

Low-Cost Passive IR Sensing with RS08KA

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1 Introduction

This document describes how to implement a passive infrared (PIR) motion detector using Freescale's low-cost RS08KA microcontroller family. The base function of this design is to switch on appliances, especially lighting, in response to movement. The main idea behind this solution is to replace the common analog motion detector with an ultra low-cost digital design, based on the MC9RS08KA1. The most important part of this document consists of the detection algorithm and the method for measuring the analog signal from the PIR sensor.

This document focuses on a software sigma-delta analog-to-digital conversion method, and shows in detail all parts of the hardware and software implementation of a passive infrared (PIR) detector.

The main feature of this document is a demonstration of the capabilities of the low-cost RS08KA series of MCUs. It also shows fully functional and practical implementation and use of ultra-low-cost microcontrollers, but does not include some necessary peripherals for measuring and creating complex solutions using PIR sensing.

All schematics, board layout, and complete software pack are available on freescale.com.

Features include:

- Design of low-cost PIR motion detector based on HC9RS08KA MCU

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Introduction

- Implementation of software sigma-delta converter based on analog comparator
- Implementation of measurement of input user values
- Filtration method for signals from the PIR sensor
- Power switching by using two additional components: relay and triac
- Possibility of light dimming for the triac

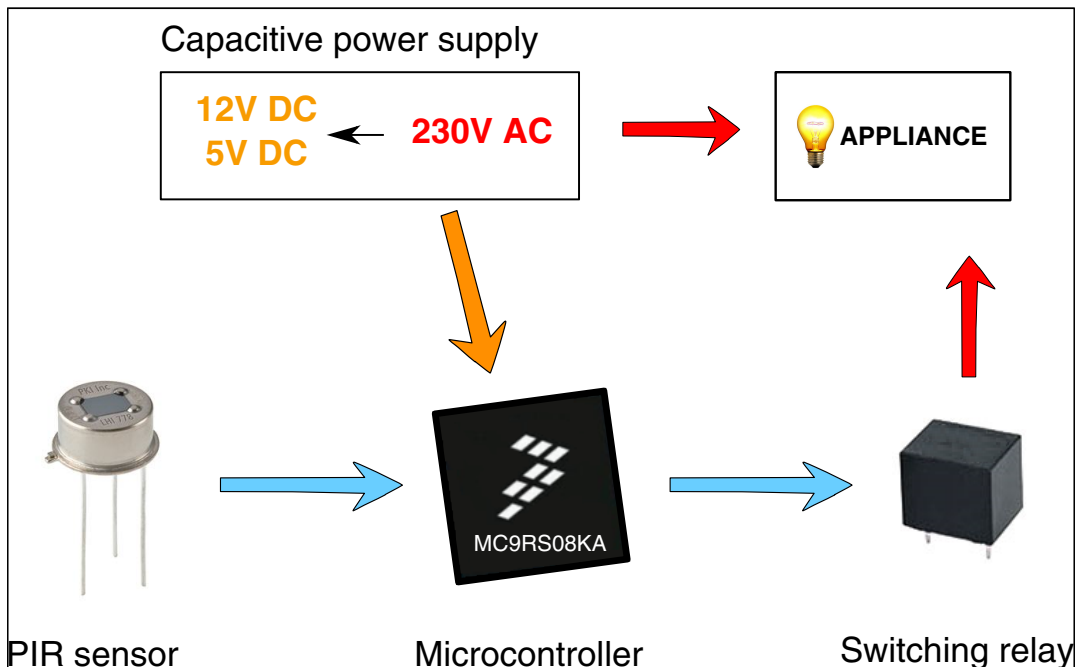


Figure 1. Block schematic for all applications using relay output

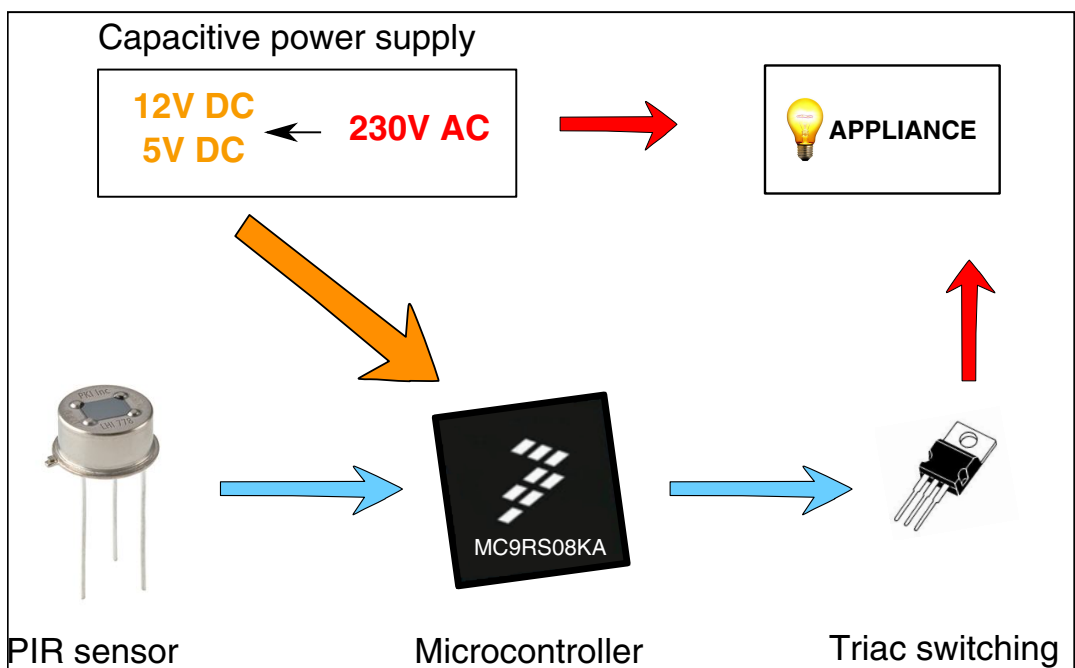


Figure 2. Block schematic for all applications using triac output

2 Sigma-delta conversion

The key point of this reference design is to demonstrate how to use the low-cost RS08KA microcontroller family in a PIR sensor application. The RS08KA MCU family does not include an internal A/D converter; therefore, measuring the signal from the PIR sensor is managed via a modified conversion based on an analog comparator and other passive components. This measuring method is detailed in the following part of this document. The basic principle is shown in [Figure 3](#).

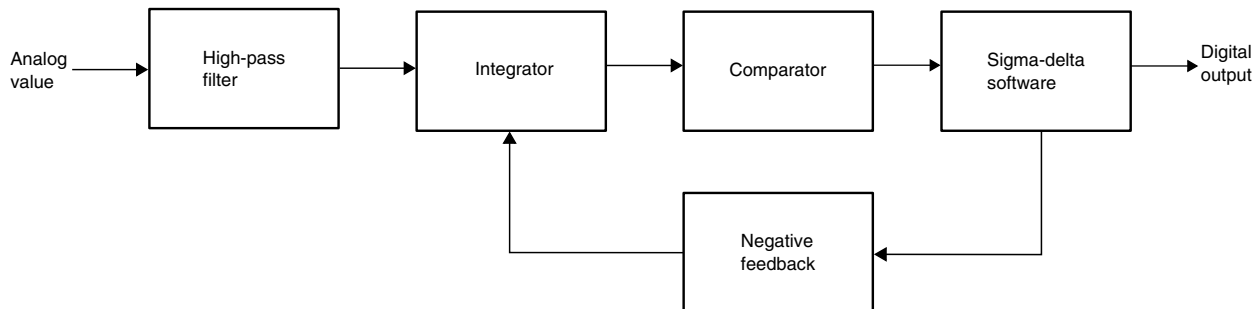


Figure 3. Block diagram of basic sigma-delta conversion

2.1 Sigma-delta conversion method

One of the most important aspects of the sigma-delta technique is the ability to use it for converting an analog signal to a digital signal. Some high-end MCUs implement a hardware sigma-delta ADC peripheral. The RS08KA family of MCUs does not include an AD converter; therefore the converter is implemented via software and external components. The application discussed in this document uses an internal analog comparator with bandgap reference. This method of signal conversion uses a minimum of additional components. The most important feature of this conversion method is the ability to realize an application like this on low-cost microcontrollers without an analog-to-digital (A/D) conversion peripheral.

