# E-Field Lighting Controller with Wireless Connectivity

## Devices Supported:

**MC1321x**
**MC33794**

Document Number: DRM096
Rev. 0
11/2007

## *How to Reach Us:*


**Home Page:**
www.freescale.com

**E-mail:**
support@freescale.com

**USA/Europe or Locations Not Listed:**
Freescale Semiconductor
Technical Information Center, CH370
1300 N. Alma School Road
Chandler, Arizona 85224
+1-800-521-6274 or +1-480-768-2130
support@freescale.com

**Europe, Middle East, and Africa:**
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

**Japan:**
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064, Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

**Asia/Pacific:**
Freescale Semiconductor Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 26668334
support.asia@freescale.com

**For Literature Requests Only:**
Freescale Semiconductor Literature Distribution Center
P.O. Box 5405
Denver, Colorado 80217
1-800-441-2447 or 303-675-2140
Fax: 303-675-2150
LDCForFreescaleSemiconductor@hibbertgroup.com





DRM096
Rev. 0
11/2007

## Chapter 1
## Introduction


1.1 Introduction . . . . . . . . . . 1-1
1.2 Benefits of the Solution . . . . . . . . . . 1-2
1.3 MC1321x Microcontroller . . . . . . . . . . 1-3
1.3.1 General Platform Features . . . . . . . . . . 1-4
1.3.2 Microcontroller Features . . . . . . . . . . 1-5
1.3.3 RF Modem Features . . . . . . . . . . 1-6
1.4 MC33794 E-Field Imaging Device . . . . . . . . . . 1-6
1.4.1 MC33794 Features . . . . . . . . . . 1-6
1.4.2 Typical Applications . . . . . . . . . . 1-7


## Chapter 2
## Control Theory


2.1 Dimming of Lights . . . . . . . . . . 2-1
2.1.1 Modern Control Topology . . . . . . . . . . 2-1
2.1.2 Harmonic Frequency Noise . . . . . . . . . . 2-2
2.1.3 Light Bulbs Buzzing . . . . . . . . . . 2-2
2.2 An Alternative Solution to Control Panel Applications . . . . . . . . . . 2-3
2.2.1 Principle of Operation . . . . . . . . . . 2-3


## Chapter 3
## Intelligent Switch Description


3.1 System Specification . . . . . . . . . . 3-1
3.2 System Overview . . . . . . . . . . 3-2
3.3 Intelligent Switchboard Overview . . . . . . . . . . 3-2
3.4 Touch Panel Board Overview . . . . . . . . . . 3-4
3.5 Control Process . . . . . . . . . . 3-5
3.6 Dimming solution . . . . . . . . . . 3-6
3.6.1 Dimming Mechanism . . . . . . . . . . 3-7
3.6.2 Zero-Cross . . . . . . . . . . 3-8
3.7 Power Supply . . . . . . . . . . 3-8
3.7.1 Linear Regulator NCP551SN33T1 . . . . . . . . . . 3-9
3.8 E-Field Sensing . . . . . . . . . . 3-10
3.8.1 ADC Conversion . . . . . . . . . . 3-11
3.8.2 Touch Panel Connector . . . . . . . . . . 3-11
3.9 Power Management . . . . . . . . . . 3-12
3.10 Intelligent Switchboard Hardware Overview . . . . . . . . . . 3-13
3.10.1 Microcontroller . . . . . . . . . . 3-13
3.10.2 BDM . . . . . . . . . . 3-14
3.10.3 Buttons . . . . . . . . . . 3-14
3.10.4 LED Indicators . . . . . . . . . . 3-14

3.10.5 Power Supply Jumper . . . 3-14
3.10.6 Fuse . . . 3-15
3.10.7 Antenna Design . . . 3-15
3.10.8 EMI Filtering . . . 3-15
3.11 Touch Panel Board Hardware Overview . . . 3-16
3.11.1 E-Field Electrodes . . . 3-16
3.11.2 Touch Panel Identification . . . 3-16
3.11.3 Touch Panel LED Indicators . . . 3-17
3.12 Intelligent Switchboard Schematics . . . 3-18
3.13 Intelligent Switchboard PCB Layouts . . . 3-20
3.14 Intelligent Switch Bill of Materials . . . 3-21
3.15 Touch Panel Board PCB Layouts . . . 3-22
3.16 Touch Panel Bill of Materials . . . 3-25

## Chapter 4
## Intelligent Outlet Description

4.1 System Specification . . . 4-1
4.2 Board Overview . . . 4-2
4.3 Control Process . . . 4-4
4.4 Dimming Solution . . . 4-5
4.4.1 Zero-cross . . . 4-5
4.5 Power Supply . . . 4-5
4.5.1 Linear Regulator NCP551SN33T1 . . . 4-6
4.6 Power Management . . . 4-6
4.7 Intelligent Outlet Board Hardware Overview . . . 4-7
4.7.1 Microcontroller . . . 4-7
4.7.2 BDM . . . 4-7
4.7.3 Buttons . . . 4-7
4.7.4 LED Indicators . . . 4-8
4.7.5 Power Supply Jumper . . . 4-8
4.7.6 Intelligent Outlet Identification . . . 4-8
4.7.7 Fuse . . . 4-8
4.7.8 Antenna Design . . . 4-9
4.7.9 EMI Filtering . . . 4-9
4.8 Intelligent Switchboard Schematics . . . 4-10
4.9 PCB Layouts . . . 4-12
4.10 Bill of Materials . . . 4-14

## Chapter 5
## Software Design


5.1 Introduction . . . . . 5-1
5.2 Software Design Consideration . . . . . 5-1
5.3 RF Protocol Consideration . . . . . 5-1
5.3.1 SMAC (Simple Media Access Controller) . . . . . 5-1
5.3.2 Packet Structure . . . . . 5-2
5.3.3 Communication Process and Power Management . . . . . 5-3
5.4 Main Data Flow Charts . . . . . 5-4
5.5 Intelligent Switch Functions Overview . . . . . 5-5
5.6 Intelligent Outlet Functions Overview . . . . . 5-8
5.7 Dimming and Interrupts . . . . . 5-10
5.8 Firmware Functional Description . . . . . 5-11


## Chapter 6
## Application Setup


6.1 Setting Up the Demo . . . . . 6-1
6.1.1 Setting Up the Intelligent Switch . . . . . 6-1
6.1.2 Setting Up the Intelligent Outlet version 1 . . . . . 6-2
6.1.3 Setting Up the Intelligent Outlet version 2 . . . . . 6-3
6.2 Setup of the Intelligent Outlet Identificator . . . . . 6-4
6.3 Demo System Setup and Startup . . . . . 6-4
6.3.1 Intelligent Switch Device Installation . . . . . 6-5
6.3.2 Intelligent Outlet Device Installation . . . . . 6-5
6.4 Software Modification . . . . . 6-6
6.5 Demo Guide . . . . . 6-6
6.5.1 Controlled Device Determination . . . . . 6-6
6.5.2 Light Intensity Adjustment . . . . . 6-7
6.5.3 Turn On/Off Function . . . . . 6-7
6.5.4 Consideration about Normatives . . . . . 6-7


## Appendix A
## Glossary

# Chapter 1
# Introduction

## 1.1 Introduction

This reference design describes the design of light dimming devices for light bulbs, based on Freescale's MC1321x microcontroller with an 802.15.4 RF modem and controlled by the MC33794 E-Field Imaging device. The communication is based on a low power 2.4 GHz radio frequency transceiver using Simple MAC (SMAC) based on ZigBee™.

The light dimming of houshold light bulbs and lamps is a popular application. Freescale now offers its own new solution that raises the features of this application to a higher level and comfort. The design presents a light dimming demo with PWM triac control based on the MC1321x. The pulse width modulation technique (PWM) adjusts the reference sine wave of the AC power by a standard triac part. The system is fully adjustable to customer requirements by software modification.

The reference design incorporates hardware and software parts of the system, including detailed hardware descriptions and full software listings.


**Figure 1-1. System Overview**

The system consists of two kinds of applications:

- Intelligent switch is intended to replace a standard wall switch and provides dimming function on one phase of AC power. The control interface is an E-field contactless touch panel with various shapes of electrodes. The intelligent switch can also control four intelligent outlets through a 2.4 GHz radio frequency transceiver using SMAC.

- Intelligent outlets are intended to replace standard wall power outlets. The device needs the full AC power and dims the light in standard desk lamps and other portable devices. There are two versions of intelligent outlet boards, implementation in a wall outlet case and implementation in an adaptor case.

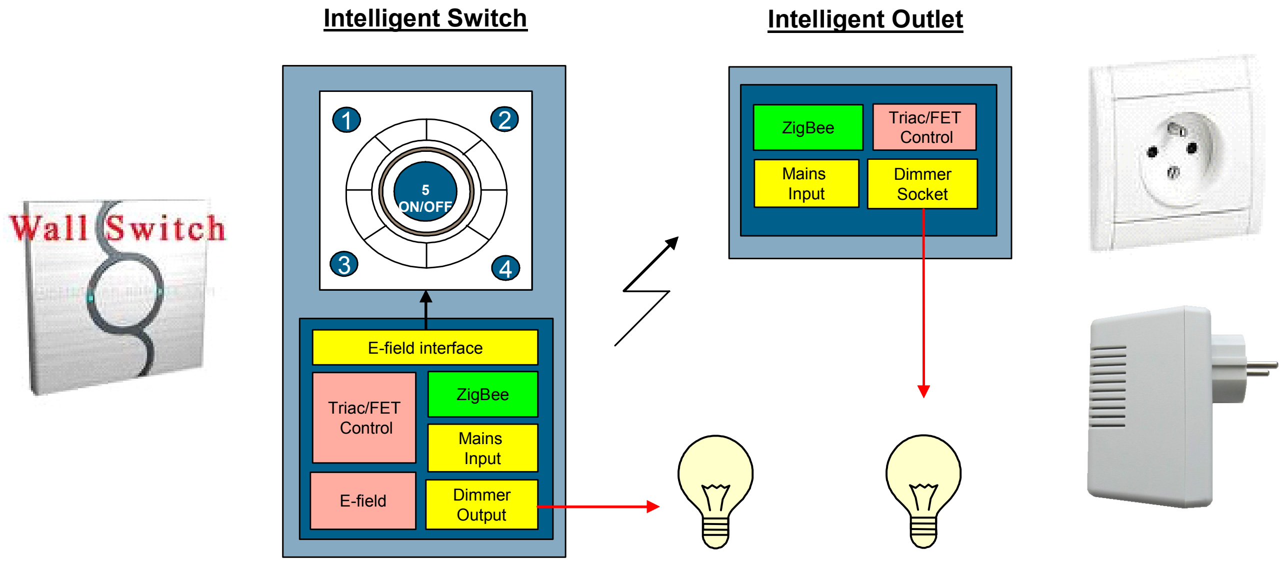


**Figure 1-2. System Block Diagram**

## 1.2 Benefits of the Solution

The application uses a stand-alone concept. The main control board is implemented in the intelligent switch by a microcontroller and an E-Field sensor. Intelligent outlets are controlled by the intelligent switch that provides the control interface. The boards are powered directly from the AC power. The application functionality can be changed via the software and hardware configuration on the PCB.

The main advantage of the intelligent switch solution is the comfortable control interface realized by E-Field technology. The E-Field electrodes are situated on the touch panel board. The shapes and positions of these electrodes can be fully customised according to requirements. It is possible to have various designs of slider, pads, or rotary control interfaces.

The other big advantage is in the RF wireless communication, using SMAC between the intelligent switch and the intelligent outlets, which provides a lot of possibilities for wireless network realization. One device can communicate on a peer-to-peer level with other devices, as master when controlling more devices at the same time, or on a slave hierarchy level. It all depends on individual protocol handling. The subnetwork, source, or destination device identifiers can be defined in the header of the protocol packet. The SMAC transceiver based on ZigBee operates in the 2.4 GHz ISM frequency band and guarantees no interference with standard home equipment.

In addition, the board can be used as a hardware platform for software development. For this purpose, the board is equipped with the BDM programming interface. This tool allows the MCU memory to be re-programmed in-circuit.

The modules are designed for easy implementation into the standard 230VAC or 115VAC home installation. It can be fitted into standard wall installation cases.

**WARNING**

Because the application runs at high voltage, it is dangerous to connect development tools directly to the board. Therefore, it is recommended to use an opto-isolated BDM programmer as the monitor and debug tool. This allows you to safely debug or examine code in-circuit.

The advantages of the presented solution can be summarized as follows:

- Reduced energy consumption and the cost savings (see table Table 1-1)
- Eliminate the need for costly three way bulbs
- Reduce the number of times you need to change your light bulbs
- Ease of adapting software to different lamp wattages
- The dimmer supports voltages of 230VAC/50Hz and 115VAC/50Hz
- Ease of re-programming the system behaviour and the software can simplify the hardware
- Contactless E-Field control interface offers various possibilities in material front cover designs
- Fully variable control interface (number, sizes, shapes of E-Field electrodes)
- Open to innovation

**Table 1-1. Energy Savings Chart for Incandescent Light Bulbs[1]**

| Light Level | Electricity Saved | Lamp Life Extended |
|---|---|---|
| 90% | 10% | Twice |
| 75% | 20% | 4 Times |
| 50% | 40% | 20 Times |
| 25% | 60% | Greater than 20 Times |

[1] Numbers are approximated

## 1.3 MC1321x Microcontroller

The MC1321x family is Freescale's second-generation ZigBee platform incorporating a low-power 2.4 GHz radio frequency transceiver and an 8-bit microcontroller into a 9x9x1 mm 71-pin LGA package.

The MC1321x solution can be used for wireless applications from simple proprietary point-to-point connectivity to a complete ZigBee mesh network. The combination of radio and a microcontroller in a small footprint package allows for a cost-effective solution. The MC1321x contains an RF transceiver, which is an IEEE 802.15.4-compliant radio operating in the 2.4 GHz ISM frequency band. The transceiver includes a low-noise amplifier, 1mW nominal output power, PA with internal voltage controlled oscillator (VCO), integrated transmit/receive switch, on-board power supply regulation, and full spread-spectrum encoding and decoding. The MC1321x also contains a microcontroller based on the HCS08 family of microcontroller units (MCU) and can provide up to 60-Kbyte of flash memory and 4-Kbyte of RAM. The onboard MCU allows the communications stack and the application to reside on the same system-in-package (SiP). The MC1321x family is organized as show in Table 1-2.

**Table 1-2. Memory Configuration**

| Microcontroller | Program Flash | Unified Data/Program RAM | Extended Features |
|---|---|---|---|
| **MC13211** | 16 Kbyte | 1 Kbyte | — |
| **MC13212** | 32 Kbyte | 2 Kbyte | — |
| **MC13213** | 60 Kbyte | 4 Kbyte | — |
| **MC13214** | 60 Kbyte | 4 Kbyte | ZigBee Stack |

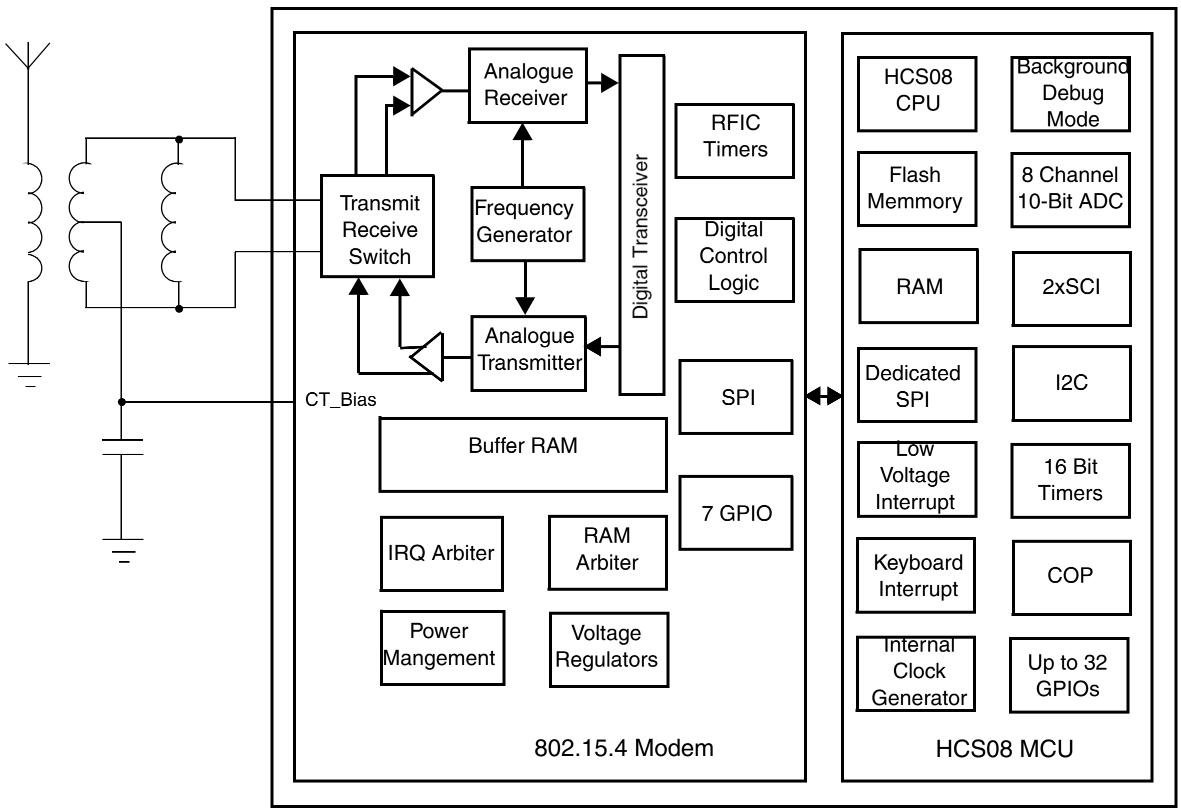


**Figure 1-3. MC13213 Block Diagram**

## 1.3.1 General Platform Features

- IEEE 802.15.4 standard compliant on-chip transceiver/modem
  - — 2.4 GHz
  - — 16 selectable channels with programmable output power
- Multiple power saving modes
- 2 V to 3.4 V operating voltage with on-chip voltage regulators for modem
- –40°C to +85°C temperature range
- Low external component count
- Supports single 16 MHz crystal clock source operation or dual crystal operation

- Support for SMAC, IEEE 802.15.4, and ZigBee software
- 9 mm x 9 mm x 1 mm 71-pin LGA

### 1.3.2 Microcontroller Features

- Low voltage MCU with 40 MHz low power HCS08 CPU core
- Up to 60-Kbyte flash memory with block protection and security and 4-Kbyte RAM
  - MC13211: 16-Kbyte flash, 1-Kbyte RAM
  - MC13212: 32-Kbyte flash, 2-Kbyte RAM
  - MC13213: 60-Kbyte flash, 4-Kbyte RAM
  - MC13214: 60-Kbyte flash, 4-Kbyte RAM with ZigBee Z-stack
- Low power modes (wait, plus three stop modes)
- Dedicated serial peripheral interface (SPI) connected internally to the 802.15.4 modem
- One 4-channel and one 1-channel 16-bit timer/pulse width modulator (TPM) module with selectable input capture, output capture, and PWM capability.
- 8-bit port keyboard interrupt (KBI)
- 8-channel 8-10-bit ADC
- Two independent serial communication interfaces (SCI)
- Multiple clock source options
  - Internal clock generator (ICG) with a 243 kHz oscillator that has a ±0.2% trimming resolution and ±0.5% deviation across voltage.
  - Start-up oscillator of approximately 8 MHz
  - External crystal or resonator
  - External source from modem clock for a highly accurate source or system low-cost option
- Inter-integrated circuit (IIC) interface with 100 kbps operation
- In-circuit debug and flash programming available via on-chip background debug module (BDM)
  - Two comparator and nine trigger modes
  - Eight deep FIFO for storing change-of-flow addresses and event-only data
  - Tag and force breakpoints
  - In-circuit debugging with single breakpoint
- System protection features
  - Programmable low voltage interrupt (LVI)
  - Optional watchdog timer (COP)
  - Illegal opcode detection
- Up to 32 MCU GPIO with programmable pullups

### 1.3.3 RF Modem Features

- Fully compliant IEEE 802.15.4 transciever supports 250 kbps O-QPSK data in 5.0 MHz channels and full spread-spectrum encode and decode
- Operates on one of 16 selectable channels in the 2.4 GHz ISM band
- –1 to 0 dBm nominal output power, programmable from –27 dBm to +3 dBm typical
- Receive sensitivity of < –92 dBm (typical) at 1% PER, 20-byte packet, much better than the IEEE 802.15.4 specification of –85 dBm
- Integrated transmit/receive switch
- Dual PA output pairs which can be programmed for full differential single-port or dual-port operation supporting an external LNA and/or PA.
- Three low-power modes for increased battery life
- Programmable frequency clock output for use by the MCU
- On-board trim capability for 16 MHz crystal reference oscillator elimminates need for external variable capacitors and allows for automated production frequency calibration
- Four internal timer comparators available to supplement the MCU timer resources
- Supports packet mode and streaming mode
- Seven GPIOs to supplement the MCU GPIO

## 1.4 MC33794 E-Field Imaging Device

The MC33794 is intended for cost-sensitive applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created. The MC33794 is intended to detect objects in this electric field. The IC generates a low-frequency sine wave, adjustable by using an external resistor, and is optimised for 120 kHz. The sine wave has low harmonic content to reduce harmonic interference. The MC33794 also contains support circuits for an MCU to allow the construction of a two-chip E-field system.

### 1.4.1 MC33794 Features

- Supports up to nine electrodes and two references or electrodes
- Shield driver for driving remote electrodes through coaxial cables
- +5.0 V DC regulator to power external circuit
- ISO-9141 physical layer interface
- Lamp driver output
- Watchdog and power-on reset timer
- Critical internal nodes scaled and selectable for measurement
- High-Purity sine wave generator tunable with external resistor
- Response time tunable with external capacitor

### 1.4.2 Typical Applications

- Appliance control panels and touch sensors
- Linear and rotational sliders
- Spill over flow sensing measurement
- Refrigeration frost sensing
- Industrial control and safety systems security
- Proximity detection
- Touch screens
- Liquid level sensing

# Chapter 2
# Control Theory

## 2.1 Dimming of Lights

People use some rooms in their houses for multiple purposes, and these different functions call for varying amounts of light. The dimmer lets you adjust light levels from nearly dark to fully lit by turning a knob or sliding a controller.

### 2.1.1 Modern Control Topology

Instead of diverting energy from the light bulb into a resistor as was done in old variable resistors dimmers, modern dimmers rapidly shut the light circuit off and on to reduce the total amount of energy flowing through the circuit. The switching cycle is built around the fluctuation of the household alternating current (AC). A modern dimmer automatically shuts the light bulb circuit off every time the current reverses direction when there is zero voltage running through the circuit. This happens twice per cycle (100 times a second). It turns the light circuit back on when the voltage climbs back up to a required limiting level of voltage.

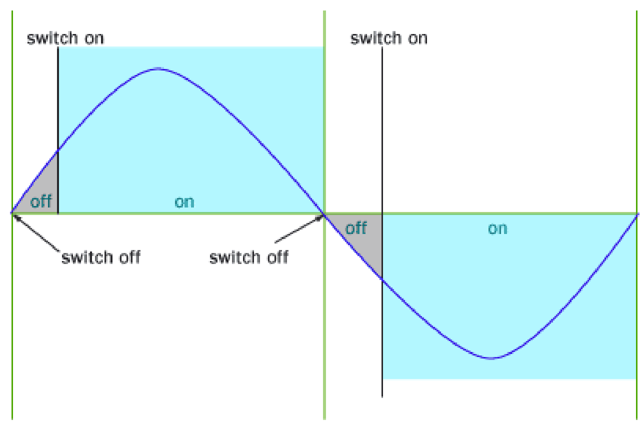


**Figure 2-1. Switching Process of Triac**

This turn-on value is based on the position of the dimmer's control interface. If the dimmer is turned to a brighter setting, it switches on immediately after cutting off. The circuit is turned on for most of the cycle, so it supplies a more average energy to the light bulb. If the dimmer is set for lower light, it waits until later in the cycle to turn back on.

#### 2.1.1.1 Triac Control

Modern AC power light dimmers use TRIACs to control the flow to the light bulbs so that only the needed part of the AC power pulse wave enters the light bulb (the PWM operation is synchronous to AC power power). It controls the brightness of the bulb by turning the bulb on for part of the time and then off for part of the time.

Electronic dimming using triacs or thyristors uses a technique that switches on the device at a certain point after the AC power has crossed the zero reference line. By nature of it's construction, the device turns off the passage of current through it when the current is zero (at the zero crossing point) because you can switch it in every cycle at a point near the zero crossing or far from it. If you switch it on near the zero crosssing, you get a brighter lamp because the device remains on longer before turning off at the next zero crossing.

#### 2.1.1.2 MOSFET Control

The MOSFET is a semiconductor part that offers more sophisticated attributes than triac. This component doesn’t close its channel when the zero level of the switched voltage is reached. The opening of this part depends only on the level of control voltage on the gate input. This is an advantage for realising various swiching options when needed. However, when this part is used in a dimmer device, it often needs special synchronization capabillities with regulated voltage and more complicated circuits. The MOSFET is also often more expensive than a triac part, which is the most persuasive factor for using a triac part. This solution is used in SCR dimmers that cut the sine wave on the front end and IGBT dimmers that cut it on the back end. This is appropriate when a dimmer regulates inductive loads.

### 2.1.2 Harmonic Frequency Noise

This sudden turning on of the triac or thyristor creates transients that buzz on the audio line at 50 or 60 Hz and the harmonics of those. This noise problem can be reduced by putting large inductors or EMI filters on the output of the triac, and this sudden rise can be smoothened to a certain extent. Because the largest current rise is at the centre of the AC waveform (where the voltage is highest, so the current is highest with resistive load), you typically find the largest amount of noise with the dimmers at around 50%. Modern high-specification dimmers have a choke or EMI filter that increases the switch-on rise time and they generally comply with standard EN55011-12 (representing the levels for residential electrical emission).

### 2.1.3 Light Bulbs Buzzing

Often, the buzzing sound of dimmed lighting systems is noticeable. This sound is due to inadequate chokes. The choke controls the rise time when the dimmer turns on. Any resistive load, such as an incandescent filament type of lamp, sees the division as equal to the same as a voltage drop. Because a filament takes a measurable amount of time to heat up or cool down, the on and off cycles blend into a steady degree of incandescence that you see as a level.

## 2.2 An Alternative Solution to Control Panel Applications

Control panels, appliances, heavy machinery, lighting controls, and anything that has push buttons requires some sort of human interaction to operate. Traditionally, push buttons are made from mechanical switches and/or multi-layer resistive touch pads that can deteriorate and become less dependable over time. The MC34940/MC33794 Electric Field Imaging devices from Freescale offers an alternative to mechanical push buttons. The MC34940/MC33794 Integrated Circuits (IC) contain the circuitry necessary to generate a low-level electric field and measure the field loading caused by objects moving into or out of the field. This is ideal for applications that desire non-contact sensing, proximity detection, and three-dimensional e-field imaging. The ICs integrate support for a microcontroller and 7 – 9 electrodes, which can be used independently to determine the size or location of an object in a weak electric field. Because it has the capability of sensing touch and proximity through the isolating surface, without direct electrical contact with the electrode metal, the problems of wear, contamination, and corrosion are eliminated. Furthermore, one of the key MC34940/MC33794 features that surpasses simple capacitive based sensors is its on-board shield driver, which makes it possibile to connect with remote touch pads up to a few metres away.

