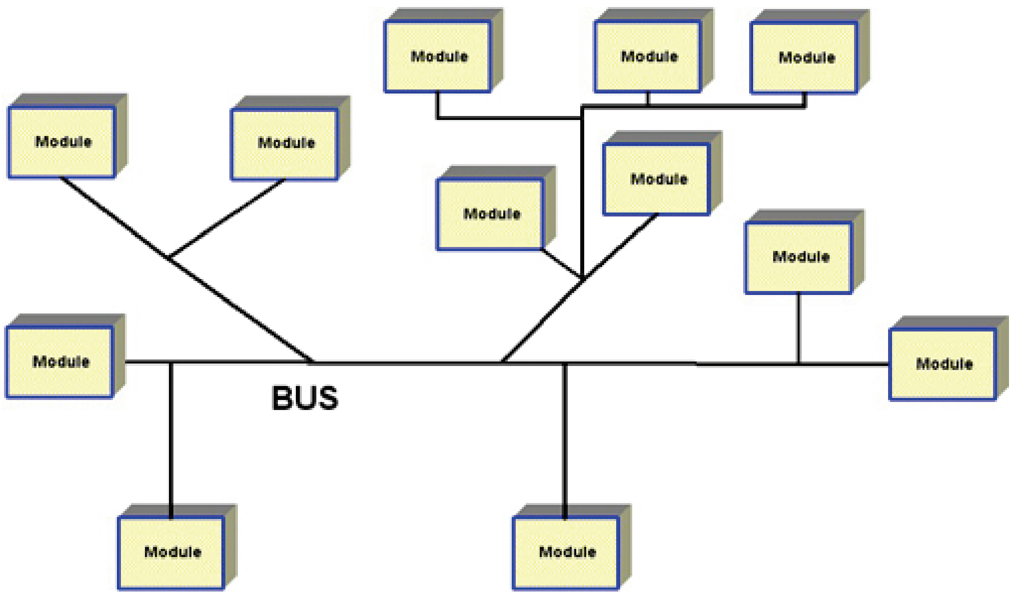

Figure 2.3: Tree Topology [2]

2.4 Interconnection

There are a lot of possibilities how a home automation system is realized in practice to transfer commands and data between the different components. Basically a distinction is drawn between “by wire” and “wireless” systems. In the following section a few bus technologies are evaluated with respect to their properties.

2.4.1 By Wire Systems

On a wire-based bus data is transmitted over one or more wires. There are a few standardized busses especially developed for building automation. There are also a lot of busses which were not directly developed for this purpose but often used in a home automation application. In the following section the most popular wired bus technologies are discussed.

2.4.1.1 KNX/EIB

KNX is a popular standardized network communication protocol for building automation which is based on an enlarged EIB (European Installation Bus) communication stack. KNX supports different communication medias like twisted pair (TP) wiring, powerline networking, radio (KNX-RF), infrared and Ethernet (KNXnet/IP). Due to standardization KNX is independent of any particular hardware platform and there are a lot of manufacturers in the so called KNX Association[1].

The media which is mostly used is twisted pair (two wires) with differential signaling at a speed of 9600 bit/s. Two additional wires (power and ground) power the bus with 30V DC. A KNX bus is a multi-master bus where the media access control is CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and so allows up to 1000 m physical segment length with a freely chosen topology but loops are not allowed. KNX also implements an error correction with retransmission to ensure correct data transmission. To interface a KNX bus special interface modules are needed because the KNX standard is not available in public. These modules are expensive and sometimes rarely available. [3]

2.4.1.2 RS-485

RS-485 (also known as EIA-485) is an interface standard for differential and serial data transmission with high immunity to electromagnetic interferences. Two wires, an inverting

[1] A full list can be found at http://www.knx.org.

and a non-inverting wire, are used to transmit one bit with a half-duplex transmission. By using four wires a full-duplex transmission is also possible. At the receivers side the difference of these two wires is interpreted. The advantage of this technology is that common mode interferences have no effect. Furthermore, distances up to 1200 m are possible in noisy environments. [4]

Due to the fact that RS-485 only specifies the physical properties the user has to take care of error correction and the protocol which might be very application specific. If a multi-master system is used, the application has to take care of the bus access control as well. Data rates up to 12 Mbit/s are possible and transceiver ICs are cheap. Some typical applications for RS-485 are building automation, light control on a stage (DMX512) or as a vehicle bus.

2.4.1.3 CAN Bus

The Controller Area Network (CAN) was originally developed in 1983 at the Robert Bosch GmbH with the purpose to reduce wiring for interconnection between control and sensor devices in a vehicle. Nowadays CAN is also used in many other applications like industrial or medical automation. CAN is a two-wire differential and message-based field bus where the whole protocol including media access control and error protection is already implemented in hardware. The user does not have to worry about collisions on the bus if two nodes want to send at the same time. CAN is typically defined for data rates from 10 Kbit/s to 1 Mbit/s which corresponds to distances of 5 km down to 40 m. Due to these properties this bus fits perfectly for data transmissions in noisy environment with immunity to common mode electromagnetic interferences. The cost of CAN hardware is balanced and there are a lot of microcontrollers with integrated CAN modules available on the market.

2.4.1.4 1-Wire Bus

1-Wire is a single wire device communication bus developed by Dallas Semiconductor to connect sensors together in a convenient way. It is a low-speed bus where each device has a unique 64-bit identifier. A single bus master is needed to poll the devices to obtain data. A 1-Wire bus is a cheap and easy way to connect sensors and actors together, but since there is only one wire, the communication over long wires can be disturbed by electromagnetic distortions easily. This drawback makes it not very suitable for a home automation system because reliability is one of the main aspects there. For more information please refer to the 1-Wire Standard [5] by Dallas Semiconductor.

2.4.1.5 Ethernet

There is also the possibility to use a standard Ethernet network, how it is used in a LAN (Local Area Network), to interconnect the different components used in a home automation system. Ethernet is a multi-master system and provides a high bandwidth which is perfectly for streaming applications like video or audio. Nevertheless, to transmit simple control commands or sensor data, there is too much overhead caused by the TCP/IP stack which is necessary to set up a connection and transmit data. Furthermore, the power consumption caused by Ethernet transceiver ICs as well as the hardware and software complexity is quite high. [6]

2.4.1.6 Powerline

Powerline describes a technique to use existing power lines installed in a building for data transmission. With a special adapter, also called powerline modem, data is modulated on the power supply line and data is received by demodulating the signal from the power supply line. A typical modulation frequency is 2-30 MHz. These high frequencies on the power supply line can result in disturbances of other services in the same frequency range. Energy saving lamps or switching power supplies can have a negative influence on the data signal on the power supply line. To provide the bus signal on all three phases of the electrical installation a phase coupling device is needed. To ensure data security data encryption should be used because data is available on every power outlet. An example for an implementation of a home automation protocol which is based on powerline communication is X10. [7]

2.4.2 Wireless Systems

If a wireless system is used there is no need to install wires which is an advantage if there is an existing building which should be automated afterwards. Nevertheless, security is a very important aspect in a home automation system and wireless systems can be attacked without touching any wires.

2.4.2.1 WLAN

A Wireless Local Area Network (WLAN) is a local radio network standard. Similar to Ethernet, the overhead is enormous compared to the bandwidth which is used to transmit sensor data and control commands used in a home automation system. The energy used to transmit data quite high. Nevertheless, WLAN can be suitable for example for audio or video streaming.

2.4.2.2 ZigBee

ZigBee is a communication protocol standard for low-power radio devices based on IEEE 802 standard. It is designed to address the unique needs of low-cost, low-power wireless sensor and control network. The standard has been developed by the ZigBee Alliance[2] with more than 230 companies involved. The development is still driven by this alliance and ZigBee products have been brought to market already. There are many applications for ZigBee, one is already building automation. The sensors, actuators and control build a mesh network all over the building. A full list of the features and the possibilities of ZigBee can be found at the official website [8].

2.4.2.3 EnOcean

EnOcean is a wireless, energy harvesting technology developed by the EnOcean Alliance[3] with many companies involved. Energy harvesting is a technique, where the small amount of energy which is needed to transmit a short data frame, is generated by electromagnetic generators, piezo generators, solar cells or thermo couplers. This means that most of the components can operate without a battery which makes them maintenance-free. Applications for these devices are for example switches, window contacts or other sensors which transmits their data wireless to a base station on an event. A drawback of this technology is the missing security. All frames can be easily captured with a suitable receiver device. A full list of the features and the possibilities of EnOcean can be found at the official website [9].

2.4.2.4 IrDA

Many remotely controllable devices use Infrared Data Association (IrDA) data transmission. Therefore, it could be convenient to control these devices with an infrared transceiver connected to the home automation control unit. Nevertheless, the distance and data rate is limited. Since a complete home automation system is distributed over the whole building, it is kind of impossible to connect all components with an optical approach. Anyway, IrDA can still be used to control devices locally.

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[2] http://www.zigbee.org

[3] http://www.enocean-alliance.org

2.4.3 Discussion

For this concrete home automation project and with respect to the properties above, a CAN bus provides a good basis to develop such a system. Compared to other technologies, a CAN bus offers the following advantages:

- The whole protocol including media access control and error protection is already implemented in hardware.
- Due to the two wire differential data transmission, the bus fits perfectly for noisy environment with immunity to common mode electromagnetic interferences.
- CAN transceivers are available on the market for many different applications.
- CAN controllers are often already integrated as a module in microcontrollers, which makes them easy to use.
- High level protocols are available, for example CANopen, DeviceNet or TTCAN.
- Compared to wireless bus technologies, CAN can not be accessed remotely since a connection to the bus wires is needed. Some wireless based systems even do not have any security implementation.
- The long term consequences of electromagnetic waves sent out by wireless based systems are not totally clear.

More detailed information about CAN will be provided later in Section 3 of the thesis.

2.5 Tasks

This section describes typical tasks of a home automation system. Of course, there are more possible tasks but the focus is at the most important ones.

2.5.1 Lighting

To switch or dim a light is a basic function of every electricity installation in a house. Nevertheless, it is controlled by a home automation system as well but with the difference that a value can be added to a specific light switch. For example, if a person enters the living room and presses the “watch a movie” button, all the lights are switched or dimmed to a preferred level for watching a movie. Another example would be a “leaving the house” button, where all lights are turned off by pressing only one button. By adding light intensity sensors and movement detectors, the lighting in a room can be adjusted by an overall intensity of light or the presence of a person. [1]

2.5.2 Shutter

For stutters or blinds, a similar approach as for controlling lights, is used. For example, by pressing the “watch a movie” button, the shutters can move to a preferred position. In many home automation systems it is possible to control several groups of shutters simultaneously, for example for each floor. Such a feature safes the resident a lot of time every day if it is not necessary to control each shutter manually. [1]

2.5.3 Heating

Heating, Ventilation and Air Conditioning (HVAC) controlled by temperature and humidity sensors are often included into a home automation system. Depending on the in and outside temperature the heating is adjusted to have a preset temperature value in a room. For example, the resident can turn off the heating when going on vacation and turn it on again remotely a few hours before arriving home. This saves money and helps the environment.

2.5.4 Security

In a home automation system, alarm sensors are used to detect state changes and then decide if an alarm has to be generated or not, depending on the condition. Often used sensors are for example magnetic window or door contacts, smoke detectors, movement detectors, glass breaking sensors etc. These sensors alarm and therefore prevent the resident for example from an out breaking fire or unauthorized access of the building. A possible feature to prevent the resident from burglars is a simulation of presence. This means that lights are switched on and off to simulate presence of a resident.

2.5.5 Audio and Video

Audio and video sources can be distributed to one or more rooms. In such a multi-room system, the channel can be selected and the volume in each room can be controlled individually. Typical audio sources are internet radio, mp3, CD etc. and typical video sources are internet streaming, DVD etc.

2.5.6 Monitoring

Monitor and visualize sensor data to the user. Interesting sensor data can be:

- Temperature of the solar collector
- Water temperature of the heating
- Energy consumption
- Wind speed
- Light intensity

2.5.7 Central Control

Central control is the ability to control and visualize the devices in a home automation system on a single terminal, for example a touch terminal.

2.5.8 Remote Control

Remote control is the ability to control and visualize the devices in a home automation system remotely, for example with a smartphone.

3 CAN Bus

3.1 Overview

The Controller Area Network (CAN) was originally developed with the purpose to reduce wiring for interconnection between control and sensors in automotive devices. Nowadays, CAN is used also in many other applications like industrial or medical automation. It is a two-wire differential and message-based field bus where the whole protocol including media access control and error protection is already implemented in hardware. So the user does not have to worry about collisions on the bus if two nodes want to send at the same time. CAN is typically defined for data rates from 10 Kbit/s to 1 Mbit/s which corresponds to distances of 5km down to 40 m. Due to these properties this bus fits perfectly for data transmissions in noisy environment with immunity to common mode electromagnetic interferences. There are a lot of microcontrollers with integrated CAN modules available on the market.

As mentioned above and regarding to the bus evaluation, a CAN bus is very reliable and has many advantages compared to other bus technologies. For this reason, the decision was made to use a CAN bus for the interconnection in this home automation system. The following section gives a short overview about this bus technology and describes the basic operation.

3.2 Technology

CAN is a multi-master serial differential bus standard for message-based data transmission between different CAN nodes. A message basically consists of an identifier and up to eight data bytes. Each node is able to send and receive messages, but not simultaneously.

The CAN protocol defines the Data Link Layer and part of the Physical Layer in the OSI reference model. Figure 3.1 shows the OSI reference model with the implemented layers in CAN standard corresponding to ISO 11898.

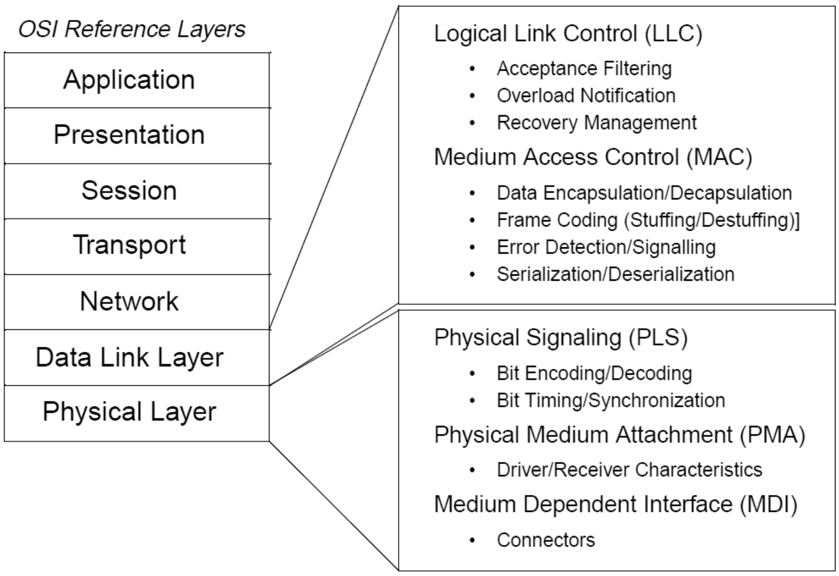


Figure 3.1: OSI Reference Model according to CAN Standard [10]

3.3 Bus Structure

The devices that are connected to a CAN bus are typically sensors, actuators and control devices. These devices are connected through a CAN transceiver, a CAN controller and a microcontroller unit (MCU) to the bus. In many MCUs, the CAN controller is already integrated. The whole device including transceiver, CAN controller and MCU is also called a “node”. The following figure shows a typical CAN bus structure with three nodes and a bus termination resistor at each end of the bus.

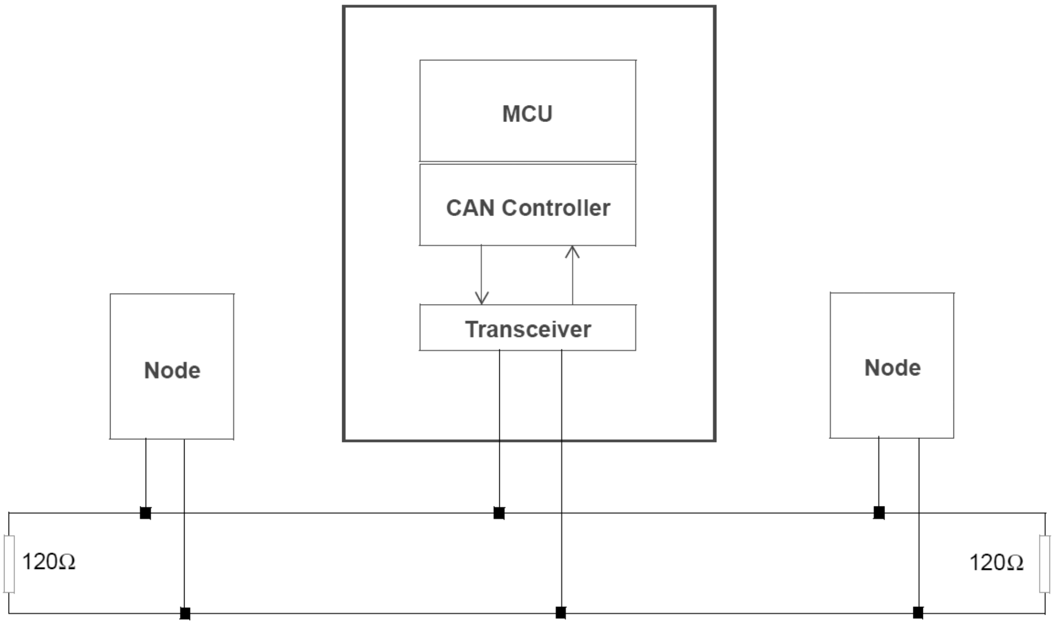


Figure 3.2: CAN Bus Structure [11]

Bus termination is used to minimize signal reflection on the ends of the bus. The ISO 11898 standard requires a line impedance of 120Ω. Therefore, each end of the bus is terminated with a 120Ω resistor. To improve electromagnetic compatibility (EMC) split termination as shown in Figure 3.3 can be used. Split termination is a modified standard termination where the single 120Ω resistor on each end of the bus is split into two 60Ω resistors with a bypass capacitor tied between of the resistors and ground. [11]

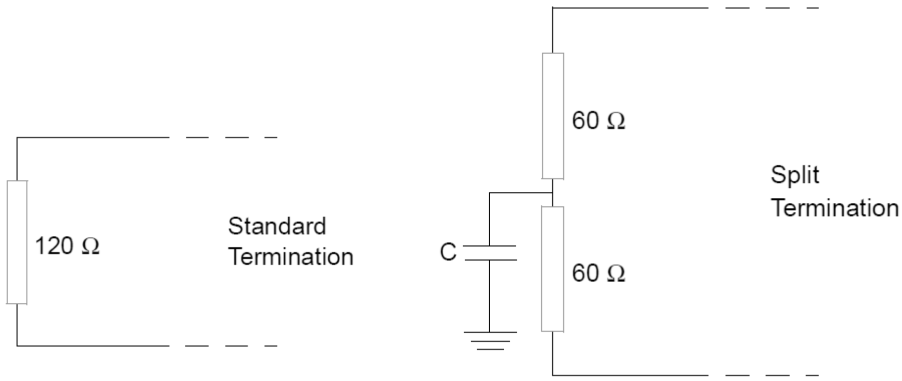


Figure 3.3: Bus Standard and Split Bus Termination [11]

Another additional improvement to increase system reliability with respect to EMC is to use common-mode chokes which are frequently used in automotive CAN. An electromagnetic interference emitted through the CAN communication bus can be filtered to limit unwanted high-frequency noise on the bus. The usage of common-mode chokes also improves the susceptibility of the transceiver to electromagnetic disturbances on the bus. These effects can lead to unexpected results due to signal integrity lost. In the worst case, an extremely high transient voltage, created under a bus-failure condition, can damage the CAN transceiver and other network components. [12]

The following figure shows a typical CAN node termination with optional ESD protection.

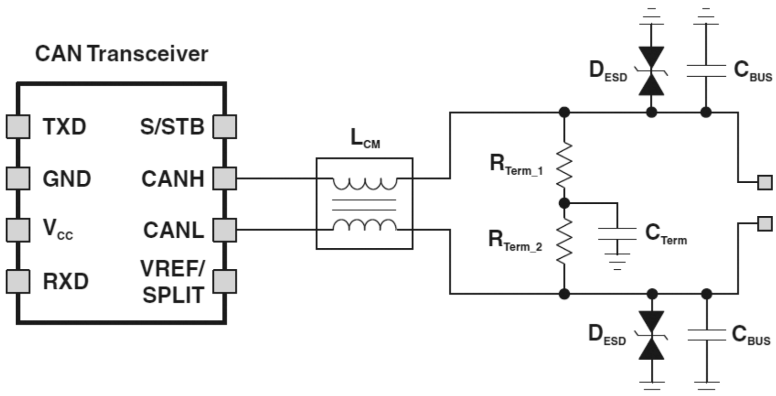


Figure 3.4: CAN Transceiver with Common-Mode Choke and split Termination [12]

The use of a common-mode choke has also the disadvantage that high transient voltages might be generated by the change in current through the inductance of the common-mode chokes if the CAN bus is shorted to DC voltages. The actual transients are highly dependent on the type and value of the common-mode choke, the CAN system architecture, termination and the location of the short circuit. [12]

The best method to avoid transients generated from common-mode chokes caused by CAN bus line shorts are:

- Remove common-mode chokes from systems where they are not needed. [12]
- Choose a common-mode choke type, value and a CAN termination to minimize transients. [12]
- Move transient suppression circuit between the common-mode choke and the transceiver pins. [12]

3.4 Bit Coding

CAN specifies two logical states, recessive (“1”) and dominant (“0”), where the differential voltage between the two wires CANH and CANL is used to represent these states to transmit a bit. The transmission of a bit on the bus is serial and non-return to zero (NRZ) coding is used. Bit stuffing is used to guarantee bus level changes for bit synchronization. Figure 3.5 shows how a bit is transmitted on the bus using the differential voltage.

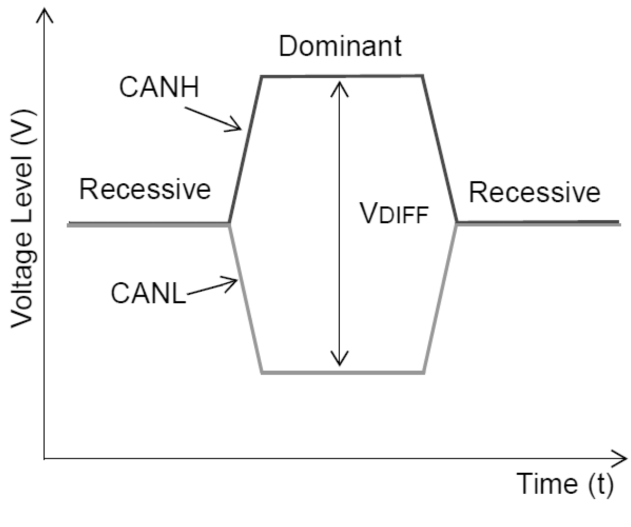


Figure 3.5: Bit Transmission [11]

3.5 Media Access and Arbitration

For media access, carrier sense multiple access/collision resolution (CSMA/CR) method is used. Every node on the network monitors the bus for no activity before trying to send a message on the bus (carrier sense). After that every node has an equal opportunity to transmit a message (multiple access). If two nodes start to transmit a message at the same time, the node with the higher message priority is granted to continue transmitting. This bit-wise arbitration scheme is free of any delay for dominant messages. [11]

3.6 Data Rate

The data rate for high-speed CAN is 1 Mbit/s and for low-speed CAN around 125 Kbit/s. The maximal achievable data rate in a network is limited by the bus length. The main reason for that are the propagation delay on the bus cable, oscillator tolerance and the delay of the transceiver. For more information please refer to the application note AN754 [13] by Microchip.

Bitrate	Bus Length
1 Mbit/s	30 m
500 Kbit/s	100 m
250 Kbit/s	250 m
125 Kbit/s	500 m
10 Kbit/s	5 km

Table 3.1: Bitrate vs. Bus Length [13]

3.7 Bit Timing

At the reception of a message, all nodes on the bus need to be synchronized. Therefore, each node has a clock generator which is synchronized to the bus using a Phase Locked Loop (PLL). The clock generator with the period T_Q generates an integer multiple of the bus bit time T_{BIT}. For the transmission of one bit, each bit time T_{BIT} consists of different segments, where the length of a segment a multiple of T_Q is. [14]

$$Bit\ Rate = \frac{1}{T_{BIT}}$$

$$T_{BIT} = T_Q(Sync\_Seg + Prop\_Seg + Phase\_Seg1 + Phase\_Seg2)$$

Table 3.2 shows the possible length of each segment.