The principle used in the detection method is based on a modified sigma-delta A/D converter. The accuracy of the conversion is dependent on a couple of factors:

- Input leakage current of the analog sense pin
- Fast charge and discharge of pin in its quiescent state

Leakage current in the integration capacitor will also cause errors in accuracy due to asymmetric charge/discharge conditions. In this application, however, it is the difference in consecutive A/D values which will cause an event trigger. As a consequence, small changes in absolute accuracy will not affect the overall result, making such a method a good choice for this application. This conversion method is linear throughout the range of conversion. This method has a lower conversion speed but one that is still fully sufficient for a PIR application.

2.2 Implementation of sigma-delta conversion in PIR application

sigma-delta conversion

The input signal from the PIR sensor is capacitively coupled to the integration capacitor C_i (15 nF) by capacitor C_f (150 μ F). The higher value of DC filtration capacitor C_f allows using lower values for the input and output resistors. This helps with higher noise resistance. Amplification is set depending on the PIR output voltage range. The PIR sensors have a very low voltage output (for example, about tens of microvolts); therefore amplification must be as high as possible. In this application an amplification of about 1400 is used.

The most important element of the measuring process is that the charging and discharging of the integration capacitor are independent of output feedback from the analog comparator. The input voltage is compared on the analog comparator with the internal bandgap reference (1.2 V), and the result from the comparator is used as negative feedback to the negative input of this comparator. The output voltage from the analog comparator is sampled by two software counters in the MCU. One is used as a loop counter and the second counts the number of output results in logic 1.

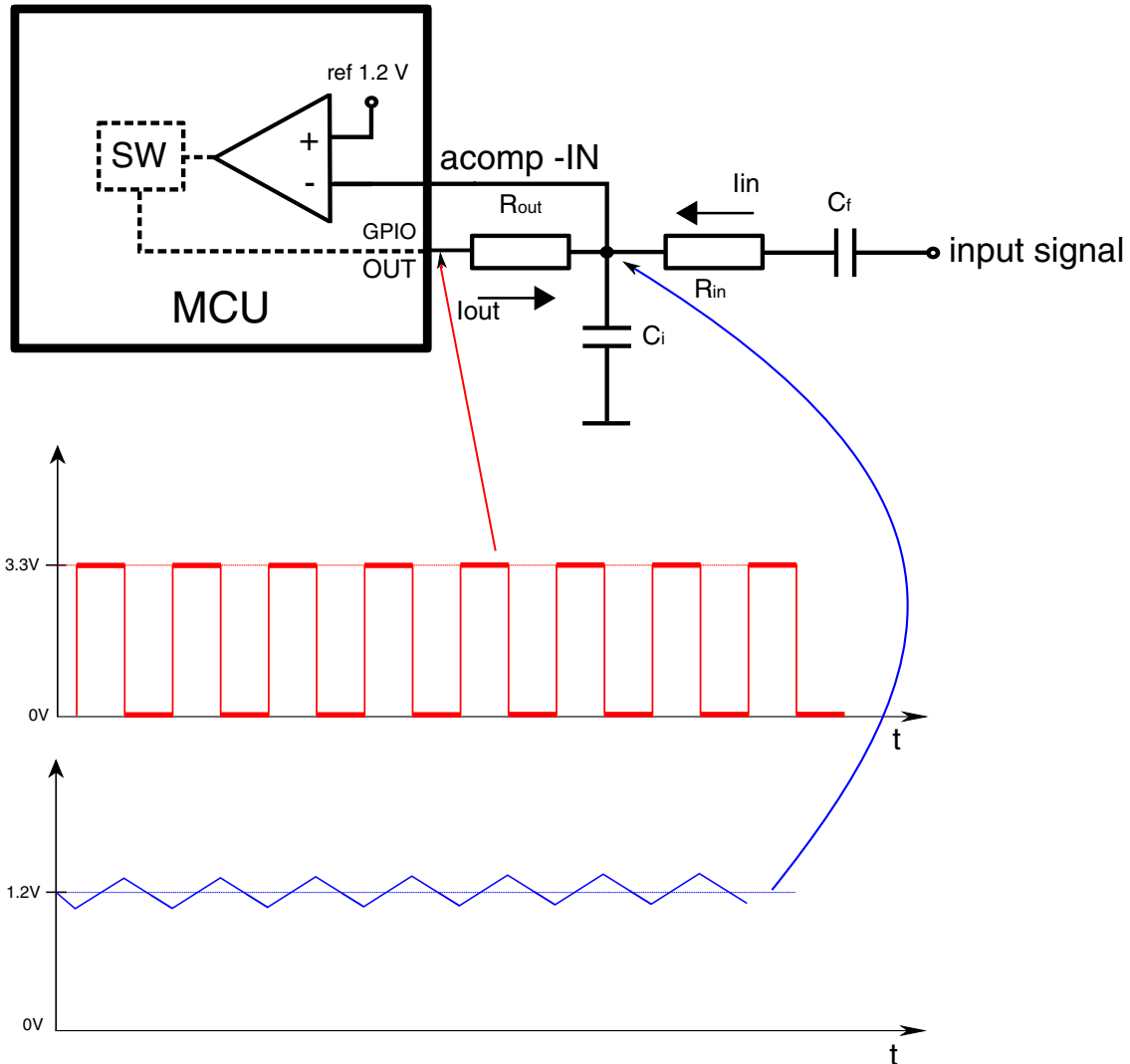


Figure 4. Basic block scheme of sigma-delta conversion method

If the value of the negative input to the comparator is lower than the bandgap value, the counter is decremented and the output value is set to a logic 1 (capacitor C_i is charged). In the second case, if the value is greater than the bandgap value, then the counter is incremented and the output value is set to logical 0 (capacitor C_i is discharged). By charging and discharging capacitor C_i , the voltage level is maintained at the bandgap level. User software running on the MCU processes the results from the comparator and returns a value representing the measured voltage.

The PIR application uses 15-bit resolution in this sigma-delta conversion method. This means that one voltage sample consists of 32768 logical states. A detailed schematic is shown in Figure 5.