### 2.2.1 Principle of Operation

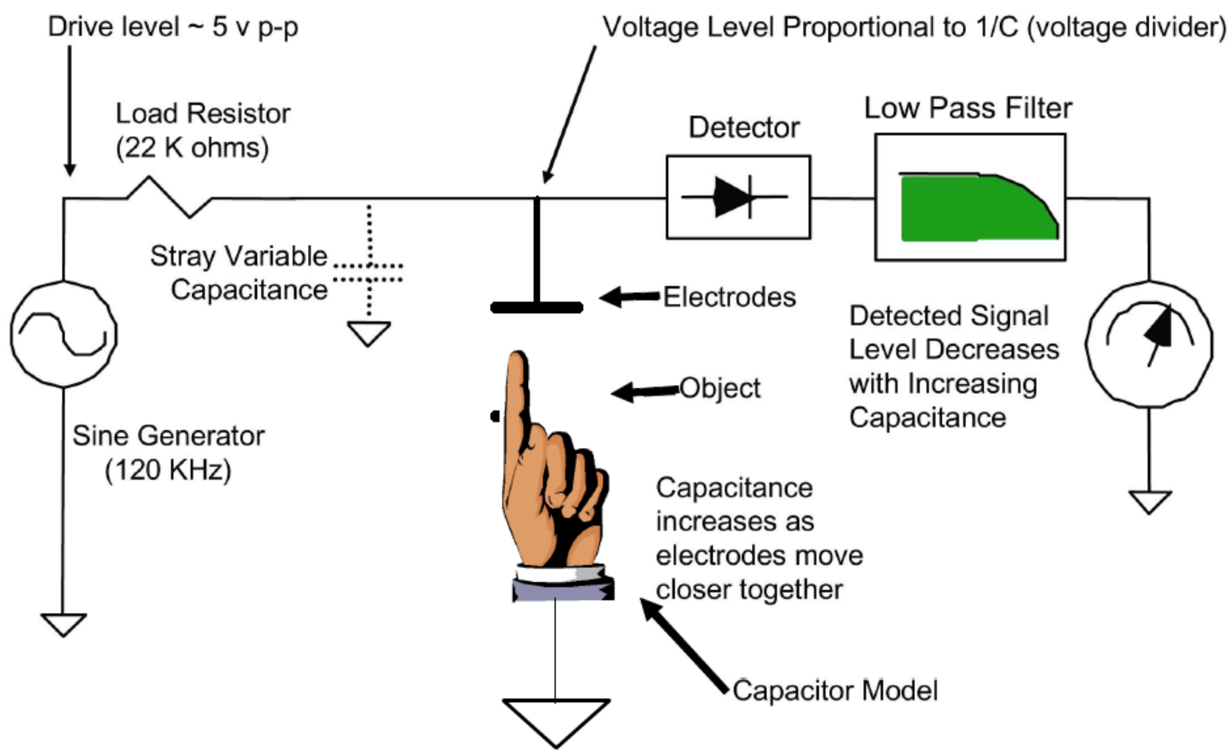


**Figure 2-2. Principle of Operation**

The MC33794 is intended for use in detecting objects using an electric field. The IC generates a low radio frequency sine wave. The frequency is set by an external resistor and is optimised for 120 kHz. The sine wave has low harmonic content to reduce potential interference at higher harmonically related frequencies. The internal generator produces a nominal 5.0 V peak-to-peak output that is passed through an internal resistor of about 22 kΩ. An internal multiplexer routes the signal to one of 11 terminals under the control of the ABCD input terminals. A receiver multiplexer simultaneously connected to the selected electrode routes its signal to a detector, which converts the sine wave to a DC level. This DC level is filtered by an external capacitor and is multiplied and offset to increase sensitivity. All of the unselected electrode outputs are grounded by the device. The amplitude and phase of the sinusoidal wave at the electrode are affected by objects in proximity. A capacitor is formed between the driving electrode and the object, each forming a plate that holds the electric charge. The voltage measured is an inverse function of the capacitance between the electrode being measured, the surrounding electrodes, and other objects in the electric field surrounding that electrode. Increasing capacitance results in decreasing voltage. The value of the series resistor (22kΩ) was chosen to provide a near linear relationship at 120 kHz over a range of 10pF to 70pF.

# Chapter 3
# Intelligent Switch Description

## 3.1 System Specification

The system dims light bulbs in one phase of the AC power. The application has the following specifications:

- The device dims a light bulbs by triac circuitry in one phase of the AC power (connection with the light bulb in series)
- Remote control of up to four intelligent outlets (defined by HW ID) in a range of tens of meters by RF transceiver
- Simple comfortable control by contactless E-Field sensing of finger touch realized by a changeable touch panel
- Targeted at the MC1321x microcontrollers and MC33794 E-Field Imaging Device
- Supported vacuum incandescent light bulbs in the power range 40-200W
- Application is powered directly from the 230 VAC/50Hz (115VAC/60Hz) AC power
- Touch panel features:
  - Offers nine e-field electrodes of a pad, rotary or slider type for system control
  - Possibility for easy connection to an intelligent switchboard via the touch panel connector
  - Touch panel is defined by a HW selector for following autodetection by the Intelligent Switch
  - The board is suitable for using as the front panel of a common wall switch
  - On the board are situated LEDs to indicate the system state
  - The possibility of covering by a thin material (plexiglass, glass)
- Control technique incorporating:
  - Closed-loop PWM generated by a timer interrupt is used to adjust the control impulses for the triac
  - Zero-cross detection of AC power voltage for synchronization of triac switching
  - Settings to regulate the range of compensation in the voltage-current offset caused by reactance in the device and light bulb (it depends on light bulb wattage too)
  - Possible memorizing of the last setting
  - Maximal dimming level is up to 90% from full light intensity of the bulb (restriction is a consequence of the bulb’s connection to the board)
- Communication technique incorporating:
  - RF communication at a frequency of 2.4GHz realized by SMAC software layer and an 802.15.4 modem implemented in one MC1321x

— Short packet message transmission for lower consumption of the boards
— Possibility to create networks of point to point communcation between devices determined by the header of the packet (source address, destination address, network ID)

## 3.2 System Overview

The intelligent switch application consists of two boards:

- Intelligent switchboard
- Touch panel

These two boards are connected together throughout Section 3.8.2, "Touch Panel Connector". See Figure 3-1 for a system overview. The whole device is described in Section 6.1.1, "Setting Up the Intelligent Switch".

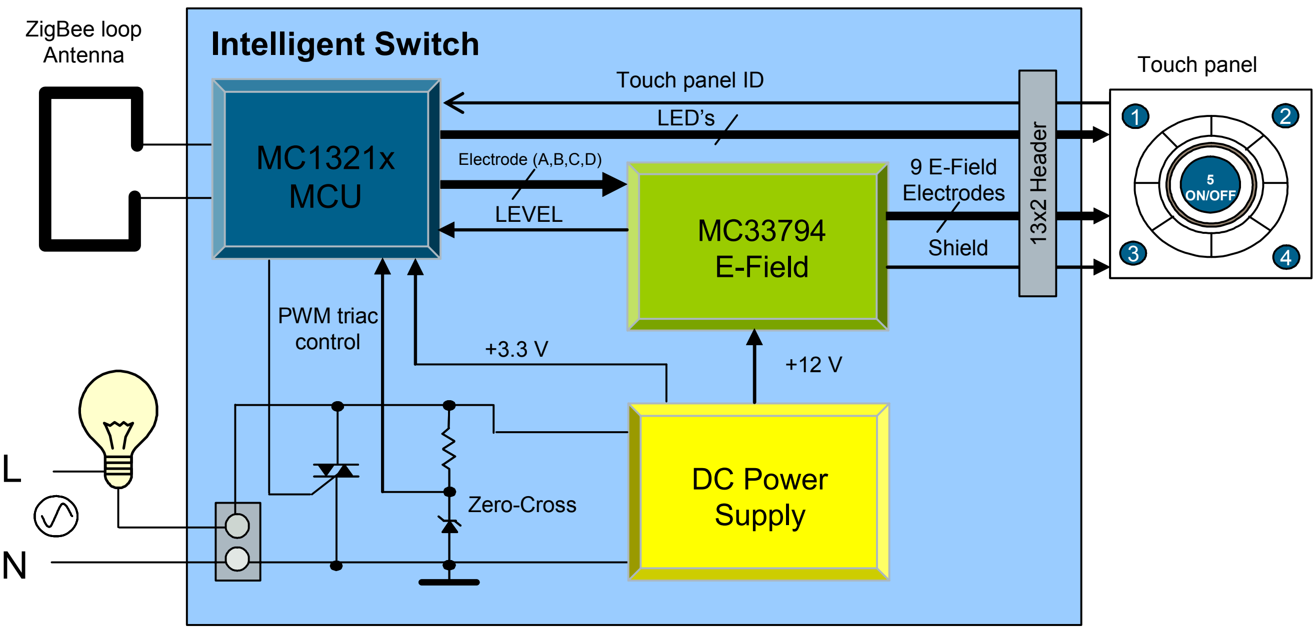


**Figure 3-1. Intelligent Switch Block Diagram**

## 3.3 Intelligent Switchboard Overview

The board utilizes a small footprint sized dual-layer printed circuit board (PCB) containing all the necessary circuitry for the MC1321x microcontroller, E-Field sensing, and transferring data over a RF radio frequency. The size and shape of the board is designed for easy installation into a standard wall switch cross-case (size ϕ 65 x 20 mm in Europe, type KP68) commonly used for serial control of a light bulb in one loop. The complete intelligent switch together with the touch panel (Section 3.4, "Touch Panel Board Overview") doesn't need replacing or any retrofitting electro-installation in the walls at home.

The components are placed on the PCB for convinient component access (touch panel connector) and to minimise the minimal influence of the electromagnetic field and high voltage differences between electrical blocks on the board. High voltage parts, including the switching power supply, zero-crossing and triac control, are separated from the MCU, E-Field chip, and RF transmitter. This causes a division of the

PCB into four parts: power supply, MCU, E-Field, and PCB antenna. The switching power supply part of the PCB is designed according to the rules of high voltage routing, widths of wires, and isolating spaces.

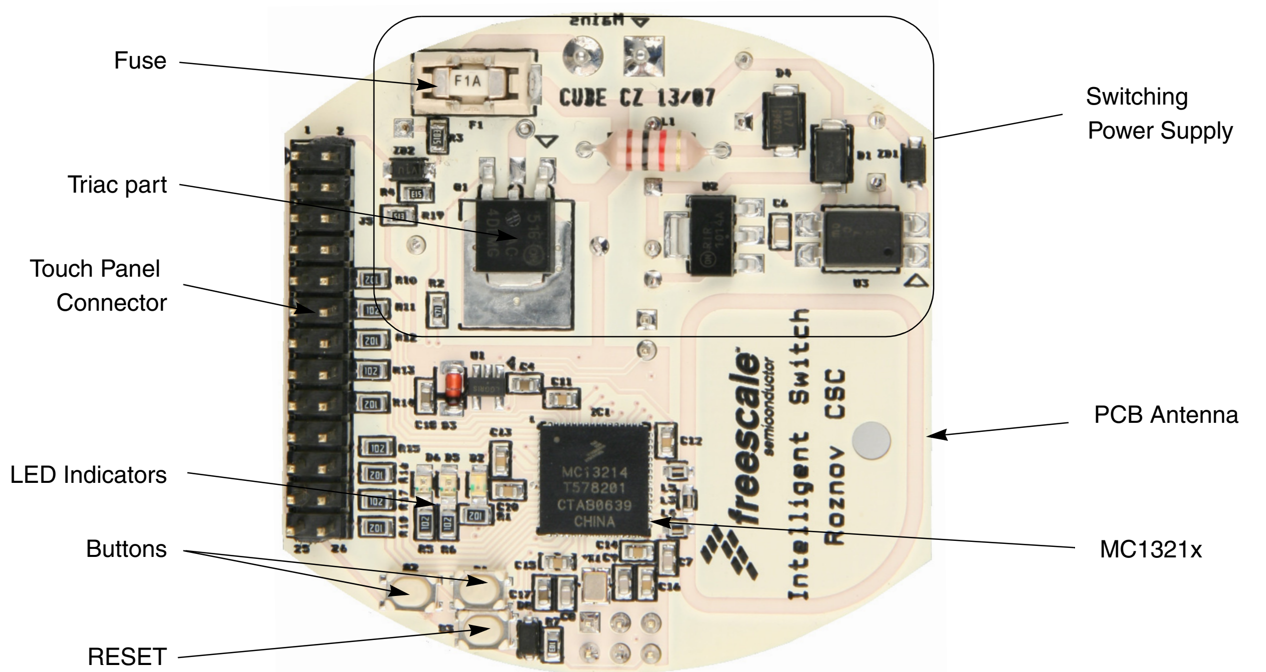


**Figure 3-2. Board Overview, Top Side**

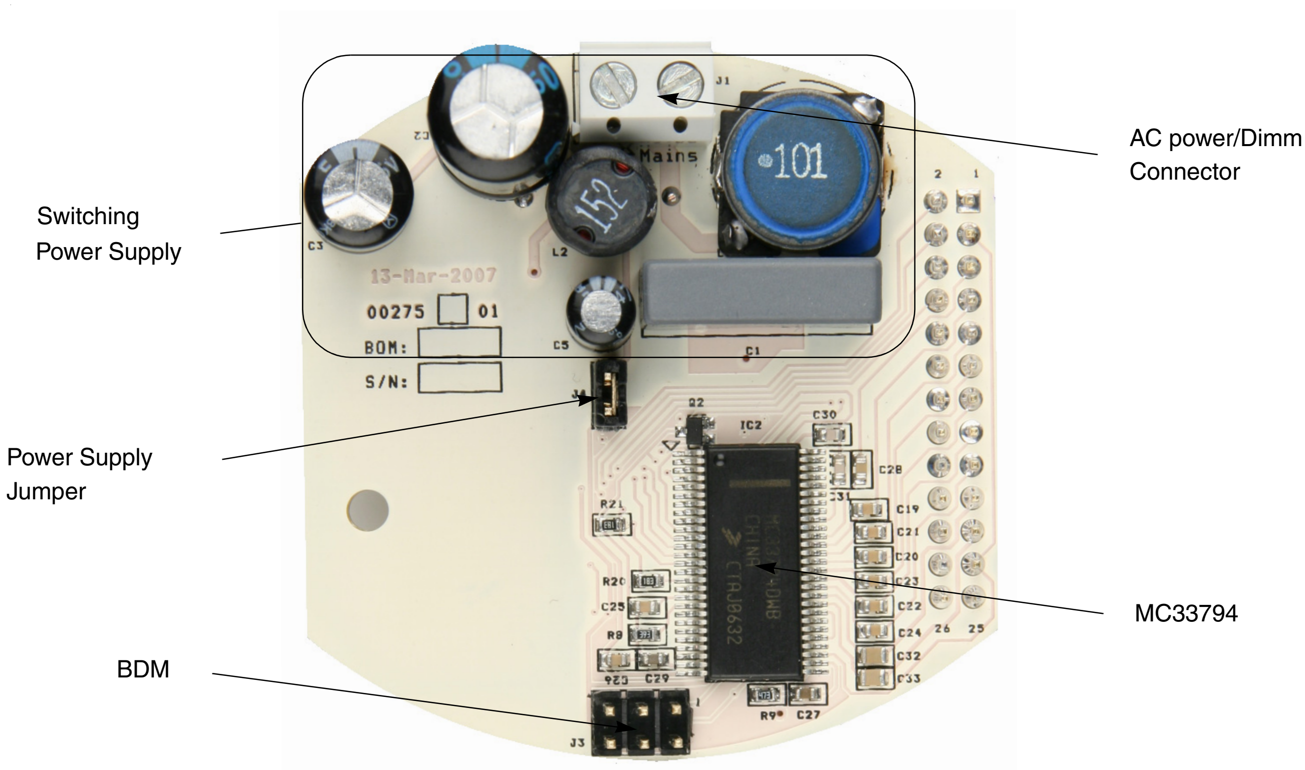


**Figure 3-3. Board Overview, Bottom Side**

## 3.4 Touch Panel Board Overview

The system can accomodate several types of touch panels that can be used according to customer requirements. The main two modifications differ in the types of fluent dimming level controls used. There is a rotary or slider controller, determined by different combinations of the e-field electrodes. A combination of four electrodes is divided into several smaller areas, making it possible to create more detecting fields. This allows for creation of a slider or rotary selector. This solution causes a lower sensitivity in these electrodes because the electrode area is divided, but there is the advantage of creating more pads. The board also contains five pads for determining the controlled intelligent outlet and a switch on/off function.

The board utilizes a small footprint sized dual-layer printed circuit board (PCB) containing few necessary parts (LEDs) with a touch panel connector. The size and shape of the board is designed for easy installation into the front face of a wall switch. The wall switch selected is from the manufacturer ABB model Element®, which is appropriate with its suitable design and shape of the front face. The touch panel board is situated above the intelligent switchboard on the front face of the wall switch mounted to the cross-case (KP68 size ϕ 65 x 20 mm) by screws. These two boards are connected through the touch panel connector. The mechanical fixing is provided only by the touch panel connector of 26 pins. The board is also equiped with two holes for attaching the whole device to a wall case. More on the installation is in chapterSection 6.1.1, “Setting Up the Intelligent Switch”.

This arrangement of parts and electrodes is with regards to component access by the user and to the influence of the electromagnetic field and high voltage differences between the boards. The possible designs are as shown: the rotary touch panel in Figure 3-4 and the slider touch panel in Figure 3-5.

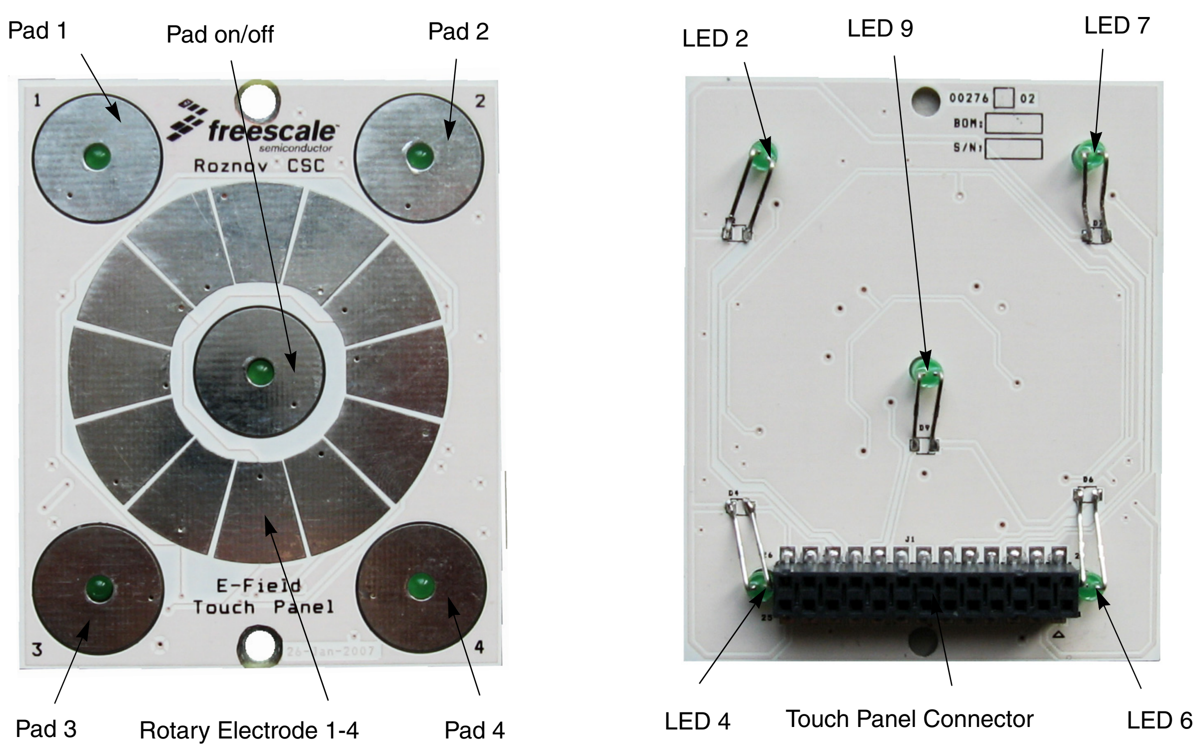


**Figure 3-4. Touch Panel Rotary Overview, Top and Bottom Side**

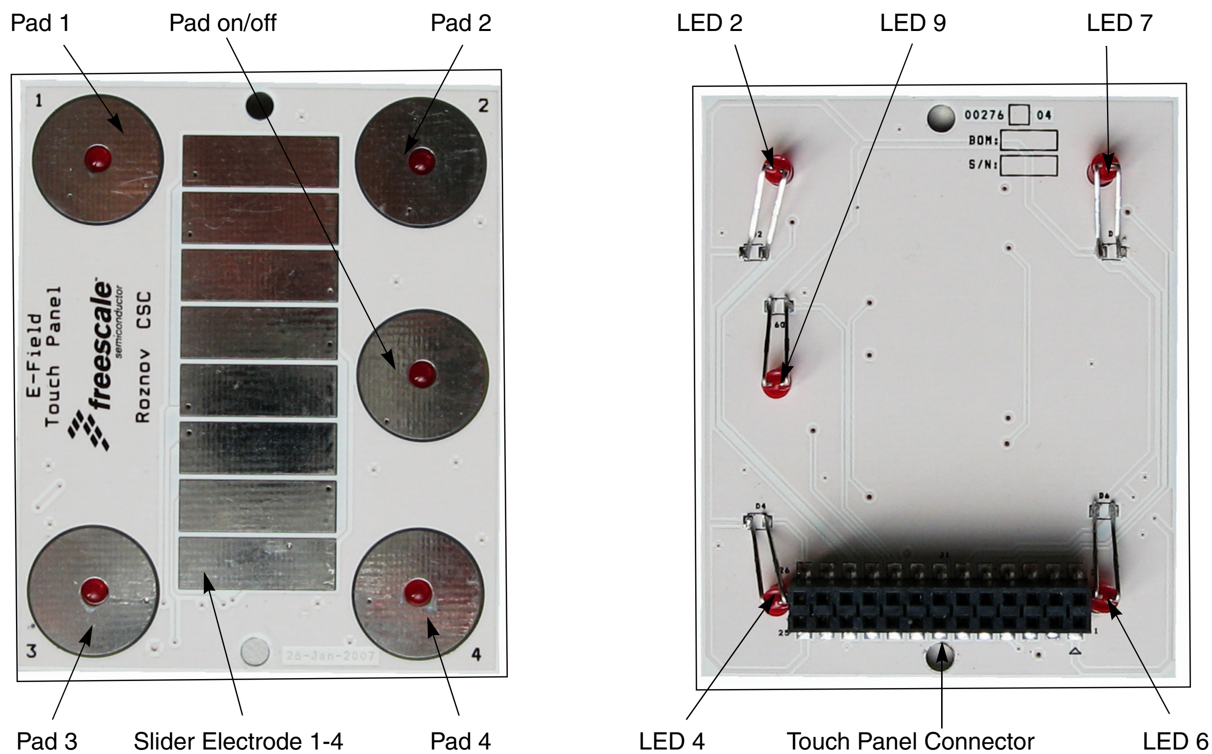


**Figure 3-5. Touch Panel Slider Overview, Top and Bottom Side**

## 3.5 Control Process

Figure 3-6 shows in more detail, how different software and hardware modules co-operate with each other. The main tasks of the board are to:

- Periodically wake-up from power saving mode when the device isn't dimming a light bulb
- Periodically control the triac by PWM synchronized to zero-cross detection if dimming is enabled
- Measure all nine E-Field electrodes of the MC33794 sensor through the analogue-to-digital converter (ADC) using pin AD0 by addressing each of them by the PTB2-PTB5 pins
- Analyse the data from the touch panel:
  - — If the remote control mode of some Outlet is activated, and then it composes a data frame using simple RF Protocol
  - — If the dimming value of this intelligent switch is adjusted, it changes internal dimming variables
- If the remote control mode is activated, send this data frame over the RF link using SMAC
- Go to sleep when the device isn't dimming a light bulb

This basic loop repeats roughly 100 times per second providing an almost real-time response from the E-Field Sensor. If power saving mode is activated when the device isn't dimming, the loop repeats roughly 25 times per second.

Several of the MC1321x MCU modules are used for the intelligent switchboard operation: ADC, internal synchronous peripheral interface (SPI), external interrupt request (IRQ), 8-bit keyboard interrupt module (KBI1), and the timer/PWM module (TPM1/TPM2).

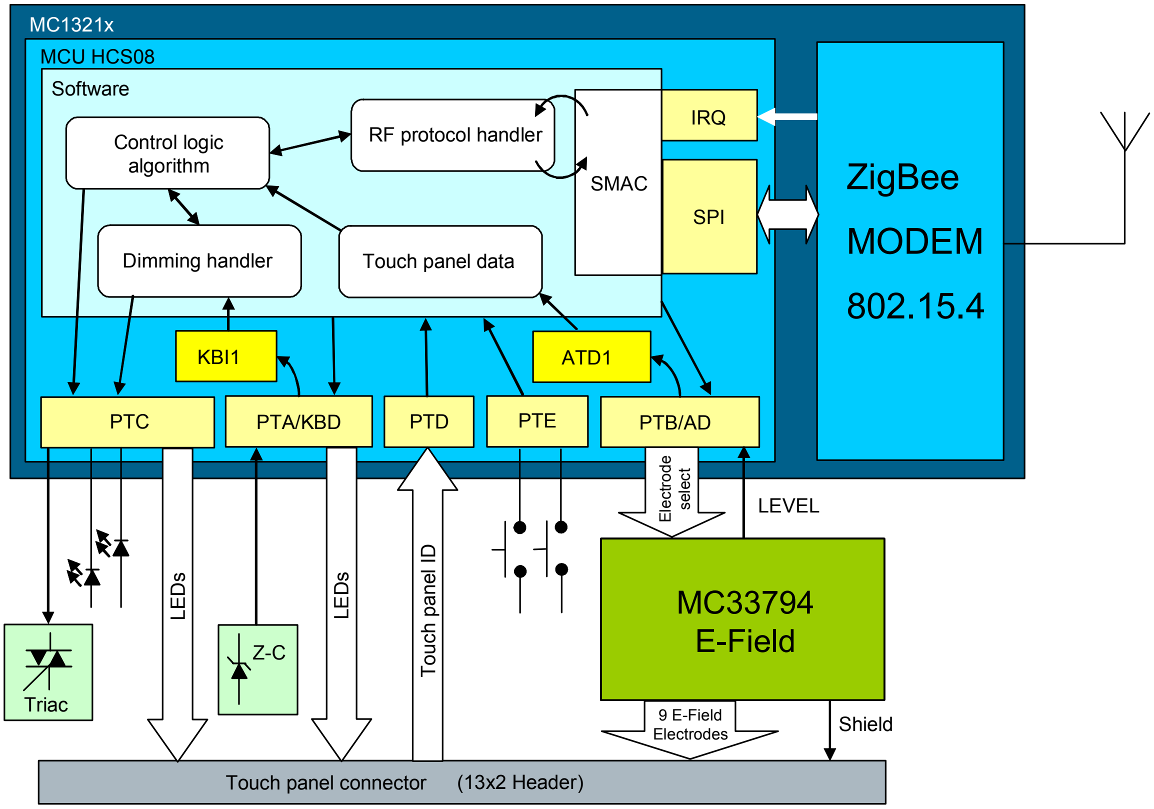


**Figure 3-6. Intelligent Switchboard Software Overview**

## 3.6 Dimming solution

The demo is intended as a low-cost solution using minimum components. The triac solution meets the expectations for a simple and safe design. The sensitive gate triac allows further reduction in the number of surrounding components and this solution doesn't need any opto-isolation parts. The sensitive gate triac can be directly controlled from an MCU pin because consumption of the gate is between 2 – 10 mA. The MCU used provides current on one standard I/O pin of up to 10 mA, so this solution is viable. The sensitive gate triac used limits the output power ability of dimming light bulbs because triacs with this feature provide only up to 600 W. It meets home application requirements where light bulbs with a wattage up to 200W are generally used. The triacs with a higher wattage need more current to the gate, and hence would need some additional gate driver (optotriac).

Direct control of the triac using an MCU pin (Section 3.6.1, "Dimming Mechanism"), without opto-isolation, needs one stable GND (non-floating) in the whole device for a proper level of voltage potentials. This is also used in realising of Section 3.6.2, "Zero-Cross," detection without opto-isolation. For this reason, the selection of an appropriate power supply with a non-floating GND is important. See Section 3.7, "Power Supply," for more details.

### 3.6.1 Dimming Mechanism

As written in Section 3.6, "Dimming solution," the sensitive gate triac part MAC4DLM was selected because it doesn't need any opto-isolation parts, and the gate can be directly controlled from an MCU pin. Maximal consumption of the gate is 10 mA in the fourth quadrant of function modes. The device uses a non-floating GND so the triac is controlled by the positive current impulses in the positive and negative halfperiods of the AC power. The triac works in the first and the fourth quadrant of diagram Figure 3-7.