	$Sync\_Seg$	$Prop\_Seg$	$Phase\_Seg1$	$Phase\_Seg2$
Description	Synchronization	Propagation Delay	Phase Segment	Phase Segment
Length in T_Q	1	1-8	1-8	1-8

Table 3.2: Bit Time Segments

The sample point of a bit is between segment 1 and segment 2. It is also possible to configure the receiver to sample the bus three times and do a majority voting. Figure 3.6 shows the sequence of the segments and the location of the sample point.

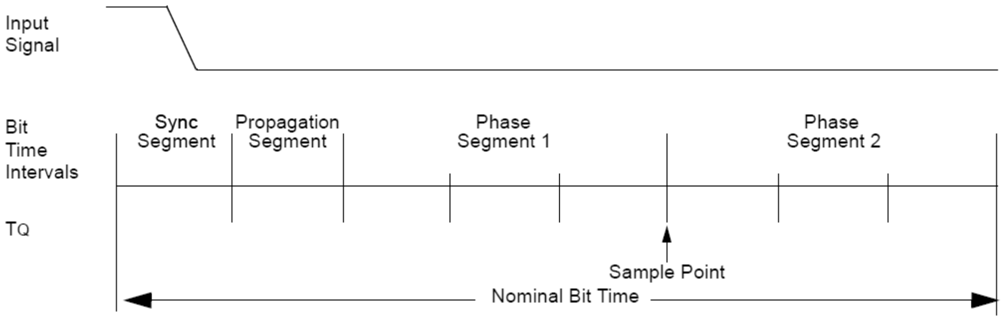


Figure 3.6: Bit Time Partitioning [14]

Figure 3.7 shows the propagation delay of a message from one node A to node B. Usually the reception of the message is then acknowledged by node B which makes the calculation of the maximum bus length more complex.

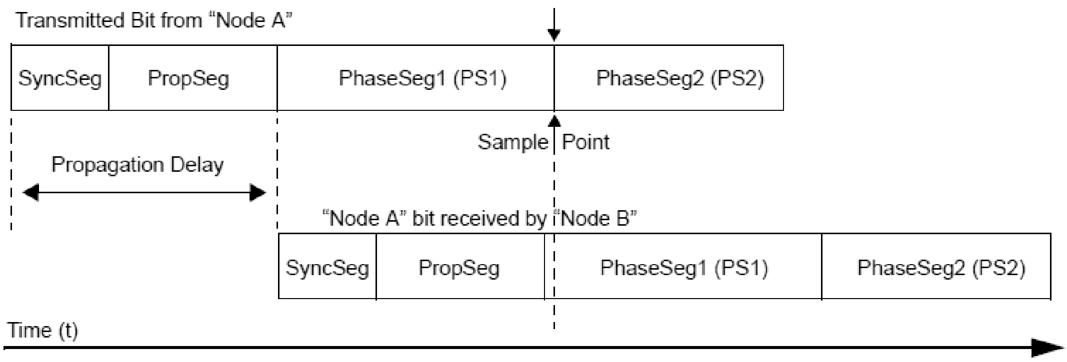


Figure 3.7: Propagation Delay [13]

3.8 Frame Format

The communication on a CAN bus is based on frames which consist of control and data bits. In this section, the different frame types are described. For more detailed information, please refer to CAN specification [15] by Bosch.

3.8.1 Data Frame

The purpose of a data frame is the transmission of user data. There are two different types, the standard and the extended data frame. The difference is only the number of identification (ID) bits. The standard data frame consists of 11 and the extended data frame of 29 identification bits. The identifier defines the message ID and also assigns a priority to it. Since “0” is the dominant bus level, low identifiers have higher priority than higher ones. The acknowledge slot (ACK) is used to confirm the reception of the message by overwriting the recessive bit by dominant one.

Figure 3.8 shows the structure of a standard and Figure 3.9 of an extended data frame.

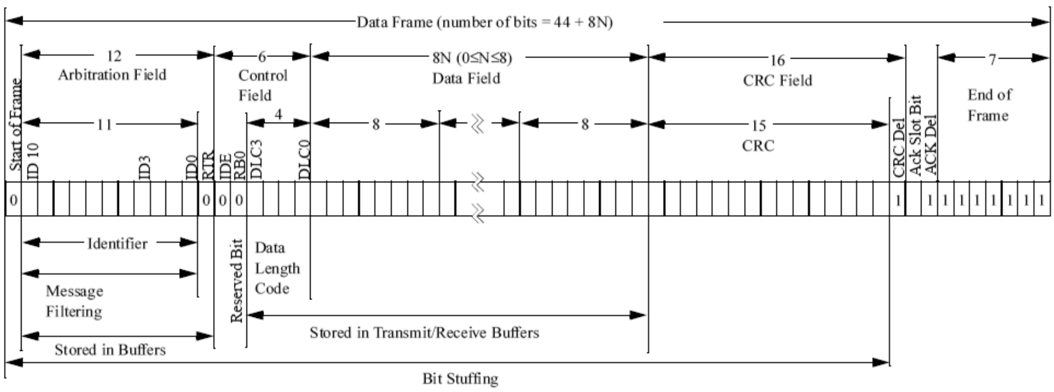


Figure 3.8: Standard Data Frame (CAN2.0A) [10]

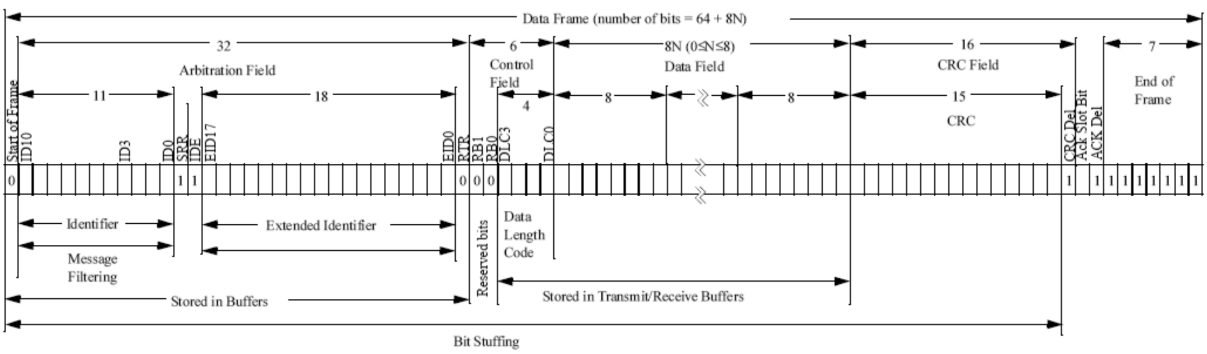


Figure 3.9: Extended Data Frame (CAN2.0B) [10]

3.8.2 Remote Frame

A remote frame is used to request data from another node. This is done by setting the Remote Transmission Request (RTR) bit to "1". The data length code (DLC) of a remote frame is the number of bytes which are expected in the answer data frame.

3.8.3 Overload Frame

An overload frame is transmitted if a delay between a remote frame and a data frame is required by a receiver.

3.8.4 Error Frame

An error frame is transmitted if a transmission error occurs on the bus. The purpose is to inform other nodes that an error occurred and they have to transmit their data again. The error frame consists of 6 or more sequential dominant bits which are a violation of the coding specification.

3.9 Error Detection

The CAN protocol provides advanced mechanisms for error detection during data transmission. The detectable errors are: form error, bit error, bit stuffing error, CRC error and acknowledge error. For more information about the different error types please refer to the CAN specification [15] by Bosch. If one of the errors above is detected by a node, it informs the other nodes immediately by sending out an error frame. After that the nodes throw away the received invalid message and also transmit an error frame. If the bus is inactive again, the sender starts to retransmit the original message. Due to this algorithm it is guaranteed that no information gets lost.

To make sure that broken nodes, which are not able to receive a message correctly, block the whole bus, every CAN controller has a specific algorithm implemented. Every CAN controller has two error counters, one transmit error counter (TXERRCNT) and one receive error counter (RXERRCNT), which are incremented if a transmit or receive error occurs. Depending on value of the counters, the controller is in a different error state. There are three stares available: "error-active", "error-passive" and "bus-off". The "error-active" state is the usual state where the node can transmit messages. In the "passive-error" state, messages and passive error frames can be transmitted. The "bus-off" state makes it temporary impossible for the node to send or receive any messages. From the “passive-error” state the controller is able to recover but from the “bus-off” state, only a reset can leave this state. [14]

Figure 3.10 shows the error state diagram and the sequence on certain conditions.

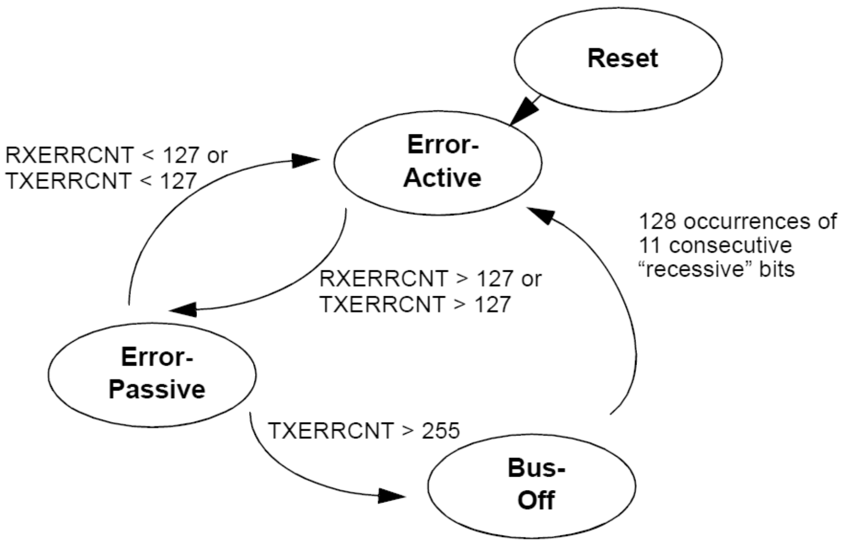


Figure 3.10: CAN Error State Diagram [14]

3.10 Transceiver

This section contains a short overview about the used CAN transceivers in the different modules.

3.10.1 SN65HVD251

The SN65HVD251 manufactured by Texas Instruments is a CAN transceiver according to ISO 11898 standard. The device is designed to operate in harsh environments with data rates up to 1 Mbps. [16]

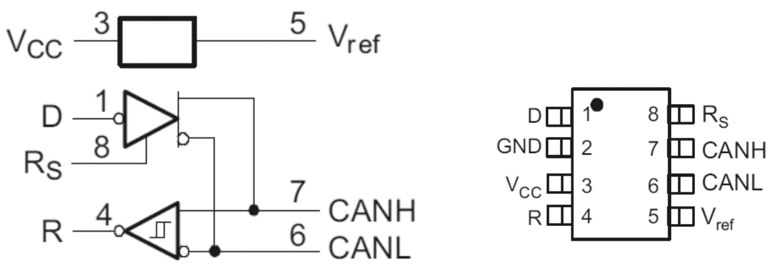


Figure 3.11: SN65HVD251 Circuit and Package [16]

3.10.2 MCP2551

The MCP2551 manufactured by Microchip is a CAN transceiver that implements ISO 11898 standard physical layer with data rates up to 1 Mbps. [17]

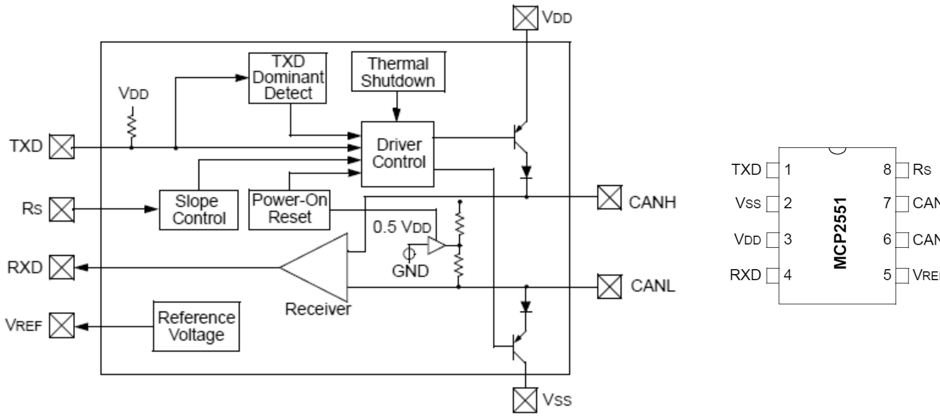


Figure 3.12: MCP2551 Block Diagram and Package [17]

3.10.3 ADM3053

The ADM3053 manufactured by Analog Devices is an isolated CAN transceiver with an integrated DC-DC converter. The device creates a fully isolated interface between CAN protocol controller and the physical layer bus with data rates up to 1 Mbps. [18]

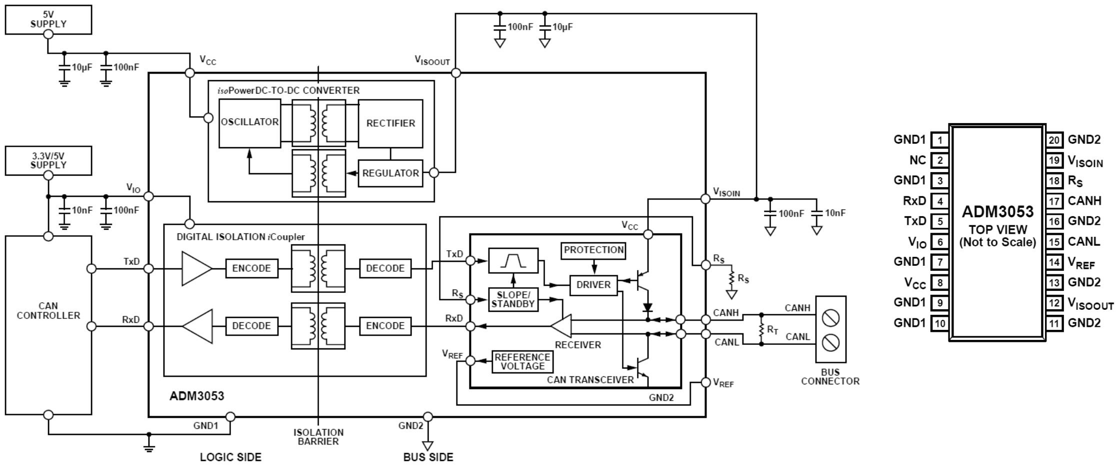


Figure 3.13: ADM3053 typical Application Circuit and Package [18]

4 System Implementation

4.1 Basic System Structure

The system implementation consists of several different components which are described later in this section more detailed. Figure 4.1 shows the block diagram of a typical home automation system configuration and how the different modules are connected with each other.

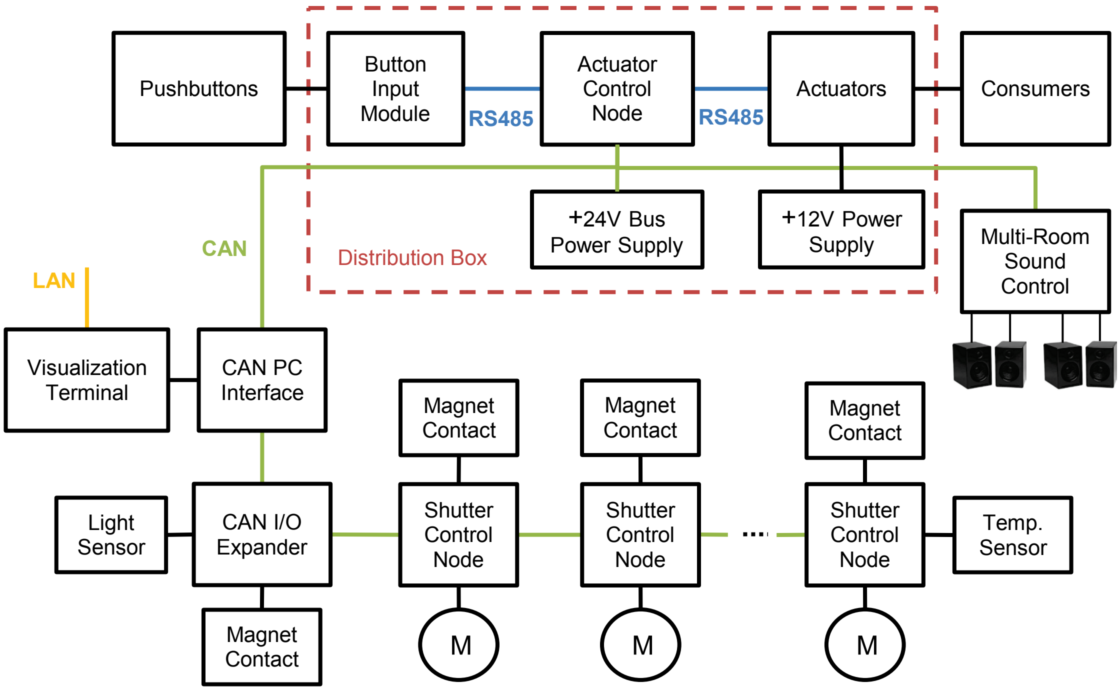


Figure 4.1: Block Diagram of the implemented System

4.2 Bus Interconnection Medium

To connect the different CAN nodes together, a suitable bus cable is needed. Therefore, an EIB/KNX certified bus cable is used. This cable has a typical green colored jacket to make it easy to distinguish from other cables. It has two twisted pairs of 0.8 mm² wires which are all covered with a metal shield. The impedance of the cable is usually 100Ω. EIB/KNX certified bus cables have an isolation voltage of 4kV and can hence be installed next to other 230V power lines.

Two commonly used cable types are:

- YCYM 2 x 2 x 0,8
- J-Y (ST) Y 2 x 2 x 0,8, EIB edition

Figure 4.2 shows a typical KNX/EIB certified bus cable how it is used for the CAN bus in this project. The connection assignment is described in Table 4.1.

Connection	Color
+24V	Red
Ground	Black
CANH	Yellow
CANL	White

Table 4.1: Connection Assignment according to the CAN bus

Figure 4.2: KNX/EIB certified Bus Cable [19]

To connect a component to the bus, the cable is split up and connected together again using an EIB connector. The component is connected to this connector as well. Figure 4.3 shows EIB connecters manufactured by Wago.

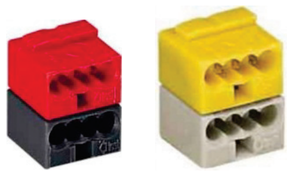


Figure 4.3: Wago EIB Connectors

4.3 Bus Power Supply

To power the modules connected to the CAN bus, a DR-75 industrial power supply manufactured by Mean Well is used. It is a 230V to 24V switching power supply and delivers up to 75W. The supply can be mounted to the DIN rail TS-35 and comes with several features and protections, for example short circuit, overload, over voltage and over temperature protection. For more information about the DR-75 power supply, please refer to the datasheet [20].

Figure 4.4: Mean Well DR-75 Power Supply and Wire Assignment [20]

4.4 Module Power Supply

4.4.1 Step-Down Converter

The MAX1837 manufactured by Maxim Semiconductor is a high-efficiency step-down converter which converts the 24V bus supply voltage to a preset 5V output voltage to power the modules connected to the bus. The converter delivers load currents up to 250mA with efficiency over 80% at a 24V input voltage. On no load operation the quiescent current is only 12µA.

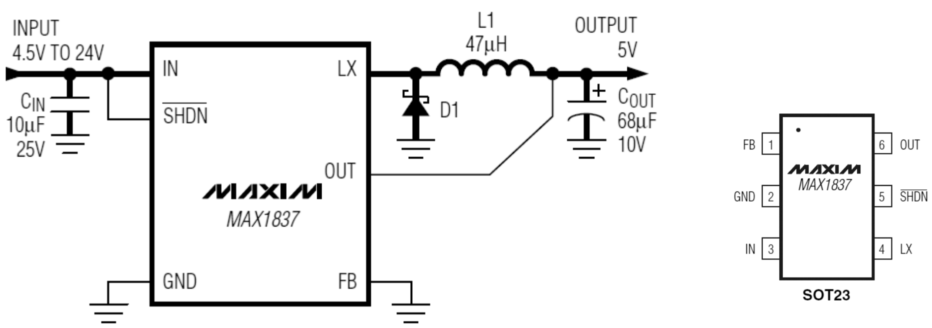


Figure 4.5: MAX1837: typical Operation Circuit and Package [21]

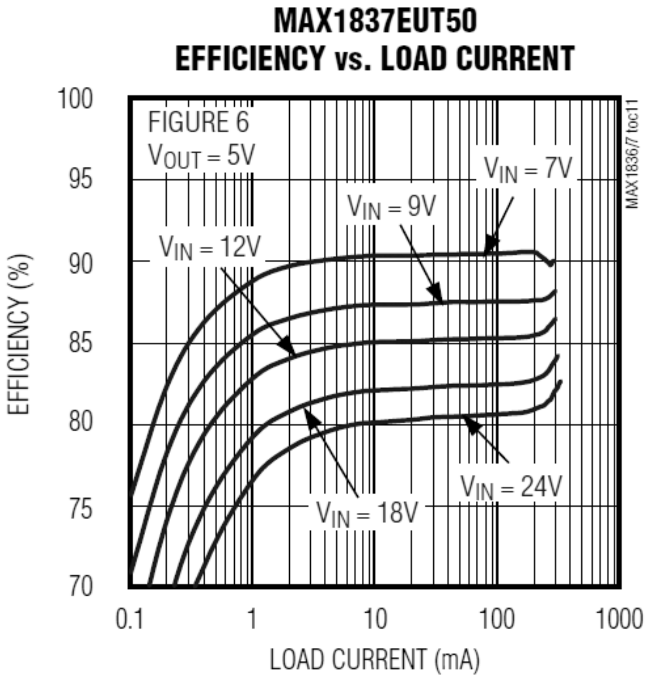


Figure 4.6: MAX1837: Efficiency vs. Load Current [21]

4.4.2 Fixed Voltage Regulator

For simple modules with low current consumption it is not necessary to have a step-down converter. Instead, a fixed voltage regulator can be used to power the circuit. Therefore a TPS7A6550 linear low-dropout regulator manufactured by Texas Instruments is used. This device is designed for low power consumption and quiescent current less than 25µA. It delivers load currents up to 300mA at 5V output voltage with a maximum input voltage of 40V.

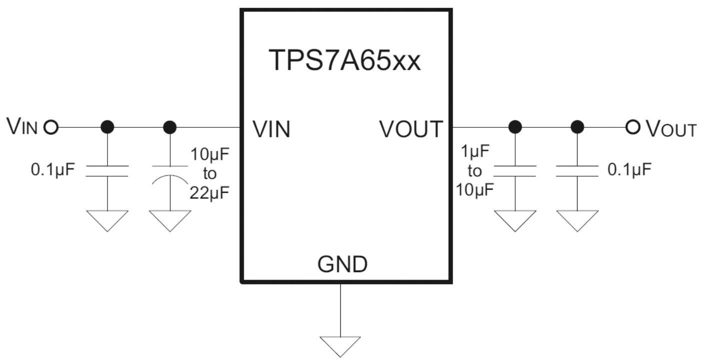


Figure 4.7: TPS7A6550: Typical Application Circuit [22]

4.5 Microcontroller

4.5.1 General

The PIC18F4685 microcontroller of the PIC18F family manufactured by Microchip is an 8 bit RISC microcontroller with many features and already integrated peripherals. The microcontroller is the control unit of each CAN node in this project. It has an already built-in CAN module which makes it unnecessary to have an external CAN controller.

4.5.2 Features of the PIC18F4865

This section describes the main features of the microcontroller as well as the pinout of the used package and a functional block diagram. The main features are:

- 64 Kbyte Flash Program Memory
- 3 Kbyte Data SRAM
- 1 Kbyte Data EEPROM
- 10 MIPS (at 40 MHz)
- CAN 2.0B Module
- SPI, I²C, USART
- 8 channel 10-Bit ADC
- 4 Timer (1x8-Bit, 3x16-Bit)
- Supply Voltage: 2,0V-5,5V

Figure 4.8 shows the pinout of the PIC18F4685 microcontroller in 44-pin TQFP package.