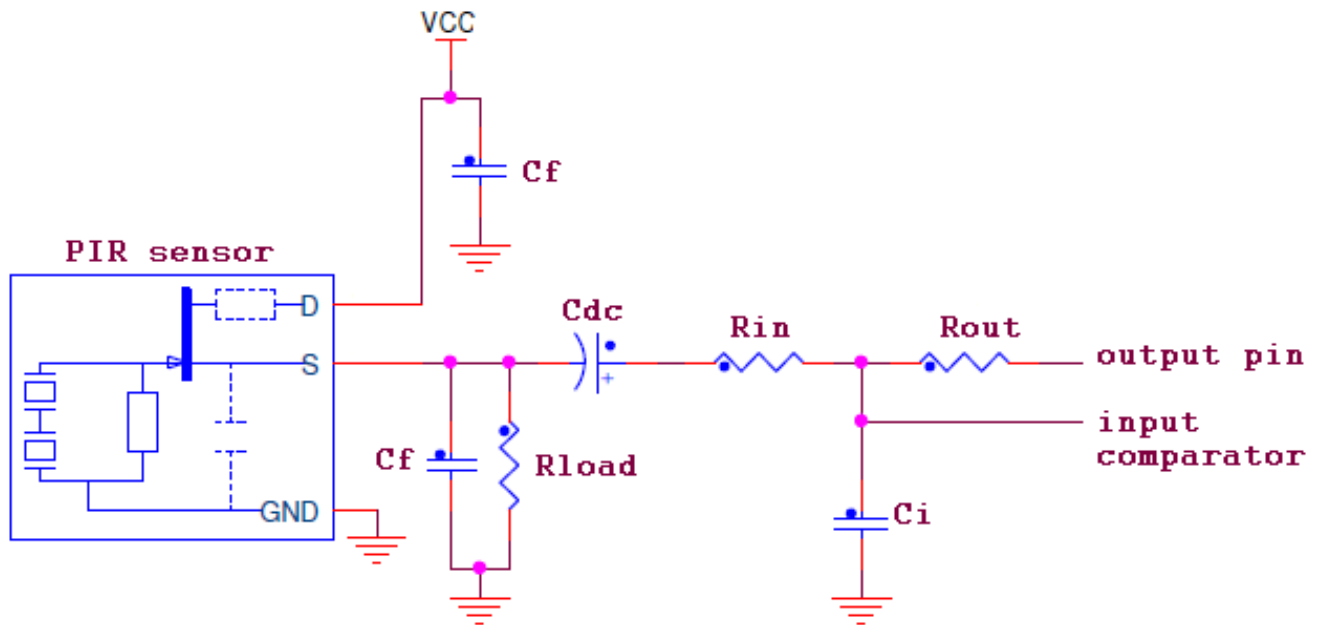


Figure 5. Complete schematic of sigma-delta converter

3 Hardware implementation

The hardware implementation includes two versions of a PIR application with different power switching outputs and power supplies:

- Relay power output version
- Triac power output version

Each of these hardware implementations consists of three individual parts:

- Sigma-delta measurement
- User input
- Power switching (with power supply)

All of these are described in detail in the following subsections. The final version of the board for both solutions is shown at the end.

3.1 Power supply and switching

Capacitive power supply with relay switching

Hardware implementation

For this PIR application, a capacitive transformerless power supply was chosen. The complete schematic is shown in [Figure 6](#). This capacitive power supply uses a bridge rectifier with two Zener diodes. The Zener diodes in the bridge work as rectifier diodes and also stabilize the output voltage to 24 V. The application uses two voltages. First, 24 V is used for driving the relay output. The second voltage is a stabilized 5 V for the MCU supply. Positive voltage regulator 78L05 is used to reduce voltage ripple. Maximal output current is about 45 mA .

[Figure 6](#) also includes the switching part of the application. The first method of power switching uses a component relay. The relay is driven by the MCU via a bipolar transistor with protection diode D5. The switching section is designed for 24 V relay output.

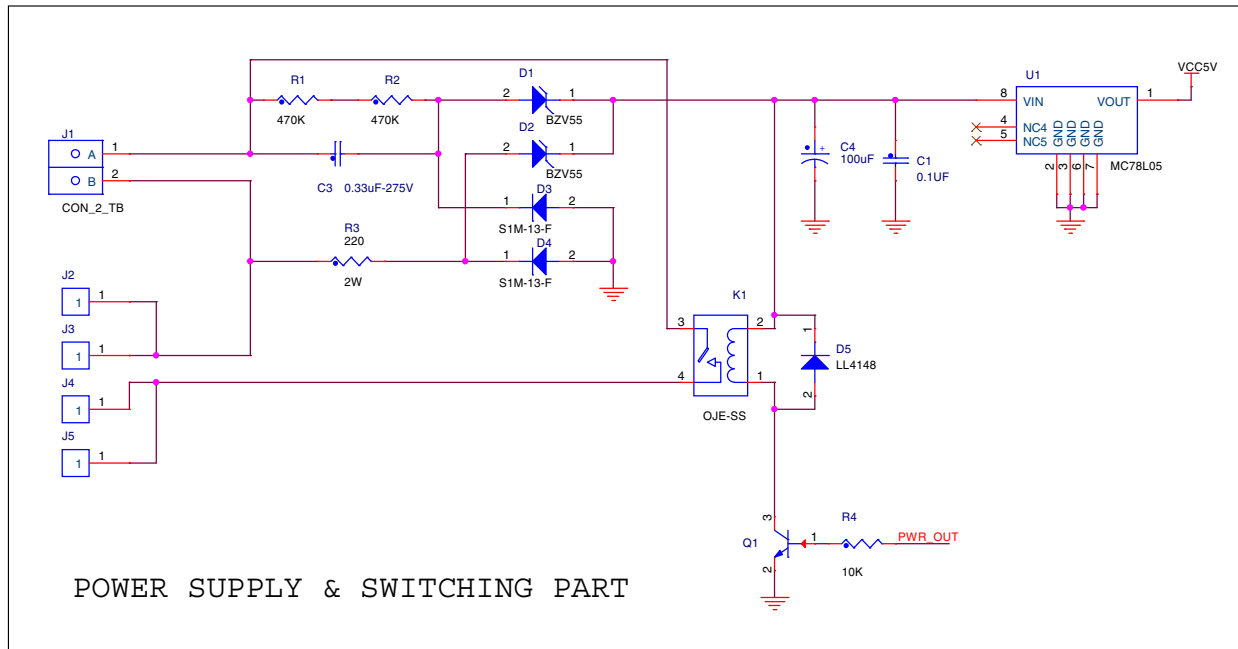


Figure 6. Capacitive power supply and relay switching schematic

Capacitive power supply without rectifier bridge and with triac switching

This variant of the power supply has lower power loading and is therefore targeted only for the triac version. This capacitive power supply uses one Zener diode for rectification and a second diode for creating virtual ground. Linear negative voltage regulator 79L05 is used to stabilize the output voltage, due to the polarity of the triac switching. For this reason the logic of the design must be reversed from 5 V to -5 V, compared to the relay design. All connections are shown in [Figure 7](#).

The schematic also includes power switching with a triac. The triac is connected to -5 V power supply and is driven by the MCU via resistor R15 (680 Ω).

The main disadvantage of this low-cost power supply is in using the negative voltage regulator, because the price of the negative regulator compared to positive is much higher.

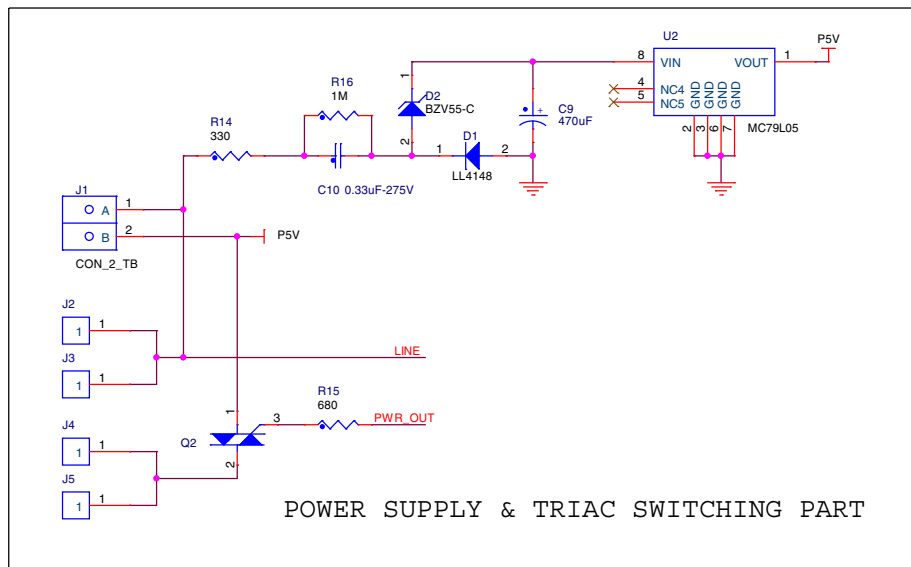


Figure 7. Schematic of capacitive power supply without rectifier bridge and with triac switching

3.2 User input measurement

Input measurement is a time delay measurement taken from a capacitor and a trimmer, with an optional sensor for both input values.