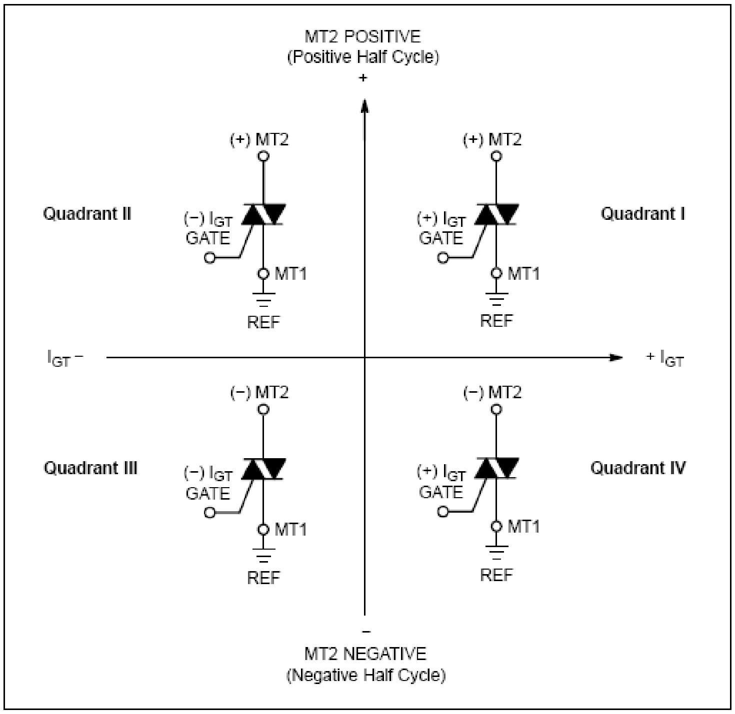


**Figure 3-7. Quadrant Definitions for a Triac**

The MC1321x used provides current of up to 10 mA only on ports C and F. The I/O pin PTC6 on port C is used for this purpose. The PTC6 pin is set as output and connected to the triac gate via the resistor R2, with a value 470 Ω for current limitation. The subcircuit is shown in Figure 3-16.

The triac is connected in parallel with the AC power Connector so that the whole device has influence as a regulated conductance on the AC power wire, because no load is connected in series with this part. This fact enables dimming regulation of the AC power on one phase, where the load (light bulb) is connected in front of the whole intelligent switchboard. On a positive impulse on PTC6, the triac is opened with 0 Ω. When voltage on the triac (between the anode and cathode) reaches the zero value, the triac is then closed with an infinite impedance.

There is a choke, L6 connected in series with the triac, with a 220 µH value. The choke partially suppress EMI harmonic frequencies generated by the switching of the triac and smoothes the current spikes through the triac. It also protects the power supply from steep changes of input voltage. See Section 3.10.8, "EMI Filtering," for more information.

### 3.6.2 Zero-Cross

The dimming function using the triac on AC power voltage can't be realized without zero-cross detection. See the schematic Figure 3-16. This function is needed to synchronize the impulses for triac control. This design uses a simple zener diode ZD2 for this purpose. The resistor, R3, with value 510 kΩ is connected in series with this diode. This zener diode stabilises the 230VAC/115VAC and the R3 limits high current to roughly 0.5 mA. Resistor R3 has a wattage loading of roughly 100mW so an SMD 0805 case was selected. Although the highest possible input voltage level for the MCU input is 3.3 V, the value of the zener diode is 6.2 V because tests showed that zener diodes with a value around 3.3 V are not able to stabilize the 230VAC. This is caused by the small 0.5 mA current limited by the resistor R3. If a smaller value resistor is used, a bigger power stress would be generated for this resistor. The half voltage divider, from 6.2 V to 3.1 V, created from resistors R4 and R19 has to be situated in parallel to the ZD2 zener diode.

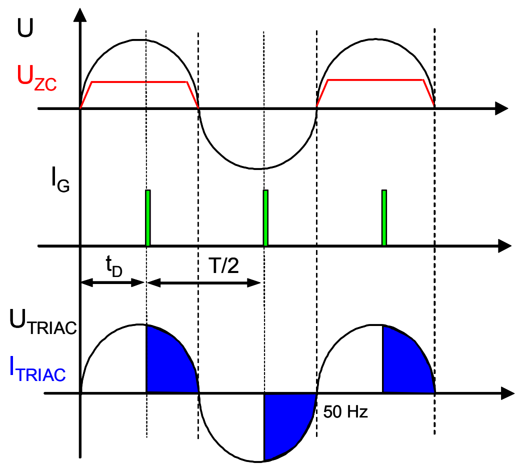


**Figure 3-8. Dimming Process**

This circuit generates impulses according to the shape of sinusoidal AC power voltage. When a positive halfcycle of the AC power is reached, the circuit generates a perpendicular positive impulse with a level of 3.1 V and in the negative voltage area it generates a zero voltage. See Figure 3-8. These impulses generate an external MCU interrupt, allowing synchronization of the dimming process. For this purpose, pin PTA5/KBD5 of the MCU is used, and it can be set to generate an external interrupt on a rising edge by the internal module KBI. On the PCB, this signal is doubled to pin PTA7/KBD7 for safety. This software function is described in Section 5.7, "Dimming and Interrupts". The zero-cross doesn't need opto-isolation by an optocoupler and the output can be directly connected to the MCU pin because there is a GND used that isn't floating and the potentials levels are equal.

## 3.7 Power Supply

Common power supplies directly powered from the AC power use a transformer, diodes bridge and stabilising circuitry. The transformer is a cumbersome part not suitable in this construction. Simple circuits without a transformer use a high voltage capacitor or power resistor that cause dissipation of voltage. After dissipation, a rectifier and linear voltage regulator are used. The disadvantage of this solution is the huge size of the parts and the heat losses. A zener diode is often used as a stabilising part. However, this power supply is soft and provides current of only up to 10 mA. The maximum power consumption of the whole intelligent switch is more than this value, roughly 20 mA. The best solutions are the switching power supplies, which provide a higher output current with smaller parts without the heating. However, these power supplies are more expensive and sophisticated.

The next condition in selecting the power supply was the wide range of the input voltage. The bottom limit needs to be as low as possible and the top limit should be up to 230 V. This wide input voltage range is neccessary for a correct dimming function on one phase because the power supply is directly from the regulated voltage through the triac part. The MC1321x requires a voltage level of +3.3 V and the MC33794 sensor needs a voltage higher than +9 V, so 12 V for output voltage power supply was selected.

The power supply for this application is based on on Freescales's monolithic power switcher NCP1014. The topology is described in AN8226. This reference design needs an adjustment for the required output parameters. This solution meets all the requirements. The power supply used doesn't have an ideal output level of voltage because small fluctuations can appear when the triac switches the voltage. However, these fluctuations are negligible and don't influence the correct function of the whole topology. The power supply is able to power the device up to a maximum high limit of 90% of the triac openning. See the schematic in Figure 3-10.

The main features of this switched mode power supply (SMPS) are:

- Wide input voltage range 85 VAC – 265 VAC
- Output voltage +12  V/200 mA
- Smaller size, relatively few number of parts, lower weight, lower total cost
- Good line and load regulation, no need of additional linear regulators
- Efficient design with up to 80% efficiency
- Overload, short-circuit and thermal protected

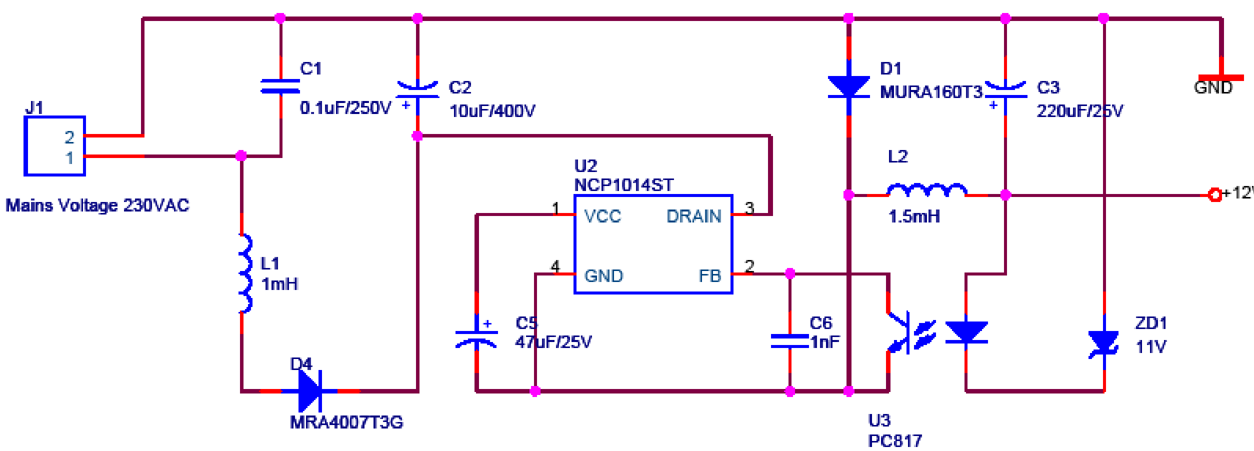


Figure 3-9. Voltage Convertor Schematic

### 3.7.1 Linear Regulator NCP551SN33T1

The MC1321x needs a power supply voltage of +3.3 V. The SMPS generates +12 V. Then the low drop voltage regulator NCP551SN33T1 (U1) transforms this voltage into +3.3 V. The subschematic of this part can be found in Figure 3-16. The diodes D3 and D8 are dedicated to power supply polarity protection.

## 3.8 E-Field Sensing

The demo was mainly intended for presentation of E-Field technology. An E-Field control interface is realised by the MC33794 sensor that provides nine electrodes. Another member of this family of proximity sensors is the MC34940-1 that provides only seven sensing electrodes. The system consists of two boards. The first board, the intelligent switch, provides the main control logic. The second board, the touch panel, is placed in front of the first board and contains the E-Field sensing pads. The concept is easily suitable for standard wall switch cases. The E-Field IC is powered by +12 V DC from the power supply described in Section 3.7, "Power Supply". The level detected from the output pin LEVEL is measured by the MCU A/D convertor through the pin ADC0. See Section 3.8.1, "ADC Conversion for more about A/D conversion. A specific electrode is selected by the A, B, C, and D pins, which are controlled from the MCU by I/O ports. All control pins for the MC33794 are situated on port PTA. A description of pin assignment is in Figure 3-10.

**Table 3-1. Electrode Selection**

| PIN/SIGNAL | D | C | B | A |
|---|---|---|---|---|
| Source(internal) | 0 | 0 | 0 | 0 |
| E1 | 0 | 0 | 0 | 1 |
| E2 | 0 | 0 | 1 | 0 |
| E3 | 0 | 0 | 1 | 1 |
| E4 | 0 | 1 | 0 | 0 |
| E5 | 0 | 1 | 0 | 1 |
| E6 | 0 | 1 | 1 | 0 |
| E7 | 0 | 1 | 1 | 1 |
| E8 | 1 | 0 | 0 | 0 |
| E9 | 1 | 0 | 0 | 1 |
| REF_A | 1 | 0 | 1 | 0 |
| REF_B | 1 | 0 | 1 | 1 |
| Internal OSC | 1 | 1 | 0 | 0 |
| Internal OSC through 22 kΩ | 1 | 1 | 0 | 1 |
| Internal Ground | 1 | 1 | 1 | 0 |
| Reserved | 1 | 1 | 1 | 1 |

The resistor R8 of value 39 kΩ determines the operating frequency of 120 kHz for the oscillator. See Figure 3-15. Electrodes (E1- E9) are used as a single button on the touch panel board. The rotary or slider on the touch panel uses electrodes E1 and E4. The SHIELD pin is connected to the shield copper layer. The GND is connected to REF_A and REF_B pins via two capacitors, C30 and C31. The VCC pin provides +5.0 V DC. This voltage is used only for enabling the SHIELD via R9 to pin 10 and for RESET disabling.

The board is also equipped by the MOSFET part NTS4001 (Q2), which provides an on/off function for the MC33794 part using a standard MCU pin. This feature is not yet utillized, but it can be used for debug purposes or to achieve lower consumption. The part Q2 can be replaced by a conducting bridge.

### 3.8.1 ADC Conversion

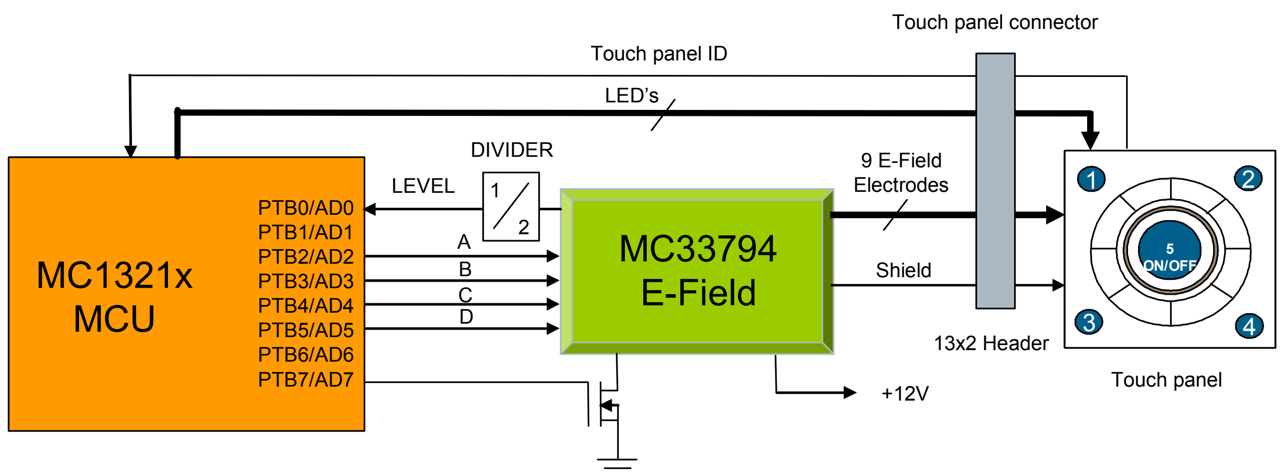


**Figure 3-10. E-Field Control**

As you can see in Figure 3-10, the analogue LEVEL output of the MC33794 needs to be connected through the DIVIDER. This is because the maximal analogue output value of the E-Field sensor is +5 V, which is above the limit of the MCU input voltage. The voltage half-divider is realized by resistors R20 and R21 of values 18 kΩ.

### 3.8.2 Touch Panel Connector

The intelligent switch and touch panel are connected by connector J5 on the intelligent switch (male) board and by J1 on the touch panel board (female). It is a standard header, sized at 2x13 pins on a 2.5 mm matrix. The connector is situated on the edge of the board for easy access. This connector mainly provides the E-Field electrodes one to nine of the MC33794, SHIELD pins, GND, and several MCU pins for LED control and a 4-bit combination of pins for touch panel identification (Section 3.11.2, "Touch Panel Identification"). The pin assignments are shown in Figure 3-11. The GND is needed in creating the 4-bit combination for identification and to ground the LEDs. The LED control pins are connected on the intelligent switchboard to the MCU via the protection resistors of value 1 kΩ. This pin setup opens up the possibilities for designing various touch panels. Electrode pins, shield, and GND are assigned symetrically to the connector, offering partial compatibility with old E-Field Development Kits and the possibility of rotating of the touch panel. This last option needs modification to the software.

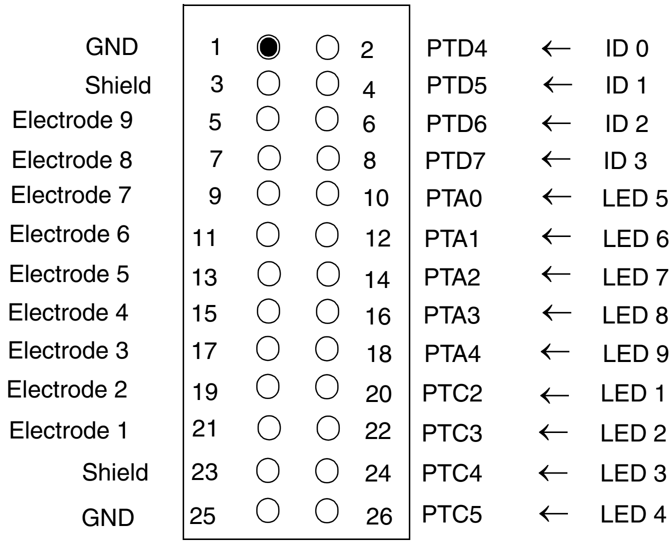


**Figure 3-11. Touch Panel Connector**

**Table 3-2. Touch Panel Connector**

| PIN | MCU Port | Function | PIN | MCU Port | Function |
|---|---|---|---|---|---|
| 1 | GND | GND | 2 | PTD4 | Touch Panel ID 1st bit |
| 3 | SHIELD | SHIELD | 4 | PTD5 | Touch Panel ID 2nd bit |
| 5 | ELECTRODE 9 | Rotary/Slider Electrode 1 (E9) | 6 | PTD6 | Touch Panel ID 3rd bit |
| 7 | ELECTRODE 8 | Rotary/Slider Electrode 2 (E8) | 8 | PTD7 | Touch Panel ID 4th bit |
| 9 | ELECTRODE 7 | Rotary/Slider Electrode 3 (E7) | 10 | PTA0 | LED5 (Rotary LED) |
| 11 | ELECTRODE 6 | Rotary/Slider Electrode 4 (E6) | 12 | PTA1 | LED6 (Pad 3) |
| 13 | ELECTRODE 5 | Pad 3 (E5) | 14 | PTA2 | LED7 (Pad 1) |
| 15 | ELECTRODE 4 | Pad 1 (E4) | 16 | PTA3 | LED8 (Rotary LED) |
| 17 | ELECTRODE 3 | Pad on/off (E3) | 18 | PTA4 | LED9 (Pad on/off) |
| 19 | ELECTRODE 2 | Pad 2 (E2) | 20 | PTC2 | LED1 (Rotary LED) |
| 21 | ELECTRODE 1 | Pad 4 (E1) | 22 | PTC3 | LED2 (Pad 2) |
| 23 | SHIELD | SHIELD | 24 | PTC4 | LED3 (Rotary LED) |
| 25 | GND | GND | 26 | PTC5 | LED4 (Pad 4) |

## 3.9 Power Management

Although the board is powered directly from AC power, this device contains features for lower consumption. The intelligent switch is intended for applications at home as a standard wall switch, so this means the device is turned on for a long time. Most of the time, the device is in stand-by mode. Achieving lower consumption involves a combination of STOP3 mode in the MCU, 75 ms Doze mode in the 802.15.4 modem, and shorter transmitted packets. When the device is permanently functioning (dimming mode) power consumption is roughly 24 mA. When the device isn't dimming, the value is approximately 15 mA on a +12 V power voltage.

Typically, current consumptions of the board components in the modes used are as follows:

- MC1323x microcontroller
  - MCU HCS08:
    - Stop3 mode, 675 nA
    - Wait mode, 1 mA
    - Run mode with 16Mhz clock (no load from ports), 6.5 mA
  - 802.15.4 modem:
    - Doze mode,35 µA
    - Transmit mode, 30 mA
    - Receive mode, 37 mA
- MC33794 E-Field sensor
  - Permanently >7 mA

## 3.10 Intelligent Switchboard Hardware Overview

This section describes the sensor board in terms of hardware design. The MC1321x microcontroller drives the MC33794 E-Field sensor and provides an RF communication platform and dimming function. See schematic Figure 3-16 for reference.

### 3.10.1 Microcontroller

The system is based on an MC1321x, 8-bit, low-cost microcontroller, powered by a +3.3 V DC from the switching power supply described in Section 3.7, "Power Supply". The MCU selects each specific E-Field channel, reads output from the E-Field sensor, and takes appropriate action. It also sends control impulses to the triac part synchronized by the zero-crossing. The MC1321x also performs RF wireless communication by the SMAC to remote intelligent outlet boards. The antenna design, which is directly connected to the package, is described in Section 3.10.7, "Antenna Design". Information on the BDM programming interface is written in Section 3.10.2, "BDM". Detected levels are fed from the E-Field into the MCU A/D channel. This A/D converter works in 10-bit resolution mode. More about AD conversion is in Section 3.8.1, "ADC Conversion". The PWM output from the microcontroller, combined with direction signals, drives the triac component (Section 3.6.1, "Dimming Mechanism").

For the right clock generation, an external 16 MHz crystal is required. The two capacitors, C8 and C9, are connected in parallel to this crystal. The oscillator created generates an 8 Mhz bus clock frequency. The set of capacitors, C10 to C17, are used for noise reduction and stabilising assistant +3.3 V voltages.

### 3.10.2 BDM

The header J3 is a BDM port for use with a P&E BDM-Multilink cable, which is available from Metrowerks. The BDM cable is used with CodeWarrior™ Development Studio for the HCS08 to program the MCU flash memory as well as performing in-circuit debugging. See Figure 3-12 for the position of pin 1. The red lead of the BDM cable must align to pin 1 of J3. When using the parallel port version of the BDM cable, the BDM should be powered by a 3.3 V negative center contact power supply.

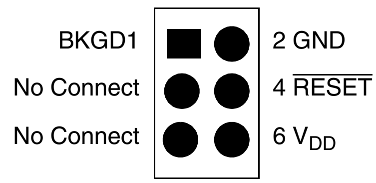


**Figure 3-12. BDM Tool Connector**

### 3.10.3 Buttons

The board is also equipped with several switches shown in Table 3-3.

**Table 3-3. Switch Description**

| Switch | MCU Port | I/O Direction | Function |
|---|---|---|---|
| S1 | PTE0 | Input (pull up) | User own programmable function (dim up) |
| S2 | PTE1 | Input (pull up) | User own programmable function (dim down) |
| RESET (S3) | — | — | Ordered RESET of whole device |

### 3.10.4 LED Indicators

The device also includes some indicator LEDs.

**Table 3-4. LED Description**

| LED | MCU Port | I/O Direction | Function |
|---|---|---|---|
| D5 | PTC0 | output | Signals a received packet by the SMAC |
| D6 | PTC1 | output | Signals a detected zero-cross edge |
| D2 | — | — | Signals the device functionality |

### 3.10.5 Power Supply Jumper

The small header J4 separates the power supply from the whole device logic. In the default function, the jumper is closed. When the device is in debugging mode, it is useful to leave J4 open and the board can be powered through this pin. You can test the output of the power supply separately using this header. See Section 6.4, “Software Modification” for other details.

### 3.10.6 Fuse

All domestic devices that work with a 230VAC power voltage need to be protected by a fuse. The current flowing through the triac is a max. 800 mA when a 200 W light bulb is used. The board is protected by the quick fuse F1 with value 1A in the SMD holder.

### 3.10.7 Antenna Design

The RF antenna was designed with the cost and board size in mind. From several PCB antenna designs available for the 2.4GHz band (F-antenna, dipole, loop), the loop antenna has been selected mainly because of the size required on the PCB. The MC1321x offers an internal switching of the RF IN (receive) and PA OUT (transmit) paths, so that two separated antennas don't need to be used. The antenna is designed as a rectangle, 19x25mm (750x984mils), made of 1.25mm (50mils) wide trace copper. The functionality of the antenna is guaranteed because the length of this loop is roughly 80 mm, which is more than a halfperiod of the 125 mm wavelength (2.4GHz).

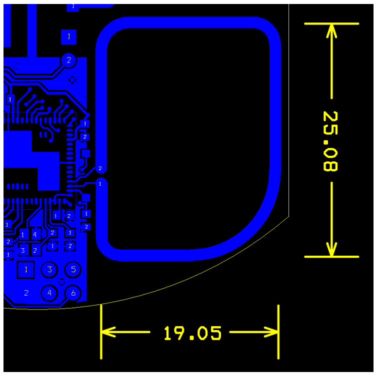


**Figure 3-13. Antenna Layout Design**

The matching is provided by the L3 coil. The L4 and L5 coils bias the transmitter output transistors to VDDA level.

### 3.10.8 EMI Filtering

The device requires a filter to limt the EMI frequencies. The choke L6 is connected in series with the triac circuitry. The function of the choke is the partial suppression of EMI harmonic frequencies generated by the switching of the triac and the smoothing of the current spikes through the triac.

The second part of filtering is a standard EMI filter created by a 47nF/230V capacitor and a double toroid coil of value 3.9mH/3A. This filter is directly connected to the 230VAC input connector. The EMI filter is an optional benefit and the device can also work without it.

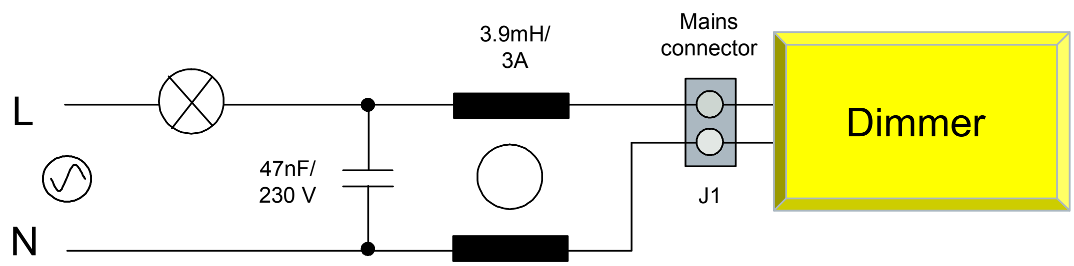


**Figure 3-14. EMI Filter Integration**

## 3.11 Touch Panel Board Hardware Overview

This section describes the touch panel boards in terms of hardware design for all versions of boards together because all have equal hardware charactersitics.

### 3.11.1 E-Field Electrodes

Table 3-5 explains the functions of the E-field electrodes.

**Table 3-5. E-Field Electrodes Description**

| MC33794 Electrode | Name on Touch Panel | Function |
|---|---|---|
| Electrode 1 | Pad 4 | The first touch IO[1] 4 is controlled/second is return to IS[1] control |
| Electrode 2 | Pad 2 | The first touch IO 2 is controlled/second is return to IS control |
| Electrode 3 | Pad on/off | Maximum/ Minimum light intensity of controlled device |
| Electrode 4 | Pad 1 | The first touch IO 1 is controlled/second is return to IS control |
| Electrode 5 | Pad 3 | The first touch IO 3 is controlled/second is return to IS control |
| Electrode 6 | Rotary/Slider Electrode 4 | The fourth divided electrode |
| Electrode 7 | Rotary/Slider Electrode 3 | The third divided electrode |
| Electrode 8 | Rotary/Slider Electrode 2 | The second divided electrode |
| Electrode 9 | Rotary/Slider Electrode 1 | The first divided electrode |

[1] IS is Intelligent Switch, IO is intelligent outlet.

### 3.11.2 Touch Panel Identification

Each kind of touch panel board has a unique combination of four bits provided by the touch panel connector. This number identifies the type of board and is read by port PTD4 – PTD7 on the MCU situated on the intelligent switchboard (Figure 3-2). On detecting this, the software makes appropriate changes in the control algorithm for the board used. A logical 0 in the combination bits is realized by the GND polarity, while the other non connected pins are logical 1.

### 3.11.3 Touch Panel LED Indicators

The board also offers some indicator LEDs.