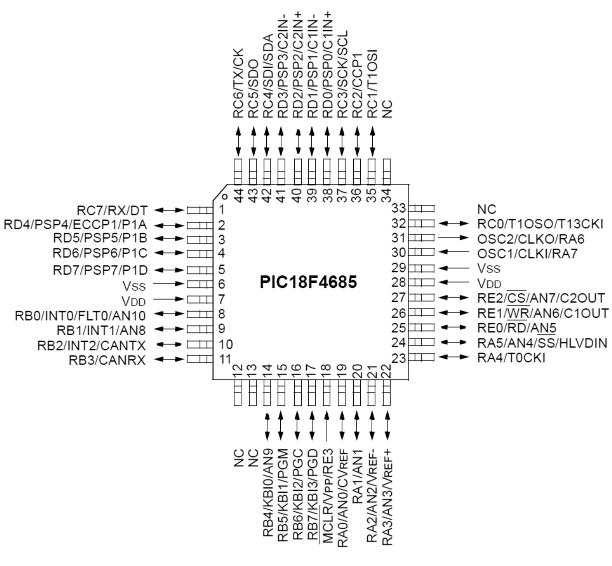


Figure 4.8: Pinout of the PIC18F4685 in 44-pin TQFP Package [14]

Figure 4.9 shows the Block Diagram of the PIC18F4685 microcontroller.

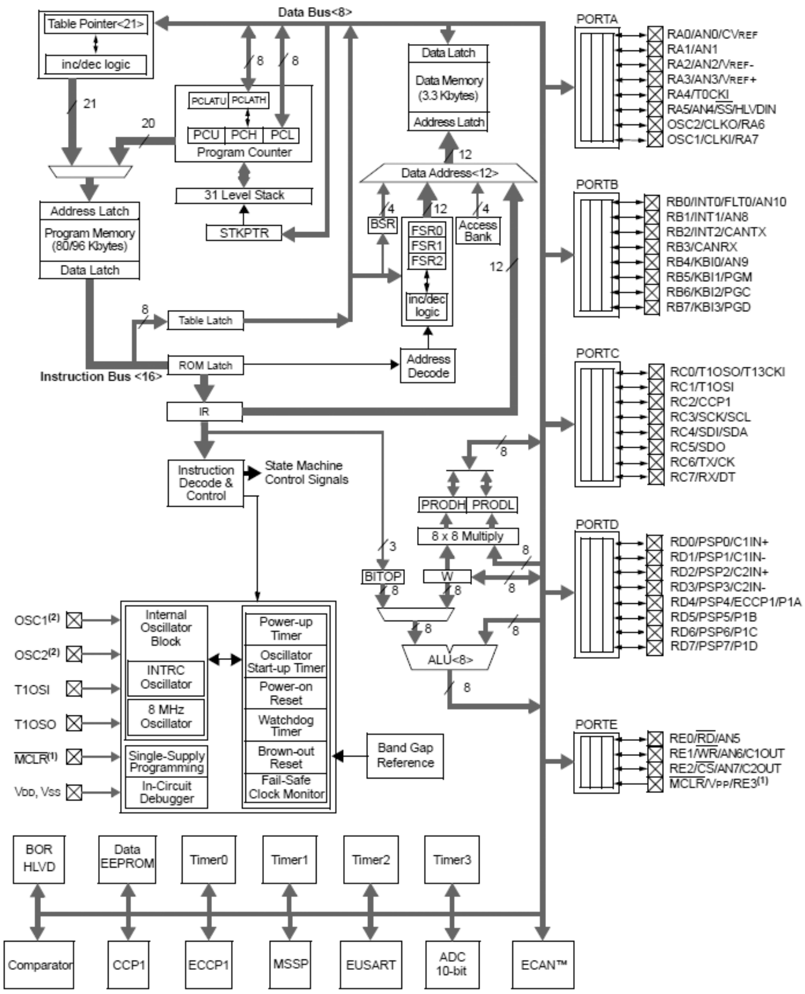


Figure 4.9: Block Diagram of the PIC18F4685 [14]

4.5.3 ECAN Module

The integrated Enhanced Controller Area Network (ECAN) module implements the CAN2.0B protocol as defined in the Bosch specifications [15]. The module is a serial interface to communicate with other devices or peripherals in noisy environments. For more information about the ECAN module please refer to the PIC18F4685 datasheet [14].

Features:

- Data Rates up to 1 Mbit/s
- 3 Transmit Buffer
- 2 Receive Buffer
- 6 programmable Receive/Transmit Buffer
- 6 Receive Filter

Figure 4.10 shows the block diagram of the ECAN module of the PIC18F4685.

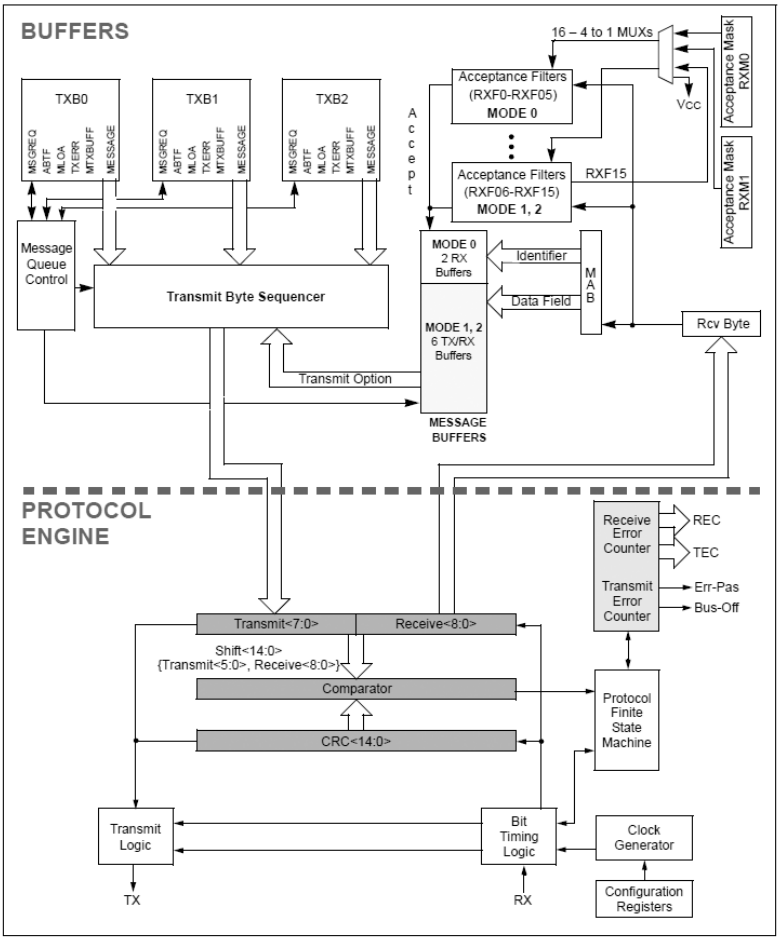


Figure 4.10: ECAN Module Block Diagram [14]

4.6 CAN I/O Expander

The MCP25055 manufactured Microchip, is a pre-programmable CAN I/O (input/output) expander implementing the CAN2.0B standard. With this device it is easy to implement a simple CAN node without needing a microcontroller. It features many peripherals, like digital I/O, four channel 10-bit A/D (analog/digital) converter and PWM (pulse width modulation) outputs. The expander is able to transmit messages automatically, for example if a digital input pin changes or an analog input exceeds a preset threshold. For more information, please refer to the datasheet [23].

This CAN I/O expander can be used for a window or door contact to monitor if it is open or closed. Therefore, a digital input is used and the device is configured that a predefined message is transmitted on a pin change. For most of the time, the device is in sleep mode and only wakes up on a pin change interrupt. Figure 4.11 shows the block diagram and the package of the MCP25055.

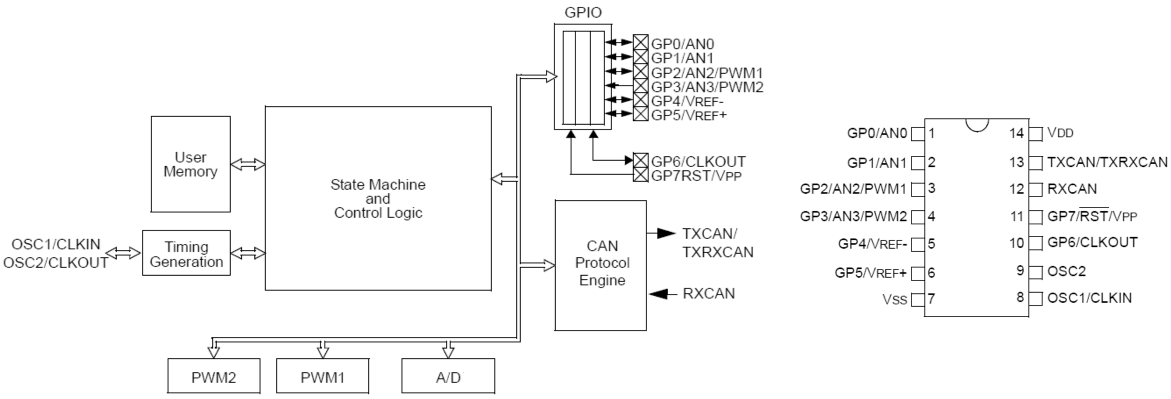


Figure 4.11: MCP25055 CAN I/O Expander Block Diagram and Package [23]

Figure 4.12 shows a prototype of a CAN I/O expander with a magnetic reed contact and two pushbuttons to simulate a door or window contact, a light intensity sensor, a piezo speaker and two LEDs.

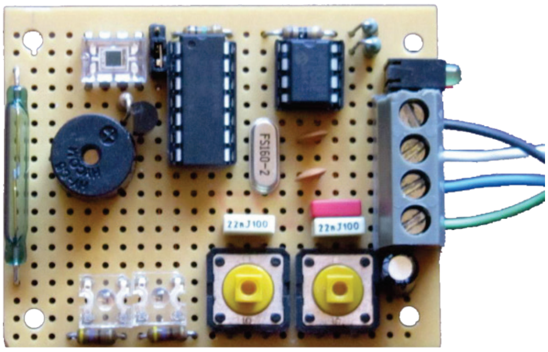


Figure 4.12: CAN I/O Expander Prototype

4.7 Actuators for Switching and Dimming

The actuators for switching and dimming are located in the fuse- or power distribution box. Due to safety and reliability reasons, already built components for switching and dimming are used. The technology used is based on the “Remote Switch System” developed by Eltako. This system belongs to the Eltako Wireless System where the actuators are located centralized in the power distribution box. The actuators are connected via a RS-485 bus and a RS-485 to wireless gateway is used to send and receive messages to and from external devices, for example wireless switches, sensors or shutter controls, located all over the building. This means, if for example a wireless switch is pressed, it sends a message to the wireless gateway which forwards the message over the RS-485 bus to the addressed actuator which performs an appropriate action.

Additionally, a pushbutton input module is available to interface 10 control inputs. The inputs are evaluated and messages are sent to the RS-485 bus containing information about which button was pressed. An action of an actuator can be assigned to a certain pushbutton. This is done by putting the actuator in teach-in mode (LRN) and press the button which should be assigned to a function. The modules used are described in the following sections. For more information about the Eltako Wireless System and their modules, please refer to the Eltako Wireless catalogue [24].

Figure 4.13 shows a typical Eltako Wireless System with different actuators connected via a RS-485 bus and wireless pushbuttons.

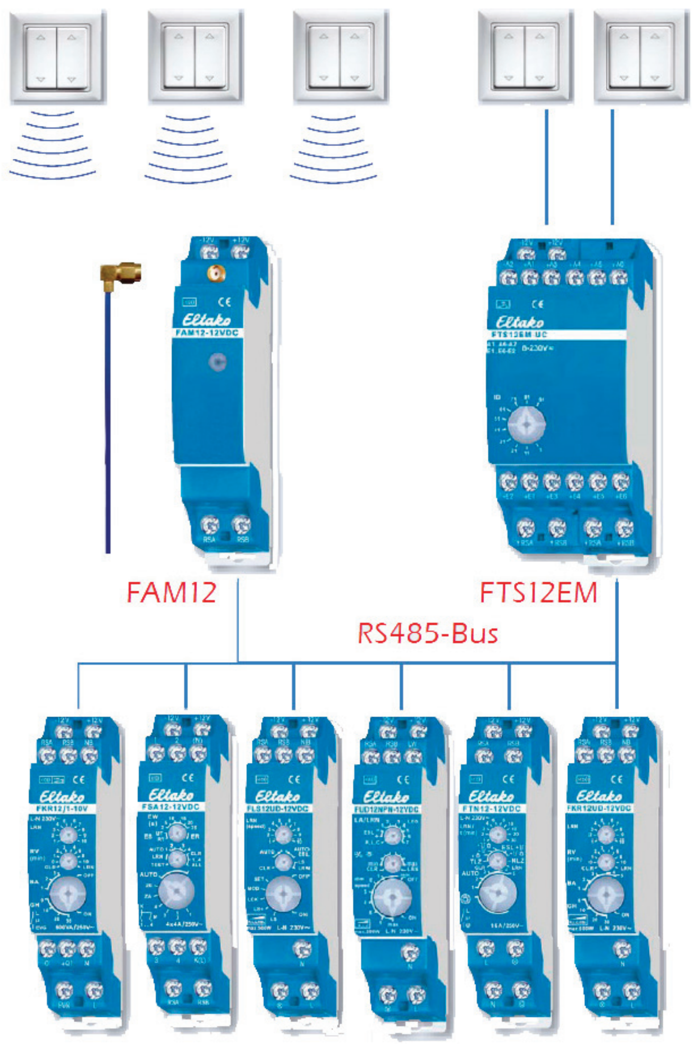


Figure 4.13: Typical Eltako Wireless System [24]

Figure 4.14 shows a typical schematic of a remote switch System.

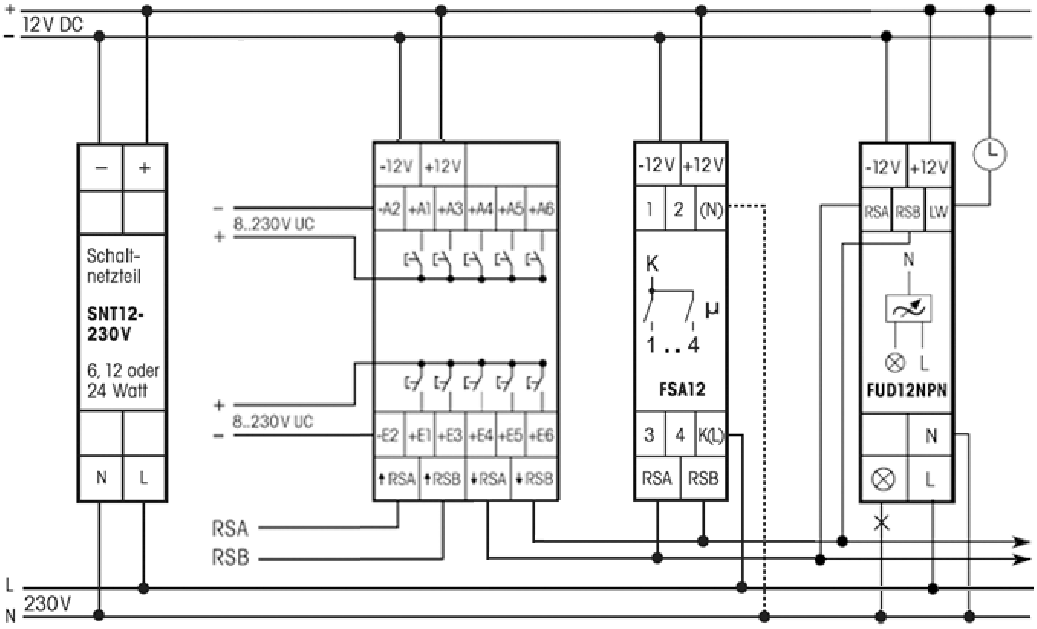


Figure 4.14: Schematic of a typical Remote Switch System [24]

4.7.1.1 Power Supply SNT12-230V

The SNT12-230V is a switching power supply unit to power the modules connected to the RS-485 bus. It should provide enough current to cover the maximum power consumption. There are different models available with different maximum load currents. Figure 4.15 shows the module and the terminal assignment.

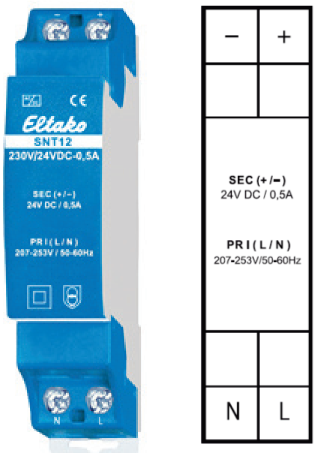


Figure 4.15: SNT12-230V Power Supply Module [24]

4.7.1.2 Pushbutton Input Module FTS12EM-UC

The FTS12EM-UC interfaces up to 10 pushbuttons where on each press or release of a button, a message is sent on the RS-485 bus containing the ID which button has been pressed or released. If more than 10 buttons are needed, these modules can be cascaded and the ID range can be selected with a rotary switch which is showed in Figure 4.17 on the right side. The isolated button interface is flexible and voltages from 8 to 253V AC and 10 to 230V DC are possible. Figure 4.16 shows the FTS12EM-UC pushbutton input module, the terminal assignment, a typical schematic and the rotary ID switch.

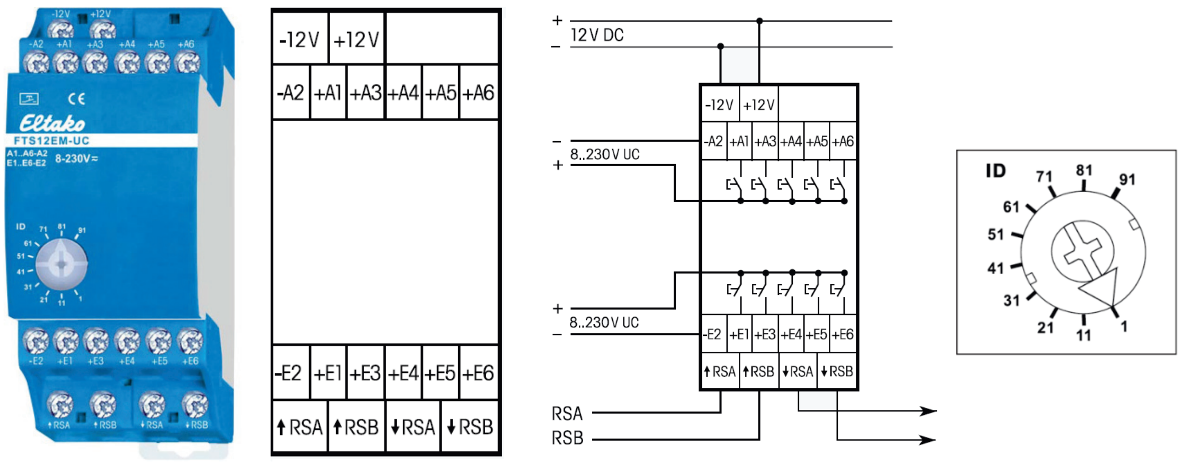


Figure 4.16: FTS12EM-UC Pushbutton Input Module [24]

4.7.1.3 Bus Switching Actuator FSA12-12VDC

The FSA12-12VDC is a 4-channel switching actuator to switch 4A/250V AC on each channel. The device uses the Eltako duplex technology (DX) where the relays are switched at the next zero cross of the power line. This technique extends the lifetime of the relay and the switched consumer device. All the features of the actuator are described in to the Eltako Wireless catalogue [24].

Figure 4.17 shows the FSA12-12VDC actuator, the terminal assignment and the rotary switches to configure the device.

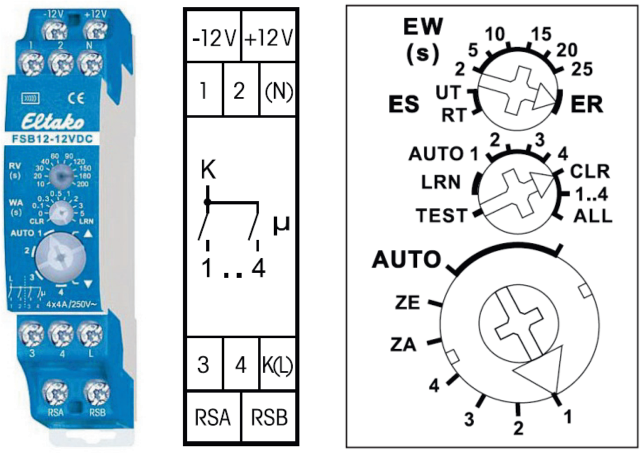


Figure 4.17: FSA12-12VDC Bus Switching Actuator [24]

4.7.1.4 Universal Dimming Actuator FUD12NPN-12VDC

The FUD12NPN-12VDC is a universal 500W power MOSFET dimming actuator for many different types of lamps. It uses also zero crossing switching to achieve soft on and off. This technique extends the lifetime of lamps. The device can be configured for many different types of operation. All the features of the actuator are described in to the Eltako Wireless catalogue [24].

Figure 4.18 shows the FUD12NPN-12VDC, the terminal assignment and the rotary switches to configure the device.

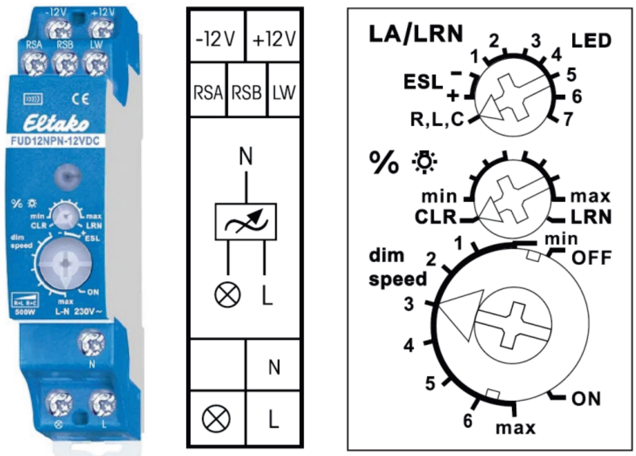


Figure 4.18: FUD12NPN-12VDC Universal Dimming Actuator [24]

4.7.1.5 Bus Switching Actuator FSR12-4x-12VDC

The FSR12-4x-12VDC is a 4-channel impulse switch actuator to switch 4A/250V AC on each channel. The device uses the Eltako duplex technology (DX) where the relays are switched at the next zero cross of the power line. This technique extends the lifetime of the relay and the switched consumer device. The device can be configured for many different types of operation. All the features of the actuator are described in to the Eltako Wireless catalogue [24].

Figure 4.19 shows the FSR12-4x-12VDC actuator, the terminal assignment and the rotary switches to configure the device.

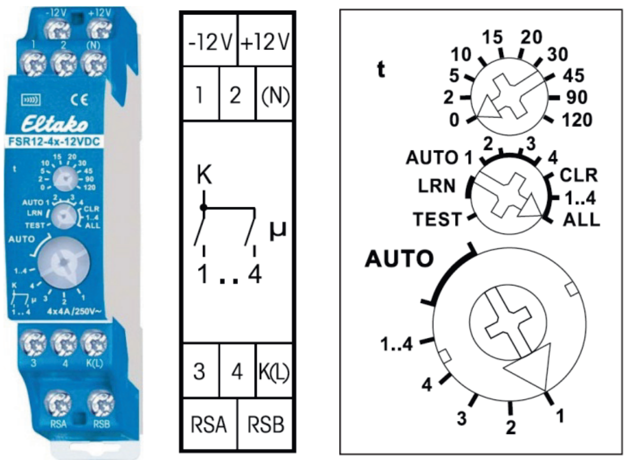


Figure 4.19: FSR12-4x-12VDC Bus Switching Actuator [24]

4.7.1.6 Roller Shutter Actuator FSB12-12V

The FSB12-12V is a 2-channel switching actuator to control two 230V roller shutter motors. The device uses the Eltako duplex technology (DX) where the relays are switched at the next zero cross of the power line. This technique preserves the motors. All the features of the actuator are described in to the Eltako Wireless catalogue [24].

Figure 4.20 shows the FSB12-12V actuator, the terminal assignment and the rotary switches to configure the device.