Setting and measuring brightness is implemented using a trimmer and an ambient light resistor with parallel connected resistor. The parallel connected resistor has the same value as the trimmer and therefore serves as the resistivity limiter of the ambient light resistor. Because of the low number of MCU pins, the value of the two variables must be combined into one.

Because BKGD is used for code programming and GPIO, in the application jumper SH1 shown in the schematic serves as a separator before programming.

Measurement of the time delay depends only on the value of the trimmer R7, which is set by the user. The complete schematic for measuring input values is shown in [Figure 8](#). This section of the application is identical for both versions of the implementation.

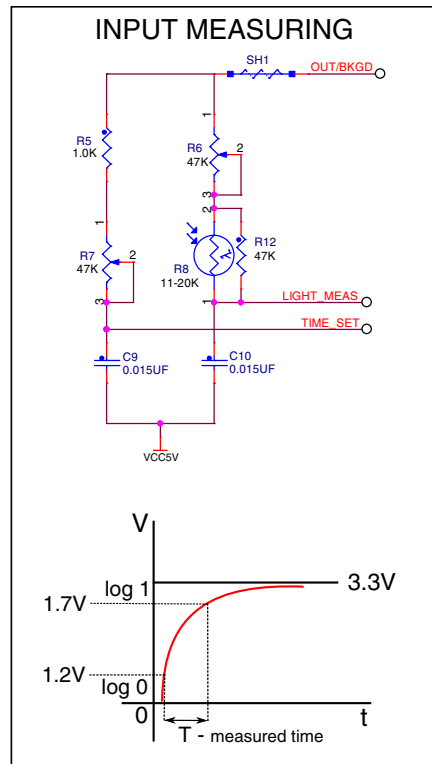


Figure 8. Schematic of ambient light and time delay measuring

3.3 Sigma-delta measurement

The PIR application uses one dual-element PIR sensor for motion detection. The complete schematic of the measurement section is shown in [Figure 9](#). An LHI778 module from PerkinElmer was used for the PIR sensor.

Two 100 nF capacitors are connected to the PIR sensor for noise filtration, and a load resistor (R11) is used to ensure the correct operation of the motion sensor. C6 and R9 function as a hi-pass filter to remove the DC signal. For the purposes of motion detection, it is sufficient to sense a signal of 2 Hz. The integration capacitor is charged and discharged via resistor R10 on output pin BKGD. The BKGD pin is also used for user input measuring of time delay and brightness via RC circuits. This measurement section is identical for the relay version and the triac version of PIR implementation.

Measuring the low voltage signal from the PIR sensor is managed by one MCU peripheral analog comparator. Because of the MCU's low pin count, only the negative input of the comparator is used, and input voltage from the PIR sensor is compared with the internal bandgap reference. The sigma-delta conversion is described in detail in the "Sigma-delta conversion" section of this application note.

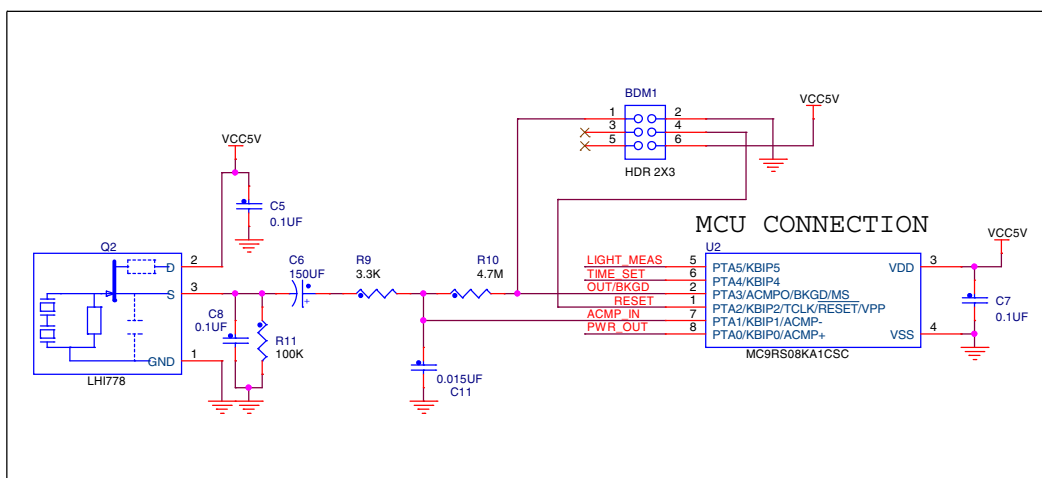


Figure 9. Schematic of sigma-delta measurement circuit

3.4 Zero-cross detection and light dimming

One of the advanced features of the triac design is the ability to use it for light dimming. This feature is included only in the version with triac power output. Light dimming means continuous regulation of light brightness when is the light turned on and also turned off. For light dimming it is important to have a circuit for measuring zero cross. This simple zero cross detector is created by two diodes and two resistors with one capacitor, as shown in Figure 10. Resistors R8 and R9 must have a package with voltage tolerance at 230 V (minimal recommended package is 1206). Light dimming has a positive impact on bulb life span.

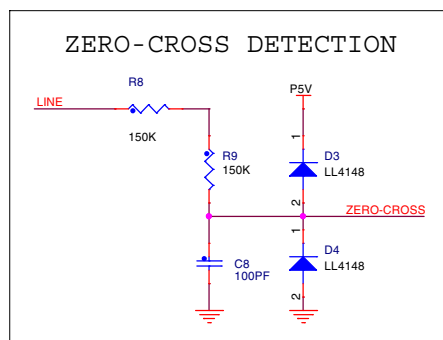
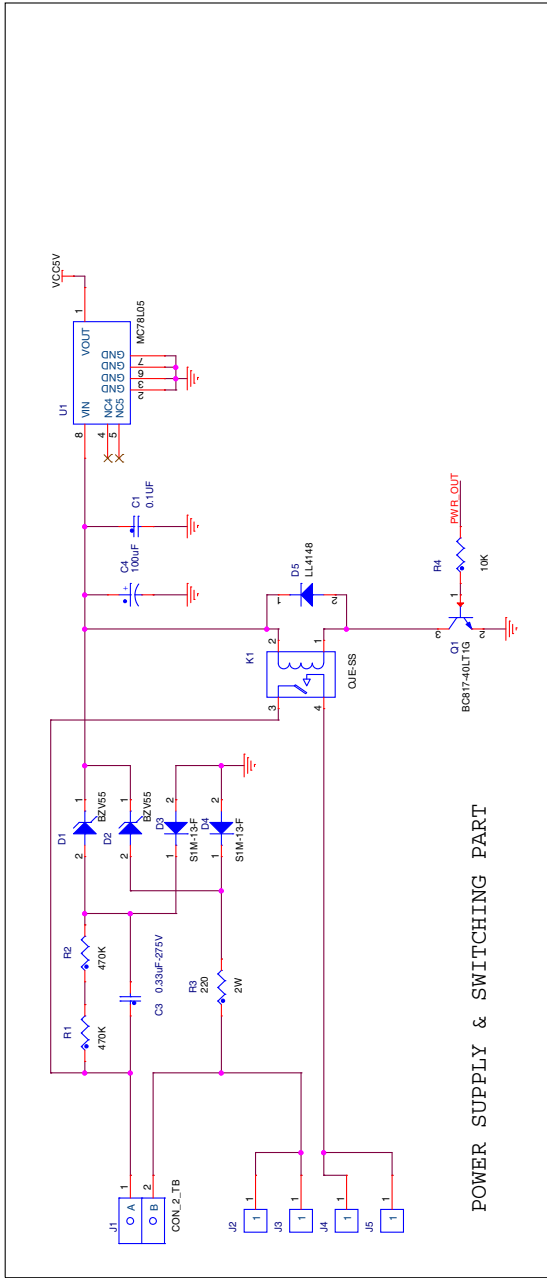