**Table 3-6. LED Description for Touch Panel Board**

| LED | Touch Panel Connector pin | MCU Port | Function |
|---|---|---|---|
| LED 1 | 20 | PTC2 | Signals a rotary movement (optional) |
| LED 2 | 22 | PTC3 | Signals when IO 2 is a controlled device |
| LED 3 | 24 | PTC4 | Signals a rotary movement (optional) |
| LED 4 | 26 | PTC5 | Signals when IO 4 is a controlled device |
| LED 5 | 10 | PTA0 | Signals a rotary movement (optional) |
| LED 6 | 12 | PTA1 | Signals when IO 3 is a controlled device |
| LED 7 | 14 | PTA2 | Signals when IO 1 is a controlled device |
| LED 8 | 16 | PTA3 | Signals a rotary movement (optional) |
| LED 9 | 18 | PTA4 | Signals when IS is a controlled device |

## 3.12 Intelligent Switchboard Schematics

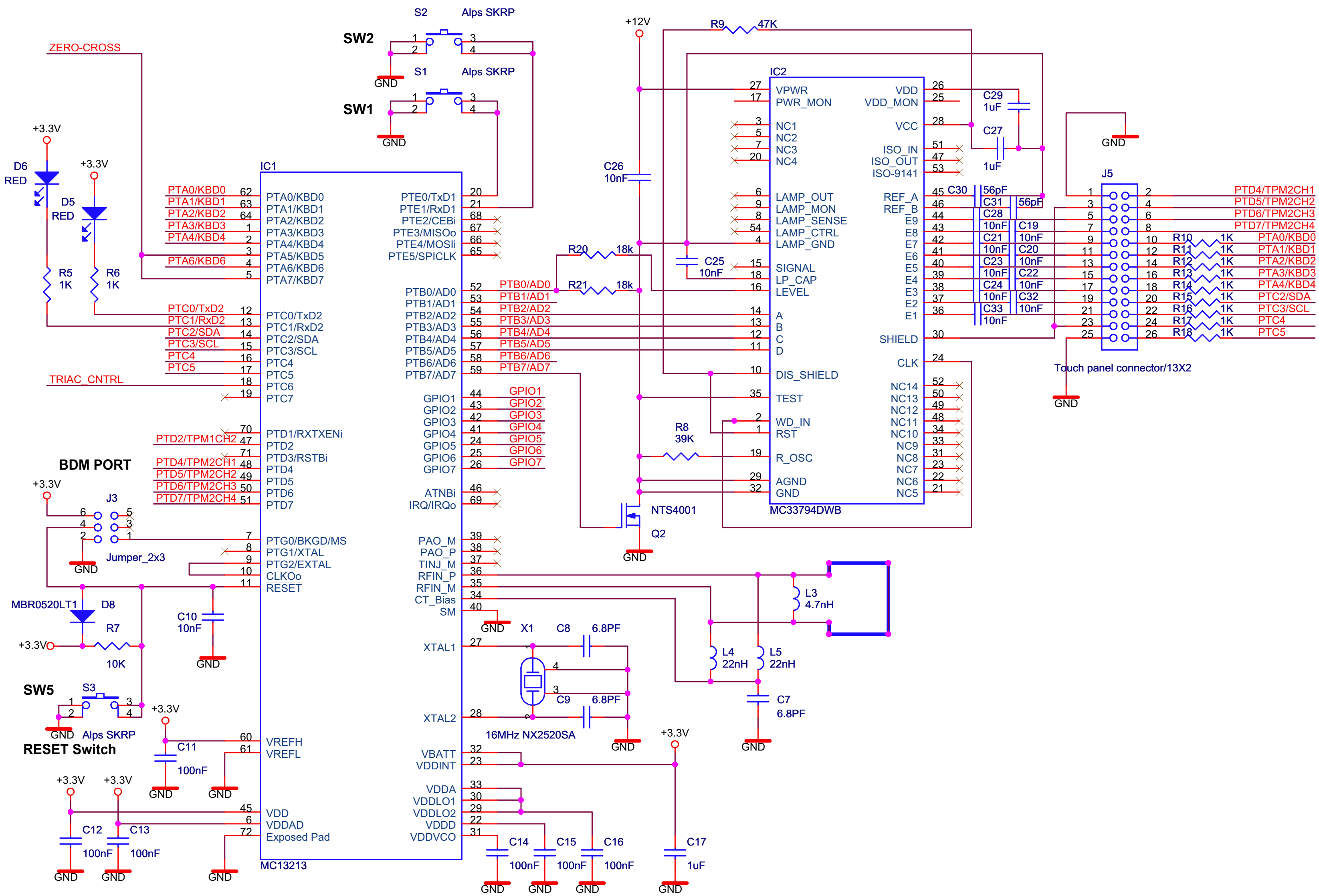


Figure 3-15. MCU and E-Field Schematic

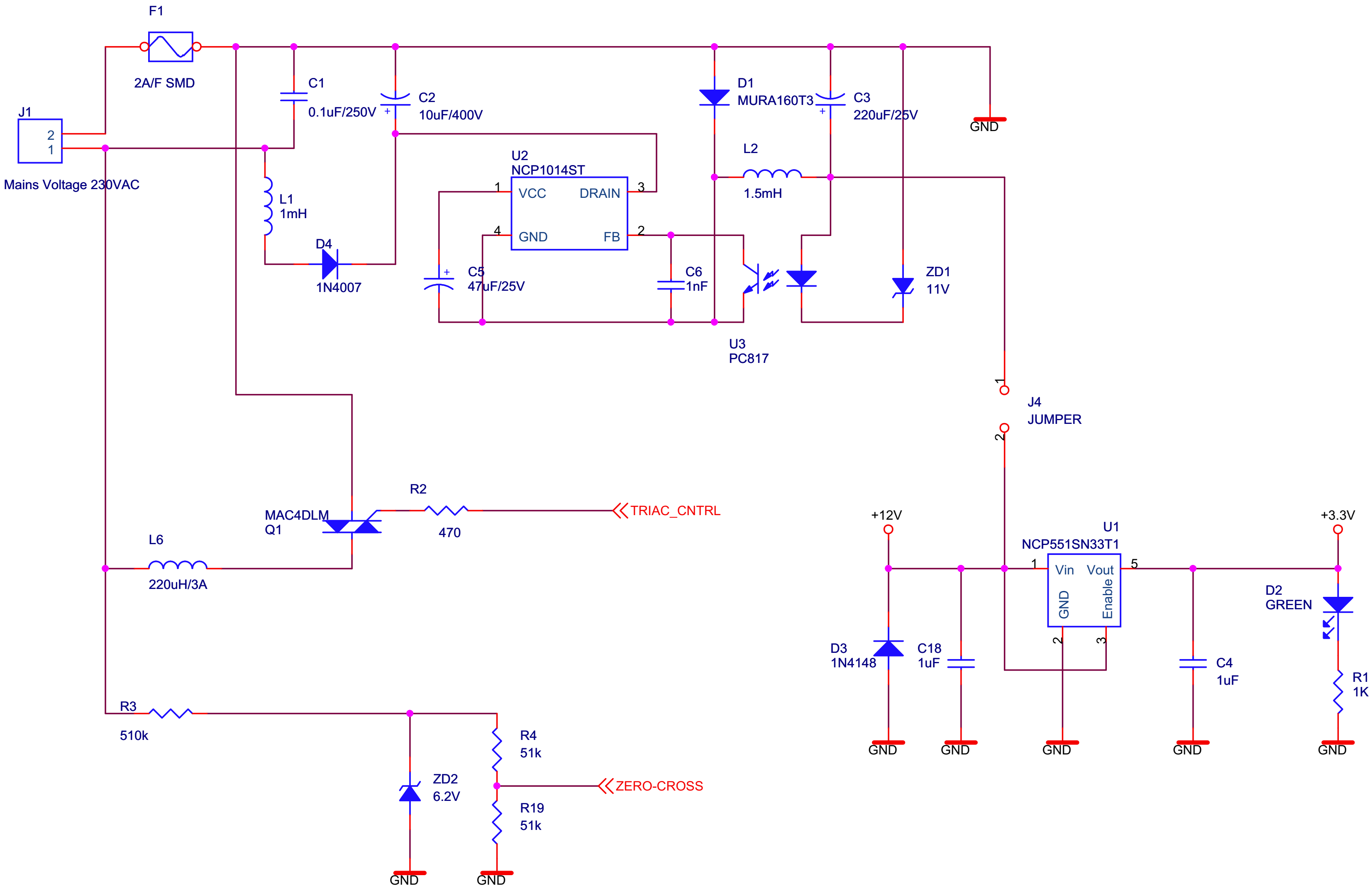


**Figure 3-16. Supply Schematic**

## 3.13 Intelligent Switchboard PCB Layouts

The board utilizes a small footprint sized dual-layer printed circuit board (PCB) so it can also use relatively small SMD 0603 parts. The size and shape of the board is designed for easy installation into a standard wall switch cross-case (size ϕ 65 x 20 mm in Europe, type KP68) commonly used for serial control of a light bulb in one loop. The dimensions of the board are 54 mm x 54 mm (2125 mils x 2125 mils). The PCB layout and parts placement can be seen in Figure 3-17 and Figure 3-18.

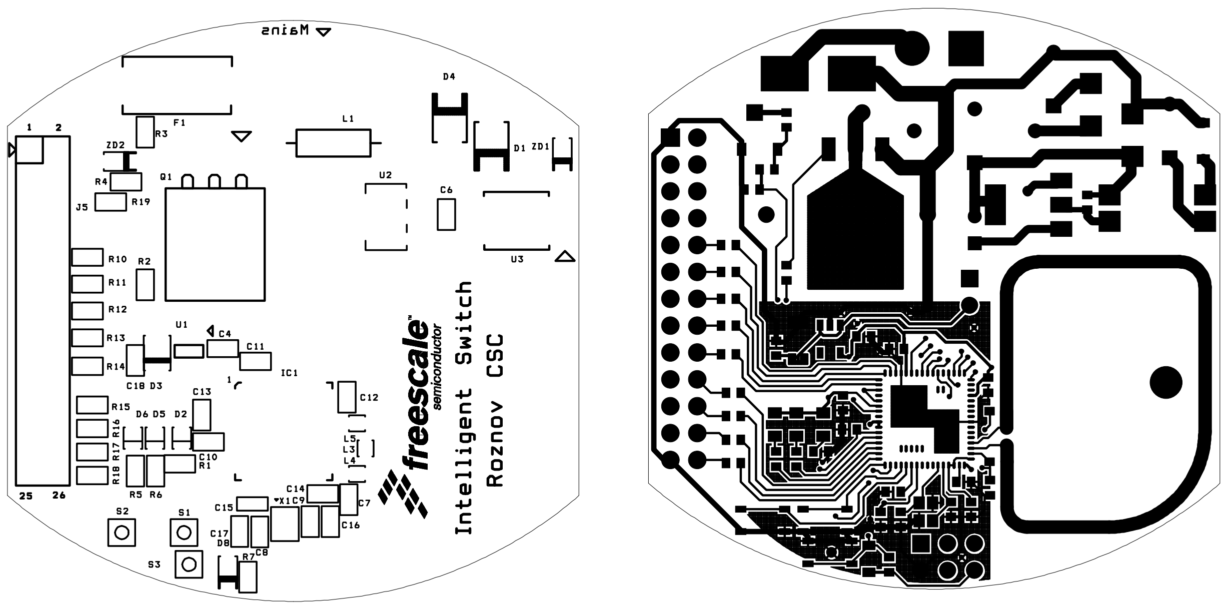


**Figure 3-17. Parts Placement and PCB Layout, Top Side**

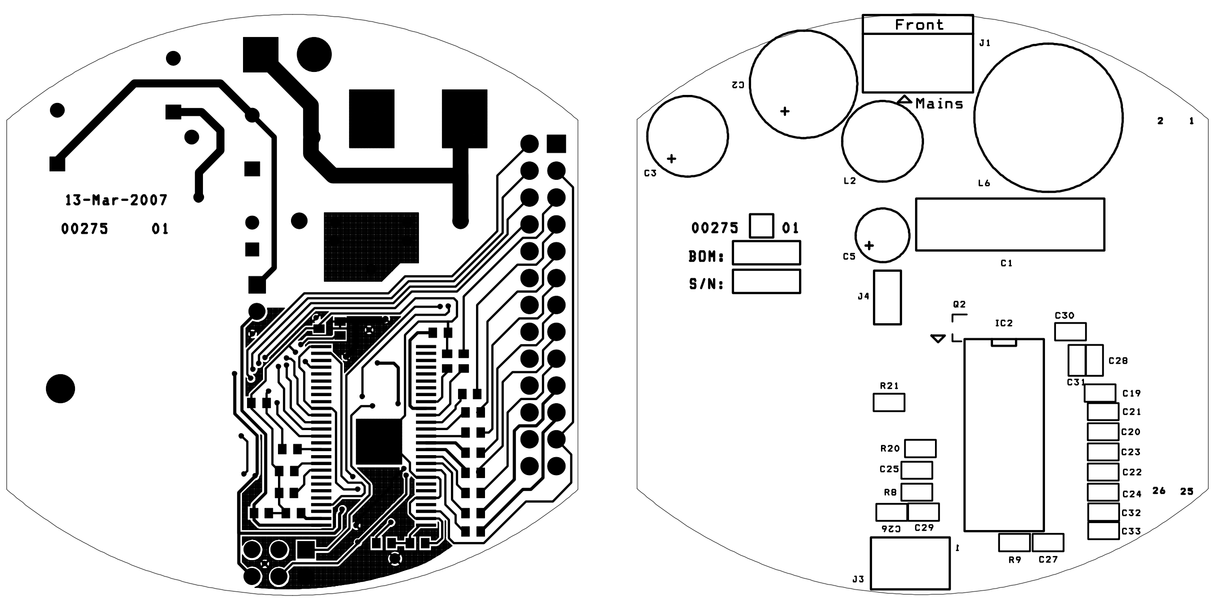


**Figure 3-18. Parts Placement and PCB Layout, Bottom Side**

## 3.14 Intelligent Switch Bill of Materials

**Table 3-7. Bill of Materials**

| Item | Quantity | Reference | Part | Manufacturer |
|---|---|---|---|---|
| 1 | 1 | C1 | 0.1µF/250V | N/A |
| 2 | 1 | C2 | 10µF/400V | N/A |
| 3 | 1 | C3 | 220µF/25V | Any acceptable |
| 4 | 5 | C4, C17, C18, C27, C29 | 1µF (0603) | Any acceptable |
| 5 | 1 | C5 | 47µF/25V | Any acceptable |
| 6 | 1 | C6 | 1nF (0603) | Any acceptable |
| 7 | 3 | C7, C8, C9 | 6.8pF (0603) | Any acceptable |
| 8 | 6 | C11, C12, C13, C14, C15, C16 | 100nF (0603) | Any acceptable |
| 9 | 12 | C10, C19, C20, C21, C22, C23, C24, C25, C26, C28, C32, C33 | 10nF (0603) | Any acceptable |
| 10 | 2 | C30, C31 | 56pF (0603) | Any acceptable |
| 11 | 1 | D1 | MURA160T3 | ONSEMI |
| 12 | 1 | D2 | GREEN (0805) | Any acceptable |
| 13 | 1 | D3 | 1N4148 (0805) | Any acceptable |
| 14 | 1 | D4 | MRA4007T3G | ONSEMI |
| 15 | 2 | D5, D6 | RED | Any acceptable |
| 16 | 1 | D8 | MBR0520LT1 | ONSEMI |
| 17 | 1 | F1 | 1A/F SMD | LittelFuse |
| 18 | 1 | IC1 | MC13211 | Freescale |
| 19 | 1 | IC2 | MC33794DWB | Freescale |
| 20 | 1 | J1 | AC power Voltage 230VAC | Any acceptable |
| 21 | 1 | J3 | JUMPER 2x3 | Any acceptable |
| 22 | 1 | J4 | JUMPER 1x2 | Any acceptable |
| 23 | 1 | J5 | JUMPER 13X2 | Any acceptable |
| 24 | 1 | L1 | 1 mH TL-AX | FASTRON |
| 25 | 1 | L2 | 1.5mH RFB0810-152L | CoilCraft |
| 26 | 1 | L3 | 4.7nH (0603) | Any acceptable |
| 27 | 2 | L4, L5 | 22nH (0603) | Any acceptable |
| 28 | 1 | L6 | 220µH/3A PCV-0-224-03L | CoilCraft |
| 29 | 1 | Q1 | MAC4DLM | ONSEMI |
| 30 | 1 | Q2 | NTS4001 | ONSEMI |

Table 3-7. Bill of Materials (continued)

| Item | Quantity | Reference | Part | Manufacturer |
|---|---|---|---|---|
| 31 | 12 | R1, R5, R6, R10, R11, R12, R13, R14, R15, R16, R17, R18 | 1K (0603) | Any acceptable |
| 32 | 2 | R4, R19 | 51K (0603) | Any acceptable |
| 33 | 2 | R20, R21 | 18K (0603) | Any acceptable |
| 34 | 1 | R2 | 470 (0603) | Any acceptable |
| 35 | 1 | R3 | 510K (0805) | Any acceptable |
| 36 | 1 | R7 | 10K (0603) | Any acceptable |
| 37 | 1 | R8 | 39K (0603) | Any acceptable |
| 38 | 1 | R9 | 47K (0603) | Any acceptable |
| 39 | 3 | S1, S2, S3, | SKRPADE010 | ALPS |
| 40 | 1 | U1 | NCP551SN33T1 | ONSEMI |
| 41 | 1 | U2 | NCP1014ST | ONSEMI |
| 42 | 1 | U3 | PC817 SMD | SHARP |
| 43 | 1 | X1 | 16MHz NX2520SA | NDK |
| 44 | 1 | ZD1 | MMSZ5241BT1G (11V ) | ONSEMI |
| 45 | 1 | ZD2 | MMSZ6V2T1G (6.2V) | ONSEMI |

## 3.15 Touch Panel Board PCB Layouts

The board utilizes a small footprint sized dual-layer printed circuit board (PCB) so it can also use relatively small SMD 0603 parts. The dimensions of the board are mainly limited by the dimensions of the connector and the size of the front face from the wall switch case.

As described in Section 3.4, “Touch Panel Board Overview,” the size and shape of the board is designed for easy installation into the front face of a wall switch (Element®, made by ABB). The dimensions of the board are 65 mm x 55 mm (2559 mils x 2165 mils). The following figures show the two most widely used touch panels designs. The PCB layouts and parts placements can be seen in figures Figure 3-19 to Figure 3-22. Together with the intelligent switch, the board is implemented inside a standard cross-case (size $\phi$ 65 x 20 mm in Europe, type KP68). The whole design can be easily implemented into a standard home electro-installation without retrofitting.

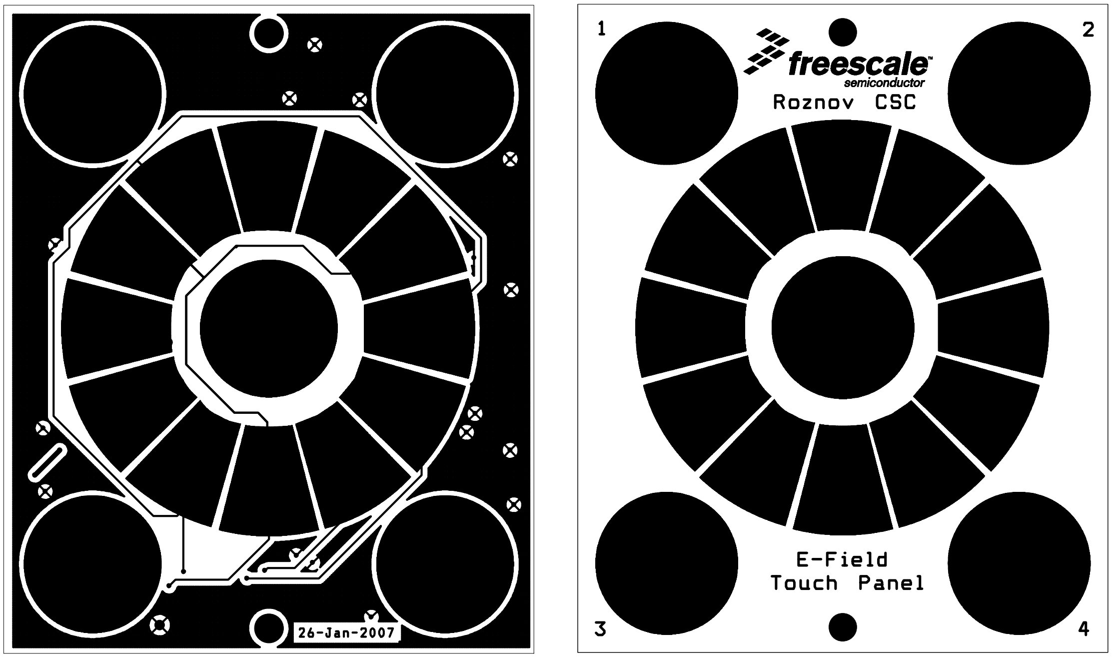


**Figure 3-19. Rotary Touch Panel, Parts Placement and PCB Layout, Top Side**

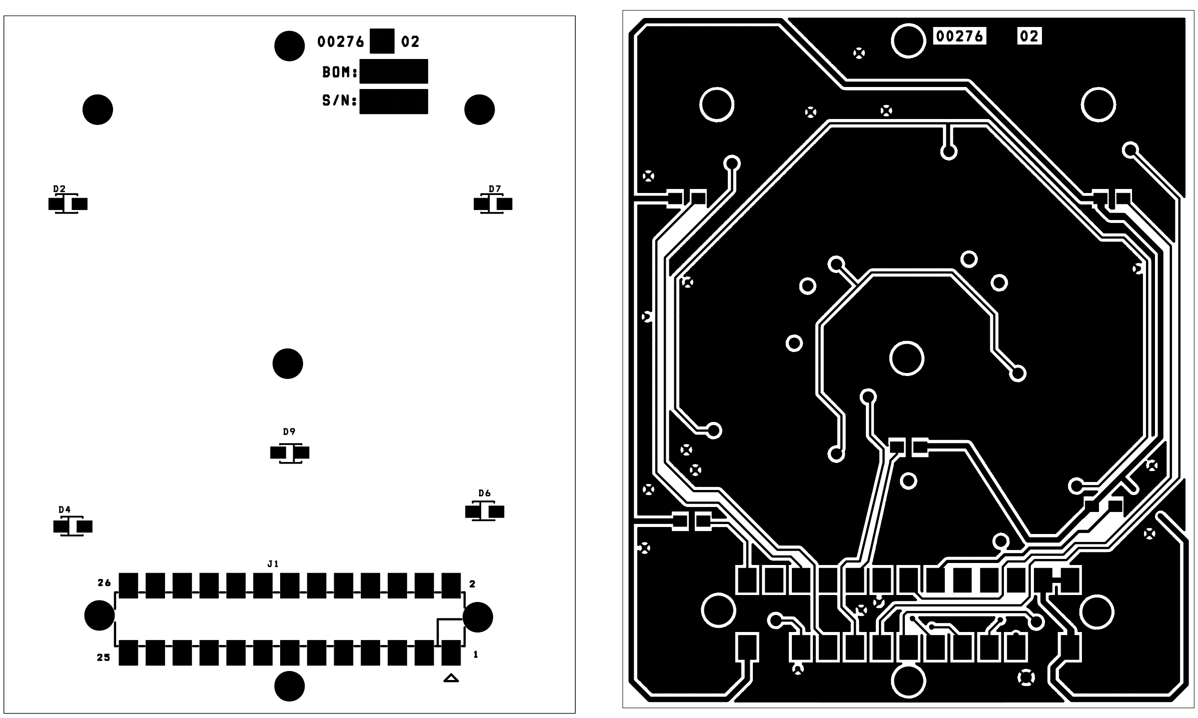


**Figure 3-20. Rotary Touch Panel, Parts Placement and PCB Layout, Bottom Side**

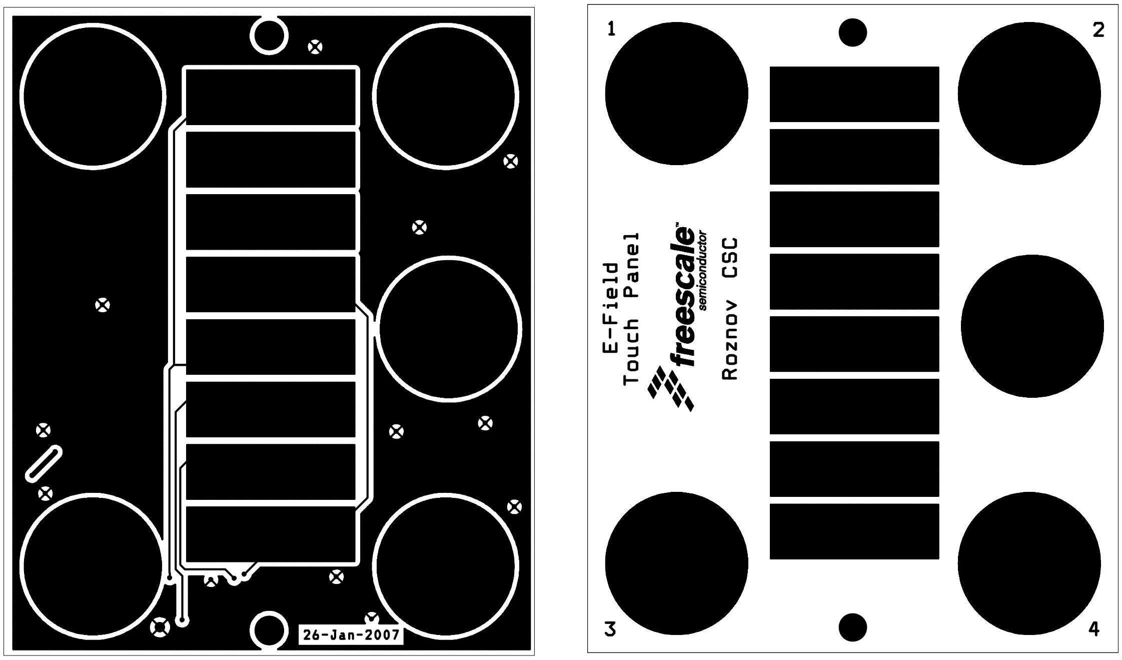


**Figure 3-21. Slider Touch Panel, Parts Placement and PCB Layout, Top Side**

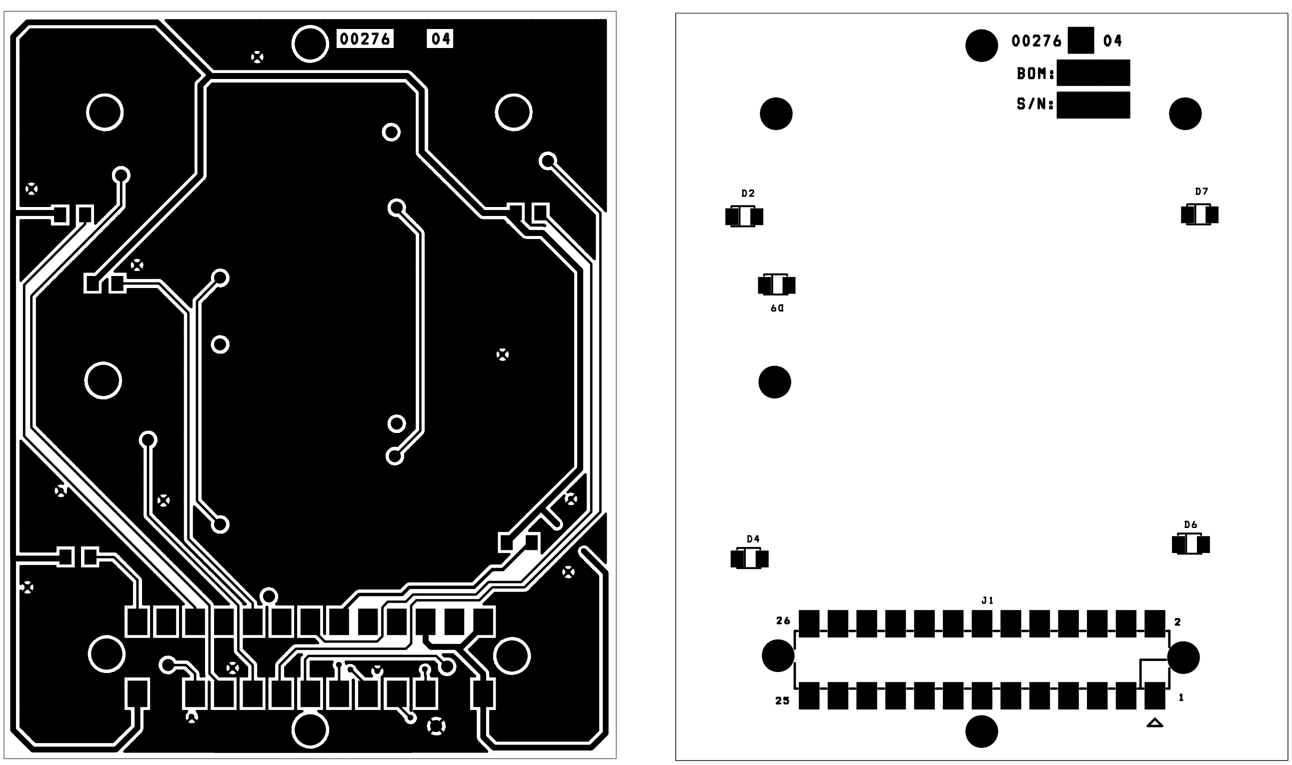


**Figure 3-22. Slider Touch Panel, Parts Placement and PCB Layout, Bottom Side**

## 3.16 Touch Panel Bill of Materials

**Table 3-8. Bill of Materials Touch Panel**

| Item | Quantity | Reference | Part | Manufacturer |
|---|---|---|---|---|
| 1 | 9 | D1, D2, D3, D4, D5, D6, D7, D8, D9 | GREEN ($\phi$ 3 mm) | Any acceptable |
| 2 | 1 | J1 | SSM-113-S-DV | Samtec |

# Chapter 4
# Intelligent Outlet Description

## 4.1 System Specification

The system dims a light bulb in a desk lamp on AC power voltage. The application has the following specifications:

- The device dims a light bulb in a desk lamp or some usable device via triac circuitry on the AC power voltage (the dimmer is connected in parallel with a load)
- Dimmer is remotely controlled by the intelligent switch through the RF communication platform
- The board identification is defined by the HW selector in the RF wireless network of four intelligent outlets
- Targets the MC1321x microcontrollers
- Supports vacuum incandescent light bulbs in the power range 40 – 200 W
- Application is powered directly from 230 VAC/50 Hz (115 VAC/60 Hz) AC power using a SMPS
- Control technique incorporates:
  - Closed-loop PWM generated by a timer interrupt to adjust the control impulses for triac
  - Zero-cross detection of AC power voltage for triac synchronization
  - Settings to regulate the range of compensation in the voltage-current offset caused by reactance in the device and light bulb (it depends on the light bulb wattage too)
  - Possible memorizing of the last setting
  - Maximal dimming level is up to full light intensity of the bulb
- Communication technique incorporating:
  - Communication at a frequency of 2.4 GHz realised by SMAC software layer and an 802.15.4 modem implemented in one MC1321x
  - Short packet messages transmission for low-power consumption in the application
  - Possibility to create networks of point-to-point communcation between other devices determined by the message header (source address, destination address, network ID)

## 4.2 Board Overview

The whole design is similar to the intelligent switch application, but without E-Field equipment. The topololgy is shown in Figure 4-3. The intelligent outlet was realized in these two board modifications:

- Intelligent Outlet Version 1 is the board intended for implementation in the standard wall outlet case. See Figure 4-1. The board utilizes a small footprint sized dual-layer printed circuit board (PCB) containing all the necessary circuitry for the MC1321x microcontroller and for transferring data over an RF radio frequency. The placing of the parts used is designed to fit a standard internal outlet socket. Underneath there is free space for this purpose. The board is connected by the cables to this socket. The installation of the board is described in Section 6.1.2, "Setting Up the Intelligent Outlet version 1". The size and shape of the board is designed for easy installation into a standard wall outlet cross-case (size ϕ 65 x 40 mm in Europe type, KU68) commonly used in distribution of 230VAC AC power voltage in the home. The intelligent outlet board doesn't need replacing or any retrofitting of electro-installation in the walls at home.