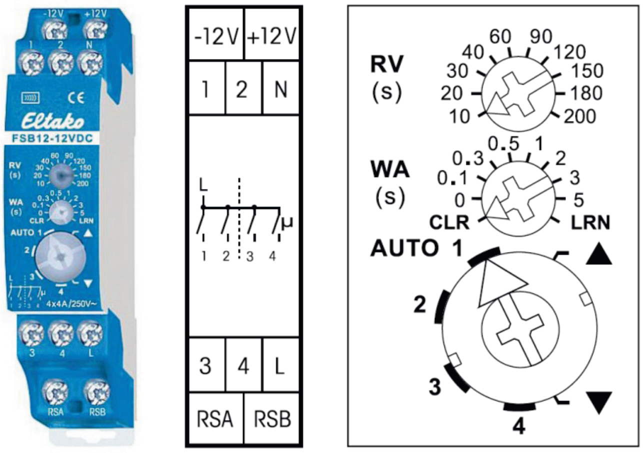


Figure 4.20: FSB12-12V Roller Shutter Actuator [24]

4.7.2 RS-485 Communication Protocol

The RS-485 bus used for the modules mentioned above, is configured with a baud rate of 9600 bit/s, no parity and 1 stop bit (9600,N,1). Table 4.2 shows the basic structure of a RS-485 telegram. For more detailed information, please refer to the protocol description [25] by EnOcean.

Bit 7	Bit 0
SYNC_BYTE1 (A5 Hex)	
SYNC_BYTE0 (5A Hex)	
H_SEQ	LENGTH
ORG	
DATA_BYTE3	
DATA_BYTE2	
DATA_BYTE1	
DATA_BYTE0	
ID_BYTE3	
ID_BYTE2	
ID_BYTE1	
ID_BYTE0	
STATUS	
CHECKSUM	

Table 4.2: RS-485 Data Telegram

The following tables give example telegrams and describe the device specific telegrams of the modules mentioned in Section 4.7

```
FTS12EM-UC
A5 5A 0B 05 70 00 00 00 00 00 00 0B 00 8B      // Press Button 0x0B
A5 5A 0B 05 00 00 00 00 00 00 00 0B 00 1B      // Release Button 0x0B

A5 5A 0B 05 50 00 00 00 00 00 00 0C 00 6C      // Press Button 0x0C
A5 5A 0B 05 00 00 00 00 00 00 00 0C 00 1C      // Release Button 0x0C
```

Table 4.3: Example Output of the FTS12EM-UC

FSR12-4x-12V DC

```
Direct switching command, FUNC=38, Command 1, (like EEP 07-38-08).
Separately for each channel.
There is the possibility to block* the switching state with absolute pri-
ority so that it cannot be changed by other taught-in pushbuttons.
ORG =              0x07
Data_byte3 =       0x01
Data_byte2 =       no used
Data_byte1 =       no used
Data_byte0 =       DB0_Bit3 = LRN Button
                   (0 = teach-in telegram, 1 = data telegram)
                   DBO_Bit2 =  1: block* switching state,
                               0: do not block switching state
                   DBO_Bit0 =  1: switching output ON,
                               0: switching output OFF

Data telegrams have to look like date:
0x01, 0x00, 0x00, 0x09 (switching output ON, not blocked)
0x01, 0x00, 0x00, 0x08 (switching output OFF, not blocked)
0x01, 0x00, 0x00, 0x0D (switching output ON, blocked)
0x01, 0x00, 0x00, 0x0C (switching output OFF, blocked)
```

Table 4.4: Communication Protocol FSR12-4x12 V DC [24]

FUD12NPN

```
Direct transfer of dimming value from 0 to 100%, similar to
FUNC=38, Command 2
ORG =              0x07
Data_byte3 =       0x02
Data_byte2 =       dimming value in % from 0 to 100 dec.
Data_byte1 =       dimming speed
                   0x00 = the dimming speed set on the dimmer is used.
                   0x01 = very fast dimming speed …. to …
                   0xFF = very slow dimming speed
Data_byte0 =       DB0_Bit3 = LRN Button
                   (0 = teach-in telegram, 1 = data telegram)
                   DB0_Bit0 = 1: Dimmer ON, 0: Dimmer OFF.

Teach-in telegram BD3..DB0 must look like this: 0x02, 0x00, 0x00, 0x00
Data telegrams BD3..DB0 must look like this, for example:
0x02, 0x32, 0x00, 0x09 (dimmer on at 50% and internal dimming speed)
0x02, 0x64, 0x01, 0x09 (dimmer on at 100% and fastest dimming speed)
0x02, 0x14, 0xFF, 0x09 (dimmer on at 20% and slowest dimming speed)
0x02, 0x.., 0x.., 0x08 (dimmer off)
```

Table 4.5: Communication Protocol FUD12NPN [24]

FSB12

```
Direct drive command with specification of runtime in s.
FUNC=3F, Typ=7F (universal)
ORG =              0x07
Data_byte3 =       -
Data_byte2 =       runtime in seconds 1-255 dec, the runtime setting on the
                   device is ignored.
Data_byte1 =       command:
```

```
                   0x00 = Stop
                   0x01 = Up
                   0x02 = Down
Data_byte0 =       DB0_Bit3 = LRN Button
                   (0 = teach-in telegram, 1 = data telegram)

Teach-in telegram BD3..DB0 must look like this: 0xFF, 0xF8, 0x0D, 0x80
It is possible to interrupt at any time by pressing taught-in buttons!
```

Table 4.6: Communication Protocol FSB12 [24]

4.8 Actuator Control Node

The actuator control node module is located in the power distribution box, together with the actuators for switching and dimming, mentioned in Section 4.7. It splits up the RS-485 bus between the pushbutton input module and the actuators. The task of this node is to receive messages from the pushbutton input module on the RS-485 bus and forward them via RS-485 to the actuators as well as to the CAN bus. The purpose is that every state change of an actuator is reported to the CAN bus and commands received via CAN are forwarded to the RS-485 bus of the actuators. Similar like the wireless gateway used by the original Eltako Wireless System, mentioned in Section 4.7, the CAN actuator control node operates as a RS-485 to CAN gateway. It consists basically of a microcontroller unit, a CAN interface and a RS-485 interface. The module is powered by the +24V bus power supply described in Section 4.3.

Figure 4.21 shows how the CAN actuator node is integrated into the system.

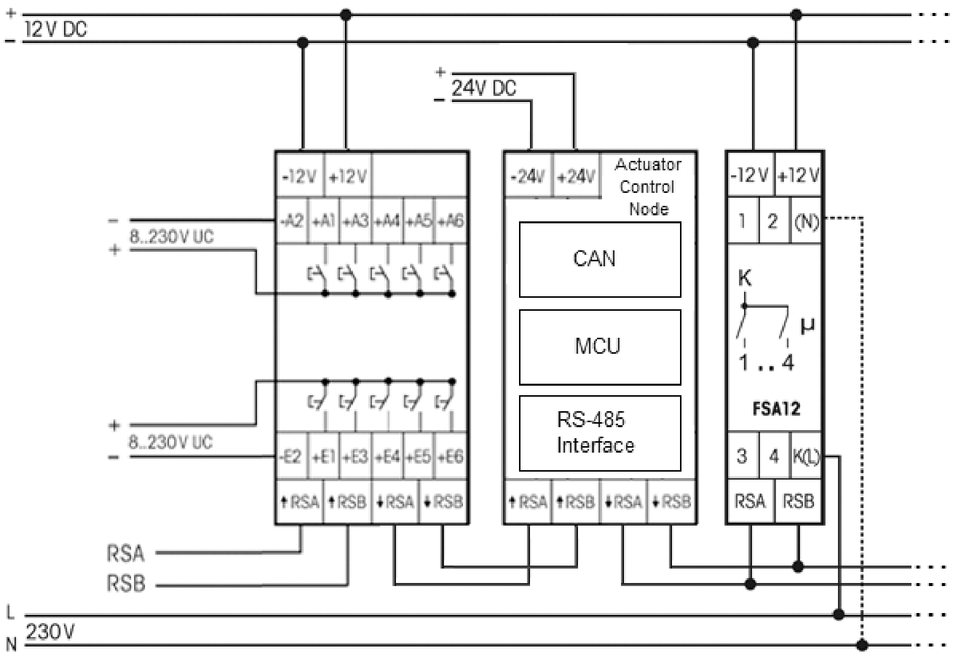


Figure 4.21: CAN Actuator Control Node Integration

4.8.1 CAN Interface

The SN65HVD251, manufactured by Texas Instruments, is a CAN transceiver according to ISO 11898 standard. The device is designed to operate in harsh environments with data rates up to 1 Mbps. It is used in the actuator control node to provide an interface to the CAN bus. More information about the device can be found in the SN65HVD251 datasheet [16].

Figure 4.22 shows the SN65HVD251 circuit and its package.

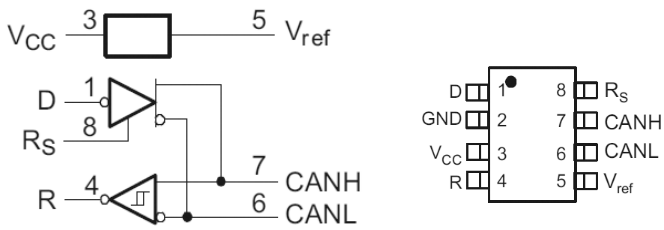


Figure 4.22: SN65HVD251 Circuit and Package [16]

4.8.2 RS-485 Interface

The ADM2582, manufactured by Analog Devices, is an isolated RS-485 transceiver with data rates up to 16 Mbps. The device already includes an integrated isolated DC-DC power supply. An isolated transceiver is used because the modules are powered from different power supplies. Figure 4.23 shows the schematic of a typical application of the ADM2582. For more information about this device, please refer to the ADM2582 datasheet [26].

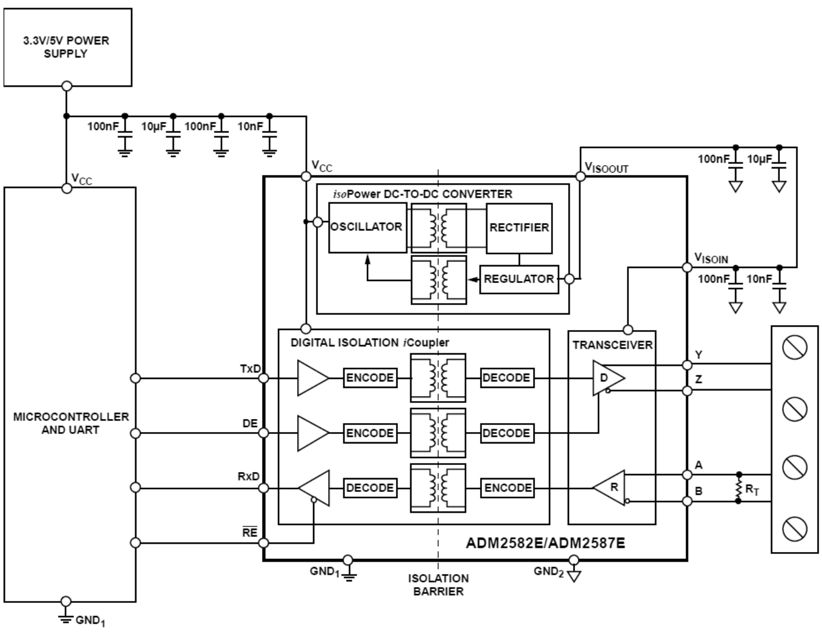


Figure 4.23: Typical application of the ADM2582 [26]

4.8.3 Fall-back Mode

If the CAN actuator control node fails or the bus power supply is turned off, the actuator control node is bypassed with a relay which connects the RS-485 bus of the remote switch input module with the actuators directly. Due to this action, comfort functionality gets lost but it is still possible to switch and dim lights by pressing a button. In fall-back mode, state changes of actuators are not reported to the visualization unit and commands send through the touch panel have no impact.

Figure 4.24 shows how the fall-back mode concept is realized in the actuator control node.

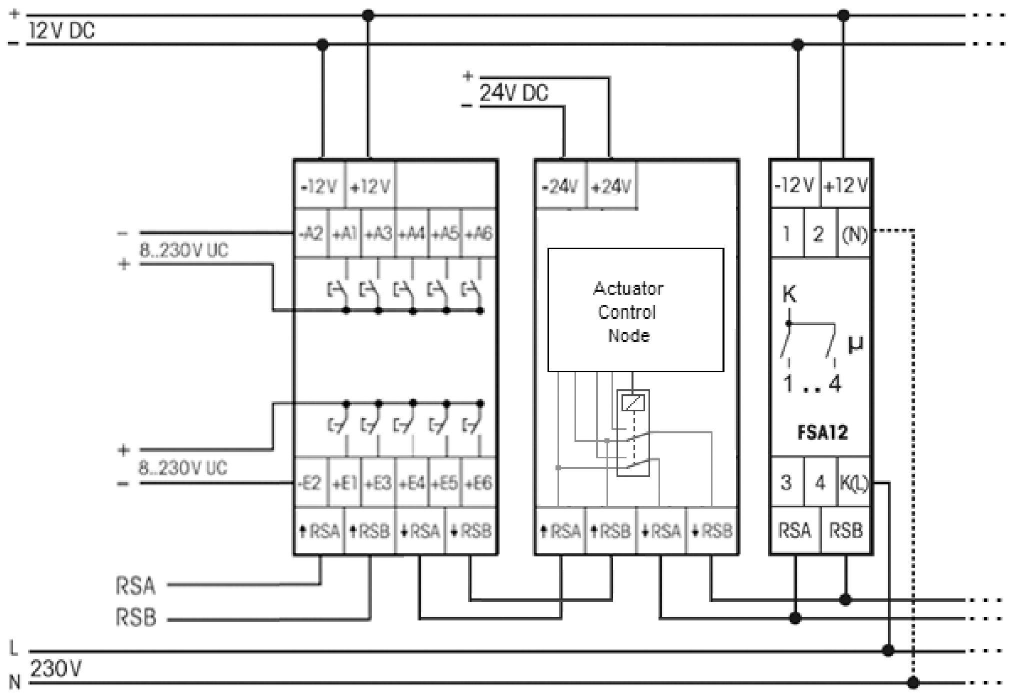


Figure 4.24: Fall-back Concept of the Actuator Control Node

4.8.4 Energy Consumption Measurement

Modern electricity meter provide an interface where they output a certain number of pulses corresponding to the actual electricity consumption. An example for such an interface is the S0 interface, where a certain number of pulses are outputted for each consumed kWh. Often, the output is already realized with an optocoupler and has only to be counted with a digital input pin of a microcontroller. After conversation and averaging over a definite time, the actual and the total energy consumption can be provided on the CAN bus. Figure 4.25 shows a typical S0 interface and how it is connected to a microcontroller input.

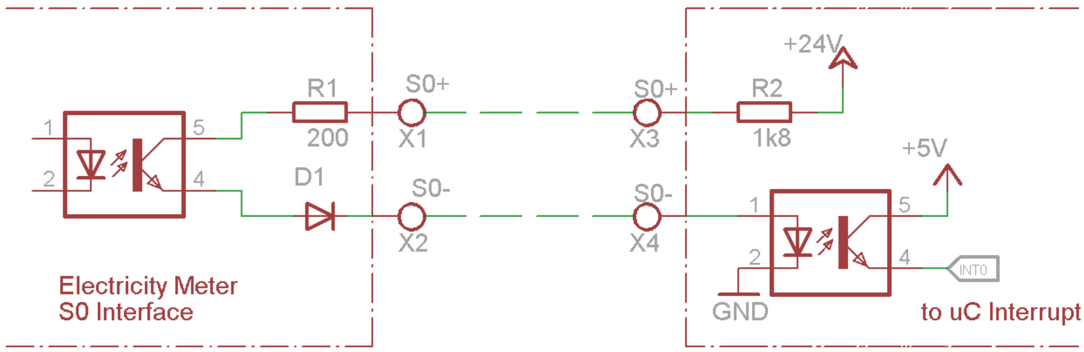


Figure 4.25: S0 Interface of the Electricity Meter

4.8.5 Prototype

The schematic and the layout of the prototype can be found in Appendix A.

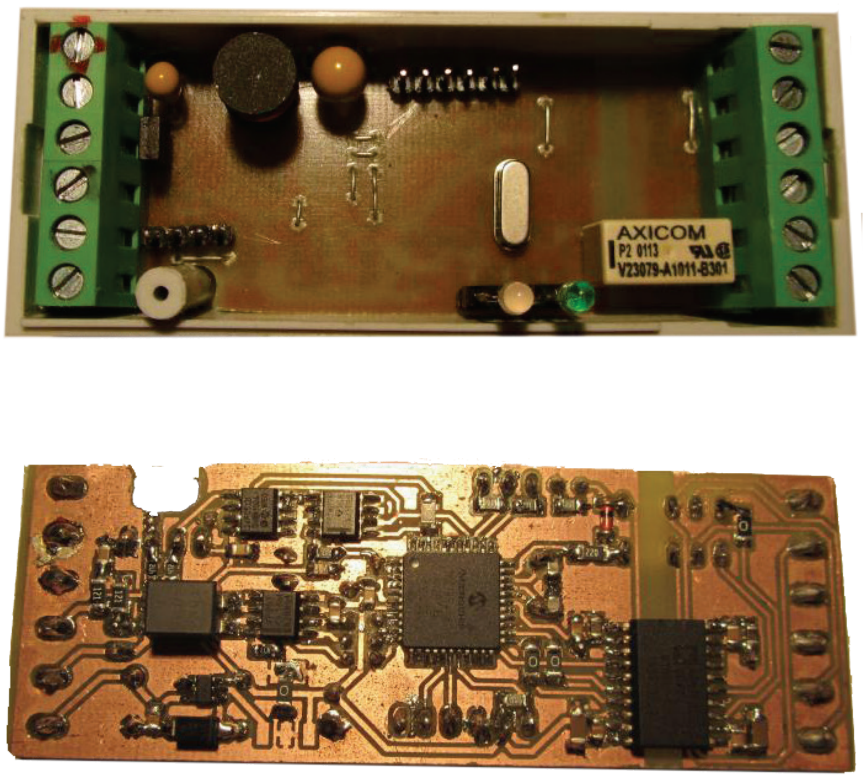


Figure 4.26: CAN Actuator Control Node Prototype

4.9 CAN Bus PC Interface

The CAN bus PC interface is a module that provides an isolated CAN interface to a PC. On the one side, the module is connected to the CAN bus, on the other side via USB to a computer. With this module it is possible to send and receive messages to and from the CAN bus. It is used to give the visualization terminal access to the bus to control the actuators and get sensor data.

4.9.1 USB Interface

The FT232R manufactured by FTDI is a USB (Universal Serial Bus) to serial UART (Universal Asynchronous Receiver Transmitter) interface. The device does not need many external components and has already a lot of features included. For more detailed information, please refer to the FT232R datasheet [27] by FTDI. Figure 4.27 shows a typical application circuit and the package of the FT232R.

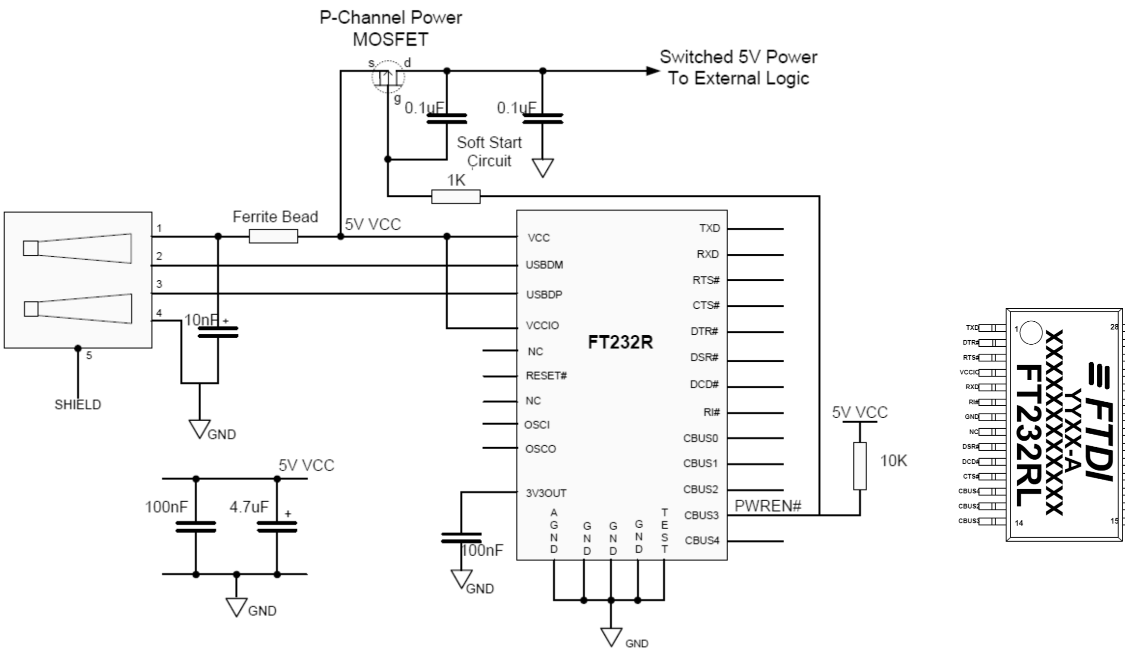


Figure 4.27: FT232R typical Application Circuit and Package [27]

4.9.2 CAN Interface

The ADM3053 manufactured by Analog Devices is an isolated CAN transceiver with an integrated DC-DC converter. The device creates a fully isolated interface between CAN protocol controller and the physical layer bus with data rates up to 1 Mbps. [18]

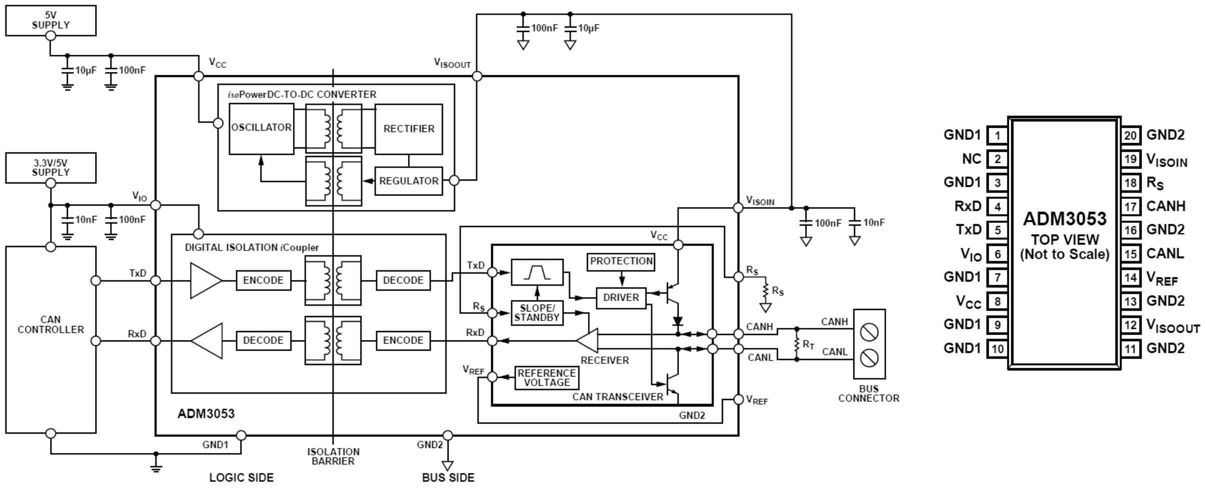


Figure 4.28: ADM3053 typical Application Circuit and Package [18]

4.9.3 CAN Engine

The CAN engine is a programming component which provides transmit and receive routines to communicate with other devices over the CAN bus. This component can easily be integrated into a user application. Additional helping and configurations functions are also implemented, for example to determine the bus power state, to configure the operation mode or the bus termination resistor.

4.9.4 Prototype

The schematic and the layout of the prototype can be found in Appendix A.