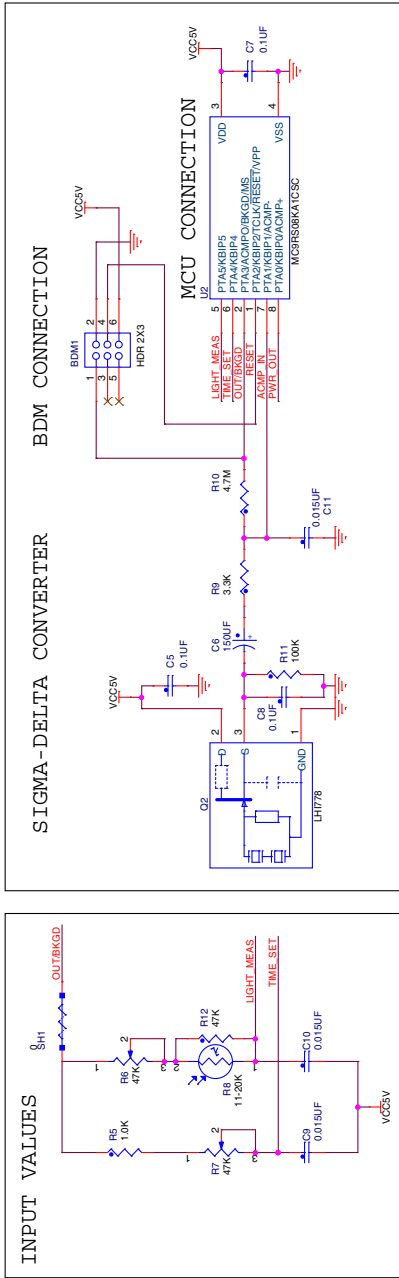
Figure 10. Zero-cross detection circuit

3.5 Complete schematic

The complete schematic of each application is shown here: with relay power output (Figure 11) and triac power output (Figure 12).

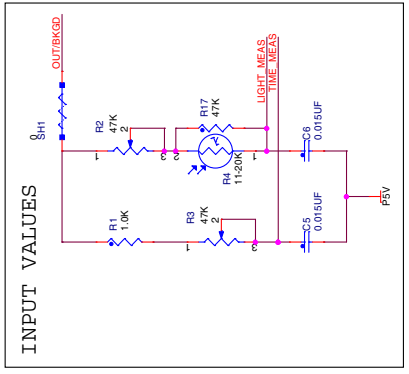
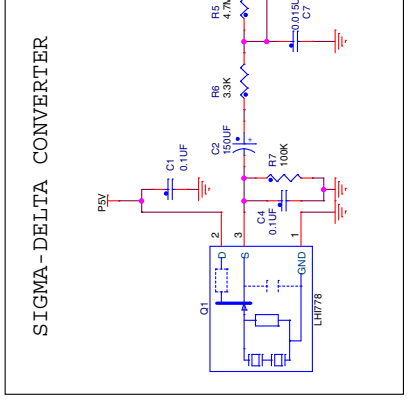
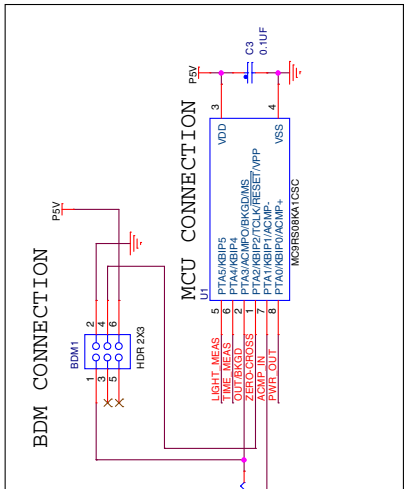
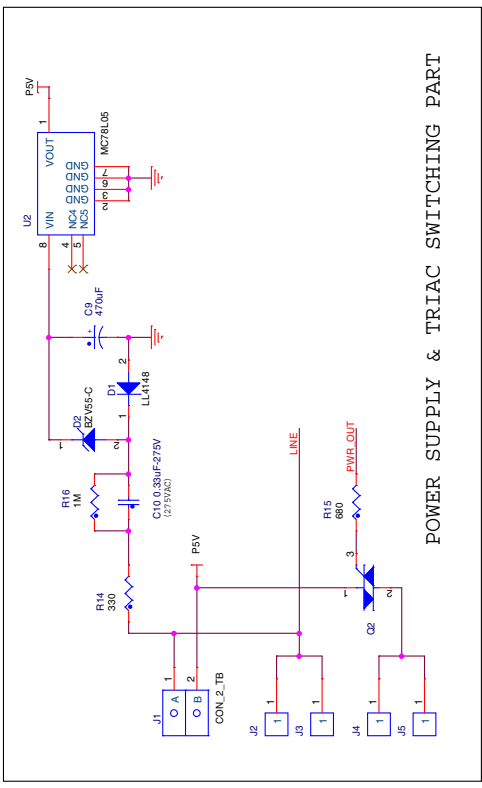
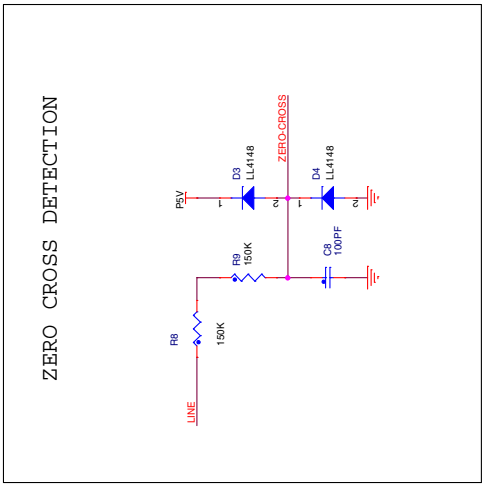


POWER SUPPLY & SWITCHING PART



INPUT VALUES
SIGMA-DELTA CONVERTER
BDM CONNECTION
MCU CONNECTION

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4 Software implementation

This section describes all algorithms and programming techniques used in the PIR motion solution. The main part of the software is focused on measuring voltage from the PIR sensor, but also included are input measurement with filtration and the complete structure of application.

The software is not platform-dependent. It can be used also on higher-end MCU platforms.

The behavior of the main application is shown in [Figure 13](#).