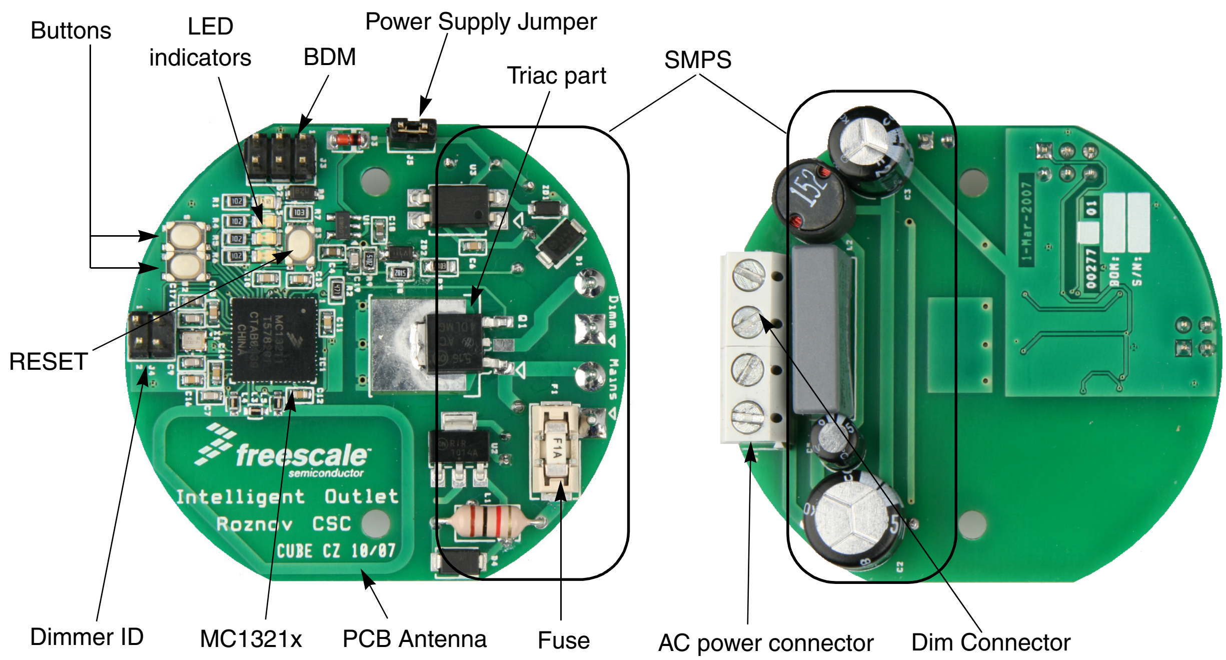


**Figure 4-1. Intelligent Outlet Version 1 Overview, Top and Bottom Side**

- Intelligent Outlet Version 2 is a reduced version of the Intelligent Outlet Version 1 board. See Figure 4-2. This board is universal and can be implemented in various kinds of cases. The board utilizes a small footprint sized dual-layer printed circuit board (PCB) containing all the necessary circuitry for the MC1321x microcontroller and for transferring data over an RF radio frequency. The size and shape of the board is designed for easy installation into a case equipped with the male socket for plugging into the wall outlet and a female AC power socket for receiving a desk lamp plug.

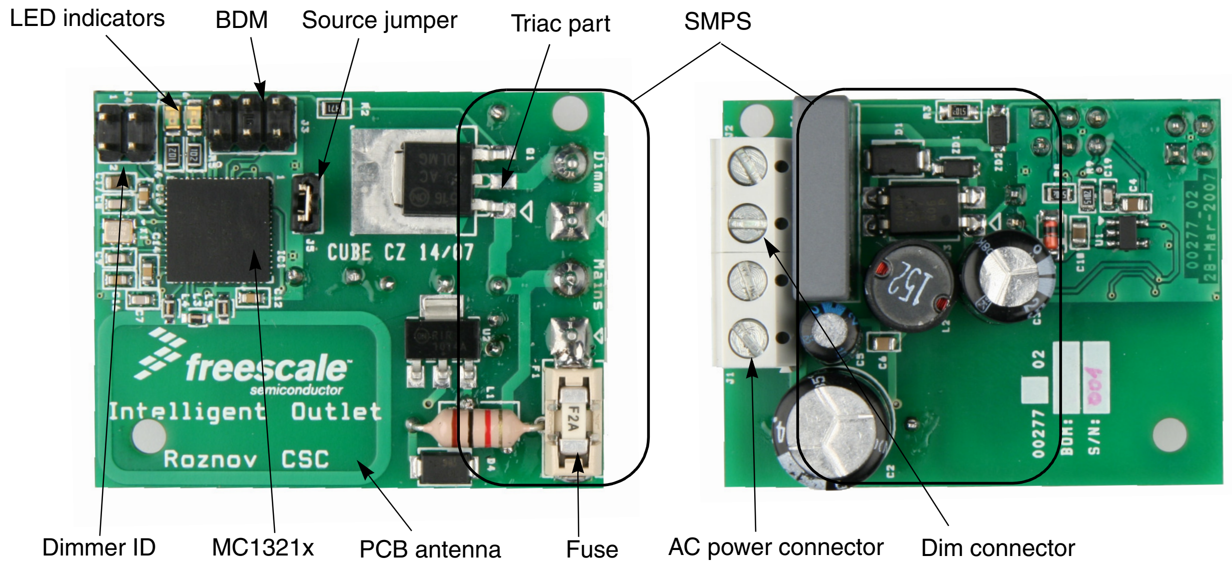


**Figure 4-2. Intelligent Outlet Version 2 Overview, Top and Bottom Side**

The main reason for developing two versions of the board was the implementation into different cases. The differences between these two boards are minimal. The placing of the parts is not equal and some redundant parts were removed. The description in the following chapters covers both versions of the boards and the eventual differences are highlighted.

The board layout is designed for easy component accessibility for minimal influence by the electromagnetic field and for the high voltage on the board. The high voltage part (this includes the switching power supply, zero-crossing and triac control) is separated from the MCU and RF transmitter. This causes a division of the PCB into three logical parts: power supply, MCU, and PCB antenna.

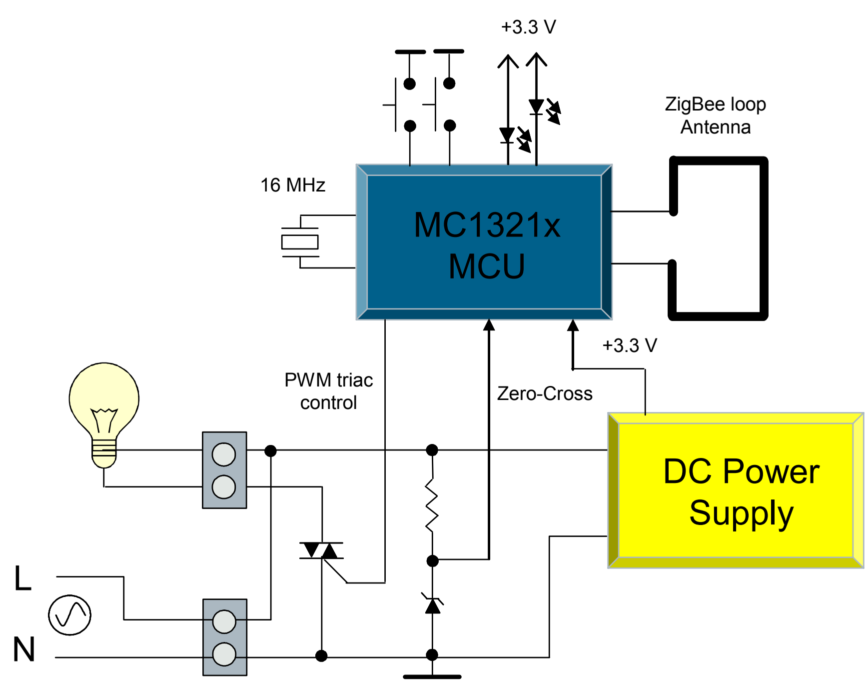


**Figure 4-3. Intelligent Outlet Block Diagram**

## 4.3 Control Process

Figure 4-4 shows in more detail how the different software and hardware modules co-operate with each other. The main tasks of the MCU (application) is to:

- Periodically wake-up from power saving mode when the device isn't dimming the light bulb
- Control periodically triac by PWM synchronized to zero-cross detection if light dimming is enabled
- Periodically receive data frames via the RF link by using of SMAC (Simple Media Access Controller)
- Analyse the received data, compare the dimmer ID with the destination address from the packet, and make following adjustments to the internal dimming variables
- Go to sleep when the device isn't dimming a light bulb or wait for another receive window

This basic loop repeats roughly 40 times per second providing an opening in the SMAC receive window combined with STOP modes of the MCU. Several of the MC1321x hardware modules are used for the intelligent outlet board operation: internal synchronous peripheral interface (SPI), external interrupt request (IRQ), 8-bit keyboard interrupt module (KBI1) and timer/PWM module (TPM1/TPM2).

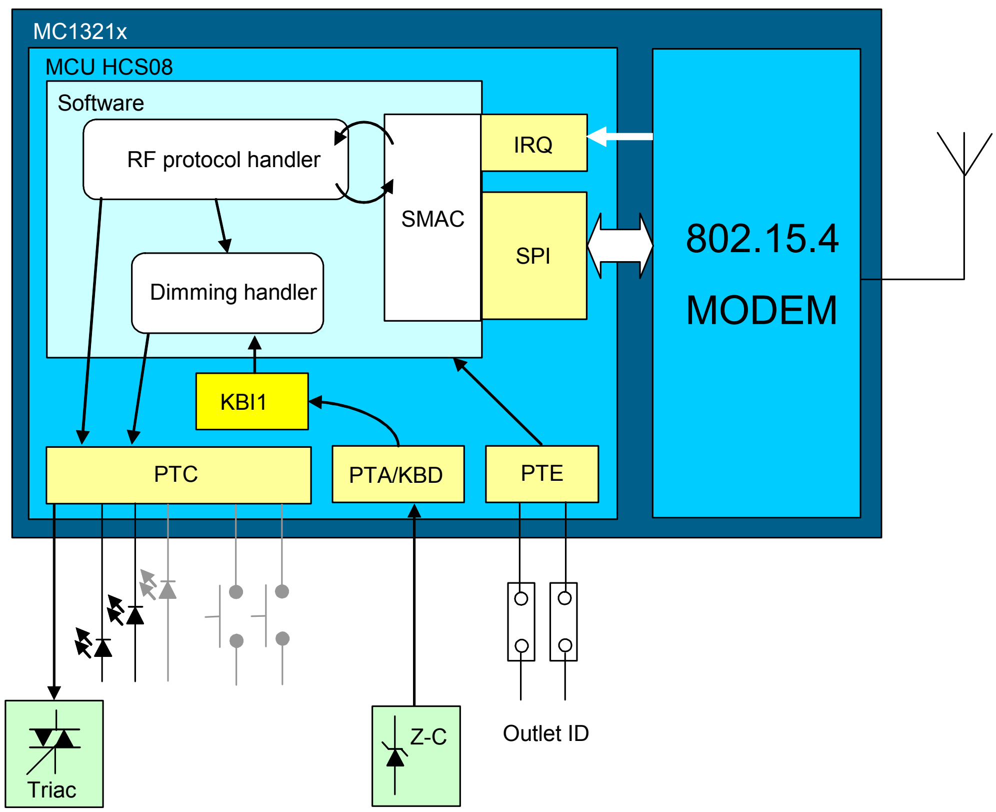


**Figure 4-4. Intelligent Outlet Board Software Overview**

## 4.4 Dimming Solution

The intelligent outlet concept is designed similarly to the intelligent switch. To realise the dimming function, triac part MAC4DLM (Q1) was selected. The reasons for using this solution are described in Section 3.6, "Dimming solution". A sensitive gate triac was selected for the number of parts reduction. This sensitive gate triac can be directly controlled from an MCU pin because consumption of the gate is between 2 – 10 mA. The sensitive gate triac used limits the output power ability of the light bulb dimming because triacs with this feature provide only 600 W. The MC1321x used provides current of up to 10 mA only on ports C and F, so the I/O pin PTC5 on port C is used for this purpose. The PTC5 pin is set as output and is connected to the triac gate via resistor R2 with value 470 Ω for current limitation. The subcircuit is shown in Figure 4-10.

Direct control of the triac using an MCU pin without opto-isolation needs one stable GND (non-floating) in the whole device for the correct level of voltage potentials. This is also used in realising zero-cross detection without opto-isolation. See Section 4.5, "Power Supply," for more details.

The triac, together with the load (light bulb), is connected in parallel with the AC power connector. This is different for the intelligent switch described in Section 3.6.1, "Dimming Mechanism," where the load was connected in front of the whole board. A positive impulse on PTC5 opens the triac. When the voltage on the triac (between the anode and cathode) reaches a zero value, the triac is closed with an infinite impedance. See Figure 3-8.

### 4.4.1 Zero-cross

The zero-cross fuction is realized similarly as in the intelligent switchboard. This design uses zener diode, ZD2, for this purpose. See the schematic in Figure 4-10. Resistor R3, with a value 510 kΩ, is connected in series with this diode. Resistor R3 has a wattage loading of roughly 100mW so it's the better to use SMD 0805. Although the highest possible input voltage level for the MCU input is 3.3 V, the value of the zener diode is 6.2 V because the tests showed that zener diodes with a value of around 3.3 V are not able to sufficiently stabilize the 230 VAC. Parallel to the ZD2 zener diode there must be a half-voltage divider from 6.2 V to 3.1 V, created from resistors R4 and R19 with values of 51 kΩ. At the end of the zero-cross chain capacitor, C19 is implemented to make the impulses more perpendicular.

This circuit generates impulses according to the shape of the AC power sinusoidal voltage. These impulses generate external MCU interrupts allowing synchronization of the dimming process. For this purpose, pin PTA4/KBD4 of the MCU is used and can be set to generate an external interrupt on the rising edge by internal module KBI. This signal is on the PCB, doubled to pin PTA7/KBD7 for safety. This software function is described in Section 5.7, "Dimming and Interrupts". The zero-cross doesn't need opto-isolation by an optocoupler, and the output can be directly connected to the MCU pin because there is a GND used that isn't floating and levels of potentials are equal. For more details, see Section 3.6.2, "Zero-Cross".

## 4.5 Power Supply

The power supply used is the same as the power supply implemented in the intelligent switch. The reasons for selecting this solution and attributes are written in Section 3.7, "Power Supply". The schematic of the example can be seen in Figure 3-9. It is a switched mode power supply (SMPS) with output voltage +12 V/200 mA.

The power supply is based on on Freescale's monolithic power switcher NCP1014. The topology is described in AN8226. This reference design needs an adjustment for the required output parameters. This solution meets all requirements. The power supply used doesn't have an ideal output voltage level because small fluctuations can appear when the triac switches the voltage. However, these fluctuations are negligible and don't influence the correct functioning of the whole topology. The power supply is able to power the device up to a maximum high limit of 90% of triac openning.

The main features of this SMPS are:

- Wide input voltage range 85 VAC – 265 VAC
- Output voltage + 12 V / 200 mA
- Smaller size, relatively few number of parts, lower weight, lower total cost
- Good line and load regulation, no need of additional linear regulators
- Efficient design with up to 80% efficiency
- Overload, short-circuit and thermal protected

### 4.5.1 Linear Regulator NCP551SN33T1

The MC1321x needs a power supply voltage of +3.3 V. The SMPS generates +12 V. Then the low drop voltage regulator NCP551SN33T1 (U1) transforms this voltage to +3.3 V. The subschematic of this part can be found in Figure 4-10. The diodes D3 and D8 are dedicated for power supply polarity protection.The diode D8 is not implemented in the Intelligent Outlet Version 2 design.

## 4.6 Power Management

Although the board is powered directly from AC power, this device contains features for lower consumption. The intelligent outlet is intended for application at home as a standard outlet, so this means the device is turned on for a long time. Most of the time, the device is in stand-by mode. To achieve lower consumption, there is a combination used of STOP3 mode in the MCU, 27 ms Doze mode in the 802.15.4 modem, and shorter transmitted packets. When the device is permanently functional (dimming mode), power consumption is roughly 17 mA. When the device isn't dimming, the value is approximately 11 mA on a +12 V power voltage.

Typically, current consumptions of the board components in modes used are as follows:

- MC1321x microcontroller
  - MCU HCS08:
    - Stop3 mode, 675 nA
    - Wait mode, 1 mA
    - Run mode with 16Mhz clock (no load from ports), 6.5 mA
  - 802.15.4 modem:
    - Doze mode,35 µA
    - Transmit mode, 30 mA
    - Receive mode, 37 mA

## 4.7 Intelligent Outlet Board Hardware Overview

This section describes the sensor board in terms of hardware design. The MC1321x microcontroller drives the MC33794 E-Field sensor and it provides the RF communication platform and dimming function. See schematic Figure 4-9 and Figure 4-10 for reference.

### 4.7.1 Microcontroller

The system is based on an MC1321x, 8-bit, low-cost microcontroller, powered by a +3.3 V DC from the switching power supply described in Section 4.5, “Power Supply”. The MCU sends impulses to the triac part synchronized by the zero-cross. The MC1321x also performs wireless data reception from the RF transceiver in the intelligent switchboard. The antenna design is directly connected to the package and described in chapter Section 4.7.8, “Antenna Design”. The PWM output from the microcontroller, combined with directional signals, drives the triac component (Section 4.4, “Dimming Solution”).

For the proper clock generation, there is a required external 16 MHz crystal. The two capacitors, C8 and C9, are connected in parallel to this crystal. The oscillator created generates 8 Mhz bus clock frequency. The set of capacitors, C10 to C17, are used for noise reduction and to stabilise the assistant +3.3 V.

### 4.7.2 BDM

Header J3 is a BDM port for use with a P&E BDM-Multilink cable available from Metrowerks. The BDM cable is used with the CodeWarrior™ Development Studio for the HCS08 to program the MCU flash memory as well as performing in-circuit debugging. See Figure 4-5 for the position of pin 1. The red lead of the BDM cable must align to pin 1 of J3. When using the parallel port version of the BDM cable, the BDM pod should be powered by a 3.3V negative centre contact power supply.

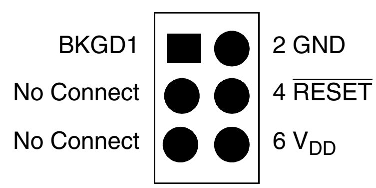


**Figure 4-5. BDM Tool Connector**

### 4.7.3 Buttons

The additional buttons are implemented only in the Intelligent Outlet Version 1 board. Table 4-1 explains their functions.

**Table 4-1. Switch Description for Intelligent Outlet Version 1**

| Switch | MCU Port | I/O Direction | Function |
|---|---|---|---|
| S1 | PTC3 | Input (pull up) | User own programmable function (dimm up) |
| S2 | PTC4 | Input (pull up) | User own programmable function (dimm down) |
| RESET (S3) | — | — | Ordered RESET of whole device |

### 4.7.4 LED Indicators

The devices also include some indicator LEDs.

**Table 4-2. LEDs Description for Intelligent Outlet Version 1**

| LED | MCU Port | I/O Direction | Function |
|---|---|---|---|
| D5 | PTC2 | output | Signals a received packet by SMAC |
| D6 | PTC1 | output | Signals a detected zero-cross edge |
| D7 | PTC0 | output | User own programmable function (not used) |
| D2 | — | — | Signals the device functionality |

**Table 4-3. LEDs Description for Intelligent Outlet Version 2**

| LED | MCU Port | I/O Direction | Function |
|---|---|---|---|
| D5 | PTC2 | output | Signals a received packet by SMAC |
| D6 | PTC1 | output | Signals a detected zero-cross edge |

### 4.7.5 Power Supply Jumper

The small header J5 separates the power supply from the whole device logic. In the default function, the jumper is closed. When the device is in debugging mode, it is useful to leave J5 open and the board can be powered through this pin. You can test the output of the power supply separately using this header. See Section 6.4, “Software Modification,” for other details.

### 4.7.6 Intelligent Outlet Identification

The function is realised by a simple header of 2 × 2 pins. The high level for one of two bits information is selected by closing two vertical pins. This combination identifies the intelligent outlet board in the RF wireless network. These headers are connected to the pins PTE0 and PTE1. The signification of the bits is marked on the PCB by the numbers one and two. See Section 6.2, “Setup of the Intelligent Outlet Identificator”.

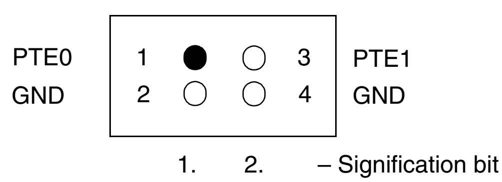


**Figure 4-6. Intelligent Outlet ID**

### 4.7.7 Fuse

All domestically used devices which work with 230VAC AC power voltage need to be protected by of the fuse. The current flowing through the triac is a maximum 800 mA when a 200VA light bulb is used. This board is protected at least by the quick fuse F1 with value 1A in an SMD holder. The fuse is connected in series with the L phase from the AC power voltage connector.

## 4.7.8 Antenna Design

The PCB layout RF antenna was designed with cost and board size in mind. From several PCB antenna designs available for the 2.4 GHz band (F-antenna, dipole, loop), the loop antenna has been selected mainly because of the size required on the PCB. The MC1321x offers an internal switching of the RF IN (receive) and PA OUT (transmit) paths, so that two separate antennas aren't needed.

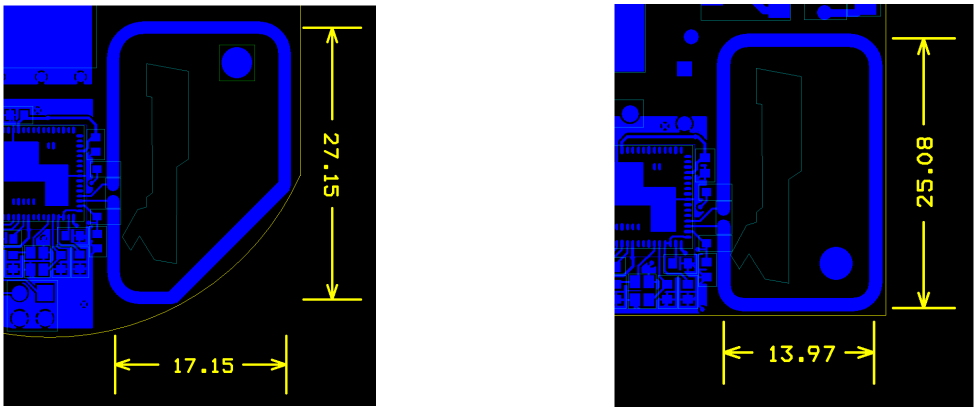


**Figure 4-7. Antenna Layout Design, PCB Ver. 1 and Ver. 2**

The antenna is designed as a rectangle, 17 × 27 mm (670 × 1062 mils) and 14 × 25 mm (551 × 984 mils), made of 1.25 mm (50 mils) wide trace copper. The functionality of the antenna is guaranteed because the length of this loop is roughly 80 mm which is more than a halfperiod of the 125 mm wavelength (2.4 GHz). The matching is provided by the L3 coil. The L4 and L5 coils bias the transmitter output transistors to the VDDA level.

## 4.7.9 EMI Filtering

The standard EMI filter is created by a 47nF/230V capacitor and a double toroid coil of 3.9mH/3A. This filter is directly connected to the 230VAC input connector of the device. The function of the filter is to partially suppress EMI harmonic frequencies generated by the switching of the triac and SMPS and to smooth the current spikes through the triac. The EMI filter is an optional benefit and the device can also work without it.