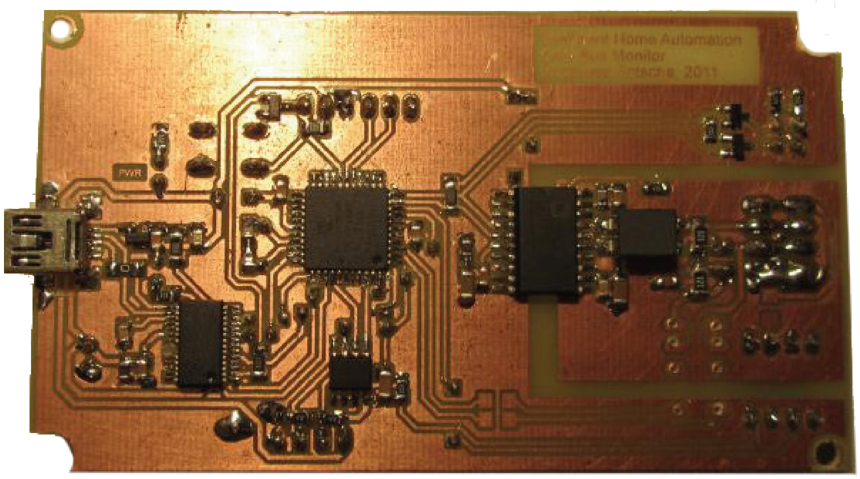


Figure 4.29: CAN Bus PC Interface Prototype

Figure 4.30: CAN Bus PC Interface assembled

4.10 Shutter Control Node

The main task of this node is to control the shutter. Nevertheless, since there is a microcontroller involved, other useful tasks can be done as well. The node basically consist of a microcontroller unit (MCU) with a CAN interface, four de-bounced digital inputs, a 1-wire interface for temperature sensors and a relay circuit to switch the motor of the shutter.

4.10.1 Shutter Control Node

This node provides an additional possibility to control a shutter decentralized compared to the centralized shutter actuator is mentioned in Section 4.7.1.6. To switch a shutter motor on, off and to select the direction, two relays are needed. Figure 4.31 shows the part of the circuit where the motor is controlled. There are now two ways to control the shutter, either by pressing the local up or down switch connected to the de-bounced input, or by sending an appropriate command to the node via the CAN bus interface.

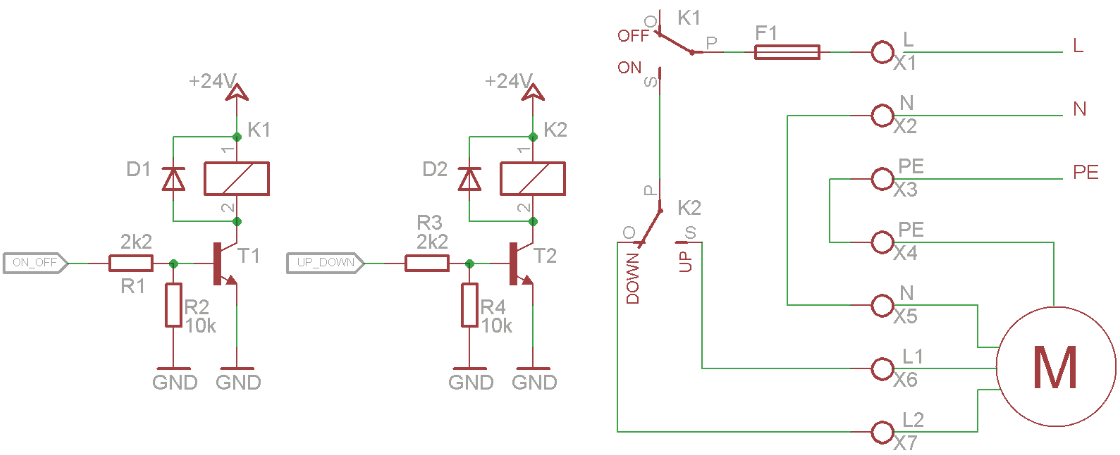


Figure 4.31: Shutter Control

4.10.2 Temperature Sensor

The DS18S20 is a 1-wire temperature sensor manufactured by Maxim. It is used to measure inside and outside temperatures with accuracy of 0.5°C. Each sensor has a unique 64-bit serial code stored in a Read Only Memory (ROM) for identification if more than one device is attached to the same bus. For more information about the 1-wire bus or the DS18S20, please refer to the datasheet [28].

The temperature sensor is interfaced with a single channel 1-wire master which is connected via an I²C (Inter Integrated Circuit) bus to the microcontroller. Figure 4.32 shows a typical application circuit of this 1-wire master device. For more information, please refer to the DS2482-100 datasheet [29] by Maxim.

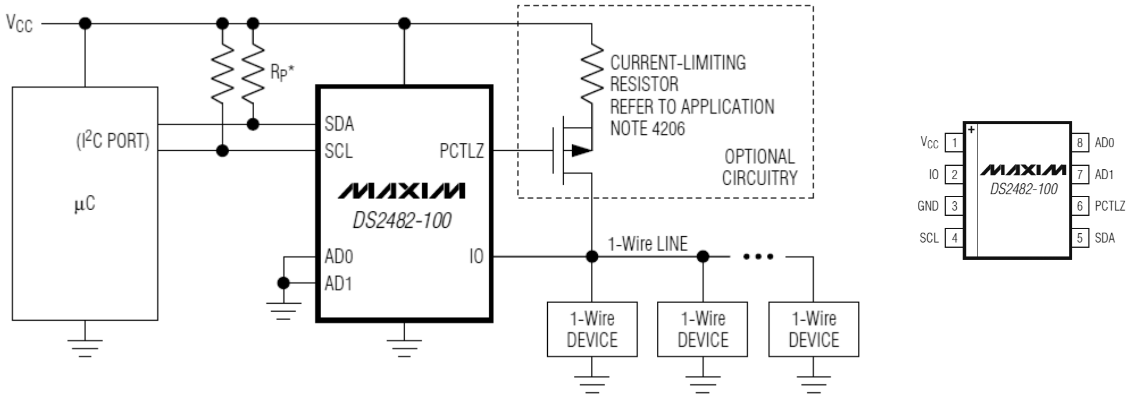


Figure 4.32: DS2482-100 Single Channel 1-Wire Master and Package [29]

Figure 4.33 shows the block diagram of the DS18S20 temperature sensor and the package.

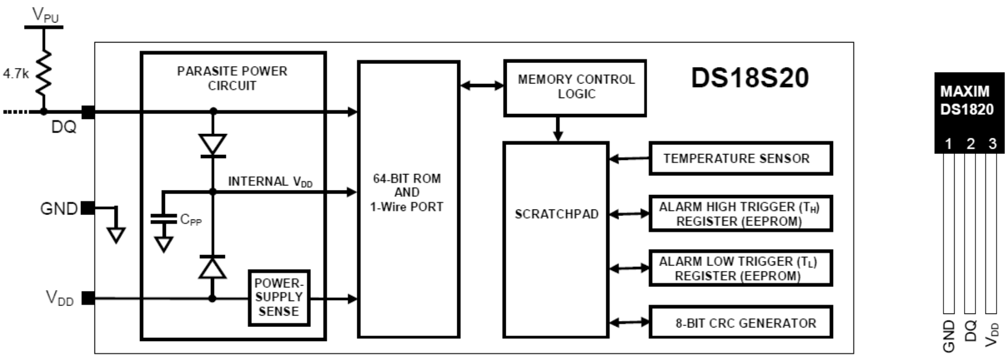


Figure 4.33: DS18S20 Block Diagram and Package [26]

4.10.3 Window Contact

A magnetic contact is used as an opening detector to monitor windows or doors. This can be used as a burglar alarm or as a reminder to close a window when the building is left. The magnetic contact is either mounted on the surface of the window or directly built-in. The maximum contact load capacity is 24V/0.2A. The contact is closed in idle state. For more information, please refer to the MK1010 datasheet [30] by Abus. The magnetic contact is connected to the debounced digital input of the node.

Figure 4.34 shows the MK1010 magnet contact kit and the schematic and Figure 4.36 shows the mounting of the contact.

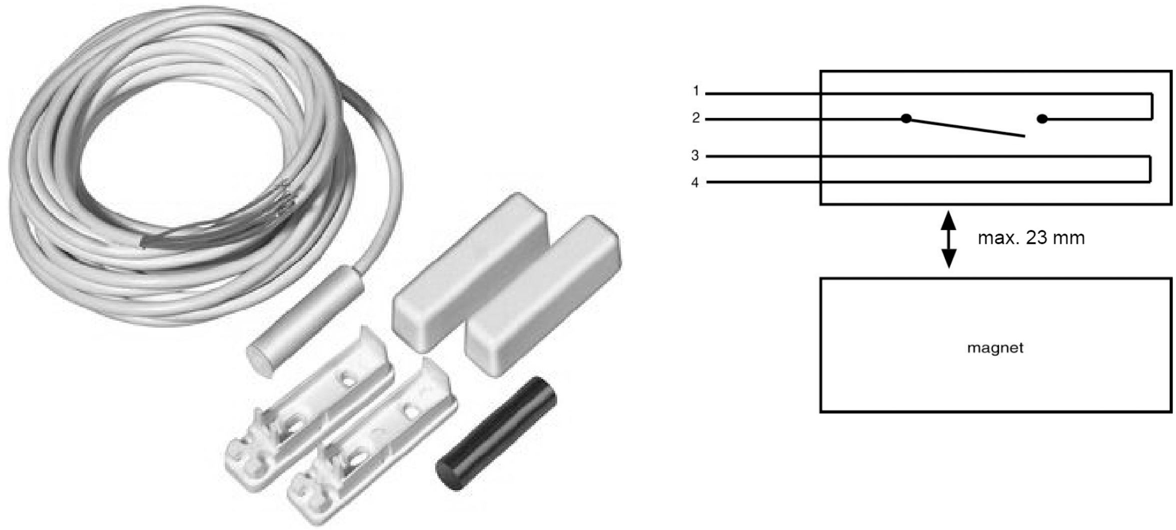


Figure 4.34: MK1010 Magnetic Contact Kit [30]

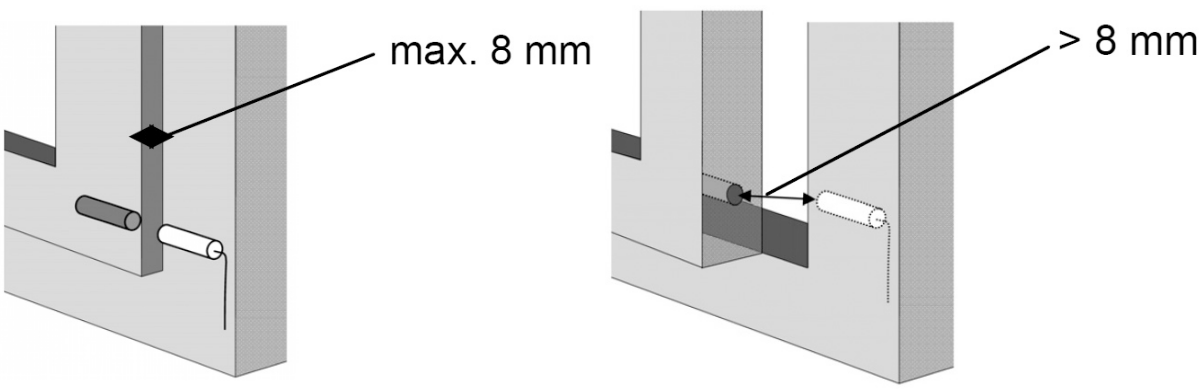


Figure 4.35:Magnetic Contact Mounting [30]

4.10.3.1 Prototype

The following figure shows the prototype of the shutter control node. The schematic can be found in Appendix A.

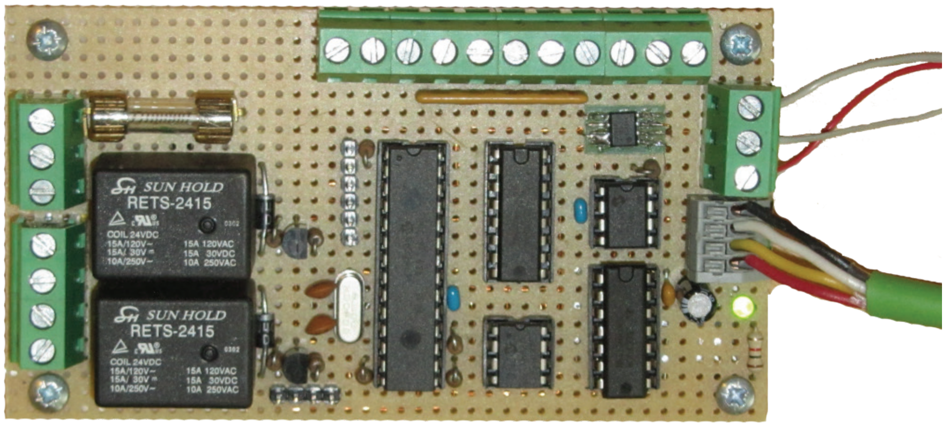


Figure 4.36: Shutter Control Node Prototype

4.11 Multi-Room Sound Control

With the multi-room sound control, it is possible to distribute a single audio source, for example mp3, internet radio, CD etc. to different rooms and control the volume individually. The sound control is based on a microcontroller unit (MCU) with a CAN bus interface as well as four stereo audio amplifier with volume control. With this, it is possible to control the volume of each channel separately and each channel can be muted. Figure 4.37 shows the block diagram of system.

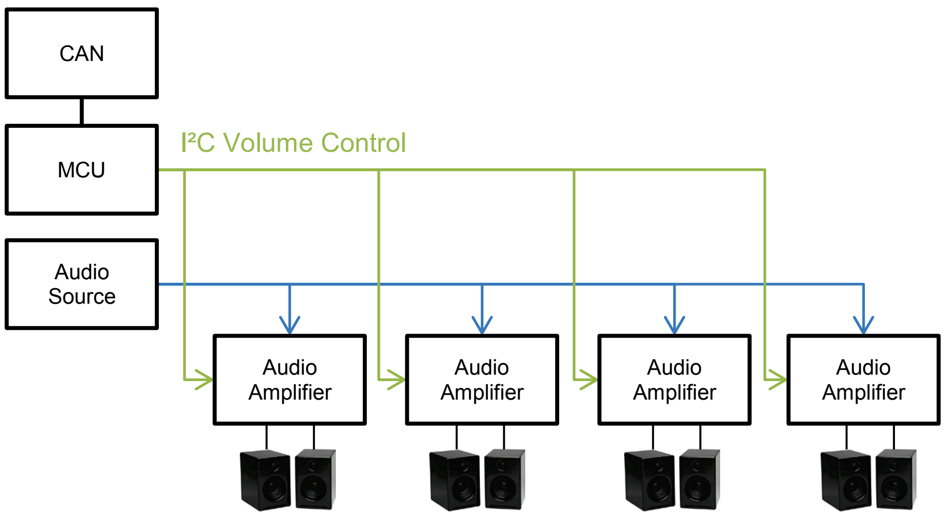


Figure 4.37: Multi-Room Sound Control Block Diagram

To adjust the volume of each channel, a TPA0172 stereo audio amplifier, manufactured by Texas Instruments, is used. This device comes with an I²C (Inter-Integrated Circuit) interface, with that the volume can be set in a range of -60 to 20 dB. The output power is 2W at a load of 4Ω for each channel. Figure 4.38 shows a typical application circuit of the TPA0172. For more information about the TPA0172, please refer to the datasheet [31].

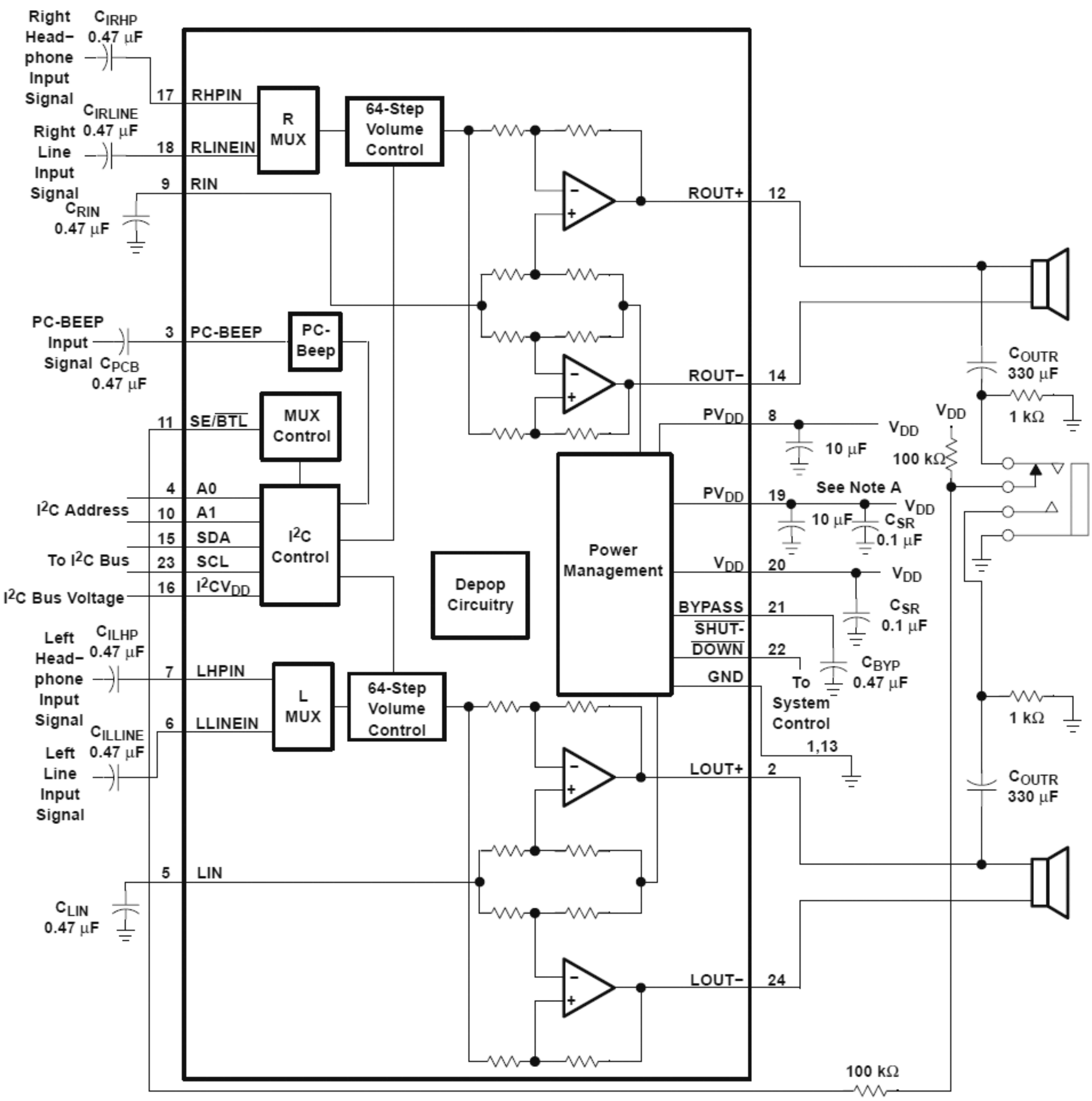


Figure 4.38: TPA0172 Stereo Audio Amplifier [31]

4.12 Over Temperature Detection

All the mentioned CAN nodes above have a built-in over temperature feature which consists out of a temperature sensor which is connected to an interrupt input of the microcontroller. If the temperature of a module rises above a certain pre-configured threshold, an interrupt is generated which reports itself by sending a CAN message. By this, different actions can be taken, for example show an error at the visualization terminal and turn off the electricity in the affected segment.

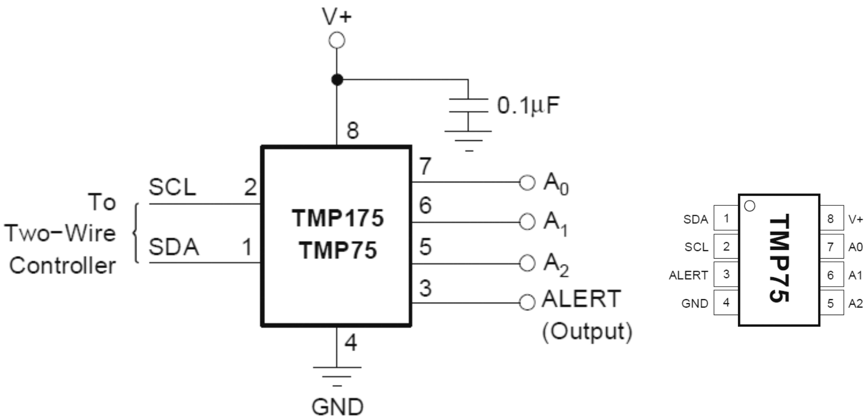


Figure 4.39: TMP75 Pin Assignment and Package [32]

5 Visualization

The purpose of the visualization is to visualize, monitor and control the actual state of the devices. Therefore, a touch terminal with a visualization software running is used. The visualization terminal is usually located at a frequently passed place, for example the kitchen or the living room. Often, it is directly integrated into the wall. The user interface should be intuitively, self-explaining and well-designed to guide the user through the menu in a logical way. The menu should be well structured to make it easy for the user to find the action, he wants to take, quickly. Since a visualization terminal is on a location where the resident often remains, it can be useful to display other information than concerning the home automation system. Some useful features could be a weather forecast, news, a notepad, a web browser etc.

The visualization software for this home automation system is divided into two halves. On the left half of the screen, there is the main menu with a categorized list to access the submenus. On the right half of the screen, there is a tab control to switch between different types of information. The bottom consists of a menu button to go back to the main menu as well as some favorite shortcut buttons.

Figure 5.1 shows how the main screen of the visualization software looks like.

Figure 5.1: Screenshot of the Visualization Software

5.1 House Structure

To make it easy to navigate through the house and find the actuators and sensors quickly, a house structure is needed. Therefore, the house is divided into floors for example basement, ground floor and first floor. Each floor is subdivided into rooms for example kitchen, living room, office and bath room. Each room contains the different actuators and sensors which are located in this room for example, lights, temperature sensors, windows contacts, heater etc. If for example the user wants to turn on the main light in the living room he has to navigate to the ground floor, living room and then press the “main light on” button.

Figure 5.2: Rooms

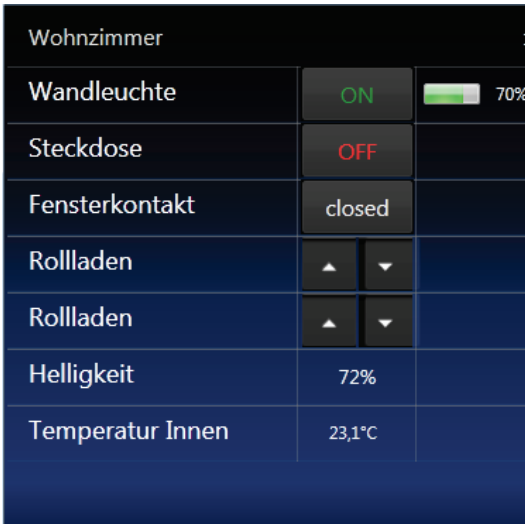


Figure 5.3: Devices in a Room

Additionally, there is the possibility to show all devices in a certain floor. This can be done by selecting the floor in the room list.

Figure 5.4: Devices in a certain Floor

The house structure with all the devices is stored in a Microsoft Access database where the visualization software accesses it. Alternatively, the house structure could be stored in an xml file or equivalent. The only difference is the data access method.

Figure 5.5 shows the relations between the tables of the database.