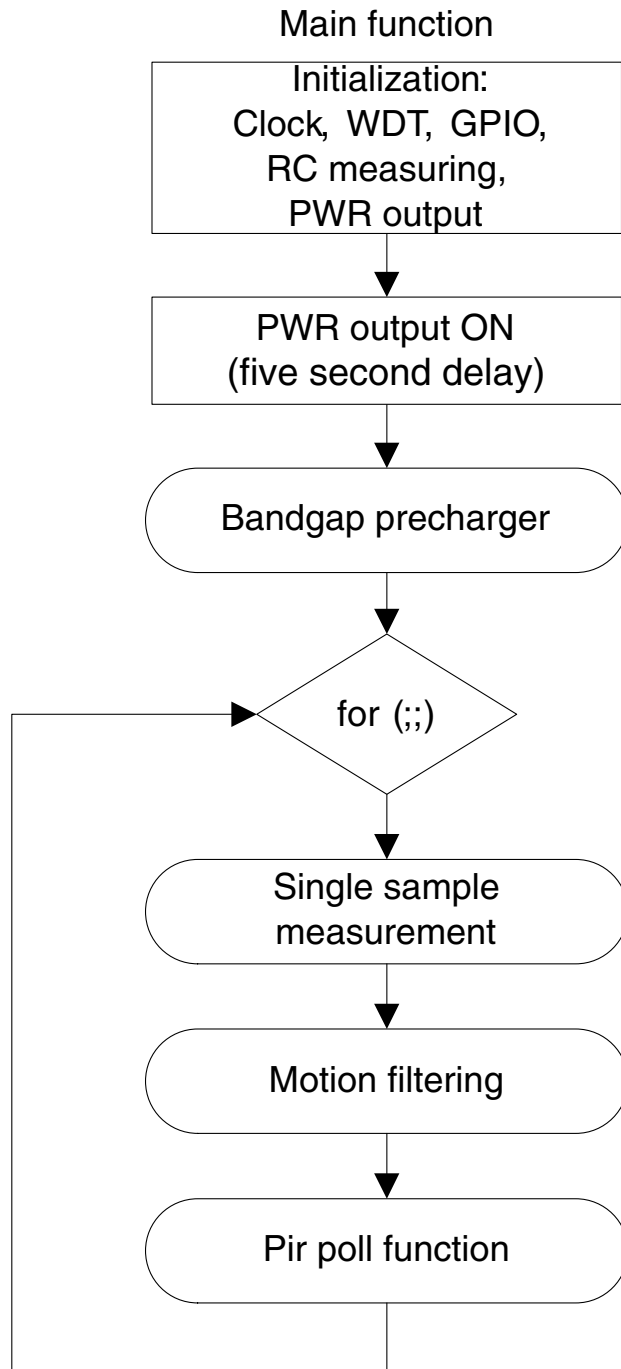


Figure 13. Motion detection software flowchart

4.1 Precharging and discharging bandgap voltage

After all peripherals are initialized, the relay is turned on for five seconds. Then the function to precharge the input filtration capacitor is called via the GPIO pin. Precharging of this capacitor allows speedup of sigma-delta converter initialization. The bandgap precharging procedure is shown in [Figure 14](#).

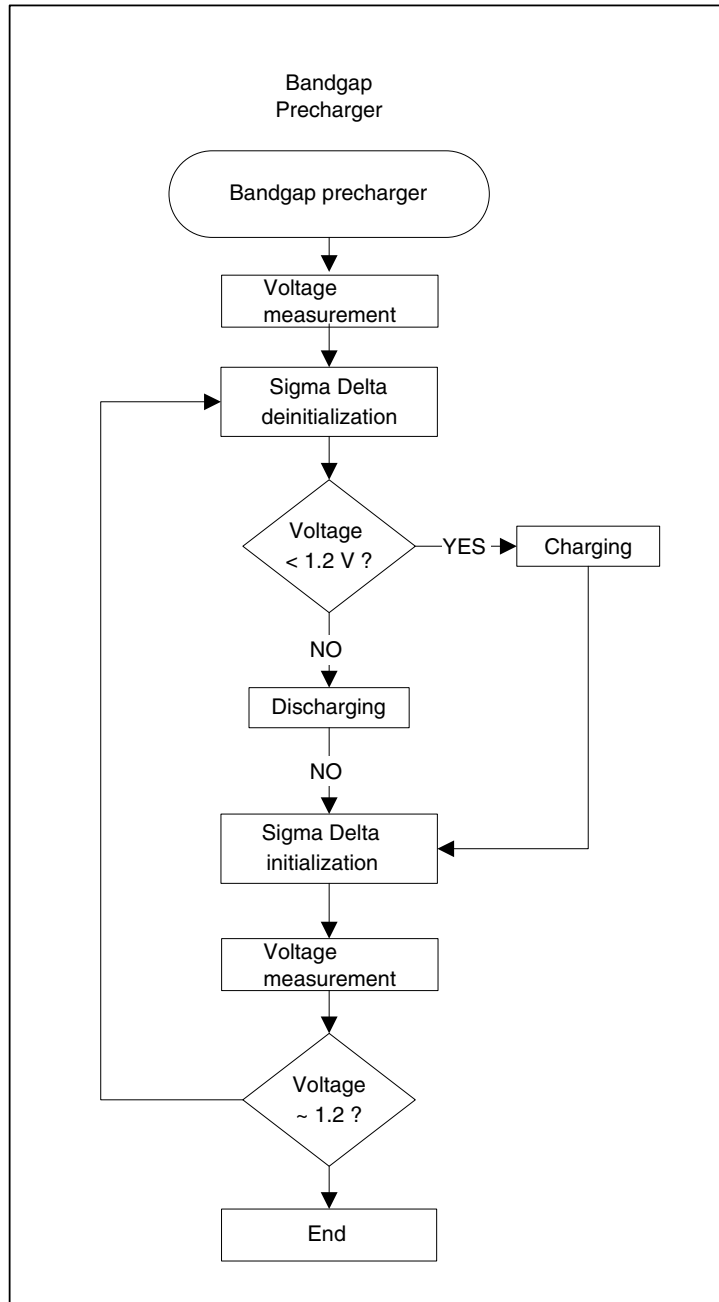


Figure 14. Bandgap precharging flowchart

The next code block shows the function for precharging of integration capacitor to bandgap value. This function serves for faster charging and discharging of input DC capacitor via the GPIO pin.

```

/*****//*!
* @brief function is used for pre-charging or pre-discharging of input
*         DC-filtration capacitor
*
*****/
void SWSD_BandgapPreCharger(void)
{
    Byte cnt;
    cnt = 0;
    // capacitor is charged ~5 V
    if(SWSD_OneSampleMeasuring() == 0)
    {
        do
        {
            // discharging capacitor to voltage 1.2 V
            SWSD_ChargingTimeDelay(SWSD_DISCHARGE);
        }while((SWSD_OneSampleMeasuring() <= BANDGAP_SAMPLES) && (++cnt));
    }
    // capacitor is discharge ~0 V
    else if(SWSD_OneSampleMeasuring() == BANDGAP_SAMPLES)
    {
        do
        {
            // charging to bandgap value 1.2 V
            SWSD_ChargingTimeDelay(SWSD_CHARGE);
        }while((SWSD_OneSampleMeasuring() >= BANDGAP_SAMPLES) && (++cnt));
    }
    SWSD_Init(); // initialization of sigma-delta measuring
}

/*****//*!
* @brief 100ms delay with init and deinit of analog comparator
*
*****/
static void SWSD_ChargingTimeDelay(byte charge_state)
{
    Byte ix;

    SWSD_DeInit(); // deinitialization of analog comparator
    ACMP_IN_DD = OUTPUT; // direction to output
    ACMP_IN_D = charge_state; // CHARGE or DISCHARGE of input DC-filter capacitor

    for(ix=0; ix<SWSD_REPEAT; ix++)
    {
        asm nop;
        __RESET_WATCHDOG();
    }
    SWSD_Init(); // initialization of sigma-delta converter
    ACMP_IN_DD = INPUT; // direction to input
}

```

4.2 Single-sample measurement

The basis of sigma-delta measuring is a function performing single-sample measurement. This function returns a number of values of logical 1 in one cycle — this number depends on the resolution set in the header file. The next section shows the flowchart and code block for this function.