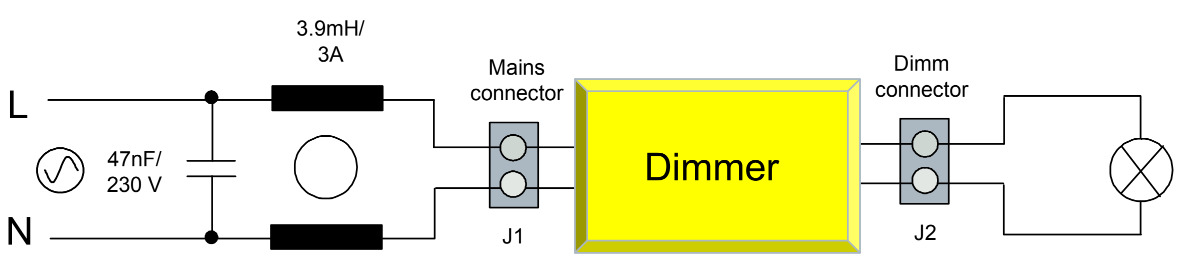


**Figure 4-8. EMI Filter Integration**

## 4.8 Intelligent Switchboard Schematics

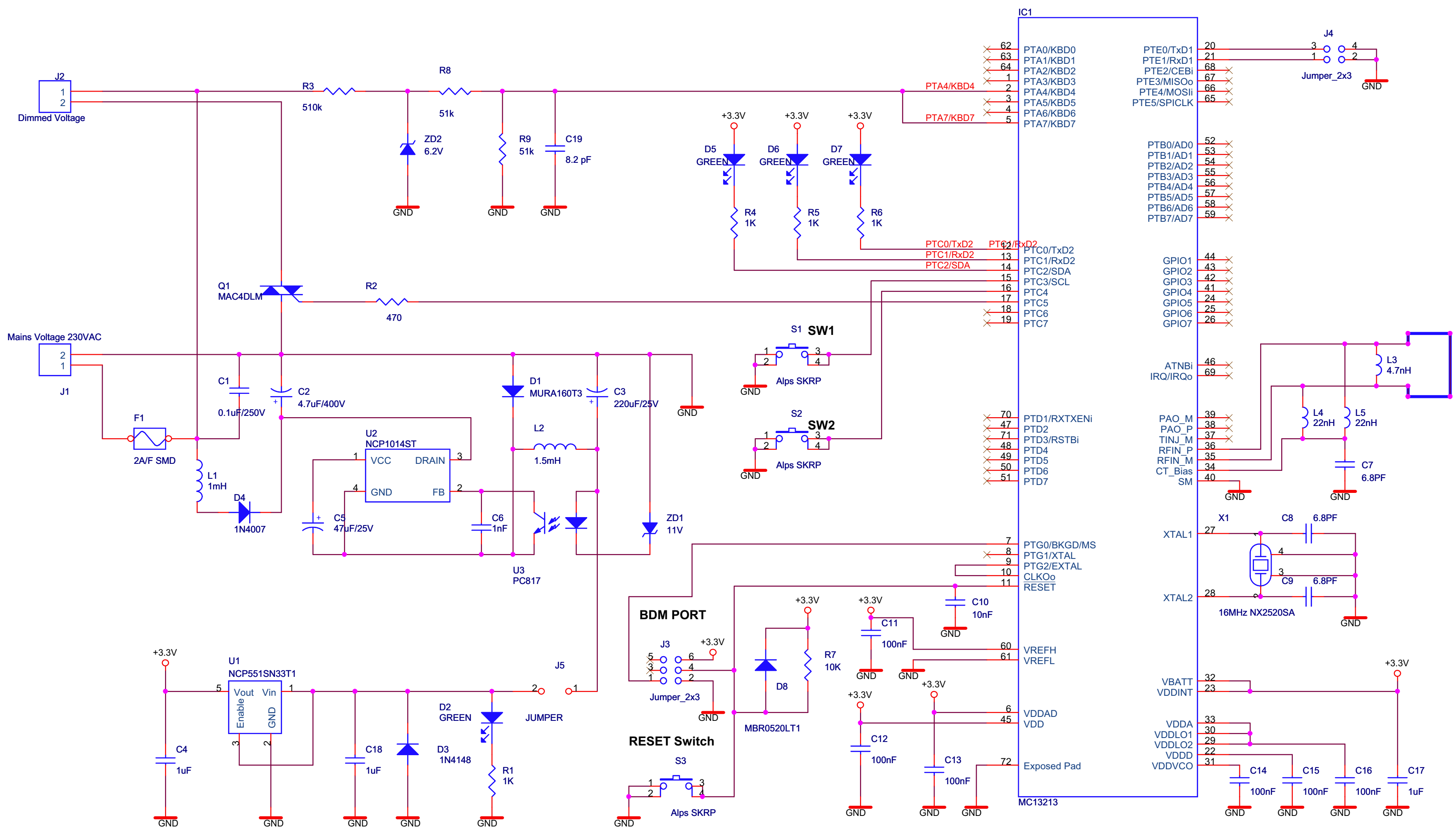


**Figure 4-9. Intelligent Outlet Version 1, Schematic**

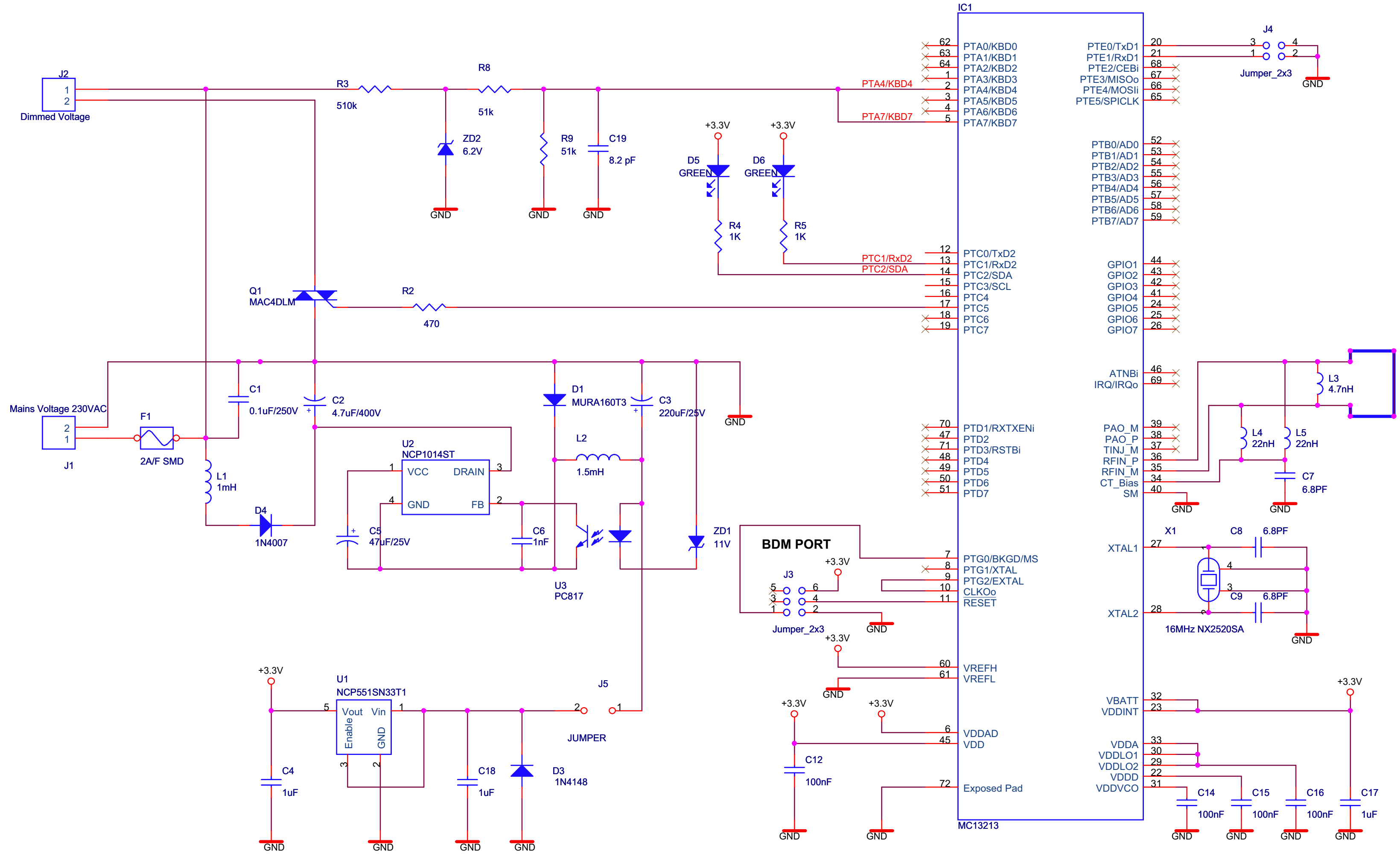


**Figure 4-10. Intelligent Outlet Version 2, Schematic**

## 4.9 PCB Layouts

The board utilizes a small footprint sized dual-layer printed circuit board (PCB). The dimensions of the board are mainly limited by dimensions of the connectors and power supply design. The board is designed according to the rules for designing high voltage devices. According to the limitation of 230VAC safety isolation, spacing between lines and their widths allows for a minimal current of 1A. As written in Section 4.2, “Board Overview,” the design is realized in two types of boards.

The size and shape of the Intelligent Outlet Version 1 is designed for easy installation into a standard wall outlet cross-case (size ϕ 65 x 40 mm in Europe, type KU68), commonly used in the distribution of 230VAC AC power voltage in the home. The dimensions of the board are 55 mm x 50 mm (2165 mils x 1968 mils). The PCB layout and parts placement can be seen in Figure 4-11 and Figure 4-12.

Intelligent Outlet Version 2 is a reduced and minimalised version of Intelligent Outlet Version 1 board. This board can be implemented in various kinds of cases, such as the line voltage adapter. The dimensions of the board are 45 mm x 35mm (1771 mils x 1377 mils). The PCB layout and parts placement can be seen in Figure 4-13 and Figure 4-14.

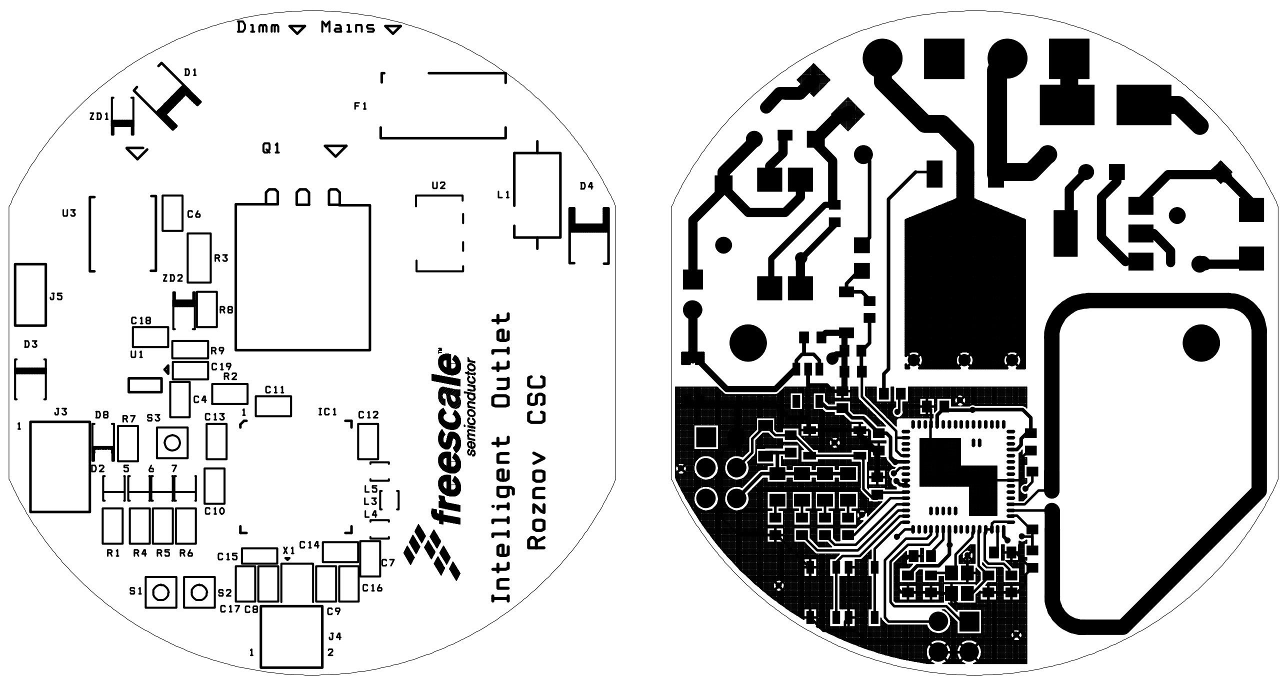


**Figure 4-11. Intelligent Outlet Version 1, Parts Placement and PCB Layout, Top Side**

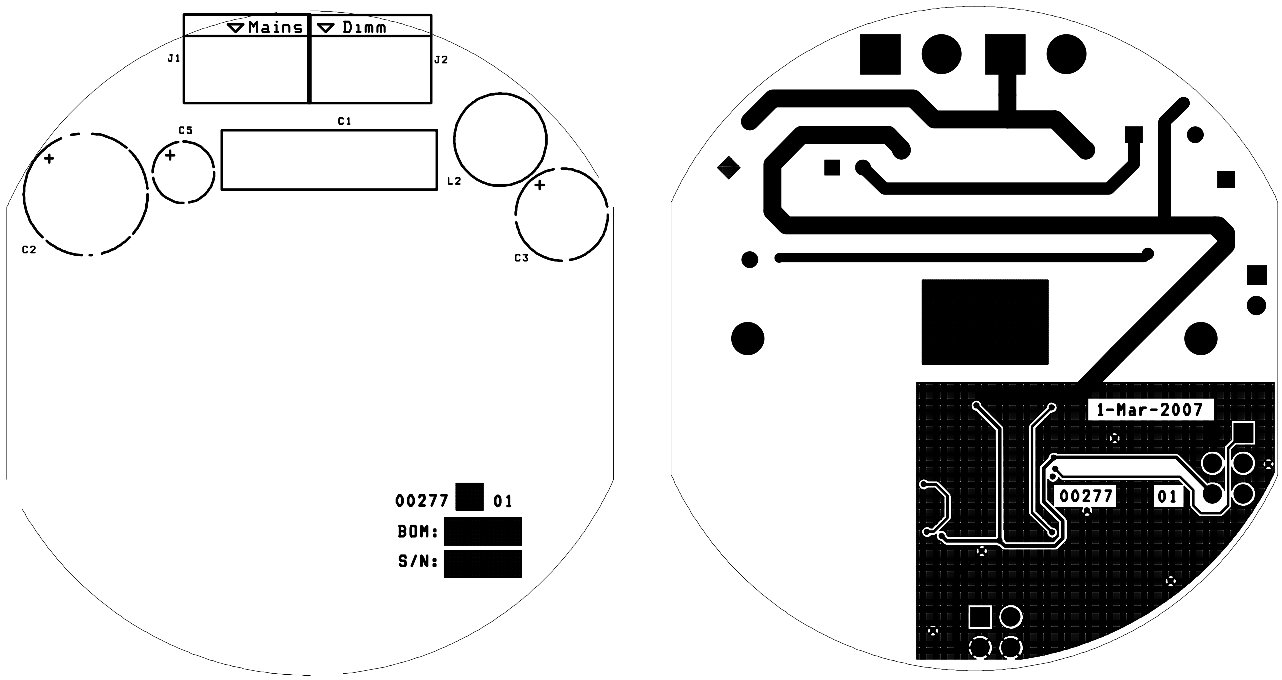


Figure 4-12. Intelligent Outlet Version 1, Parts Placement and PCB Layout, Bottom Side

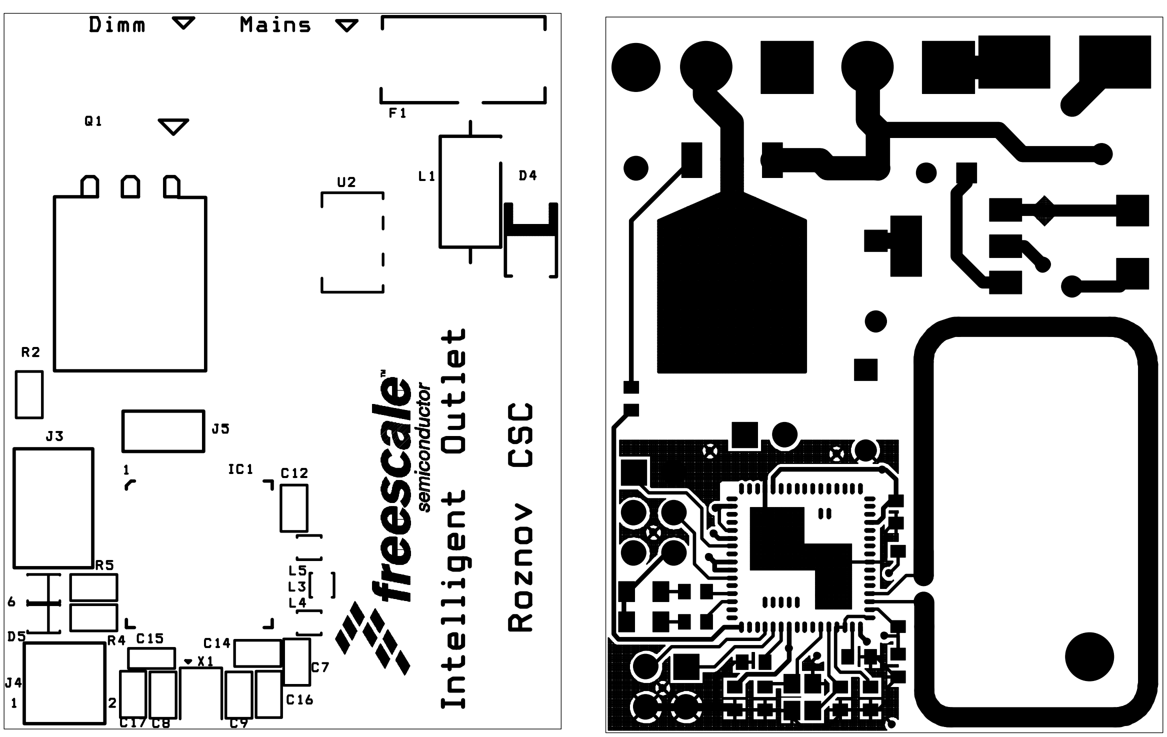


Figure 4-13. Intelligent Outlet Version 2, Parts Placement and PCB Layout, Top Side

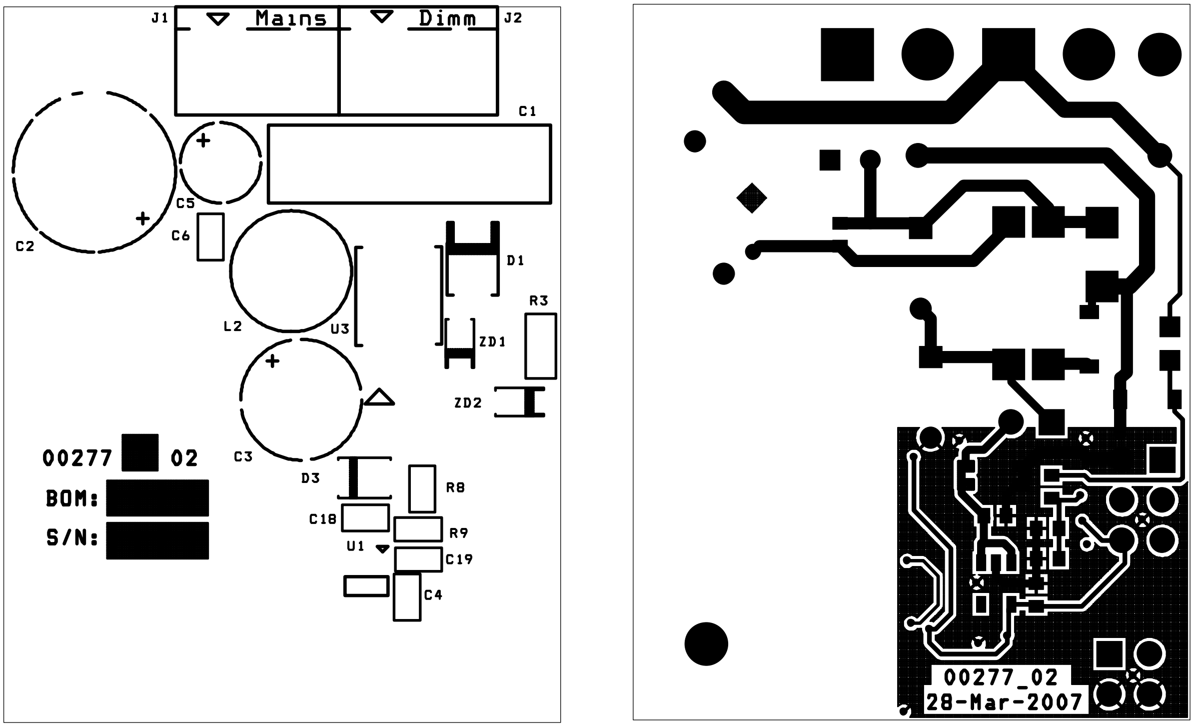


**Figure 4-14. Intelligent Outlet Ver.2, Parts Placement and PCB Layout, Bottom Side**

## 4.10 Bill of Materials

**Table 4-4. Bill of Materials**

| Item | Quantity | Reference | Part | Manufacturer |
|---|---|---|---|---|
| 1 | 1 | C1 | 0.1µF/250V | Any acceptable |
| 2 | 1 | C2 | 4.7µF/400V | Any acceptable |
| 3 | 1 | C3 | 220µF/25V | Any acceptable |
| 4 | 3 | C4 C17 C18 | 1µF (0603) | Any acceptable |
| 5 | 1 | C5 | 47µF/25V | Any acceptable |
| 6 | 1 | C6 | 1nF (0603) | Any acceptable |
| 7 | 3 | C7 C8 C9 | 6.8pF (0603) | Any acceptable |
| 8 | 6 | C11[1], C12, C13[1], C14, C15, C16 | 100nF (0603) | Any acceptable |
| 9 | 1 | C10[1] | 10nF (0603) | Any acceptable |
| 10 | 1 | C19 | 8.2pF (0603) | Any acceptable |
| 11 | 1 | D1 | MURA160T3 | ONSEMI |
| 12 | 1 | D2[1] | GREEN (0805) | Any acceptable |
| 13 | 1 | D3 | 1N4148 (0805) | Any acceptable |

**Table 4-4. Bill of Materials (continued)**

| Item | Quantity | Reference | Part | Manufacturer |
|---|---|---|---|---|
| 14 | 1 | D4 | MRA4007T3G | ONSEMI |
| 15 | 3 | D5, D6, D7[1] | RED | Any acceptable |
| 16 | 1 | D8* | MBR0520LT1 | ONSEMI |
| 17 | 1 | F1 | 1A/F SMD | LittelFuse |
| 18 | 1 | IC1 | MC13211 | Freescale |
| 19 | 1 | J1 | AC power Voltage 230VAC | Any acceptable |
| 20 | 1 | J2 | Dimmed Voltage | Any acceptable |
| 21 | 1 | J3 | JUMPER 2x3 | Any acceptable |
| 22 | 1 | J4 | JUMPER 2x2 | Any acceptable |
| 23 | 1 | J5 | JUMPER 1X2 | Any acceptable |
| 24 | 1 | L1 | 1 mH TL-AX | FASTRON |
| 25 | 1 | L2 | 1.5mH RFB0810-152L | CoilCraft |
| 26 | 1 | L3 | 4.7nH (0603) | Any acceptable |
| 27 | 2 | L4, L5 | 22nH (0603) | Any acceptable |
| 28 | 1 | Q1 | MAC4DLM | ONSEMI |
| 29 | 4 | R1[1], R4, R5, R6[1] | 1K (0603) | Any acceptable |
| 30 | 2 | R8, R9 | 51K (0603) | Any acceptable |
| 31 | 1 | R2 | 470 (0603) | Any acceptable |
| 32 | 1 | R3 | 510K (0805) | Any acceptable |
| 33 | 1 | R7[1] | 10K (0603) | Any acceptable |
| 34 | 3 | S1, S2, S3 | SKRPADE010 | ALPS |
| 35 | 1 | U1 | NCP551SN33T1 | ONSEMI |
| 36 | 1 | U2 | NCP1014ST | ONSEMI |
| 37 | 1 | U3 | PC817 SMD | SHARP |
| 38 | 1 | X1 | 16MHz NX2520SA | NDK |
| 39 | 1 | ZD1 | MMSZ5241BT1G (11V ) | ONSEMI |
| 40 | 1 | ZD2 | MMSZ6V2T1G (6.2V) | ONSEMI |

[1] Not implemented in Intelligent Outlet Version 2 board

# Chapter 5
# Software Design

## 5.1 Introduction

The section describes the software design blocks for the intelligent switch (IS) and intelligent outlet (IO) application together because the functions are equal for both parts. The software description comprises these topics:

- Software Design Consideration
- RF Protocol Consideration
- Main Data Flow Charts
- Dimming and Interrupts

## 5.2 Software Design Consideration

The intelligent switch executes E-Field processing, dimming, and control of an intelligent outlet using RF wireless communication. E-Field electrode value readings are taken by the MCU by selecting the appropriate channel lines (Table 3-1) and then reading the value on the MCU A/D module. This function is alternated by the dimming function started by a zero-crossing. The next asynchronous function is sending control messages via the RF transceiver using the remote control. The application also gives feedback through the LEDs on the touch panel.

The intelligent outlet receives wireless data from the intelligent switch and it dims the light bulb through the triac part. This dimming is synchronized with the line voltage zero-crossing.

## 5.3 RF Protocol Consideration

The demo is intended as a presentation of an RF wireless communication platform at 2.4 GHz frequency. Following chapters explain the structure of the communication.

### 5.3.1 SMAC (Simple Media Access Controller)

The SMAC is a simple ANSI C based code stack available as sample source code that can be used to develop proprietary RF transceiver applications using the MC1321x 802.15.4 Modem.

The development of the light dimming application software is based on the free SMAC stack available from Freescale. The SMAC version 4.1a was used. Modifications were made because the original version does not support the HCS08 family. All changes were made using conditional compile options, using the ZSTARQG8 and ZSTARJW32 definitions. This modified SMAC is the one used from the ZSTAR project, and the entire descriptions of all the functions and changes can be found in Design Reference Manual ZSTARRM Rev. 3

A fully detailed description of the SMAC is in the SMAC Reference Manual (SMACRM.pdf), available together with the SMAC source code.

## 5.3.2 Packet Structure

The application uses a simple protocol for an RF transfer of information between the intelligent switch and intelligent outlet. Only simple commands such as LIGHT_UP (light intensity up), LIGHT_DOWN (light intensity down), and LIGHT_SWITCH (light switch ON or OFF) are transmitted. There is also transmitted data that can define the value of the changes. The protocol is built on top of the SMAC drivers available for the MC1312x transceiver family. The protocol used is regularly monodirectional, allowing the set up of communication between one independent intelligent switch and four intelligent outlets. However, it is easily possible to realize various combinations of control topology. You can control the same or more intelligent outlets by several intelligent switches if they all have the same network identifier. Because the transmitted messages are simple, it is possible to change the control attributes for the destination outlet by software changing in the intelligent switch. Also, it doesn't matter if one packet is not received, because the dimming value is memorized in the controlled device (not by sender) and the transmitted message changes this value.

All data is transferred in structured as shown in Figure 5-1. This protocol is primarily targeted at simple demo purposes, allowing a fast transfer of the control commands data in short packets with minimum overheads and with minimum loads (short receive windows and transmit packets, etc.).

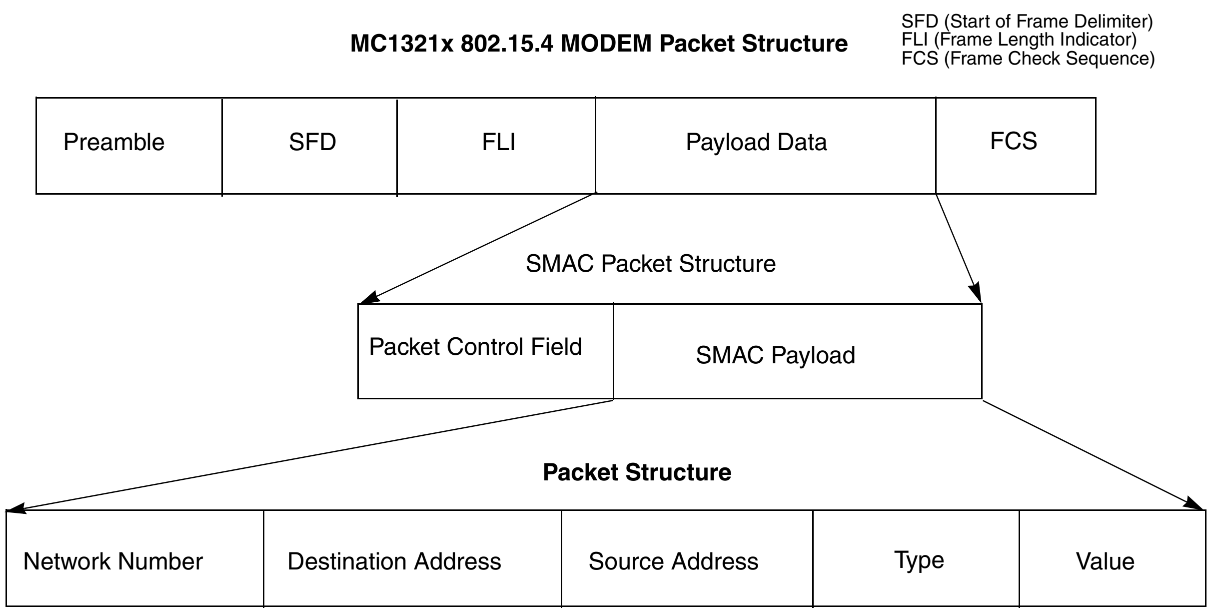


**Figure 5-1. Packet Structure**

The LDD packet is contained inside the MC1321x MODEM standard packet structure, which is consistent with the IEEE 802.15.4 Standard. The SMAC library transparently adds a 16-bit packet control field (see chapter 7.2.1.1 of IEEE 802.15.4 Standard specifications) to differentiate packets from ZigBee and other standards.