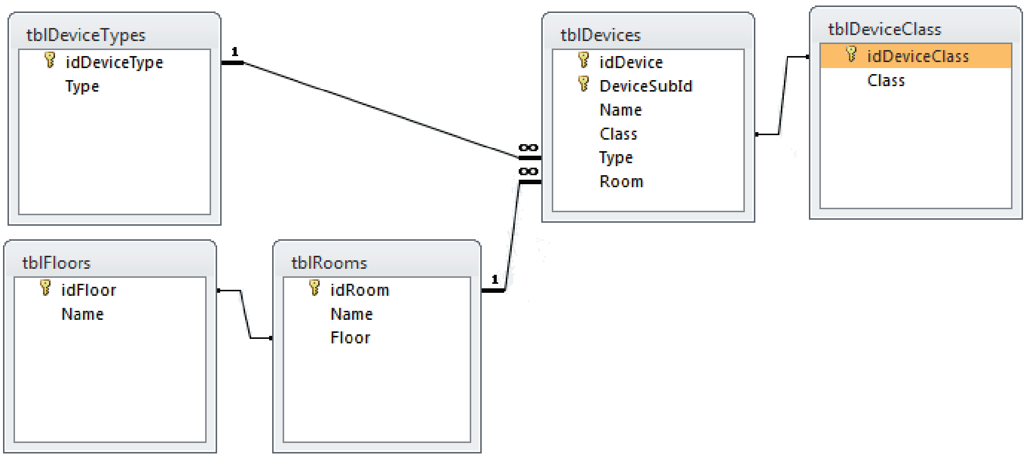


Figure 5.5: Database Relations

With these relations a table containing all devices in the house can be entered by selecting device identification, a name, a class, a type and a room where the device is located.

idDevice	DeviceSubId	Name	Class	Type	Room
2000	1	Rollladen	Beschattung	Rollladen_auf_ab_stop	Büro
1617	0	Temperatur	Heizung	Temperatur_DS18S20	Büro
469895424	1	Fensterkontakt	Fensterkontakt	Fensterkontakt_auf_zu	Büro
469895424	2	Fensterkontakt	Fensterkontakt	Fensterkontakt_auf_zu	Esszimmer
11	14	Deckenleuchte	Beleuchtung	Licht_toggle	Esszimmer
1618	0	Temperatur	Heizung	Temperatur_DS18S20	Esszimmer
11	12	Steckdose	Stromversorgung	Licht_toggle	Küche
11	11	Wandleuchte	Beleuchtung	Licht_toggle	Küche
1619	0	Temperatur	Heizung	Temperatur_DS18S20	Schlafzimmer
11	17	Wandleuchte	Beleuchtung	Dimmer_toggle_dim	Wohnzimmer
11	15	Steckdose	Stromversorgung	Licht_toggle	Wohnzimmer
469895424	0	Fensterkontakt	Fensterkontakt	Fensterkontakt_auf_zu	Wohnzimmer
2000	2	Rollladen	Beschattung	Rollladen_auf_ab_stop	Wohnzimmer
86	0	Temperatur Innen	Heizung	Temperatur_DS18S20	Wohnzimmer
469893376	0	Helligkeit	Helligkeit	Helligkeit_MCP	Wohnzimmer
2000	0	Rollladen	Beschattung	Rollladen_auf_ab_stop	Wohnzimmer

Table 5.1: tblDevices

idDeviceCla	Class
1	Beleuchtung
2	Beschattung
3	Heizung
4	Fensterkontakt
5	Stromversorgung
6	Temperatur
7	Helligkeit
8	Multiroomsound
9	Energieverbrauch

Table 5.2: tblDeviceClass

idDeviceType	Type
1	Licht_an_aus
2	Licht_toggle
3	Dimmer_an_aus_dim
4	Dimmer_toggle_dim
5	Rollladen_auf_ab_stop
6	Fensterkontakt_auf_zu
7	Steckdose_an_aus
8	Steckdose_toggle
9	Heizung_reg
10	Temperatur_DS18S20
11	Helligkeit_MCP

Table 5.3: tblDeviceTypes

idRoom	Name	Floor
1	Küche	EG
2	Esszimmer	EG
3	Wohnzimmer	EG
4	Büro	EG
5	Gardarobe	EG
6	WC	EG
7	Schlafzimmer	OG
8	Bad 1	OG
9	Gästezimmer	OG
10	Flur	OG
11	Bad 2	OG
12	Kinderzimmer 1	OG
13	Kinderzimmer 2	OG
14	Multimediaraum	KG
15	Waschküche	KG
16	Vorratsraum	KG
17	Werkstatt	KG
18	Terasse	Sonstiges
19	Garage	Sonstiges
20	Einfahrt	Sonstiges

Table 5.4: tblRooms

To save the actual state of a device, another table is used to save the state on an incoming state change message.

idDevice	DeviceSubId	StateTime	Byte0	Byte1	Int0	Int1	Double0	Double1	String0	String1
11	11	26.11.2011-12:37:30.110	1	0	0	0	0	0		
11	12	26.11.2011-12:37:51.341	1	0	0	0	0	0		
11	14	26.11.2011-12:36:47.903	0	0	0	0	0	0		
11	15	26.11.2011-12:37:31.094	1	0	0	0	0	0		
11	17	26.11.2011-12:37:41.106	3	33	0	0	0	0		
86	0	26.11.2011-12:39:56.313	0	0	0	0	22,87	0		
1617	0		0	0	0	0	0	0		
1618	0		0	0	0	0	0	0		
1619	0		0	0	0	0	0	0		
2000	0		0	0	0	0	0	0		
2000	1		0	0	0	0	0	0		
2000	2		0	0	0	0	0	0		
469893376	0	26.11.2011-12:39:52.616	76	0	0	0	0	0		
469895424	0	26.11.2011-12:39:05.539	0	0	0	0	0	0	close	
469895424	1	26.11.2011-12:38:47.735	1	0	0	0	0	0	open	
469895424	2	26.11.2011-12:38:46.737	1	0	0	0	0	0	open	

Table 5.5: tblDeviceState

5.2 Light Control

The lights and dimmers are switched on and off by pressing a button right next to the device. Its caption indicates the actual state. “ON” means that the device is currently switched on and “OFF” that it is switched off. Dimmable devices offer additionally the possibility to dim to a certain value. By pressing on the progress bar next to the button, a slider pops up to adjust the value between 0 and 100%.

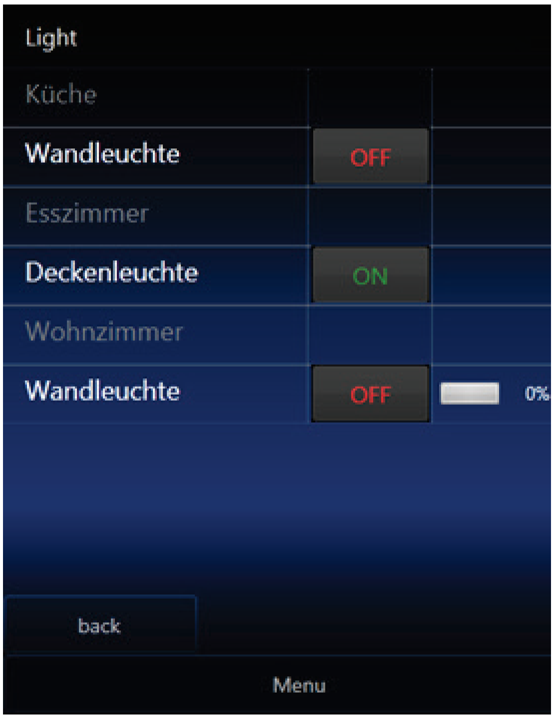


Figure 5.6: Light Control

Power sockets are controlled in the same way as switchable lights since they are switched by the same module.

5.3 Shutter Control

Shutters can be controlled by pressing the up or down button depending on the direction it should move. By pressing the percentage value next to the buttons, a menu pops up to move the shutter to a specific position. To control a group of shutters centrally, a button can be defined as a favorite to fulfill this task.

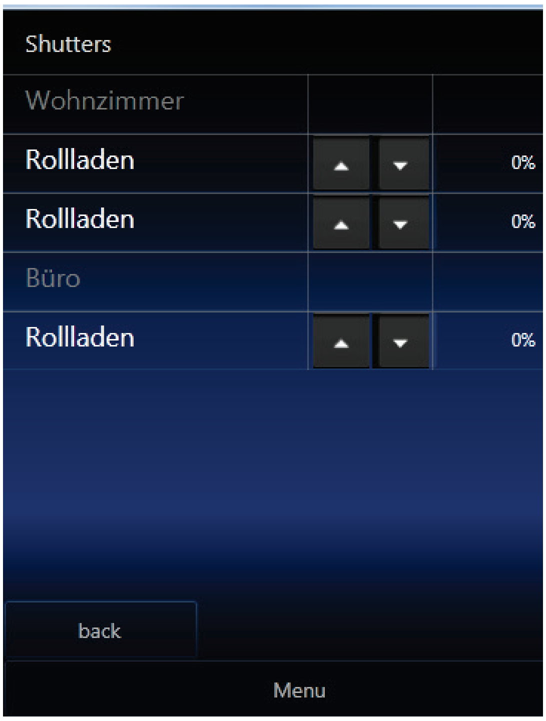


Figure 5.7: Shutter Control

5.4 Temperature Sensors

Temperature sensors are monitored in the heating menu. Temperatures of interest can be room temperatures, outside temperature, water temperature of the solar collector etc.

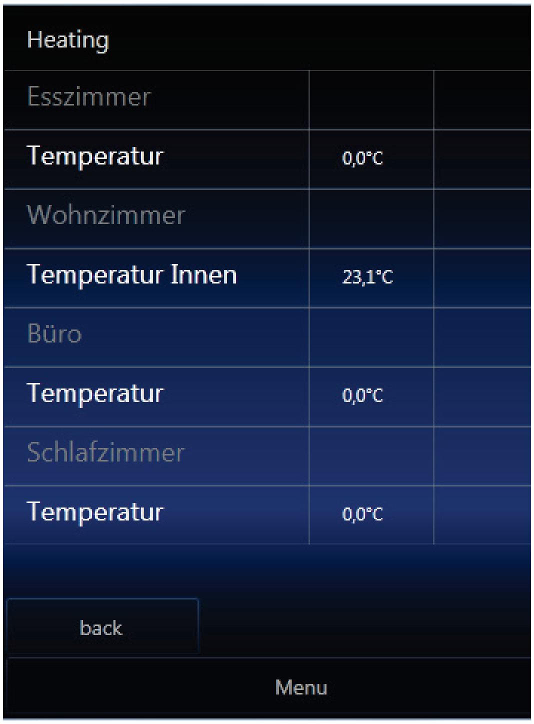


Figure 5.8: Temperature Sensor

5.5 Window and Door Contacts

Window and door contacts are monitored due to security reasons. A notification mechanism allows reacting immediately for example in the case of an attempt burglary. Additionally, the system can check whether windows and doors are closed and alert the resident when leaving the house or a storm is coming up.

Figure 5.9: Door and Window Contacts

5.6 Alarm

Different alarm conditions can be collected and evaluated to notify the resident. This submenu is reserved for future use.

5.7 Cameras

The camera tab offers the possibility to embed webcam sources. The cameras can be streamed from the internet or from the local network. Cameras can be located for example at the main entrance or around the building. Figure 5.10 shows the stream of a public webcam on the internet.

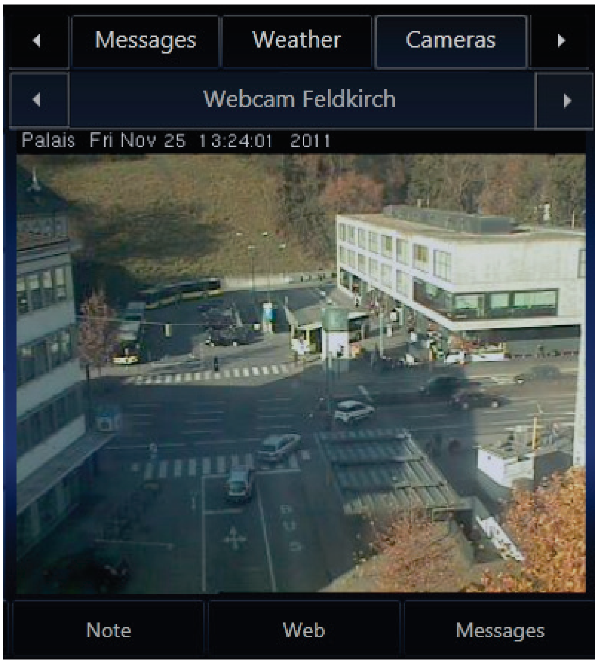


Figure 5.10: Webcam

5.8 Scenes

This submenu is used to provide pre-sets to quickly recall a stored light ambience and shutter configuration. Such pre-sets can be for example in the living room for watching a movie, having dinner etc.

5.9 Automatic

This submenu is used to schedule events and actions which are triggered by a certain time or sensor. Such events can be for example to turn on the light at the doorway when it is dark outside, to move the shutters up in the morning etc.

5.10 Messages

This tab shows status and system messages of the system. It helps the system administrator to test and configure the system. The message list shows the message identification (ID), a message text and the timestamp when the message arrived.

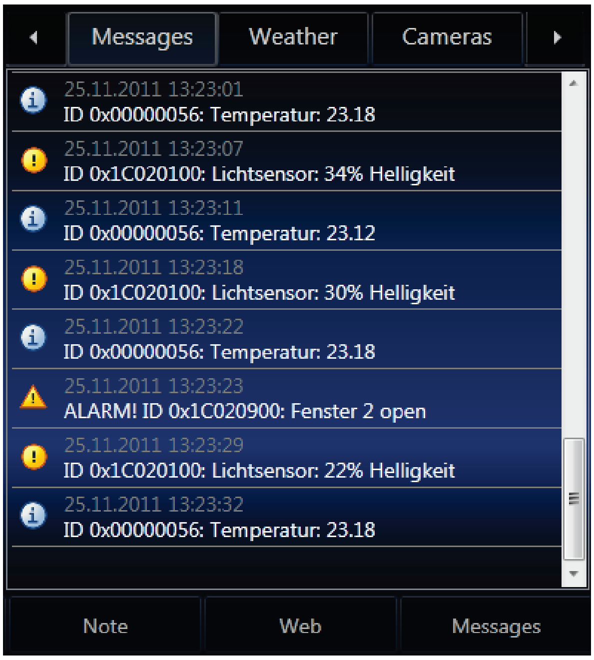


Figure 5.11: Status and System Messages

5.11 Weather Forecast

Google provides a service where a weather forecast can be requested by submitting the location of interest. The communication is handled by HTTP (Hypertext Transfer Protocol) and the return is a xml file with all the necessary data.

The request for example the weather forecast for the location “Graz” in German, the following URL has to be sent: http://www.google.com/ig/api?weather=Graz&hl=de&us=de

The return for this request looks like the following:


```
<xml_api_reply version="1">
  <weather module_id="0" tab_id="0" mobile_zipped="1" row="0" section="0">
    <forecast_information>
      <city data="Graz, Styria" />
      <postal_code data="Graz" />
      <latitude_e6 data="" />
      <longitude_e6 data="" />
      <forecast_date data="2011-11-25" />
      <current_date_time data="2011-11-25 13:50:12 +0000" />
      <unit_system data="SI" />
    </forecast_information>
    <current_conditions>
      <condition data="Bedeckt" />
      <temp_f data="36" />
      <temp_c data="2" />
      <humidity data="Luftfeuchtigkeit: 81 %" />
```

```
      <icon data="/ig/images/weather/cloudy.gif" />
      <wind_condition data="Wind: S mit 13 km/h" />
    </current_conditions>
    <forecast_conditions>
      <day_of_week data="Fr." />
      <low data="-2" />
      <high data="3" />
      <icon data="/ig/images/weather/mostly_sunny.gif" />
      <condition data="Teils sonnig" />
    </forecast_conditions>
  ...
  </weather>
</xml_api_reply>
```

It contains all the necessary information to visualize a weather forecast. Even links to images are provided. Figure 5.12 shows the weather forecast after graphical formatting.

Figure 5.12: Weather Forecast

5.12 Energy Consumption

The energy tab monitors the actual and the total energy consumption. The data comes from the actuator control node, mentioned in Section 4.8, can be connected to a S0 interface, described in Section 4.8.3, of an electricity meter to determine the actual energy consumption.

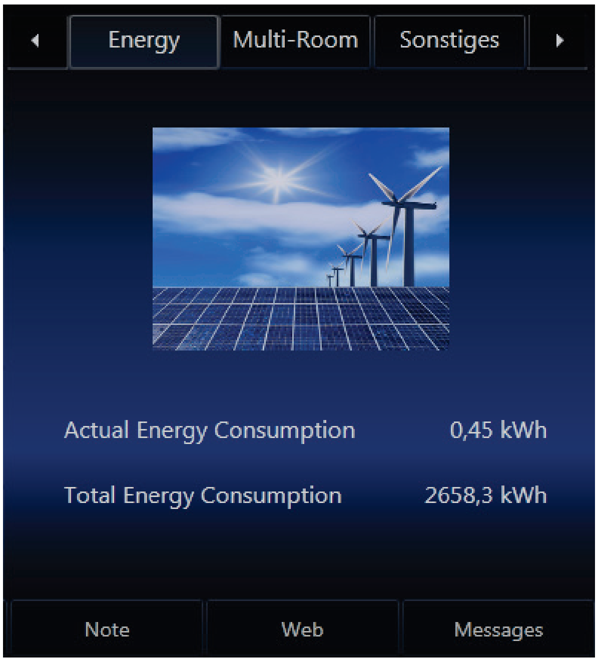


Figure 5.13: Energy Consumption

5.13 Notepad

The notepad can be used to leave messages to other residents or to write a to-do list or other notes.

Figure 5.14: Notepad

5.14 Multi-Room Sound

The multi-room sound tab offers the possibility to adjust the volume of the actual audio source which can be internet radio, mp3, CD etc. on four different channels separately. Speakers can be located for example in the kitchen, the living room, the office etc. Additionally, alarm messages or notifications can be distributed to all these speakers.

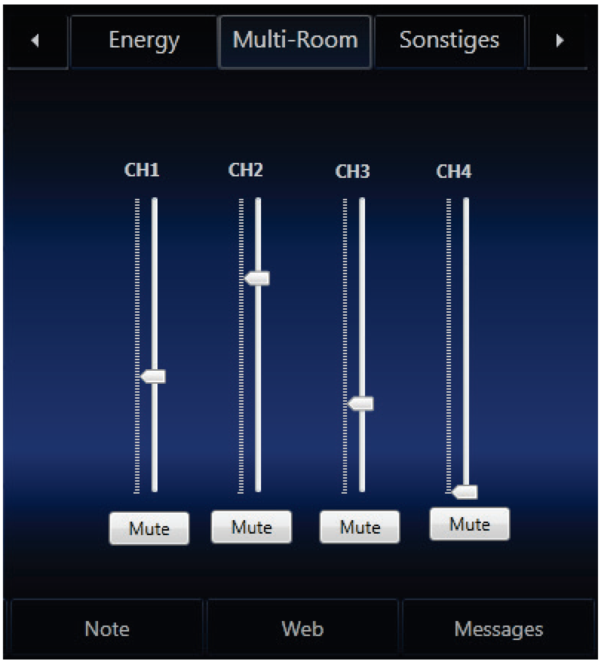


Figure 5.15: Multi-Room Sound

5.15 Web

The built-in web browser provides access to world wide web and makes it easy to quickly look up something, for example news, a recipe etc.

Figure 5.16: Web

6 Realization

This chapter compares the conventional electricity installation with the one for the implemented home automation system. Furthermore, it describes the developed demonstration system and gives an overview about the final realization by providing examples of installation plans.

6.1 Structure of the Installation

6.1.1 Traditional Electrical Installation Structure

The last years, traditional electrical installation has not changed much, although the materials used have improved and the safety standards got stricter. The basic structure is still the same, supply cables come from the fuse box to a switch and then further to the consumer. Once the installation is done it can hardly be changed which means that the flexibility is small. Nevertheless, most of the newly built houses are still done in the traditional way. [2]

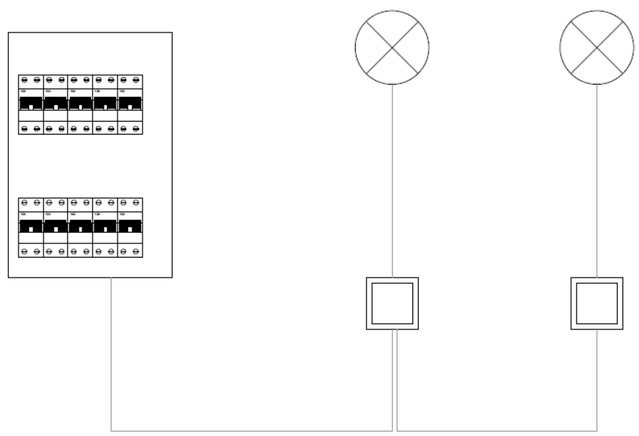


Figure 6.1: Structure of the traditional electrical Installation [2]

6.1.2 Remote-Controlled Switch Installation Structure

A remote-controlled switch centralizes the switching of a consumer in the fuse box. The cabling of the buttons as well as of the consumers is in star formation. If a button is pressed, the remote-controlled switch gets an impulse and knows that it has to switch over. The number of cables used is higher in contrast to the traditional installation. Nevertheless, the system benefits with regard to the flexibility. The function of a pushbutton can be changed easily and buttons can be added by connecting them in parallel. The pushbutton input module (described in Section 4.7.1.2) operates at a flexible input range from 8 to 230V. [2]

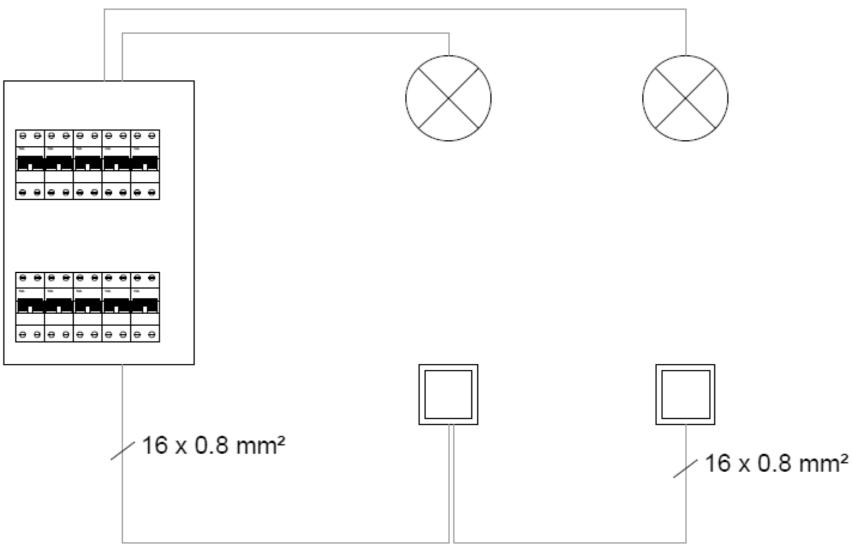


Figure 6.2: Structure of the remote-controlled Switch Installation [2]

6.2 Demonstration Wall

To test the modules and as an illustration a demonstration wall consisting of power supplies, fuses, an actuator control node, several actuators, light bulbs, pushbuttons and power sockets was built.

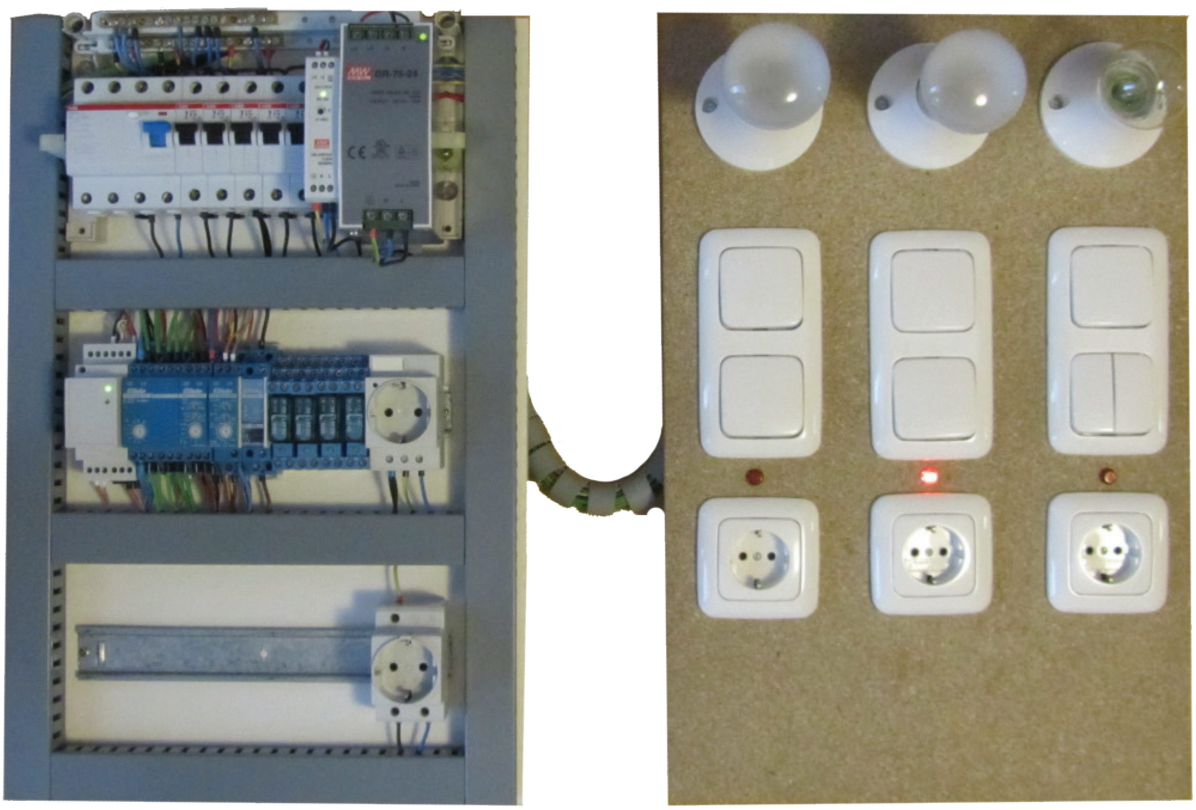


Figure 6.3: Demonstration Wall

The following figure illustrates the supply and actuator part of the demonstration wall in more detail.