Syntax:

- Word SWSD_OneSampleMeasuring(void);

Parameters:

- None

Return:

Software implementation

- cnt - value of logical 1 in buffer

Description:

- This function include two counters and counts actual logical states depending on the resolution set in the header file.

Single-sample measurement

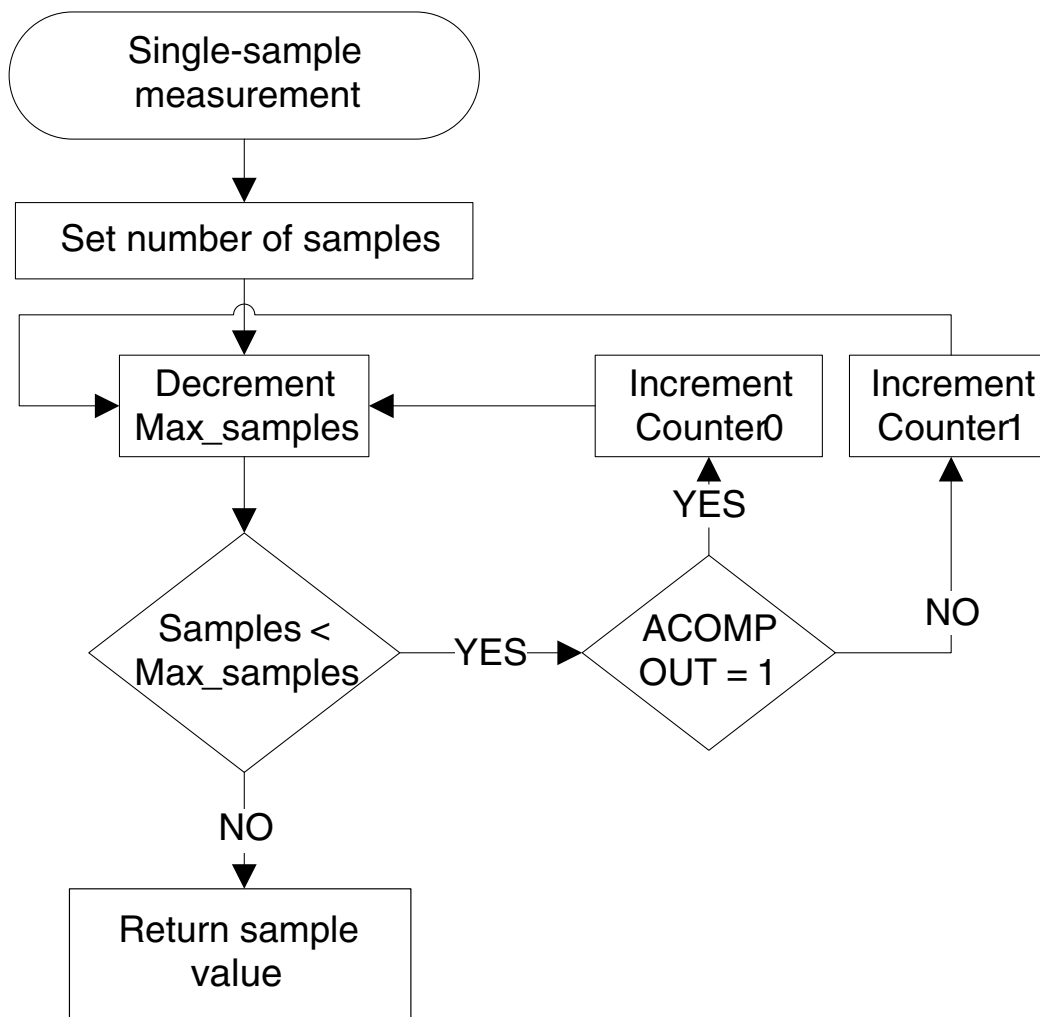


Figure 15. Sigma delta single-sample measurement flowchart

Following code block shows function for measuring of one sample.

```

/*****//*!
* @brief   Reading data from analog comparator
*
* @return  number of log 1 in one sample (depend on the number of bits)
*****/
Word SWSD_OneSampleMeasuring(void)
{
    Word i;
    Word temp_cnt0, cnt;

    cnt = temp_cnt0 = 0;
    i = SWSD_SAMPLES;

```



```

do // counting values of log 1 on the output of comparator
{
    // comparator output is in log 1
    if(ACMP_INTERNAL_OUT) //-----<
    {
        ACMP_OUT_D = 1; // SECTION A <
        cnt++; // <
    } //-----<
    // comparator output is in log 0
    else //-----<
    {
        ACMP_OUT_D = 0; // <
        temp_cnt0++; // SECTION B <
        asm nop; // <
        asm nop; // <
        asm nop; // <
    }; //-----<
} while (--i); // number of all samples depend on the bit number
return cnt; // return complete number of logical 1 in one sample
}

//-----
// For the correct measuring algorithm of sigma delta must be time intervals
// of both section (SECTION A and SECTION B) same.
//-----
    
```

4.3 Filtration of signal from PIR Sensor

Filtration of the signal from the PIR sensor is a necessary condition for the correct detection of movement. The most important feature of the filtration is the removal of spurious signals (peaks and noise).

The first element of the motion filtration is the use of two four-byte buffers for continuously saving the data in a one-second time range. The next step creates moving averages by using the two sums of the values stored in in each buffer and calculating the difference between these sums. This calculated value is compared with the static threshold which corresponds to the maximum output noise from the PIR sensor.

Complete source code of the filtration function is shown in the following code block. The system of motion filtration is displayed in detail in [Figure 16](#).

Syntax:

- Word PIR_MotionFiltering(Word new_value);

Parameters:

- new_value

Return:

- diff - difference between two moving averages

```

/*****//*!
* @brief Function for filtering of accidental peaks and noise.
* The base is derivation of processed signal
*****/
Word PIR_MotionFiltering(Word new_value)
{
    // local variables
    static Word buff0[PIR_BUFF_SIZE_4B];
    static Word buff1[PIR_BUFF_SIZE_4B];
    static LWord sum0;
    static LWord sum1;
    static Byte ix;
    Word diff;
    
```

Software implementation

```

// sum of first 4 samples
sum0 += new_value;
sum0 -= buff0[ix % PIR_BUFF_SIZE_4B];

// following sum of next 4 samples
sum1 += buff0[ix % PIR_BUFF_SIZE_4B];
sum1 -= buff1[ix % PIR_BUFF_SIZE_4B];

buff1[ix % PIR_BUFF_SIZE_4B] = buff0[ix % PIR_BUFF_SIZE_4B];
buff0[ix % PIR_BUFF_SIZE_4B] = new_value;

// differentiation between two following sums
if(sum0 > sum1)
    diff = (Word)(sum0 - sum1);
else
    diff = (Word)(sum1 - sum0);

ix++;
return diff;
}