**Table 5-1. Commands List**

| Command | Code | Direction | Function |
|---|---|---|---|
| LIGHT_UP | u | IS to IO | Increasing the light intensity by Value |
| LIGHT_DOWN | d | IS to IO | Decreasing the light intensity by Value |
| LIGHT_SWITCH | s | IS to IO | Defines the press of the on/off pad |

The LDD packet becomes a payload data for the SMAC standard packet and contains the following fields:

- Network number is the number defined in the software initialization field and is dedicated for membership definition of devices in one network group. If an equal number is not received, the packet is ignored. It is an unsigned int type of variable.
- Destination address is the number defined in the software initialization field of each intelligent outlet and is selected by the intelligent switch. It is dedicated for defining the destination intelligent outlet. If a number not equal to the device number is received, the packet is ignored. It is an unsigned char type of variable.
- Source address is the number defined in the software initialization field of the intelligent switch and is dedicated for defining the correct control source. If the right number is not received, the packet is ignored. It is an unsigned char type of variable.
- Type defines the respective type of packet (Figure 5-1) that execute this packet. It is an unsigned char type of variable.
- Value is user data used for transmitting the defining step value in remote changes to the dimming value. It is an unsigned int type of variable.

### 5.3.3 Communication Process and Power Management

Power management is realised by the combination of doze mode in the MODEM, STOP3 modes in the MCU, wait delays, and delayed windows for sending and receiving. The intelligent switch sends asynchronous commands by 27 repeated packets with 1 ms wide delays. See Figure 5-2 for a timing diagram. The command message is sent when a command is selected from the touch panel. The intelligent outlet repeatly opens the 3 ms receiving windows after 24 ms delays. In the delay time, there is space to execute doze mode in the MODEM and STOP mode in the MCU, or a simple delay according to the current state of the intelligent outlet. When the dimmer dims the light bulb, the device doesn’t use power management. When dimming is off, the power management is used. This is because of a conflict with the external interrupt generated by the zero-crossing and dimming processes. MCU wake-up from STOP3 mode is automatically realized by an extrenal IRQ generated by the 802.15.4 modem when doze mode has expired. This interrupt is also used for the zero-crossing detection needed for dimming, but it doesn’t have any influence on the wake-up of the MCU.

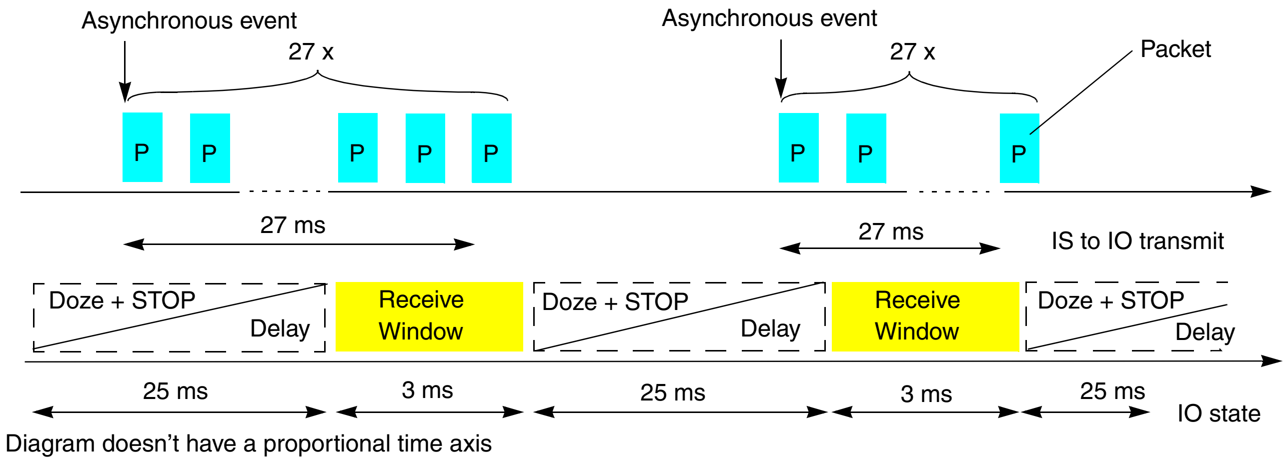


**Figure 5-2. Communication Process**

## 5.4 Main Data Flow Charts

The general overview of the control algorithm for the intelligent switch and intelligent outlets are the same, so they are described in Figure 5-3 together. The difference is the E-Field service appearance implemented in the main loop of the intelligent switch. The individual processes are described in the following sections. These general software diagrams incorporate the main routine entered from a reset and the interrupt service routines.

The main routine initializes the MCU, starts the TIM counter, enables interrupts, performs a delay to let things settle, reads the calibration values, and then enters an endless loop. This endless loop contains specific execution modules (touch panel analysis, asynchronous dimming process). The e-field is tested on every cycle and the function selected is executed. The operational modes and interrupts for the intelligent switch are described in flow charts from Figure 5-4 to Figure 5-9. The dimming function is the same for both devices as described in Section 5.7, "Dimming and Interrupts". These flow charts describe the simplified functions and modes of the system.

The names and purposes of each function and procedure are listed in Section 5.8, "Firmware Functional Description".

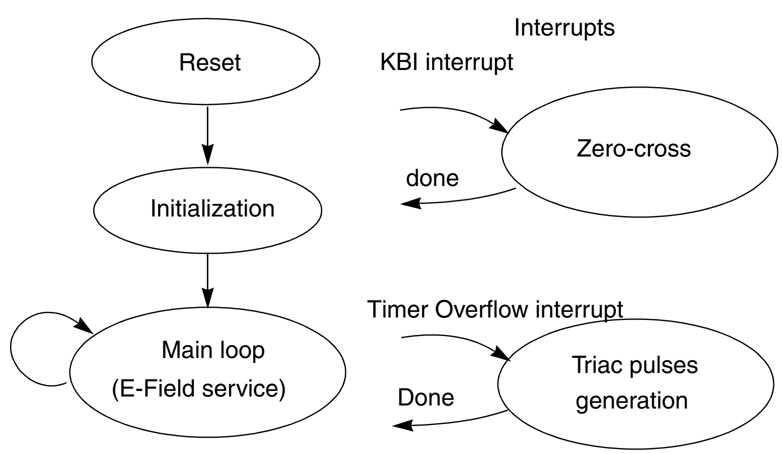


**Figure 5-3. State Diagram - General Overview**

## 5.5 Intelligent Switch Functions Overview

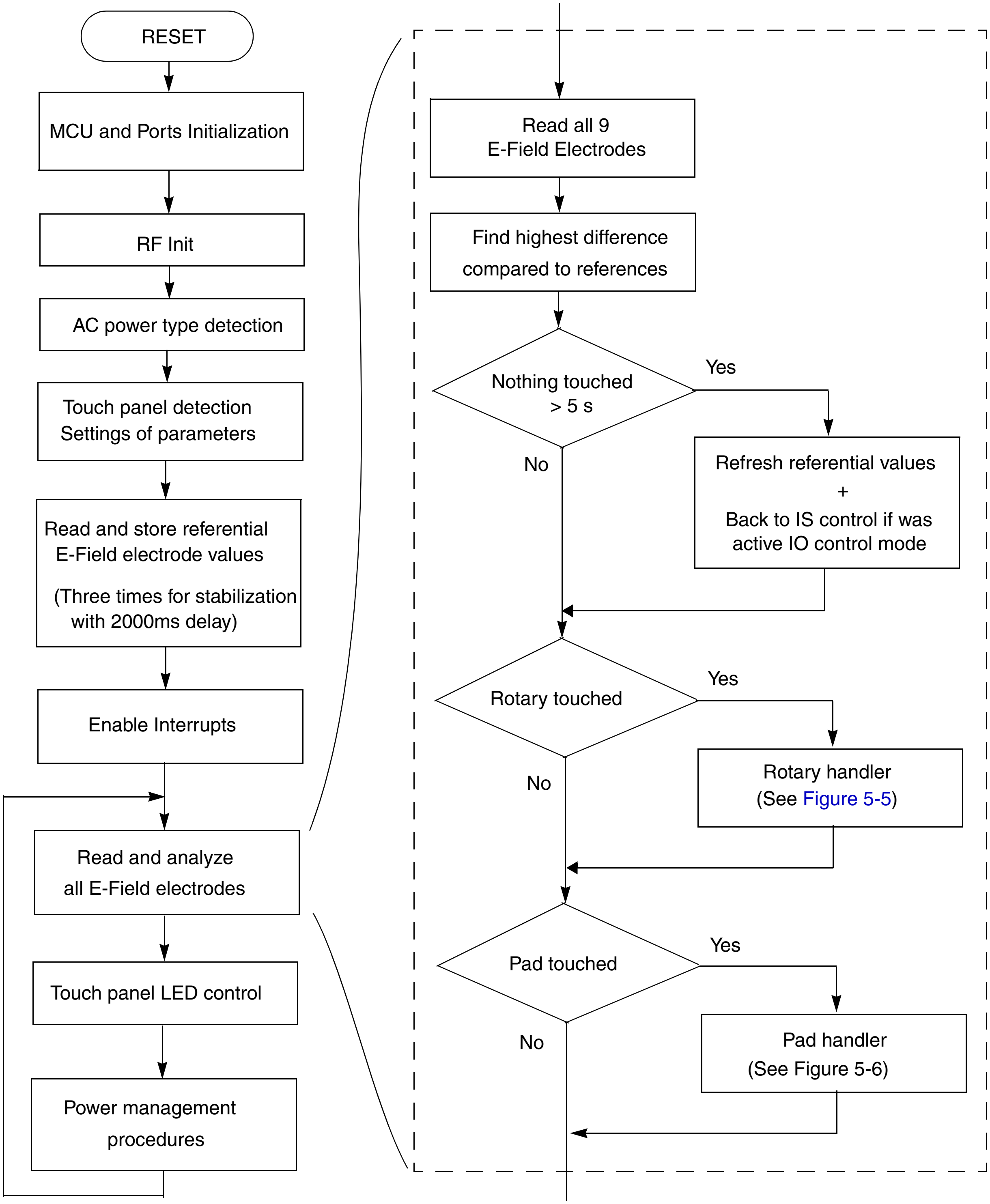


**Figure 5-4. Intelligent Switch Main Data Flow Chart**

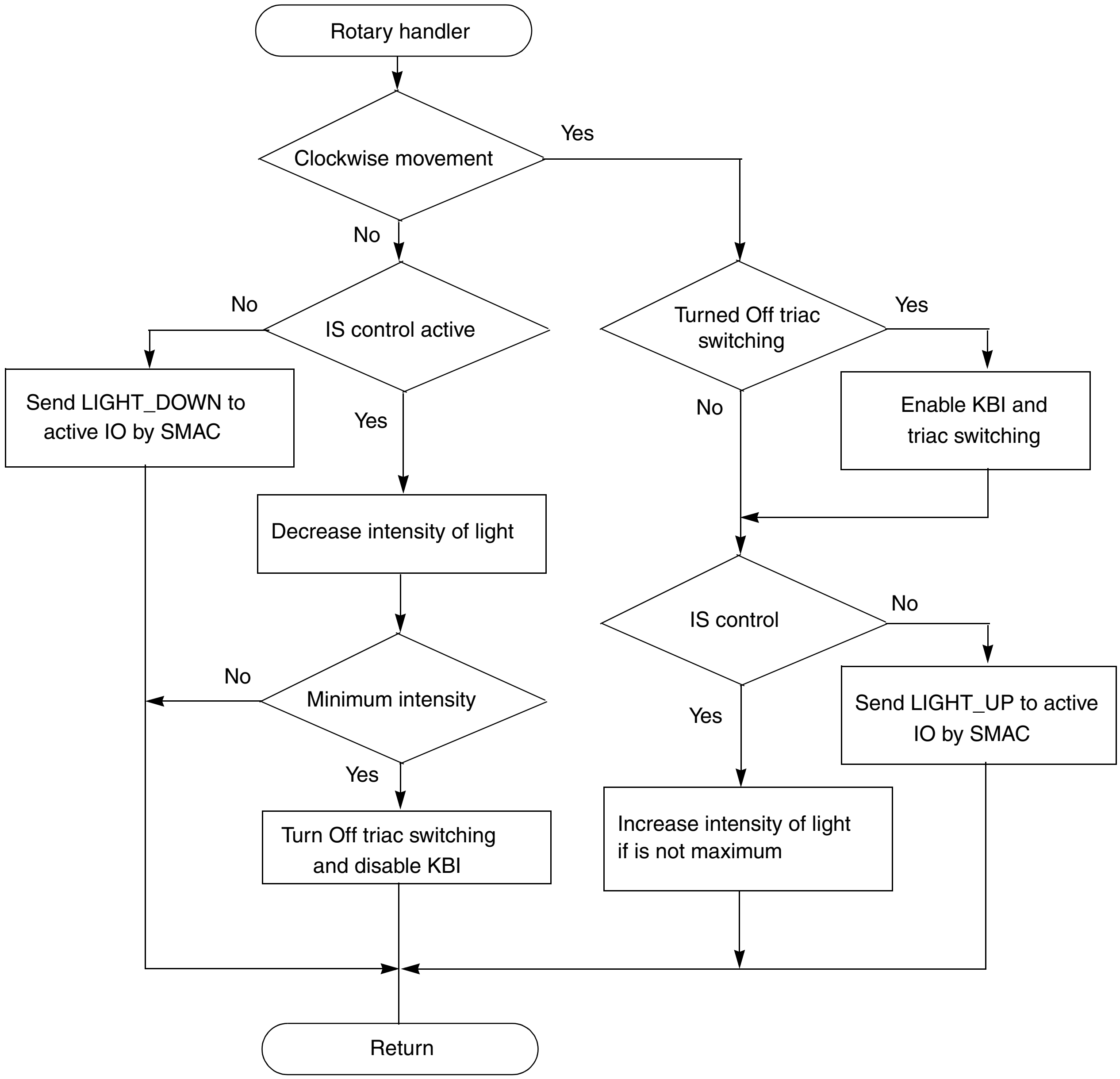


**Figure 5-5. E-Field Rotary Handler Flow Chart**

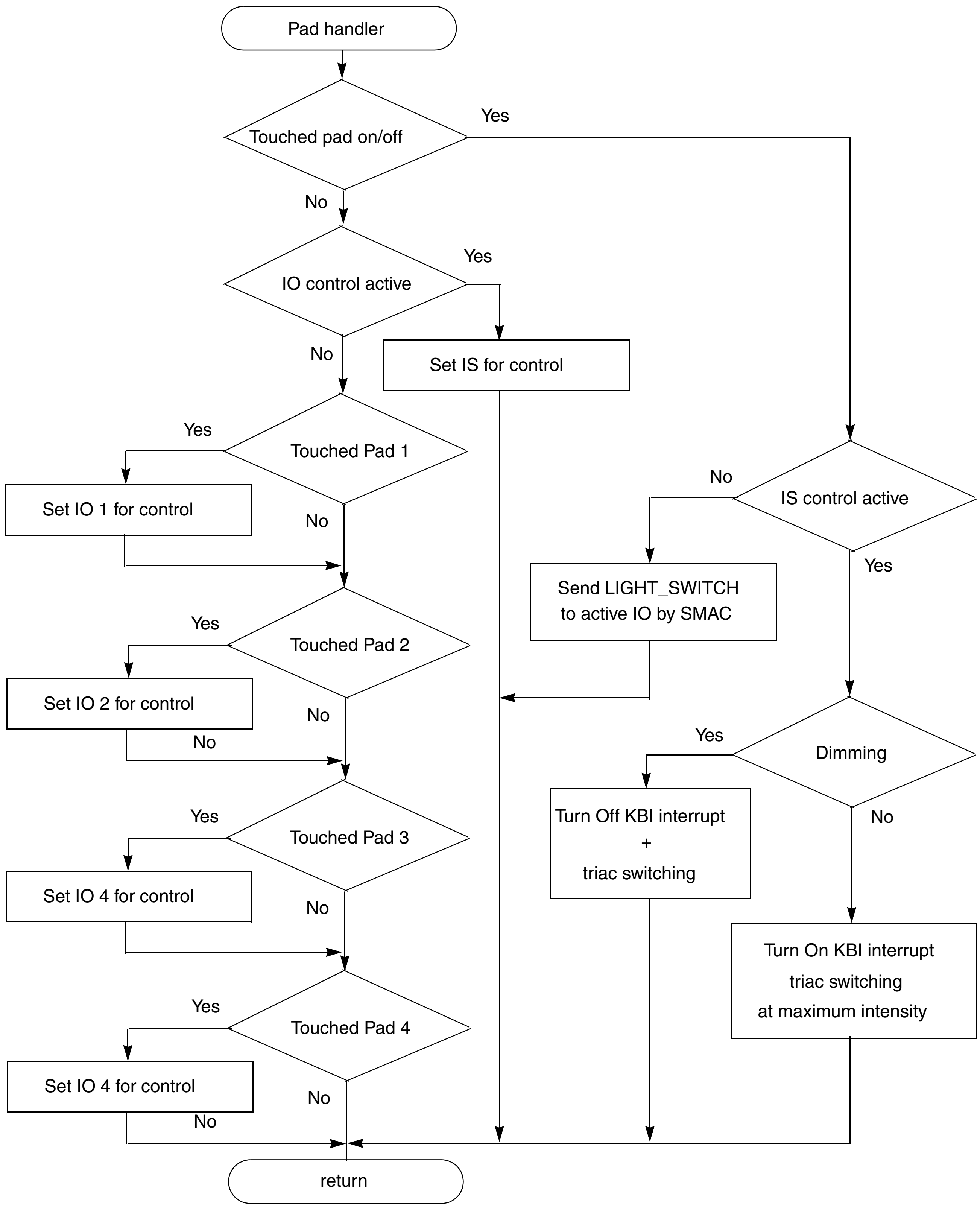


**Figure 5-6. E-Field Pad Handler Flow Chart**

## 5.6 Intelligent Outlet Functions Overview

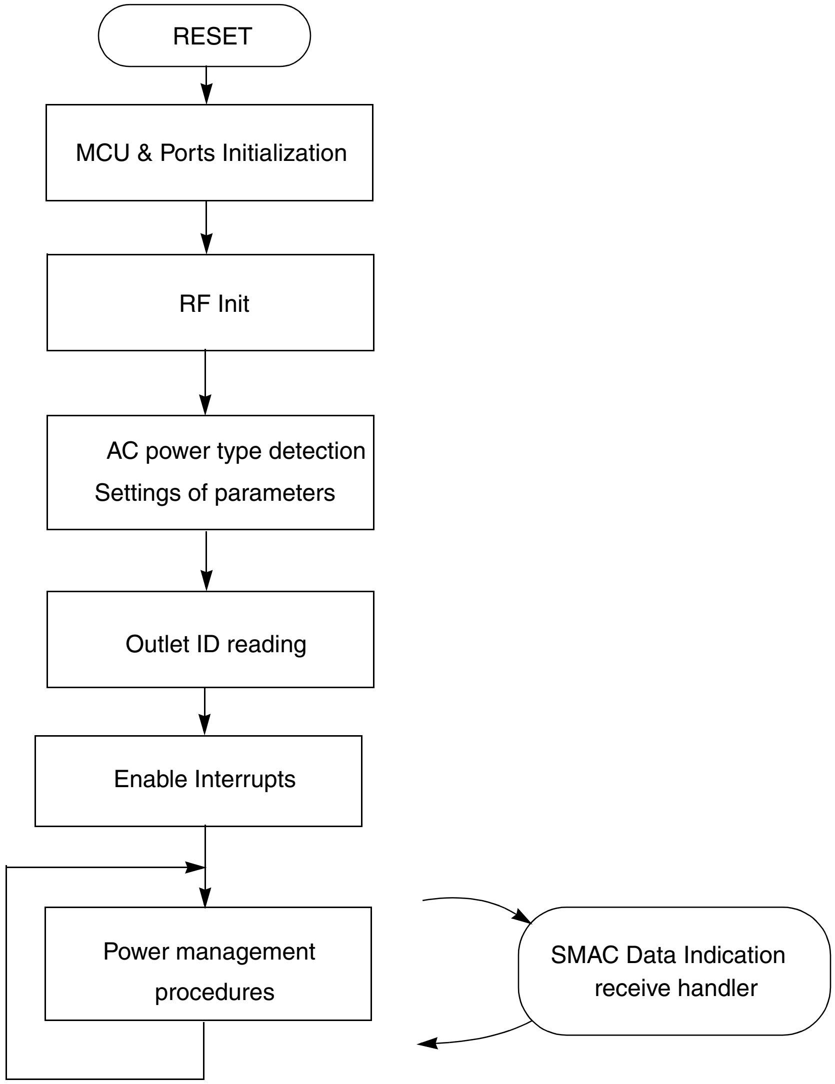


**Figure 5-7. Intelligent Outlet Main Data Flow Chart**

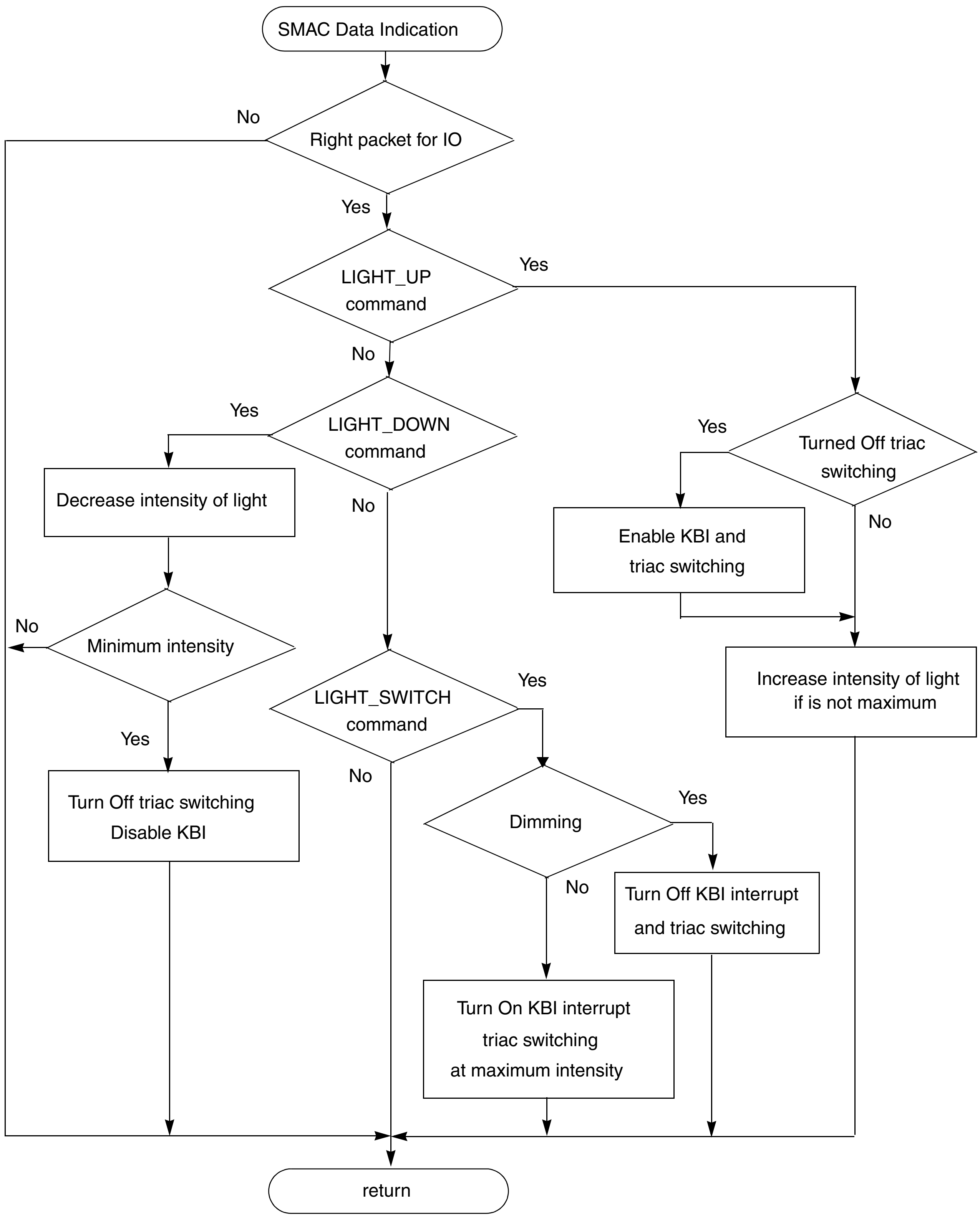


**Figure 5-8. Intelligent Outlet Data Receiving Flow Chart**

## 5.7 Dimming and Interrupts

The dimming function is initiated and synchronized by the cyclic execution of the handler routine called by the KBI interrupt module. This system is equally used in the intelligent switch and intelligent outlet software. When a zero-cross impulse appears, the KBI (MCU Keyboard Interrupt module) interrupt is generated on the rising edge of this signal. Generation of an interrupt on rising edge can only be performed on pins KBI4-7. The triac switching for the dimming function needs to be realized by two pulses to the gate of the triac. The dimming process is shown in Figure 3-8. After generating the interrupt, timer TPM2 (MCU Timer/PWM module) is enabled, which times the delay according to the required intensity of light. The application uses a TPM2 Overflow Interrupt. The TOF (TPM Overflow Flag) bit is set when the counter reaches the modulo value programmed in the TPM counter modulo registers. Then two impulses are generated to open the triac part in two halfperiods, also timed by the TPM2. The dimming function also provides a fluent change of light intensity.

Timer TPM1 generates a standard closed delay in 1 ms units. The application doesn't use the TPM1 Overflow Interrupt, but only monitors the TOF (TPM Overflow Flag) bit.