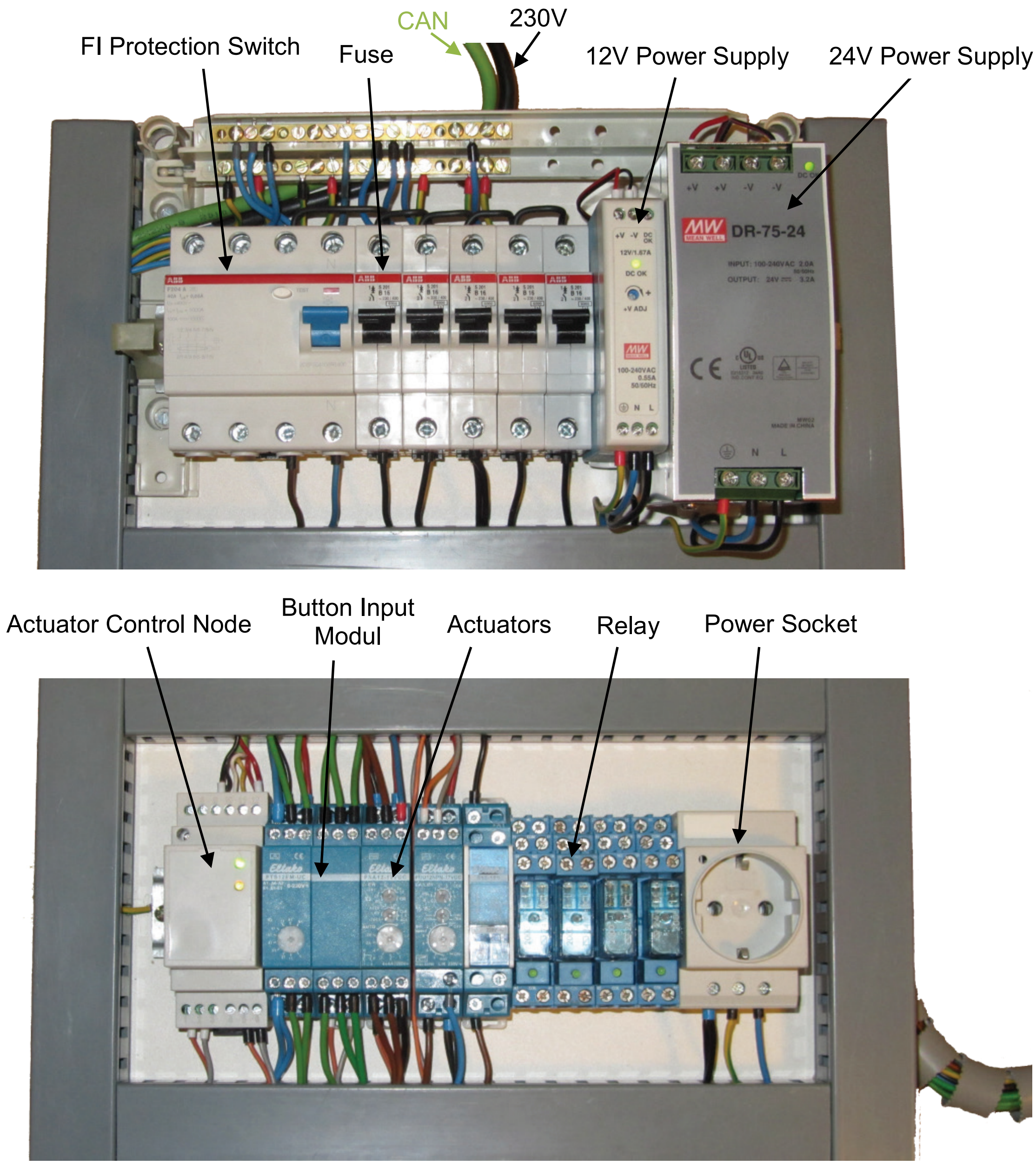


Figure 6.4: Demonstration Wall Detail

The actuator node is connected via the CAN bus with the CAN bus PC interface as illustrated in the block diagram in Section 4.1. The actuators are then fully controllable from the visualization software. Button presses affect the actuators immediately and are reported to the visualization software to update the status.

The following figure illustrates the light bulbs, pushbuttons and power sockets of the demonstration wall in more detail.

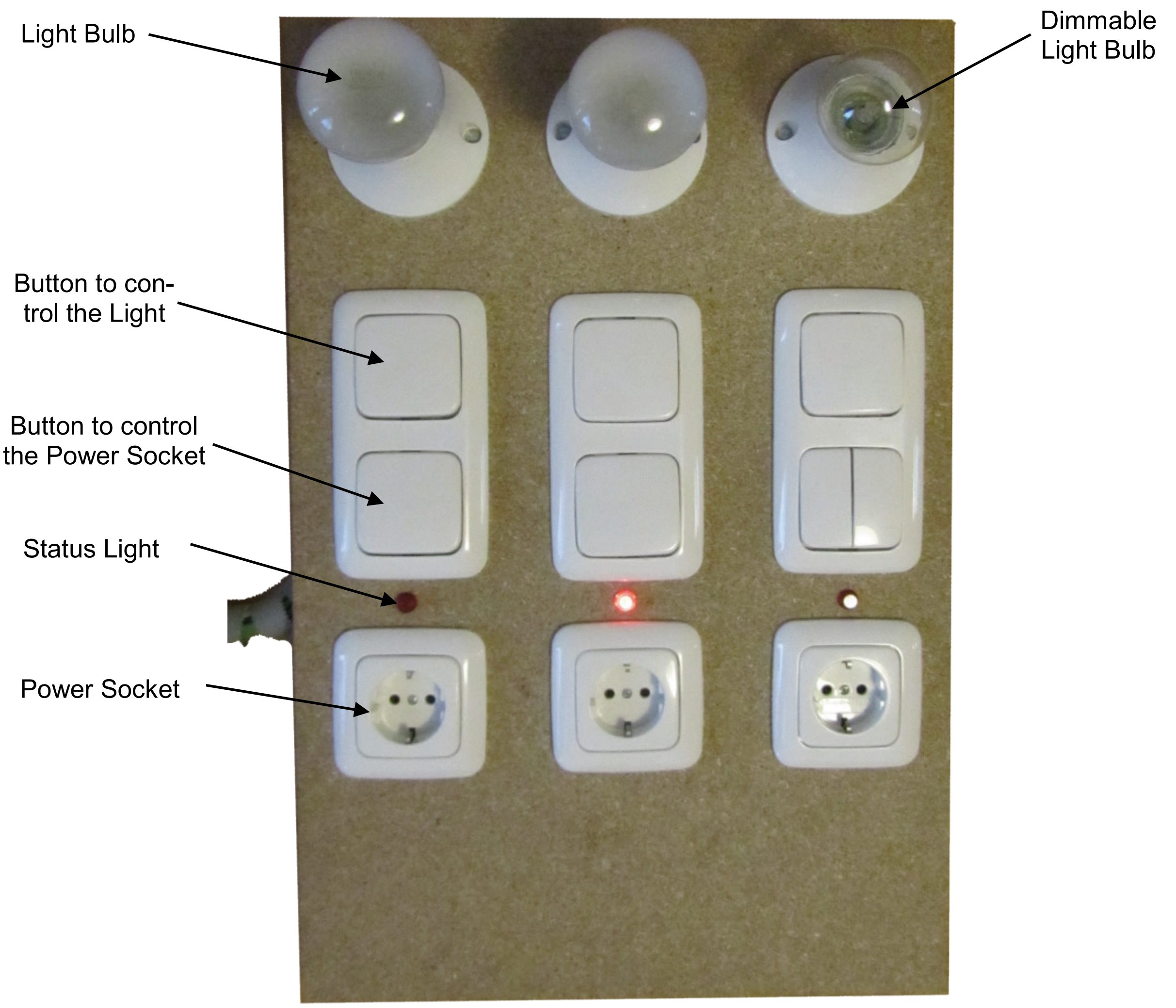


Figure 6.5: Demonstration Wall Detail

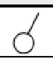
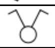
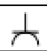
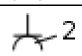
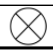
6.3 Electrical Installation Plan

The electrical installation plan consists of switches or rather pushbuttons, power sockets, lamps, speakers and shutter motors which are controlled by the shutter control node. Since a plan with all these devices included could be quite confusing, separate plans are used for each device category. Therefore, different layers are drawn for example a layer for lights, power sockets, pushbuttons, shutter motors, speakers, temperature sensors etc. A special naming convention is used to make it easy to determine the device type and how it is controlled. The naming, according to G. Kaiser [2], is done like described in the following table:

Device Type Layer	Control	Abbr.	Example
Lights	Relay	R	R12
	Dimmer	D	D12
Power Sockets	Relay	R	R64
	Dimmer	D	D64
Pushbuttons	-	PB	PB8
Switch	-	S	S24
Temperature Sensors	-	TS	TS4
Motion Detector	-	MD	MD2
Light Sensor	-	LS	LS4
Touch Panel	-	TP	TP2
Motor	-	M	M1
Speaker	-	SP	SP2
Telephone	-	T	T6
Network	-	N	N2

Table 6.1: Device Naming Convention

Furthermore, to draw the devices the following standardized electrical installation symbols are used.

Symbol	Description
	Switch
	Off switch
	2-way switch
	Series switch
	Cross switch
	Dimmer
	Pushbutton
	Pushbutton with lamp
	Power socket
	Two power sockets
	Lamp

	Speaker
M	Motor

Table 6.2: Electrical Installation Symbols

6.3.1 Light Layer

Figure 6.6 illustrates the light layer on the example of the living room, dining room and the kitchen. Lights starting with a "D" are dimmable and starting with an "R" are switchable. Lights with the same number after the first letter are switched and dimmed together. This means that they are connected together. The touch terminal is named by TP1 in the right bottom edge.

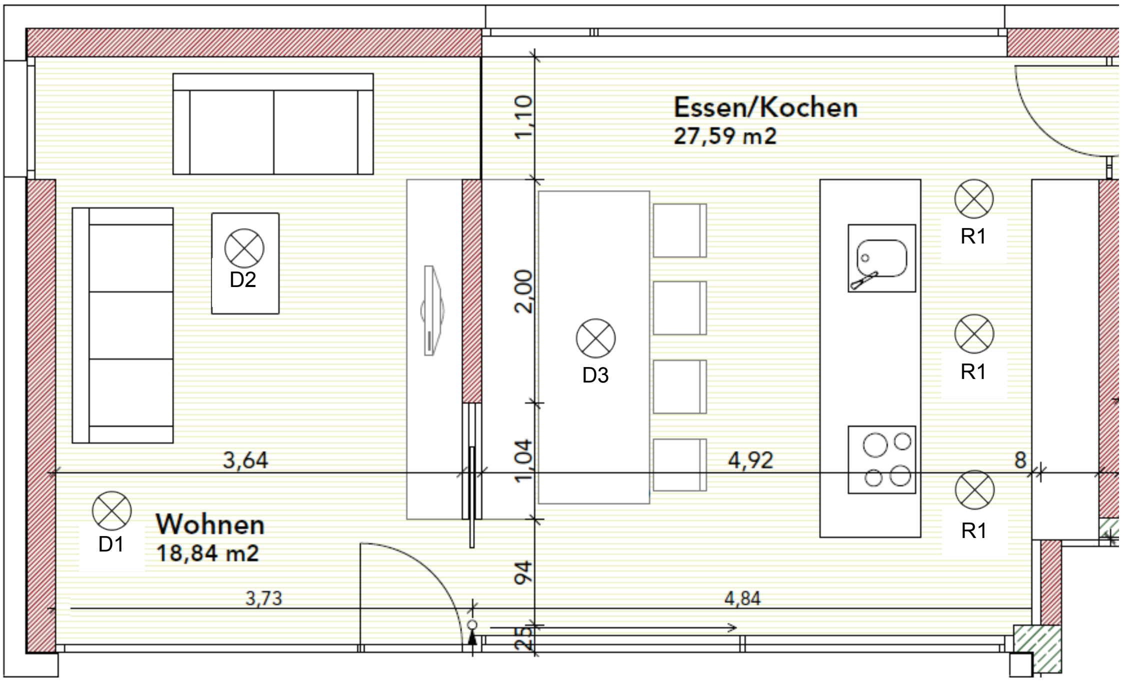


Figure 6.6: Light Layer

6.3.2 Power Socket Layer

Figure 6.7 illustrates the power socket layer on the example of the living room, dining room and the kitchen. Power sockets starting with a "D" are dimmable and starting with an "R" are switchable. Power sockets without any label are not controllable which means that they are always powered.

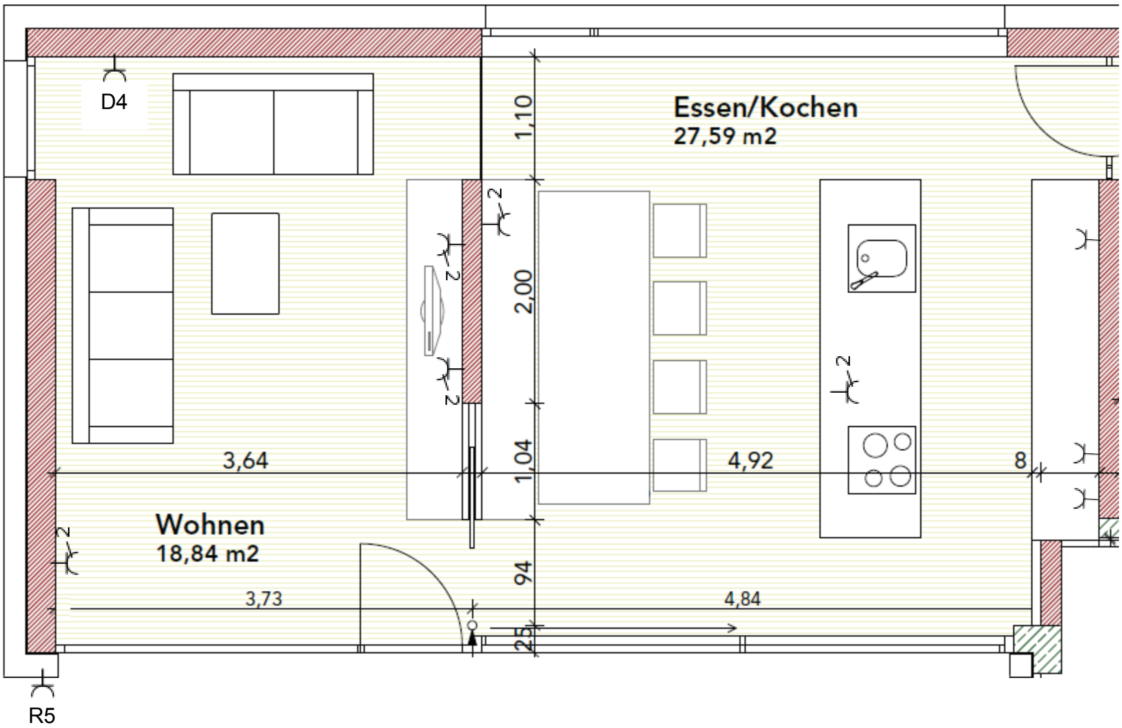


Figure 6.7: Power Socket Layer

6.3.3 Pushbutton and Switch Layer

Figure 6.8 illustrates the pushbutton and switch layer on the example of the living room, dining room and the kitchen. A switch (S) is used to switch a consumer directly in the traditional installation way. In contrast to that a pushbutton (PB) is used to generate a command for the home automation system. What function the pushbuttons have is not shown in the drawing but in the spreadsheet in Table 6.3, according to G. Kaiser [2].

Pushbutton	Function	Control	Description
PB1	Dim	D1	Floor Lamp Living Room
PB2	Dim	D2	Ceiling Lamp Living Room
PB3	Dim	D3	Ceiling Lamp Dining Room
PB4	On/Off Toggle	R1	Spotlights Kitchen
…	…	…	…

Table 6.3: Pushbutton Function Spreadsheet

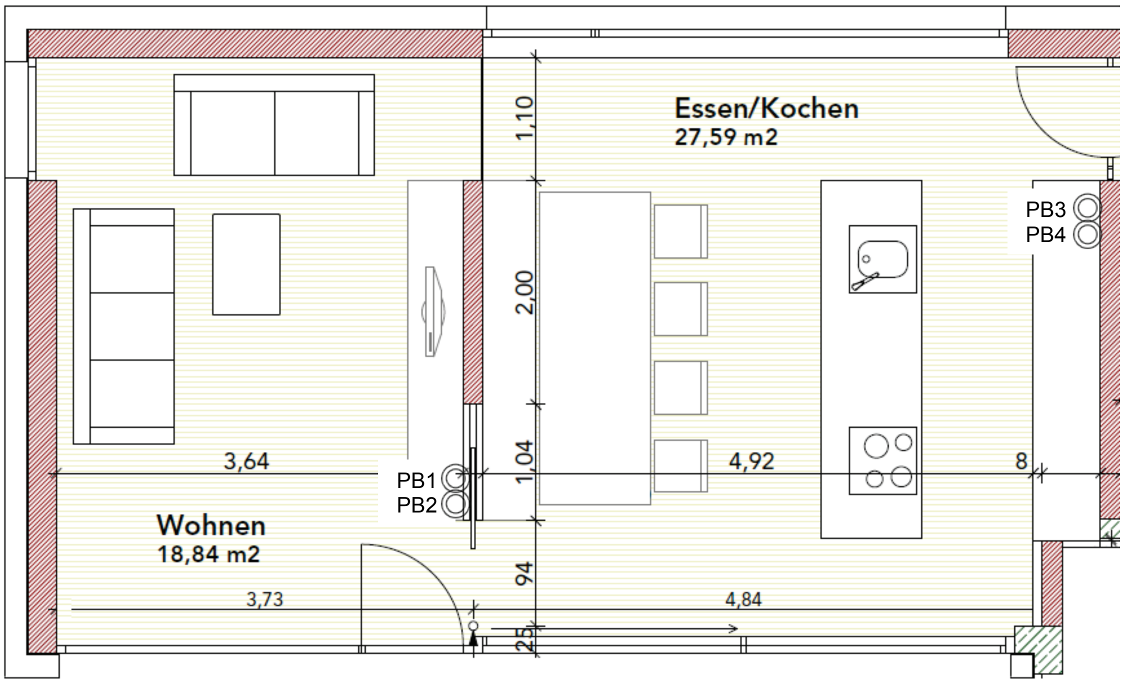


Figure 6.8: Pushbutton and Switch Layer

6.3.4 Motor Layer

Figure 6.9 illustrates the motor layer with the location of the motors with the shutter control node to control shutters or blinds.

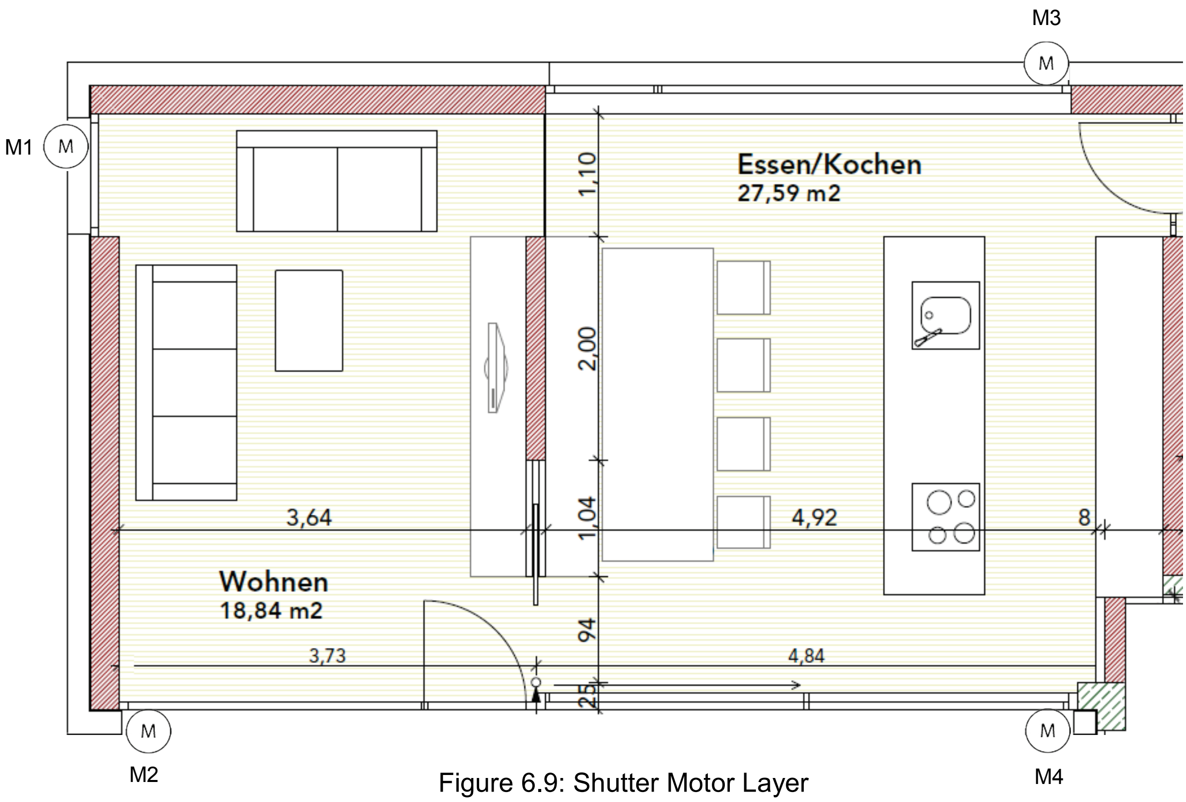


Figure 6.9: Shutter Motor Layer

6.4 CAN Bus Cable Installation

Figure 6.10 illustrates the installation of the CAN bus cable which connects the shutter control nodes, the touch terminal TP1 and the actuator control node which is located in the fuse box together.

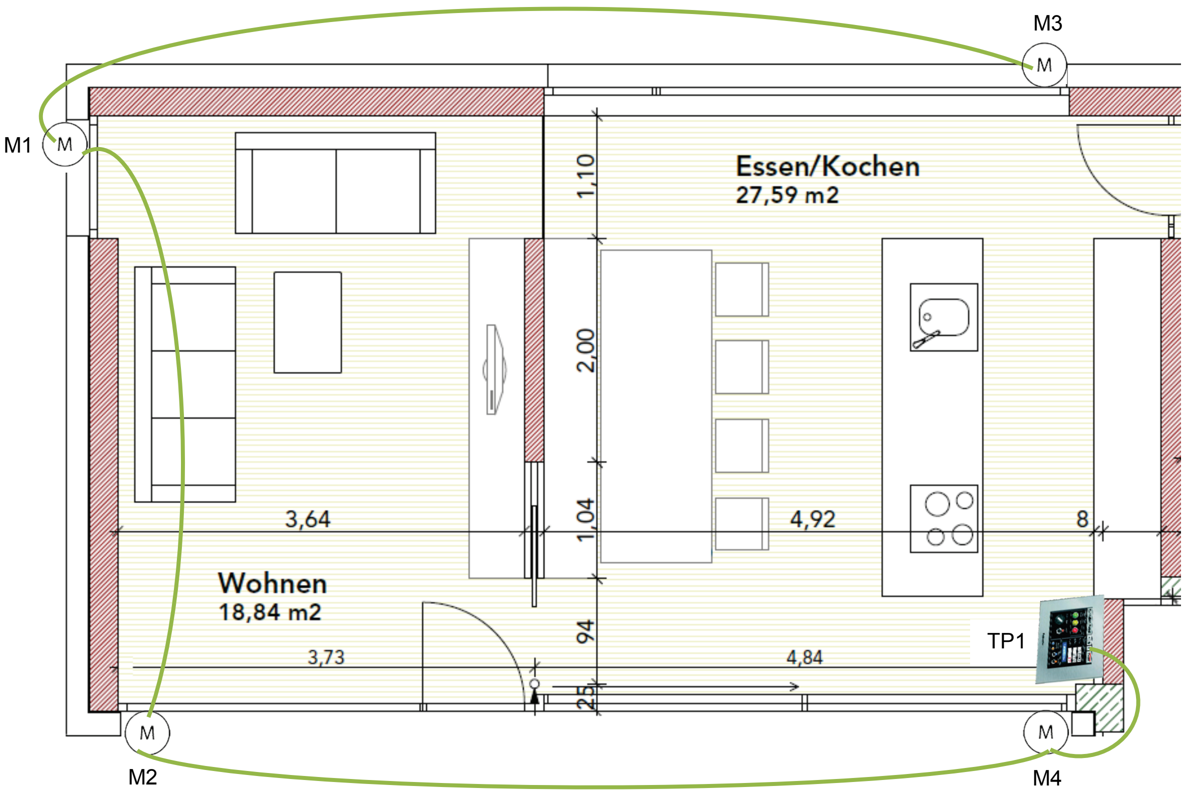


Figure 6.10: CAN Bus Installation

6.5 Comments on the Installation

This Section lists some comments on the planning of the installation.

- The user does not need to know how and through what cable the data communication is done. It is important where the pushbuttons are located and what function they have. [2]
- Meetings with the customer to find out what he wants and what the requirements are.
- If two or more pushbuttons have the same function, don't connect them decentralized in parallel. Connect them together at the button input module in the fuse box. So a later function change is easy possible.
- Use different colors for the pushbutton cables or label them to make it easy to distinguish them later.
- Wire some extra cables for pushbuttons where a future use is probable.
- Place some extra empty conduits for future installations.
- Use a spreadsheet with the function of all pushbuttons and one for all actuators to keep track of everything.
- Make sure to have enough space in the distribution box.
- For outdoor power sockets make sure that the power line is switched off if it is not used. Otherwise it would be easy, for example for a burglar, to switch off the electricity in the whole house by connecting the power line to ground. This causes the FI protection switch to fail. Therefore, the alarm system could be powerless as well. [2]

6.6 Visualization Hardware

As visualization hardware to run the visualization software a touch terminal is needed. Therefore, either a touch screen with a small ITX PC system or a tablet PC can be used. There are also quite expensive industrial PCs (IPCs) available which house both the PC and the touch screen in one case. For all these possibilities it has to be taken into account that the system provides enough computation power to run the visualization.

6.6.1 Touch Screen with ITX PC

The following two Figures show a 10” touch screen and a mainboard in the ITX form factor. This combination is the cheapest and most flexible solution to build a visualization terminal.

Figure 6.11: Faytech 10” Touch Monitor

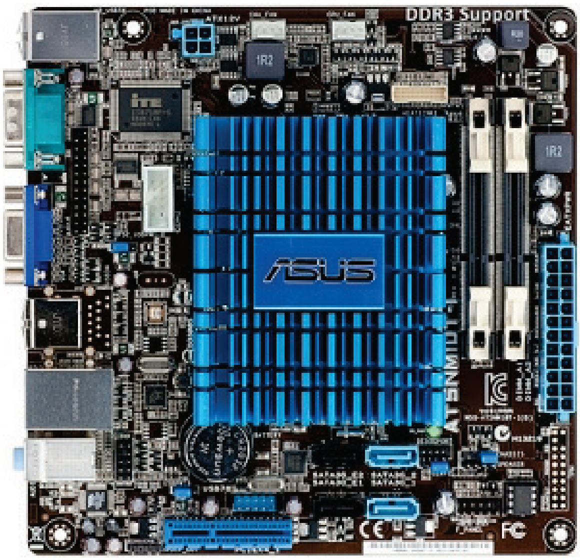


Figure 6.12: Asus ITX Mainboard with CPU

6.6.2 Tablet PC

Figure 6.13 shows a 12” tablet PC with Microsoft Windows 7 running. This solution is more expensive but very compact and well designed.

Figure 6.13: Asus 12" Tablet PC

6.6.3 Touch PC

Figure 6.14 shows a 10” touch PC which is often used in industry. This solution is designed to be integrated into a wall but is quite expensive.

Figure 6.14: Faytech 10" Touch PC

6.6.4 Discussion

Since the first solution with the touch screen and the ITX PC is the cheapest and most flexible one, it is used for development and testing the system. Flexibility is an important criterion for development because the system can run any operating system and can be extended with hardware.

7 Conclusion

"Properly speaking, such work is never finished;
one must declare it so when,
according to time and circumstances,
one has done one's best."
(J. W. Goethe, 1787)

7.1 Summary

The master thesis discusses the development of a concept of a home automation system by a concrete example of a one-family house. In the beginning a pre-study was conducted to give an introduction to the basic topology and requirements of a home automation system. An evaluation of possible bus interconnection technologies and an identification of the tasks were carried out. Due to the fact that CAN is very reliable and developed to operate in noisy environment, the decision was made to take this bus technology as a basis for the system.

A basic system structure was developed which led to a system implementation and the development of different modules. The switching and dimming of lights is controlled by the actuator control node located together with the actuators in the fuse box. Furthermore, the shutters are controlled by shutter control nodes located decentralized in the house next to the shutters. To connect the visualization terminal to the bus, the CAN PC interface module is used. To distribute an audio source to different rooms and to control their volume individually, the multi-room sound control module was developed.

Prototypes of all these modules mentioned above were built and tested within a demonstration system. The test results and the obtained experience were used to assist the planning of the final electricity installation.

7.2 Personal Reflections

I gained a lot of experience, especially in developing circuits and manufacturing prototypes. I also improved programming skills in C, Visual Basic and XAML which is used in the Windows Presentation Foundation (WPF). Furthermore, I obtained good knowledge and experience about Controller Area Network (CAN) while facing several problems and electrical effects.

During the work I got a good understanding for the home automation discipline and their challenge while coping with requirements and problems. A lesson I learned is that a good and stable basis, concerning bus communication, is very important to develop a complex system.

In my opinion, home automation systems will get more popular in near future if the installation costs are not much higher than for conventional installations. The initial expenses for purchasing and installing a home automation system pay off in the long term.

7.3 Further Work

The next step is to complete the electrical installation in cooperation with the house owners and the electrician. Furthermore, the home automation can be optimized regarding the communication protocol and the design of the modules. Some of the many features of the visualization can be improved. An alternative possibility would be to develop a visualization software which is platform independent, for example based on Java web technologies. This would make the remote access via the Internet feature easier to implement. Other features like a built-in music player can be added.

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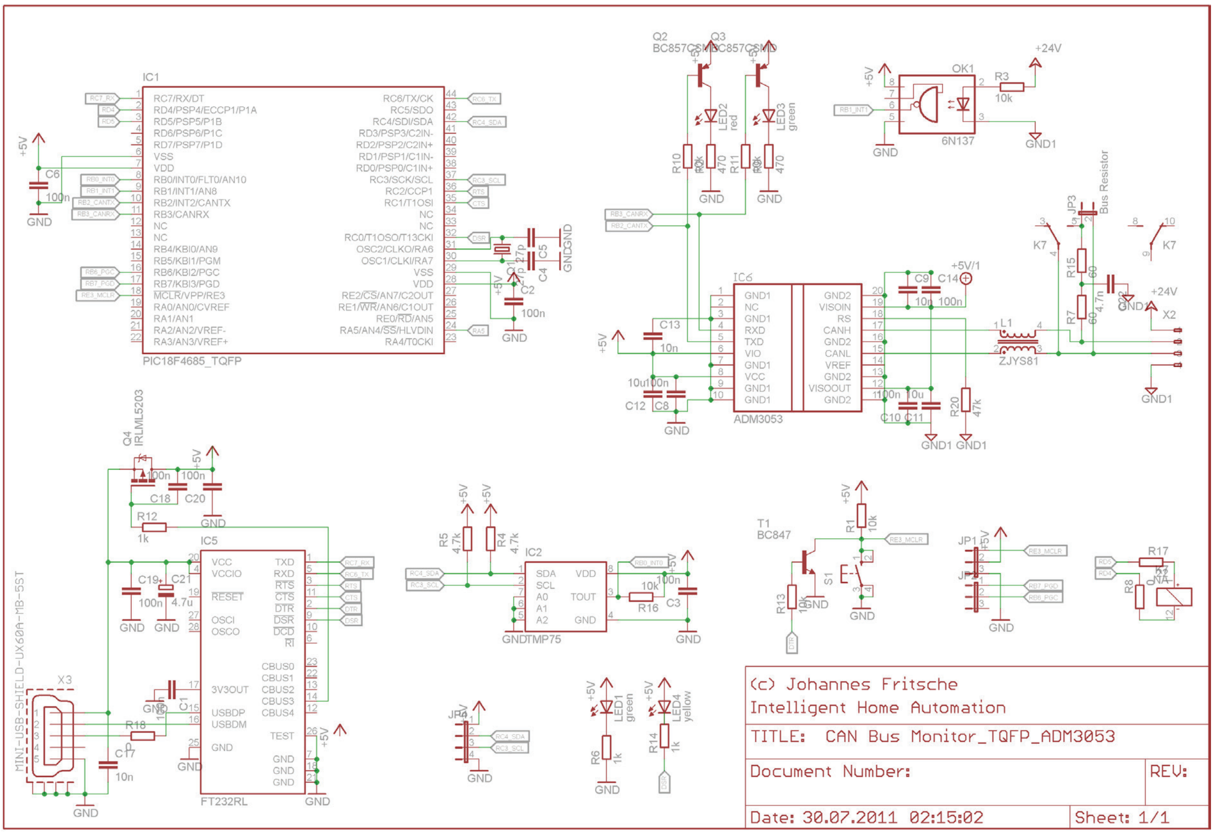
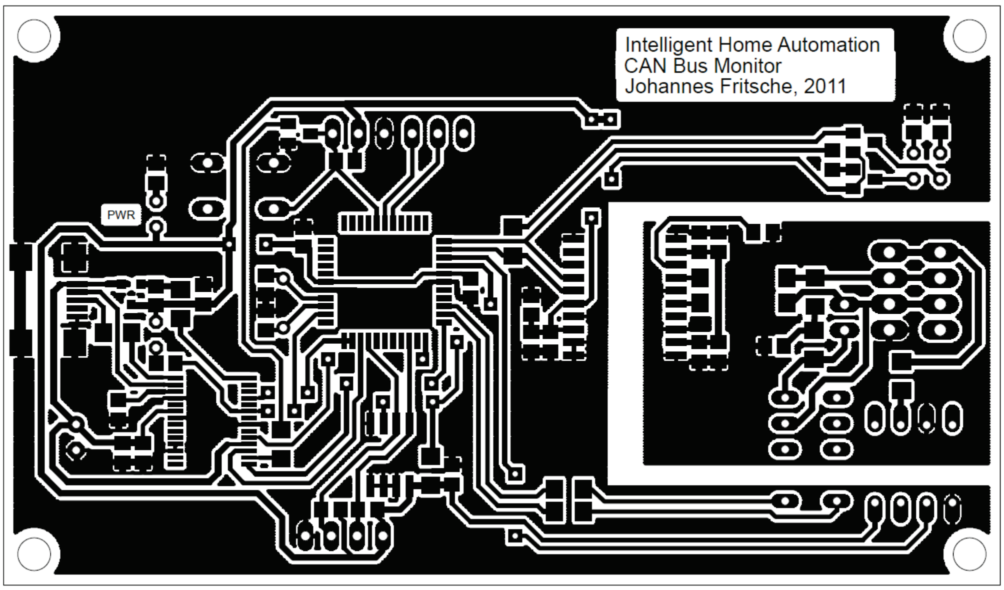
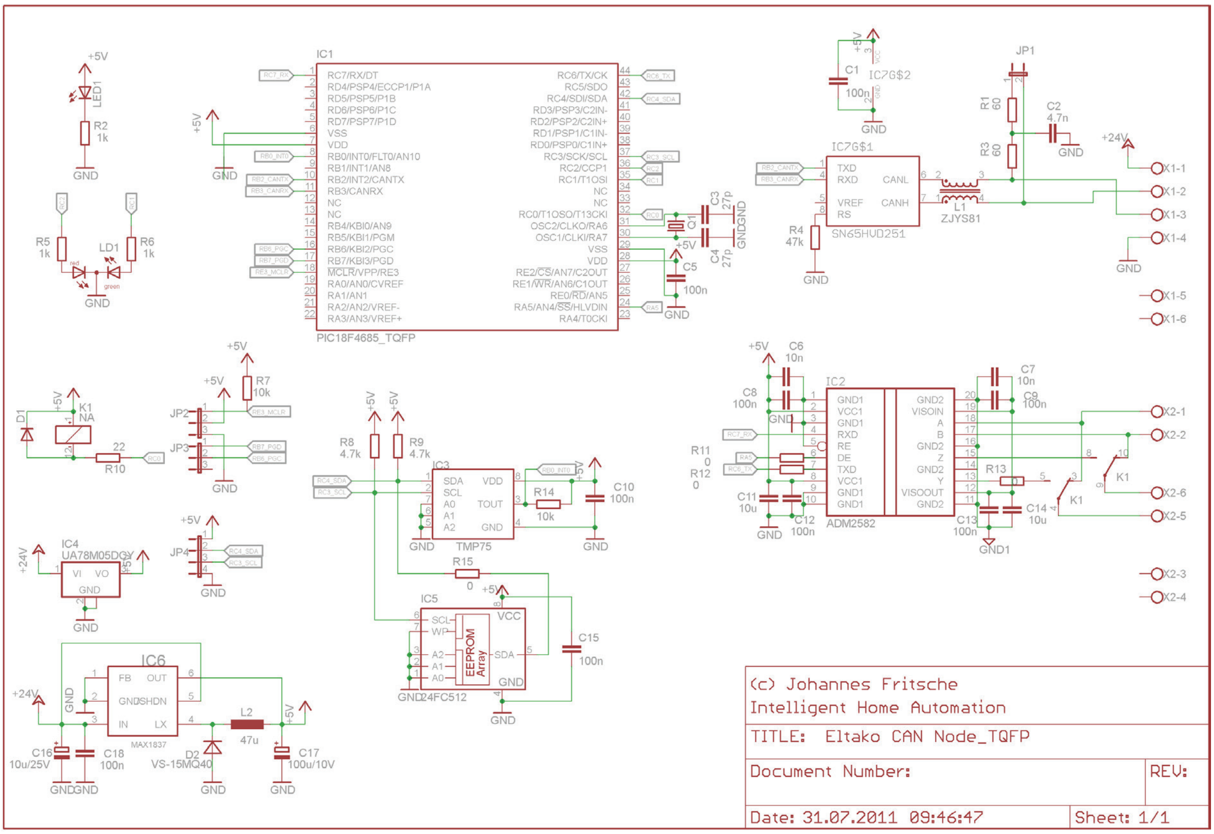
Appendix A: Schematics

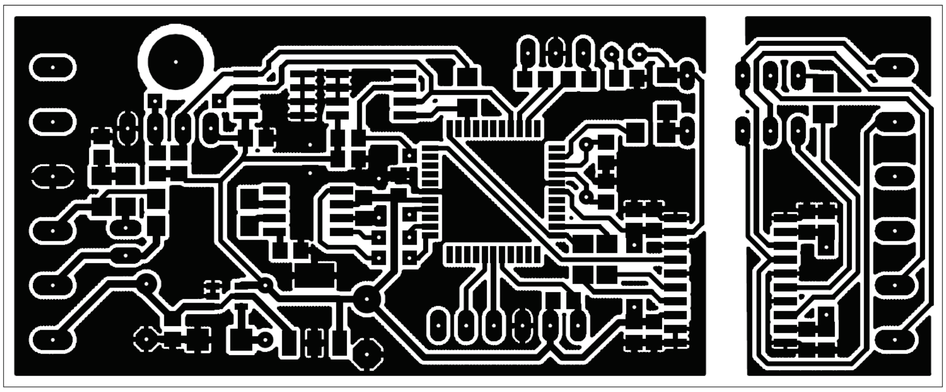
A.1 CAN Bus PC Interface



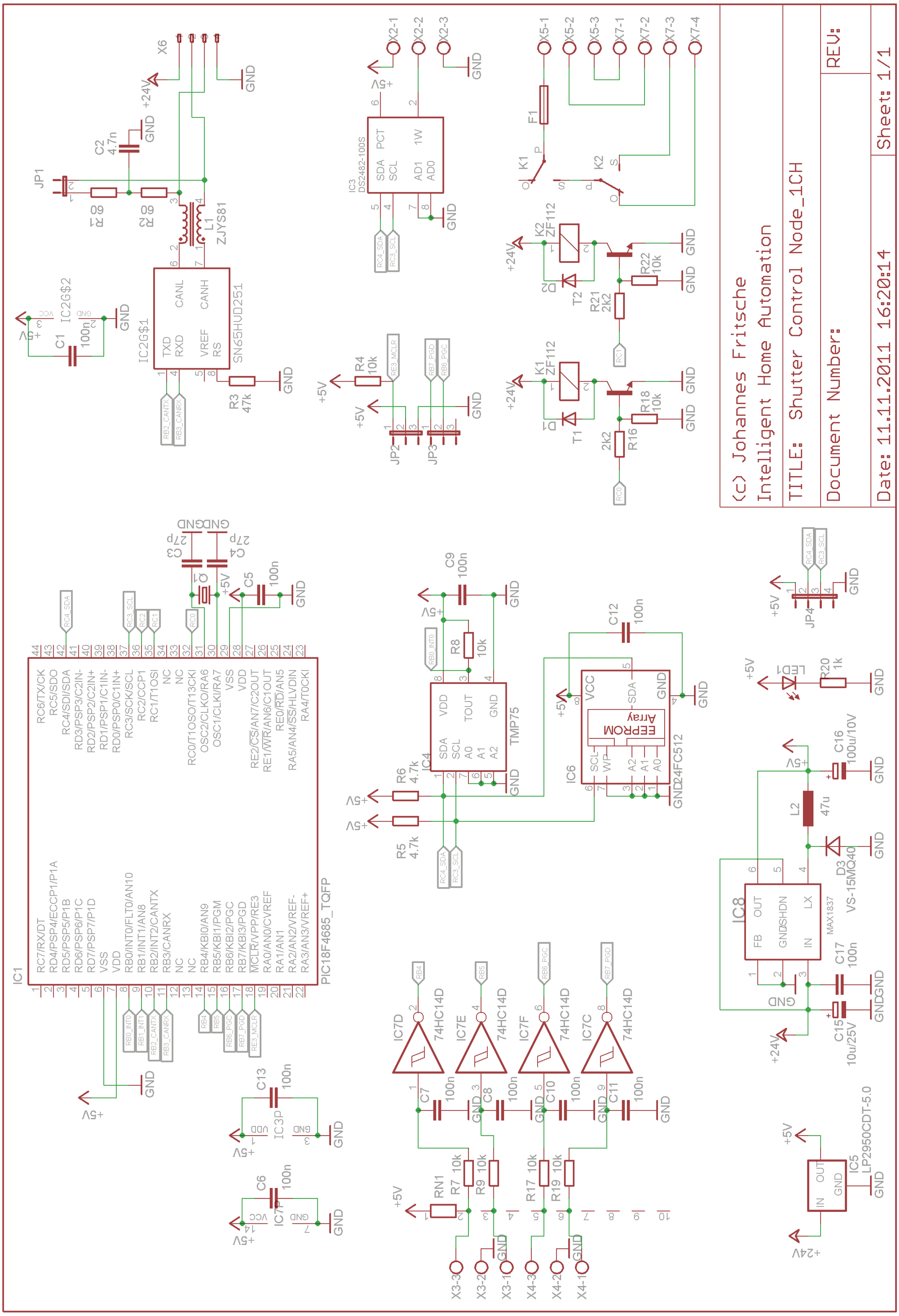


A.2 Actuator Control CAN Node

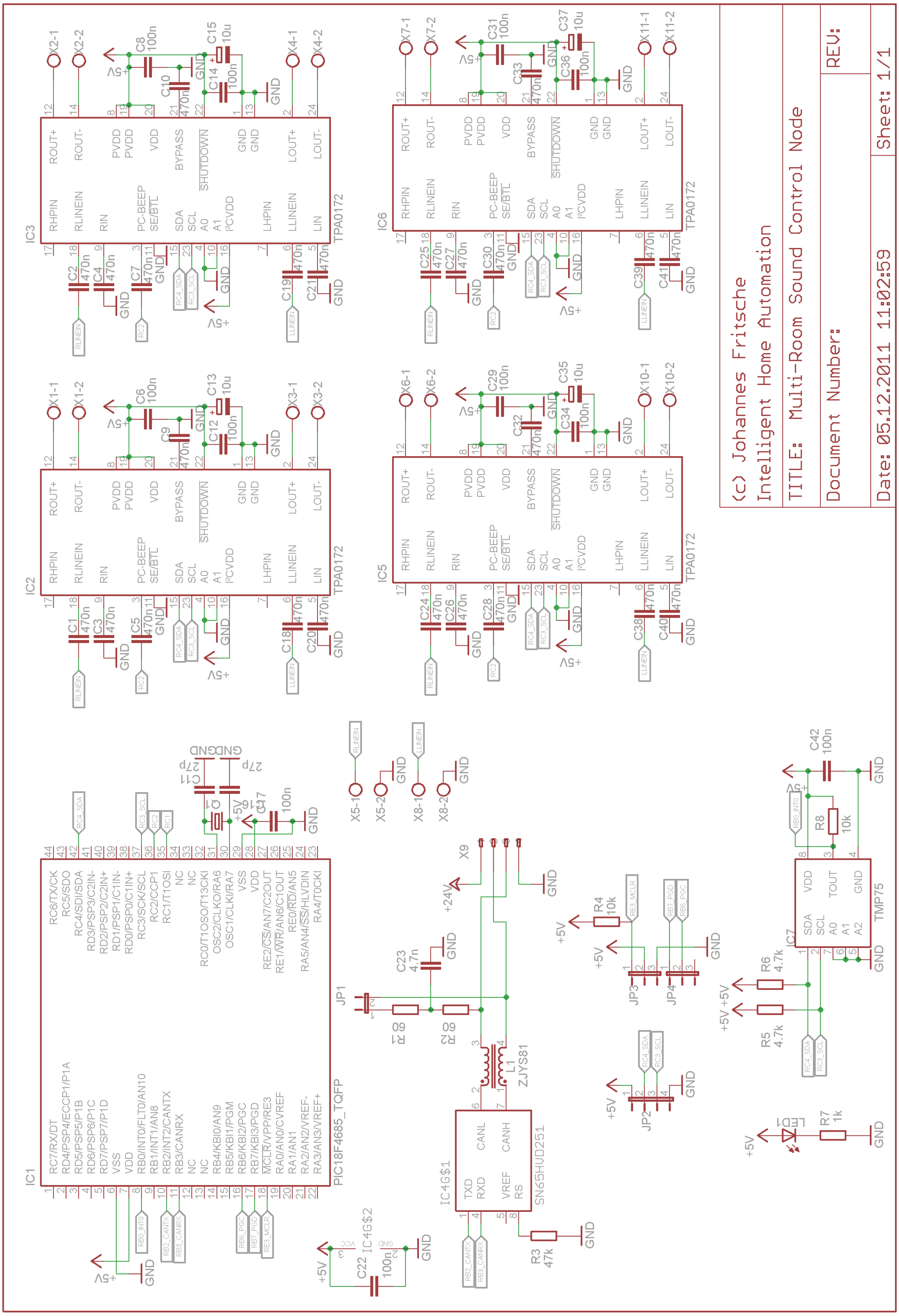




A.3 Shutter Control Node



A.5 Multi-Room Sound Control



List of Abbreviations

ACK	Acknowledge
CAN	Controller Area Network
CSMA/CR	Carrier Sense Multiple Access/Collision Resolution
DLC	Data Length Code
ECAN	Enhanced Controller Area Network
EIB	European Installation Bus
EMC	Electromagnetic Compatibility
HTTP	Hypertext Transfer Protocol
I^2C	Inter-Integrated Circuit
IrDA	Infrared Data Association
LAN	Local Area Network
MCU	Microcontroller Unit
NRZ	Non Return to Zero
PLL	Phase Locked Loop
ROM	Read Only Memory
TP	Twisted Pair
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus
WLAN	Wireless Local Area Network

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, …………………………… ………………………………………………..

(Signature)

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Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt und die den benutzten Quellen wörtliche und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

Graz, am …………………………… ………………………………………………..

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