```

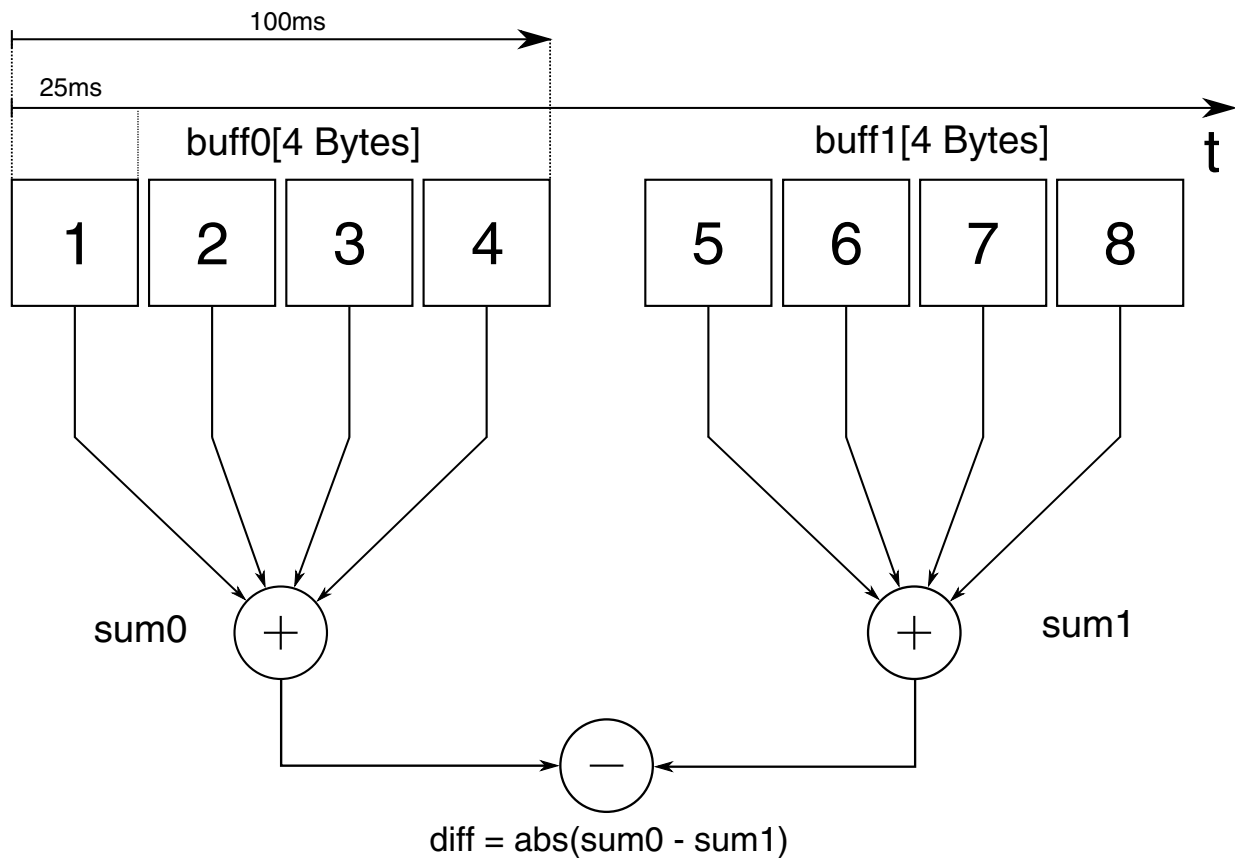


Figure 16. Motion filtering system

4.4 Sensitivity setting

The system can be made more or less sensitive by assigning larger or smaller values to the macro used to detect movement. The sensitivity can be changed in file "main.h" by increasing the macro `MOTION_THRESHOLD`. The default sensitivity setting in the software corresponds to the minimum threshold (maximum possible sensitivity).

5 Using the PIR detector

This passive infrared solution is targeted only for indoor situations, especially indoor light switches.

The main advantage of this design is the opportunity to make adjustments for the intended purpose, for example for use in burglar alarm systems, monitoring visitor presence, and light switches. Figure 17 shows the real detection range of the PIR detector.

The next important aspect of the hardware design is the use of the correct type of Fresnel lens. For our purposes a Fresnel lens with two sensor elements was used. This design is ready for implementation of different Fresnel lenses for various application types (home lighting, garden lighting, etc.).

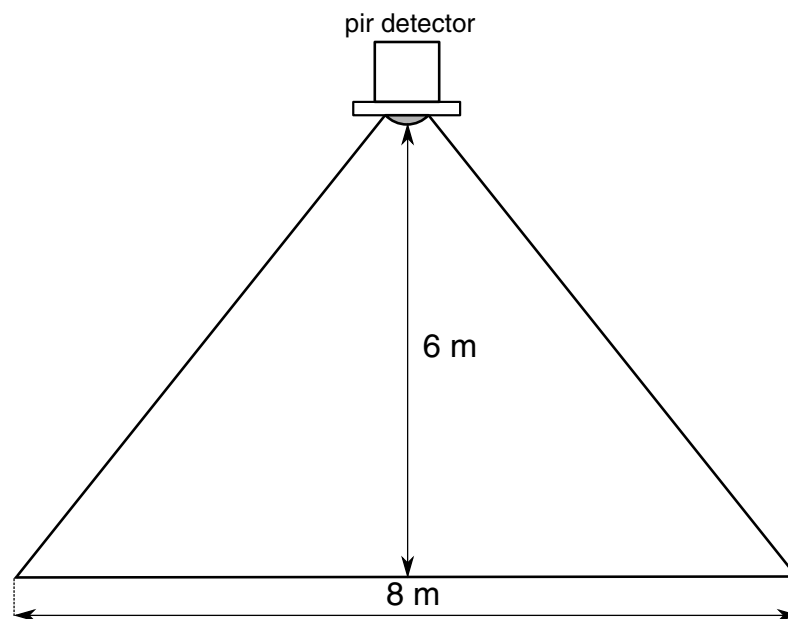


Figure 17. PIR detector maximum range

6 Bill of materials

Table 1. Bill of Materials

Part reference	Quantity	Component symbol	Description
MC9RS08KA1CSC	1	U2	Microcontroller
MC78L05	1	U1	Voltage regulator
100 nF	4	C1, C5, C7, C8	Ceramic capacitor
330 nF / 275 V	1	C3	Polypropylen capacitor
100 μ F	1	C4	Electrolytic capacitor
150 μ F	1	C6	Electrolytic capacitor
15 nF	3	C9, C10, C11	Ceramic capacitor

Table continues on the next page...

Table 1. Bill of Materials (continued)

Part reference	Quantity	Component symbol	Description
BZV55	2	D1, D2	Zener diode
S1M-13-F	2	D3, D4	Rectifier diode
LL4148	1	D5	Small signal diode
HDR 2x3	1	BDM1	Header BDM
CON_2_TB	1	J1	Power connector
Long male pin	4	J2, J3, J4, J5	Switching connector
OJE-SS	1	K1	Relay
BC817-40LT1G	1	Q1	NPN transistor
LHI778	1	Q2	Passive infrared sensor
470k	2	R1, R2	Resistor 0.25 Ω
220	1	R3	Resistor 2 Ω
10k	1	R4	Resistor 0.25 Ω
1k	1	R5	Resistor 0.25 Ω
47k	2	R6, R7	Potentiometer
11-20k	1	R8	Light dependent resistor
3.3k	1	R9	Resistor 0.25 Ω
4.7M	1	R10	Resistor 0.25 Ω
100k	1	R11	Resistor 0.25 Ω
47k	1	R12	Resistor 0.25 Ω
0	1	SH1	Shortcut connector

7 References

For more information, see the appropriate device reference manual and the documents in the following table.

Table 2. References

Document	Title
Freescale document DRM001	Passive Infrared (PIR) Intruder Detection Using the MC68HC908JK1/3
Freescale document MC9RS08KA2	MC9RS08KA2/MC9RS08KA1 Data Sheet (Also serves as reference manual)
Freescale document AN3587	Cloth Iron Controlled by MC9RS08KA2
Wikipedia article on PIR (en.wikipedia.org/wiki/Passive_infrared_sensor)	Passive infrared sensor

Table continues on the next page...

Table 2. References (continued)

Document	Title
PerkinElmer document LHI778 (http://www.perkinelmer.com/PDFs/Downloads/DTS_LHi778_LHi878_PYD1388.pdf)	Pyroelectric Dual Element Detectors For Motion Sensing

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