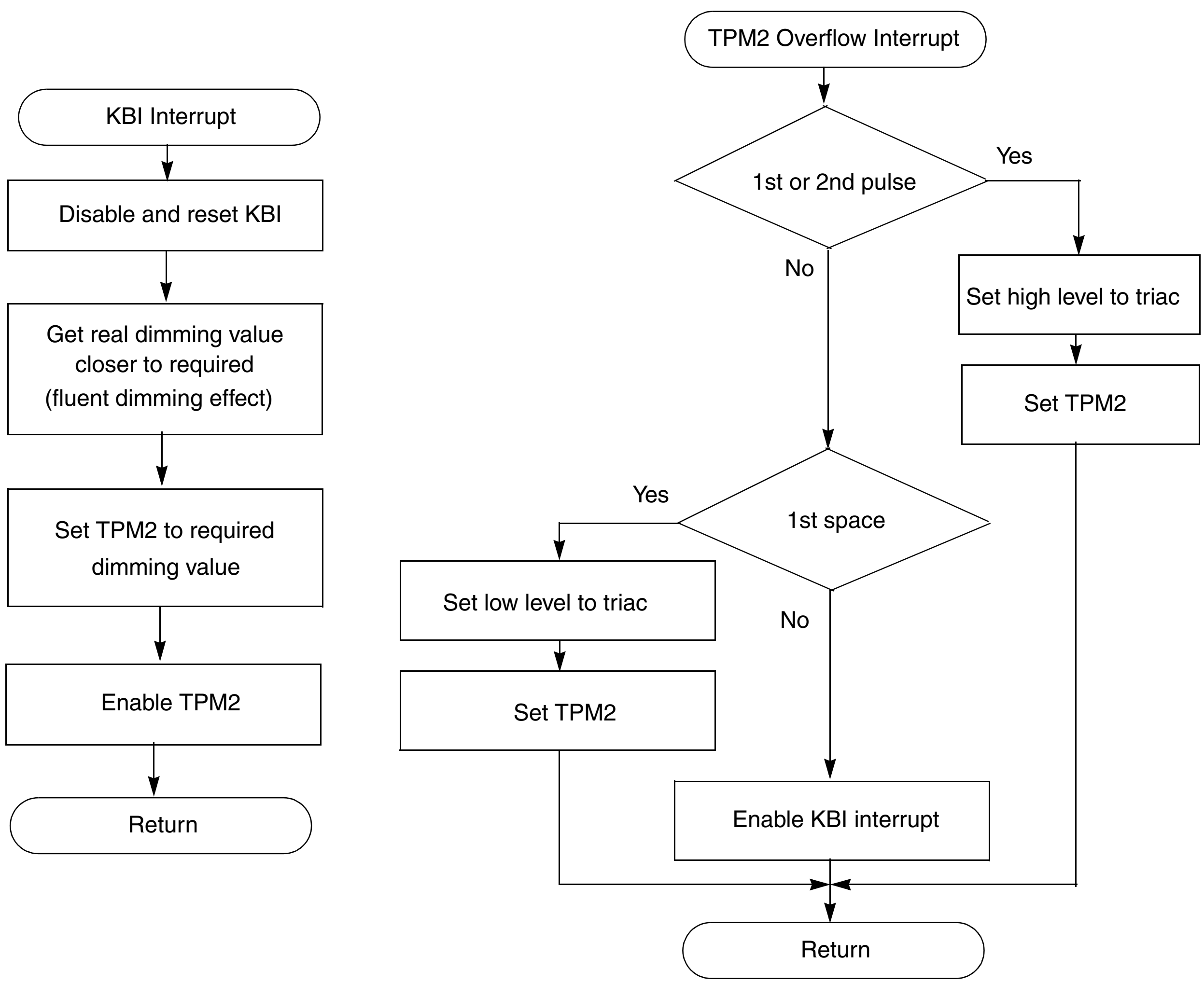


**Figure 5-9. KBI and TPM2 Overflow Interrupt Flow Charts**

## 5.8 Firmware Functional Description

**Table 5-2. Main, RFinit, MCPSDataIndication**

| Function | Main | RFinit | MCPSDataIndication |
|---|---|---|---|
| **Syntax** | Void main (void) | Void RFinit(void) | Void MCPSDataIndication (tRxPacket *) |
| **Parameters** | None | None | *rx_packet (pointer on receive packet) |
| **Return** | None | None | None |
| **Module** | Main.c | Main.c | Main.c |
| **Description** | Initializes MCU, ports and interrupts. Gets the calibration values, scans electrodes, and takes appropriate action. | Initializes the 802.15.4 modem and packet format. | Function called by the SMAC software layer when correct data is received by the 802.15.4 modem. |

**Table 5-3. Electrodes Analysis, Rotary Control Reactions**

| Function | Analyze_Electrodes | RotaryRD_Reaction | RotaryLD_Reaction |
|---|---|---|---|
| **Syntax** | Void Analyze_Electrodes(void) | void RotaryRD_Reaction(void) | void RotaryLD_Reaction (void) |
| **Parameters** | None | None | None |
| **Return** | None | None | None |
| **Module** | Main.c | Main.c | Main.c |
| **Description** | Function provides all the functions needed for E-Field control. Measures all alectrodes, finds the higher value, and the relevant reaction to a user cue. | Adequate procedures when there is clockwise rotary movement detected. | Adequate procedures when there is an anti-clockwise rotary movement detected. |

**Table 5-4. LEDs Lighting Control**

| Function | TP_LED_Rotary_Right | TP_LED_Rotary_Left | TP_LED_Control |
|---|---|---|---|
| **Syntax** | Void TP_LED_Rotary_Right (void) | Void TP_LED_Rotary_Left (void) | Void TP_LED_Control (void) |
| **Parameters** | None | None | None |
| **Return** | None | None | None |
| **Module** | Main.c | Main.c | Main.c |
| **Description** | Lighting control of LEDs situated on the rotary wheel according to clockwise rotary control. | Lighting control of LEDs situated on the rotary wheel according to anti-clockwise rotary control. | Lighting control of LEDs situated in the centre of pads according to user control. |

**Table 5-5. ADC and E-Field Initializations**

| Function | AD0_Enable | AD0_Disable | Efield_Init |
|---|---|---|---|
| Syntax | Void AD0_Enable (void) | Void AD0_Disable (void) | Void Efield_Init (void) |
| Parameters | None | None | None |
| Return | None | None | None |
| Module | Efield.c | Efield.c | Efield.c |
| Description | Routine enables ADC0 module. | Routine disables the ADC0 module. | Initialization of ports for control of the E-Field device and to get of the reference values. |

**Table 5-6. E-Field Routines**

| Function | Measure_Electrode | Get_Ref_Electrodes | Electrodes_Refresh |
|---|---|---|---|
| Syntax | Uint Measure_Electrode (void) | Void Get_Ref_Electrodes (void) | Void Electrodes_Refresh (void) |
| Parameters | None | None | None |
| Return | Unsigned Int | None | None |
| Module | Efield.c | Efield.c | Efield.c |
| Description | Measurement of the currently selected electrode | Routine refresh of the referential values of all the electrodes. | Routine refresh of the values of all the E-Field electrodes |

**Table 5-7. Delay, KBI Enable, and Disable**

| Function | DelayMS | KBI_Enable | KBI_Disable |
|---|---|---|---|
| Syntax | Void DelayMS (unsigned int) | Void KBI_Enable (void) | Void KBI_Disable (void) |
| Parameters | Unsigned int value | None | None |
| Return | None | None | None |
| Module | Efield.c | Dimming.c | Dimming.c |
| Description | Delay for the desired time. | Enables and initialises the KBI module and interrupt. | Disables the KBI module and interrupt. |

**Table 5-8. Dimming Routines and Others**

| Function | KBI_int | TPM2_int | Mains_Frequency |
|---|---|---|---|
| Syntax | Void interrupt KBI_INTNUM KBI_int (void) | Void interrupt TPM2_INTNUM TPM2_int (void) | Unsigned char Mains_Frequency (void) |
| Parameters | None | None | None |
| Return | None | None | Unsigned char |
| Module | Dimming.c | Dimming.c | Main.c |
| Description | External KBI interrupt handler body. Starts the dimming process. | TPM2 interrupt handler body. Pulse generation for triac control. | The routine returns the frequency of the AC power, which is used for detection of the line voltage type. |

# Chapter 6
# Application Setup

## 6.1 Setting Up the Demo

This E-Field Demo consists of two main parts, the Intelligent Switch (IS) + Touch Panel and Intelligent Outlet (IO). The following sections describe the installation and setup of each device. The start of the demo only requires plugging the power cord into a wall outlet with 230 VAC/50 Hz. The installation of the devices into domestic electric circuitry is described in Section 6.1.1, “Setting Up the Intelligent Switch,” Section 6.1.2, “Setting Up the Intelligent Outlet version 1,” and Section 6.1.3, “Setting Up the Intelligent Outlet version 2”.

**WARNING**

Be sure that the power cords are not connected to the 230 VAC power distribution during device installation, because this can be dangerous.

### 6.1.1 Setting Up the Intelligent Switch

It is neccessary to follow this procedure for installing the device into the demo chassis or into a domestic electro-installation:

- The first step is to connect the intelligent switchboard with the touch panel, using the touch panel connector J1 and J5. See Figure 6-1.The intelligent switch has to be equipped by a small spacer (plastic is recommended so as not to interfere with the RF capability) that keeps the distance between these two boards. This spacer is anchored in the hole on the intelligent switchboard. The connection made by the touch panel is satisfactory and mechanically sound.
- The next step is the connection of the 230 V/50 Hz power wires to the device. For this purpose, a AC power connector with a marked polarity on each input is used. The L phase of the AC power should be connected to the input with the triangle mark. See Section 6.3.1, “Intelligent Switch Device Installation”.
- The following step is the insertion of the device into the wall case. A standard cross-case (size ϕ 65 x 20 mm in Europe, type KP68) is used. The correct orientation is shown in Figure 6-2.
- Now, the touch panel can be covered with the wall switch rim and by the front panel plexiglass (1 mm thick). Altogether, it is fixed to the wall cross-case by two screws (minimal 12 mm length) that go through the plexi-glass, touch panel, and wall switch rim into the cross case front holes. The whole system is shown in Figure 6-2.

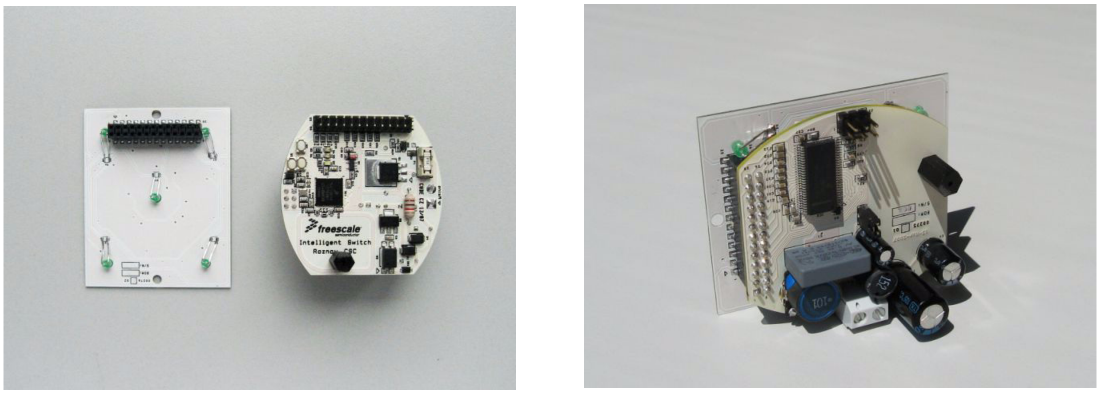

**Figure 6-1. Intelligent Switchboard connected with Touch Panel**

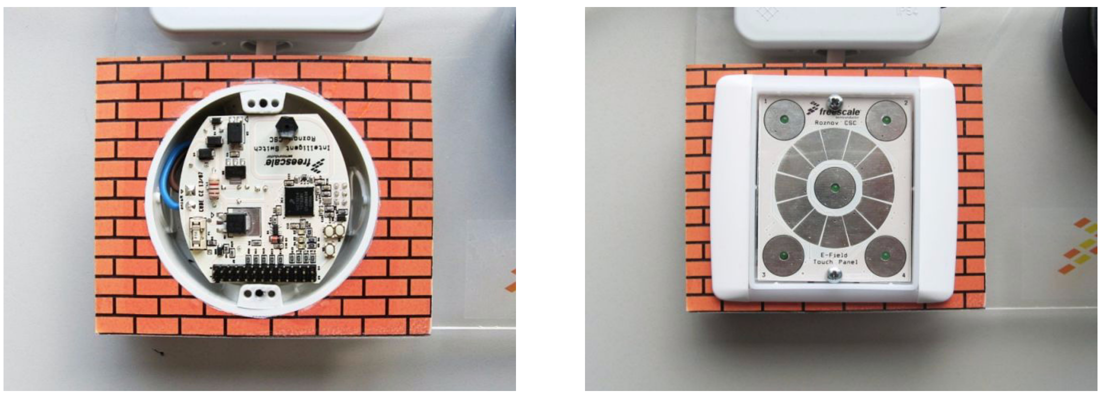

**Figure 6-2. Intelligent Switch Installation**

### 6.1.2 Setting Up the Intelligent Outlet version 1

It is neccessary to follow this procedure for device installation into a wall outlet:

- The first step is mounting the Intelligent Outlet Board version 1 on the chassis of the wall outlet (a special socket for ABB outlets with easy cable mounting equipment), with the AC power socket underneath. For this purpose, two screws are used that go through the holes situated symetrically on the PCB to the nut thread in the socket chassis. Now you can interconnect the outlet socket with the dimm connector on the PCB. See Figure 6-3 for details.
- The next step is the connection of the 230 V/50 Hz power wires to the device. For this purpose, the AC power connector with the marked polarity of each input is used. The L phase of the AC power should be connected to the input with the triangle mark. See Section 6.3.2, “Intelligent Outlet Device Installation”.
- The last step is the insertion of the device into the wall outlet case. A standard wall outlet cross-case (size ϕ 65 x 40 mm in Europe, type KU68) is used. Finally, you can close the outlet with the outside facing. The outlet is shown in Figure 6-4.

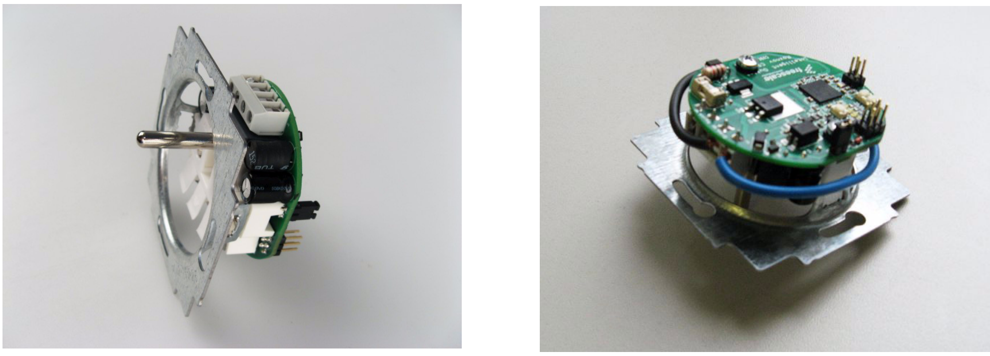

**Figure 6-3. Intelligent Outlet Board Connected with Outlet Socket Chassis**

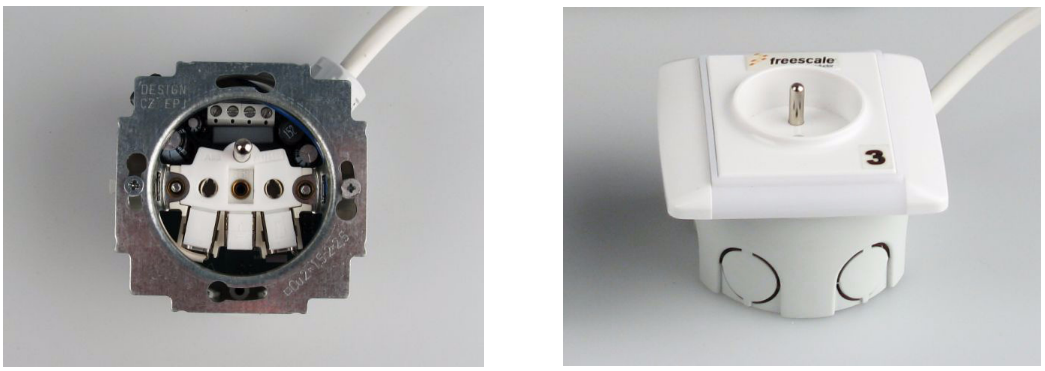


**Figure 6-4. Intelligent Outlet Installation**

### 6.1.3 Setting Up the Intelligent Outlet version 2

It is neccessary to follow this procedure for device installation into a wall outlet:

- The first step is mounting the Intelligent Outlet Board version 2 into the case equipped with two sockets (one male and one female). The board contains two holes situated in the corners of the PCB. You can use two small plastic pillars for fixing the board. See Figure 6-5 for details.
- The last item is the connection of the 230 V/50 Hz power wires and dim wires to the device. For this purpose, a AC power connector and a dimm connector with the marked polarity of each input are used. The L phase of the AC power should be connected to the input with the triangle mark. See chapter Section 6.3.2, “Intelligent Outlet Device Installation,” for more details.

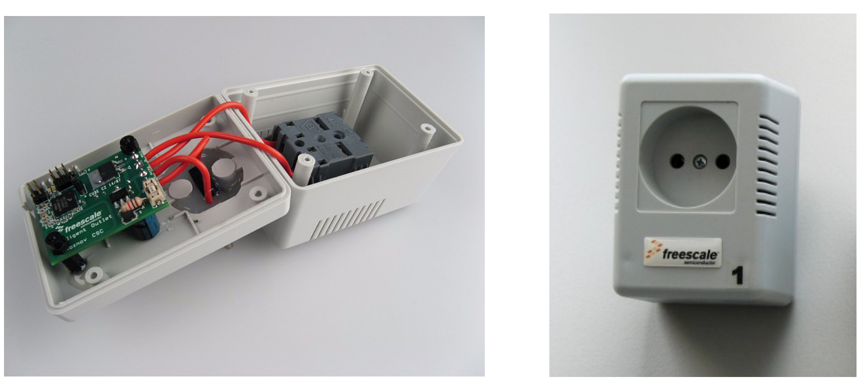


**Figure 6-5. Intelligent Outlet**

## 6.2 Setup of the Intelligent Outlet Identificator

The modifications of the intelligent outlet boards need to have a set identification number (ID). This is neccessary for identifying the device in the RF wireless network. The description of these setting headers for both boards is in Section 4.7.6, “Intelligent Outlet Identification”. The location of these headers is shown in Figure 6-6. Changing this ID during the device function doesn’t have an affect because the value is only read during the startup process. The first significant bit is marked with a 1. See Table 6-1 for pin assignments.

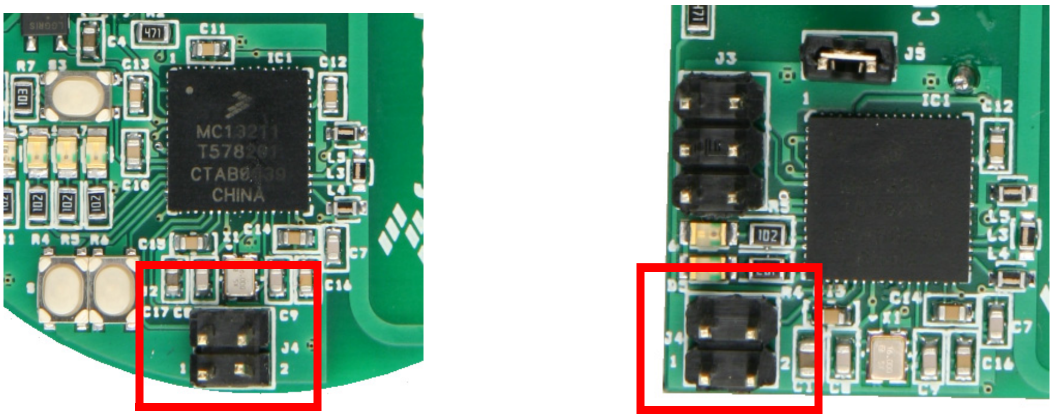

**Figure 6-6. Identificaton Header Location**

**Table 6-1. ID Selector Description**

| ID | 1st column (left) | 2nd column (right) |
|---|---|---|
| 1 | — | — |
| 2 | Closed | — |
| 3 | — | Closed |
| 4 | Closed | Closed |

## 6.3 Demo System Setup and Startup

The following steps must be completed before the Demo is started:

- Set the desired ID for the intelligent outlets (Section 6.2, “Setup of the Intelligent Outlet Identificator”).
- Make sure that power supply jumper is closed (chapter Section 3.10.5, “Power Supply Jumper” and Section 4.7.5, “Power Supply Jumper”).
- Check that the fuses are functional. See Figure 3-2, Figure 4-1, and Figure 4-2 for fuse holders locations. See chapters Section 3.10.6, “Fuse,” and Section 4.7.7, “Fuse,” for more details.
- Make sure the boards are implemented into the cases (chapters Section 6.1.1, “Setting Up the Intelligent Switch,” Section 6.1.2, “Setting Up the Intelligent Outlet version 1,” and Section 6.1.3, “Setting Up the Intelligent Outlet version 2”).

- Be sure that all the light bulbs are functional (the best is some independent device), and that there are good contacts in the sockets for the bulbs.
- Plug the desk lamps into the intelligent outlets.
- Turn on all individual parts of the demo by simply plugging the power cords into the wall outlets (Intelligent Outlet Version 2 plug by using the package socket). The calibration of the E-Field sensor is performed automatically in 2 s after switch on.
- Control the devices under the rules written in chapter Section 6.5, “Demo Guide”.

**NOTE**

Do not touch the electrodes during the 2 s calibration time because it can influence the functionality of the device.

### 6.3.1 Intelligent Switch Device Installation

The device performs the dimming function on one phase, which means that the load (light bulb) is connected in series with the board. As you can see in Figure 6-7, the light bulb is connected to connector J1, which is also the input for the powering voltage of the power supply. It means that the one wire with a light bulb is needed to implement the device. By cutting the wire, you can connect the dimmer to this loop. The connector J1 is a power line socket designed for big currents up to 10 A. On the PCB, the triangle mark recommend the connection of the L phase with the light bulb, but theoretically, it doesn’t matter which phase is connected to the input connector J1. This is a result of the device being constructed as a serial variable resistor with load.

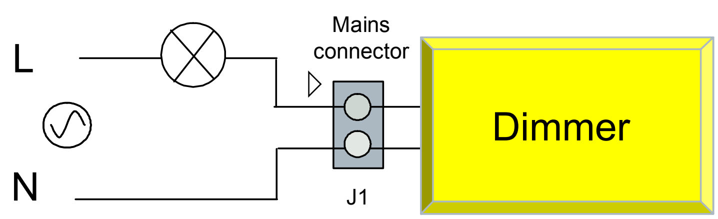


**Figure 6-7. Intelligent Switchboard Installation**

**NOTE**

If the device doesn’t work, often the reason for the malfunction is a broken light bulb because it brings the powering current for the device to a halt.

### 6.3.2 Intelligent Outlet Device Installation

The device doesn’t perform the dimming function on one phase, which means that the loading (light bulb) is connected in series with the triac and not with the whole board. As you can see in Figure 6-8, a light bulb is connected to the connector J2 (Dimmed voltage). The connector for powering the voltage for the power supply is J1 (AC power connector). It means that this construction is dedicated to implementation in a wall outlet or in cases where another socket is implemented for plugging the dimmed device. The connectors are power line sockets designed for large currents up to 10 A. On the PCB, the triangle marks recommend the connection of the L phase with the light bulb, but theoretically, it doesn’t matter which phase is connected to the input connector J1.

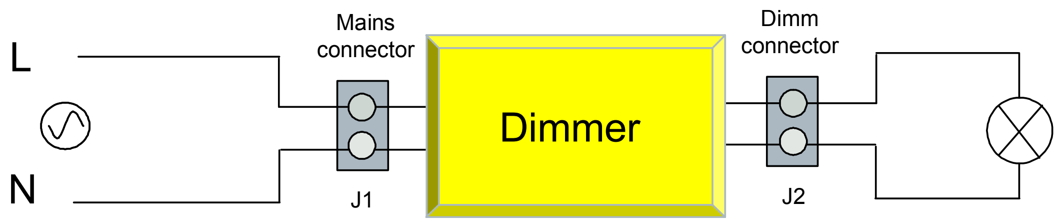


**Figure 6-8. Intelligent Outlet Board Installation**

## 6.4 Software Modification

The BDM header serves in reprogramming the function. The location and pin assignment on each board is described in Section 3.10.2, "BDM," and Section 4.7.2, "BDM".

**WARNING**

> Do not connect the BDM Multilink programmer to the BDM header when the device is powered from the AC power and it is functional (a different GND level can destroy the demo device or programmer).

If you don't have an opto-isolated programmer, you must to use an external power supply with an output voltage of 9 – 12 V and connect this source to the power supply jumper (Section 3.10.5, "Power Supply Jumper" or Section 4.7.5, "Power Supply Jumper") and the GND output to some GND point on the board. See Figure 6-9 for the correct power supply connection to each board.

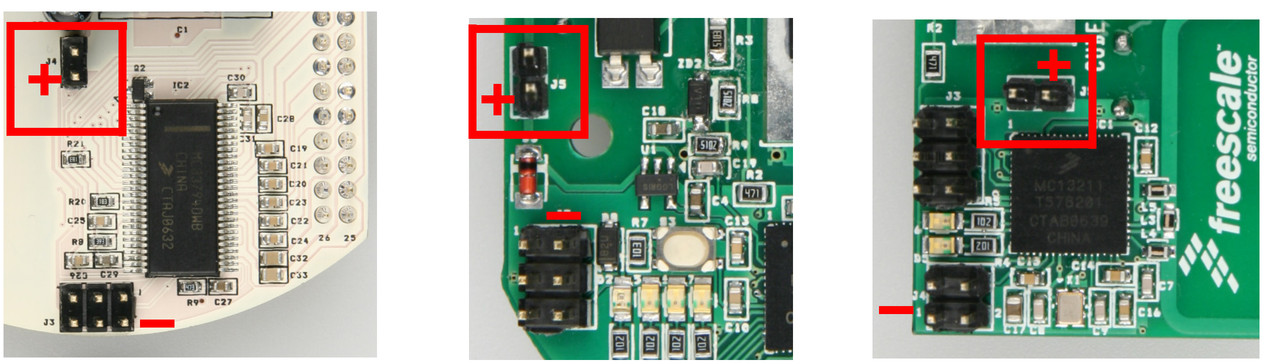

**Figure 6-9. Correct Power Supply Connection to IS, IO1 and IO2 Board**

## 6.5 Demo Guide

The demo works in three main modes: controlled device determination, light intensity adjustment and turn on/off function. If the demo system setup and startup is finished, you can continue with the control process described in the following chapters.

### 6.5.1 Controlled Device Determination

The touch panel board contains the pads for determining the currently controlled device. These selector pads for the intelligent outlets are usually situated in the corners of the board, and they are marked by the numbers of the destination outlets. There are indicator LEDs that show the currently controlled dimmer. These are situated in the center of the on/off pad and in the selector pads themselves. Only one LED can be lit at a time. When the LED in the center of the on/off pad is lit, the intelligent switch is in control and ready. The desired IO is selected by touching the corresponding pad on the IS, where the LED in the centre lights up. To return to intelligent switch control, wait five seconds or touch the pad again when it is lit. Then, the LED in the on/off pad is turned on again.

### 6.5.2 Light Intensity Adjustment

By moving the finger clockwise around the rotary row of electrodes. you increase the light intensity of the light bulb in the destined controlled device. See Figure 3-4. This increase is limited by the maximum possible light abillity of the light bulb. An anti-clockwise movement causes a decrease in the light intensity of the controlled device. The lowest limit is a zero light intensity of the light bulb.

### 6.5.3 Turn On/Off Function

Touching the on/off pad turns the selected light bulb on or off. This pad is usually situated in the center of the touch panel board.

**WARNING**

Do not cover the device by a metal or liquid material because it can cause a malfunction in the RF transceiver and E-Field function. It can also damage the device beyond repair.

**WARNING**

The demo doesn’t use protection by earthing. Only double isolation is implemented. Because of this, don’t plug devices into the intelligent outlet dimm socket that require an earthing protection. Use only those devices with a double isolation limited up to 200 W input power.

### 6.5.4 Consideration about Normatives

The device is developed in compliance of these normatives:

- CSN EN 60730-1 ed. 2:2001 — Automatic electrical control devices for home and similar purposes. Part 1: General requirements. Changes: A1:2005, A11:2002, A12:2004, A13:2005
- CSN EN 60730-2-11 :1996 — Automatic electrical control devices for home and similar purposes. Part 2: Special requirements for power regulators. Changes: A1:1998, A2:1999

# Appendix A
# Glossary

**AC** — alternating current

**ADC** — analogue-to-digital converter

**BDM** — background debug mode is a hardware device used to debug the software of an embedded system.

**DC** — direct current

**EMI** — electromagnetic interference is a disturbance caused in a radio receiver or other electrical circuit by electromagnetic radiation emitted from an external source.

**I/O** — input/output interfaces between a computer system and the external world. A CPU reads an input to sense the level of an external signal and writes to an output to change the level of an external signal

**IGBT** — isolated gate bipolar transisitor is a three-terminal power semiconductor device

**Interrupt** — a temporary break in the sequential execution of a program to respond to signals from peripheral devices by executing a subroutine

**IO** — intelligent outlet device

**IS** — intelligent switch device

**MCU** — a microcontroller is a simple computer situated on the one chip

**MOSFET** — metal-oxide-semiconductor field-effect transisitor

**PCB** — printed circuit boards mechanically support and electrically connect electronic components using conductive pathways from copper sheets laminated onto a non-conductive substrate.

**PWM** — pulse width modulation

**Reset** — to force a device into a known condition

**RF** — radio frequency is a frequency or rate of oscilation within the range of about 30 kHz and 30 GHz

**SMAC** — (simple media access controller) a simple ANSI C based code stack that can develop proprietary RF transceiver applications using the MC1321x 802.15.4 Modem.

**SMD** — are devices mounted directly onto the surface of a PCB

**SMPS** — switched mode power supply

**Triac** — semiconductor part controlled to realize the switching function of AC voltage

**ZigBee** — is the specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard