MOTION SENSOR –
Design Example for an Ambient Light Powered PIR

1. Purpose of this application note

The purpose of this Application Note is to demonstrate the feasibility of an ambient light powered radio motion sensor for indoor use based on EnOcean technology. The concept implements the following function: The lamp is manually switched on when entering the room and remains on as long as a presence is detected in the room; finally, the lamp automatically switches off within a certain time after the room is vacated.

2. Motion Sensor System Description

The system consists of two modules, both EnOcean based:

a) Light powered motion sensor as transmitter and

b) Line-powered radio receiver with switching actuator (and “Lamp ON” push-button).

Fig. 1: Light powered Motion Sensor (Prototype)

Fig. 2: Line Powered Wall Receiver (Prototype)

3. Principle

After pressing the “Lamp ON” pushbutton, the integrated timer automatically keeps the light on for a certain adjustable length of time (2...30 minutes), i.e. for 5 minutes, like a timer switch for staircase lighting. The receiver expects further presence messages in this time period.

This time is sufficient for charging the empty energy stores of the light powered radio motion sensor via its solar panel, thereby ensuring its continued long-term function (cyclically transmitting presence messages when motion detected). The transmitter can be a PTM 240C or STM110 / STM110C module that, in the case of a motion arising, sends presence messages at adjustable intervals, i.e. every minute or so (only presence messages type “Lamp ON”).

Therefore, each time a “Lamp ON” message is received from the programmed radio motion sensor within this time period, the integrated receiver timer will be re-triggered and the “Lamp ON” time subsequently re-initialized for a new period of i.e. 5 minutes.

Thus, the lamp remains ON for a further 5 minutes and stays switched on as long as further presence messages are received in this time period. The re-triggerable timer therefore functions as “missing pulse detector ”for“ Lamp ON messages: i.e. if no message is received within this preset time period, the receiver’s timer will automatically switch the lamp off at the end of that time period (“Lamp OFF”).

Once the lamp is switched off, it can be switched back on by a detected motion within the next 30 seconds. Thereafter it can only be switched on by manually pressing the on-button on the receiver again. This concept means that the lamp is always switched off automatically from the receiver end, either after a maximum of 5 minutes after the room was vacated or if a fault arises (radio motion sensor broken) independent of room vacation. The practical realization of such an EnOcean, i.e. TCM-module based receiver is quite simple and therefore needs no further explanation here.

4. System Requirements for the Motion Sensor Demo

- Minimum working environment light level at the solar cell on the ceiling shall be > 40 lx.
- PIR Sensor shall transmit motion information to the wall box receiver at least once every 60 seconds (worst case).
- Charge time for the energy storage capacitor shall not exceed 5 minutes in the lowest specified illumination environment. Otherwise stated, this time is the charge up latency time from when the lights are manually turned ON after the room was in total darkness.
- The energy stored should be enough for at least 30 seconds after the lights were turned off (totally darkness), to power the transmitter to turn lights back ON in case motion is detected within this period of time.

5. Block Diagram of the Motion Sensor

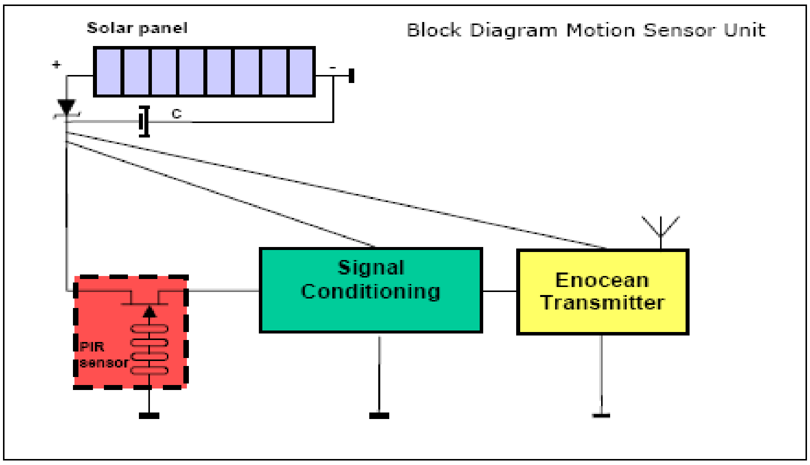

Fig. 3: Block Diagram

6. Energy Balance Calculation

The most important aspect of the dimensioning is to have lowest possible energy consumption. Since the energy is the product between current, voltage and time, this can be achieved in several ways:

Design and build the sensor circuit itself as frugally as possible. A current consumption of less than 5 µA can be achieved using adequate very low current components. Very low voltage devices must be chosen (down to 1.8 V).

Optimal emplacement, (enough light at least after the light is turned on) and enough large solar panel. Consider 40 lx as absolute lower limit requirement for the solar panel.

Important factors for function requirements regarding energy management:

Start up time (as long as possible e.g. 5…15 minutes): while the quiescent current (without transmission budget) is about 5 µA and can not be further significantly decreased, the ratio of the additional current needed to first charge the empty storage capacitor is very important. As illustrated below, a start up within 5 minutes requires one third more current (1.7 µA + 5 µA) vs. a start up within 15 minutes (0.55 µA + 5 µA). That requires an over dimensioning of the solar cell area with one third vs. one tenth for 15 minutes! The start up time is as well strongly dependent on the storage capacity value.

Storage capacity: not too large, so that a voltage of 3 V is reached within i.e. 5 minutes after switching the light on@40 lx. This should ensure that the device is ready to operate within this time period.

On the other side the storage capacitor value shall be large enough to assure full recovery of the capacitor between two consecutive messages: the maximal voltage drop on the storage capacitor < 0.3 V (i.e. from 3 to 2.7 V, worst case) during one transmission (2 ms with 20 mA) to assure the full recovery between two transmissions and function of the sensor and second to work properly at least 30 seconds after the light is switched off (auto reactivation period).

Transmission time shall be as short as possible, transmissions as rare as possible (i.e. once every 1…3 minutes). As below described, one transmission per minute adds only about 0.5 µA to the quiescent current requirements. Similar, for one transmission every 2 minutes you will need only the half of this amount makes 0.25 µA.

Scenario: start up time within 5 minutes and in average one transmission per minute by worst case illumination of 40 lx. A room is in absolute darkness for an indefinite time. The presence detector must be ready to work within i.e. 5 minutes after the light is turned on.

After light turn on available brightness for the sensor is 40 lx. Transmission cycle is (by motion) at least one message every minute.

In order to maintain the required nominal transmission power (i.e. range); the only place where "savings" can be made is with the time factor. This means at 3 V a current consumption of 15 mA for instance, the power consumption will be 3 V x 15 mA = 45 mW.

From this requirements results the transmission current averaged over time: Using an EnOcean transmitter, one transmission is made for a total 3 ms per message, the average power when transmitting is reduced by a factor of 333, and is therefore actually only 3 V x 15 mA/333, makes 135 µW (at 3 V and 45 µA).

This still seems a lot, but this power is what would be required if the transmission cycle were 1 time every second. So if the number of messages is limited to once per minute as mentioned above, this would mean one message every 60 seconds, which is 60 times less current consumption again, i.e. 45 µA/60 or 0.75 µA as an average current per minute.

The needed storage capacitor value results using the formula C x U/2 = I x t:

- C > I x t x 2/U where I = 5 µA, t = 30 seconds, U = 3 V, so C > 100 µF for auto self re-activation.
- C x 0.3 V/2 = 15 mA x 3 ms => C > 270 µF for a maximal voltage drop < 0.3 V

To fulfill both conditions the greatest value has to be chosen, respectively C must be > 270 µF, i.e. let's suppose 330 µF.

Finally the total current including start up within 5 minutes and the solar panel requirements at 40 lx:

The supply current requirement (averaged current 5 µA consumption plus initial charging of i.e. a 330 µF storage capacitor from 0 V up to 3 V within 5 minutes) is given by: 5 µA + Ic, where Ic results from:

- C x U/2 = Ic x t, where C = capacity (µF), U = voltage (volt), Ic = charging current intensity (µA) and t = time (seconds)

The min. additional charging current required for start up within 5 minutes is therefore:

- Ic (µA) = C x U/(2 x t) = 330 µF x 3 V/(2 x 300 s) = 1.7 µA (= 1/3 of the totally quiescent current!)

According thus, the required total supply current It@40 lx > 5 µA + 1.7 µA = 6.7 µA@40 lx

Note: Since one transmission exhausts maximal 3 ms x 15 mA = 45 µAs every 60 seconds while the charging current amount during this time is: 60 seconds x 1.7 µA = 100 µAs, meaning the recovery condition between two transmissions is also easily fulfilled.

According to diverse data sheets for Indoor solar cells (i.e. Sinonar, RWE-Schott) a 2.5 cm2 large single solar cell is needed to generate the needed current of 7.1µA@40 lx.

Voltage considerations: the voltage of the chosen module should be selected so that the power point voltage is near the required operating voltage of the application. As a rough estimate, you can figure that the power point voltage is about 75% of the open circuit voltage.

Due to a required total operating voltage of minimum (due to the serial Schottky diode volt-age drop) 3.1 V@40 lx, at least 8 serially connected cells with a single output voltage of about only 0.39 V at 40lx are needed (according to the same data sheets).

The last two sentences give the following essential key data for the indoor solar panel: >2.5 cm2 (single cell) x 9 cells (voltage requirements), thus giving an effective solar panel area of > 22.5 cm2 (24 µW@40 lx). For example one Sinonar SS-5649 module (8 serial single cells, 25 cm2) would deliver the required energy.

NOTE 1: a solar cell works as a current generator and while the output voltage is only light dependent to the illumination over more decades, the current varies direct proportional with the illumination and solar cell single area. Therefore the current dependence is absolute linear while the power density dependence is not quite linear (slightly reduced due to the volt-age component at lower illuminations).

NOTE 2: Due to the specific solar cell spectral sensitivity, you may need up to 30% more brightness from a fluorescent (cold light) vs. daylight or incandescent lamp for the same solar cell performance.

7. Further Circuit Description and Implementation of the Motion Sensor

The circuit is dimensioned for a 3...5 V supply voltage and works at 2.7 V and above.

The motion sensor used is a classic passive PIR dual sensor, i.e. Perkin Elmer's low-cost standard LHI878 version or the LHI1128 (quad), specially designed for ceiling mounting. These contain the dual/quad PIR element itself as well as a MOSFET acting as an impedance transformer and output amplifier. Both types can be used without any modification. Its out-put signal is processed by the amplifiers LPV511 (key data: Rail to Rail IN/OUT, working voltage>2.7 V, current consumption 0.88 µA, from NI).

Alternative device: ISL28194, guaranteed minimum working voltage 1.8 V at only 0.33 µA, or less than half LPV511, reduces the totally needed current with another 20%!

Only the dynamic signal component (motion) will be filtered and amplified by approx. >20,000 times. This amplified and filtered signal is added to a window comparator, realized with the two open-drain output MAX920 comparators (key data: Nanopower, 1.8 V upwards, current drawn <0.4 µA, open-drain output from Maxim), connected as a logical OR gate. The common comparator output triggers a mono-shot CMOS, type CD4538. This needs a quiescent current of only few Nanoamps and generates a short trigger pulse for the EnOcean transmitter (PTM or STM-based) as described below:

When a motion is detected, the mono-shot leads to a "Lamp ON" message transmission. After this moment the temporization circuit inhibits his input for a preset time period (i.e. one minute), thereby preventing the transmission of a possible subsequent message when this follows too shortly after the first message. This is in order to save energy. This also prevents unnecessary messages being transmitted every time when there is a lot of activity in the room, since the receiver timer has a preset time out of i.e. 5 minutes between two consecutive messages anyway. The RC timing combinations shall have maximized R and minimized C values in order to reduce at minimum the energy losses through capacitor charge/discharge cycles.

Instead of the used 1.8V P-Channel PowerTrench MOSFET an integrated high side load switch type i.e. MIC94070 can be considered. Advantage: an even lower needed working voltage. Disadvantage: additional quiescent current (+1µA) to the energy budget.

The line powered receiver always takes care of the "Light OFF" function. For more details please consult the respective user manuals and existent application notes.

8. Considerations about Sensor Housing Shape and Solar Cell Positioning

- The area, number, angle and shape of the solar panel can of course be further optimized to suit the design, purpose, existing lighting conditions and required start up time and transmission intervals.
- Practical usage has shown that solar panel placed on the sides at an angle of 30° to the vertical receive more light as a rule, depending on their location; this can be up to 50% more in comparison to a horizontal, downward (towards dark floor) facing solar panel.

9. Conclusions for the Sensor Realization

This feasibility study shows that a motion sensor system according to the requirements mentioned can be realized. Two simple light powered motion detector concept examples based on PTM240C and STM110(C) (both 4BS types) are illustrated below. Please note that

PTM240C is available only for the 315 MHz band. The use of a PTM240C/STM110(C) as transmitter allows dedicated assignment in an existing system, due to the possibility to send learn telegrams by pressing of a LRN push button and the using of already existing profiles.

The STM110(C) modules offer furthermore the advantage to use the additional integrated energy management and analogue/digital inputs for a longer energy storage time, monitoring of more parameters like e.g. brightness, temperature and if desired full automatic function.

Please Note: This is just a concept demonstrating the possibilities for realizing such systems in general and is not a 'final solution' that is ready for production!

10. Examples for PTM240C and STM110 based versions

In the following please find examples for PTM240C (a) and STM110 (b) based versions:

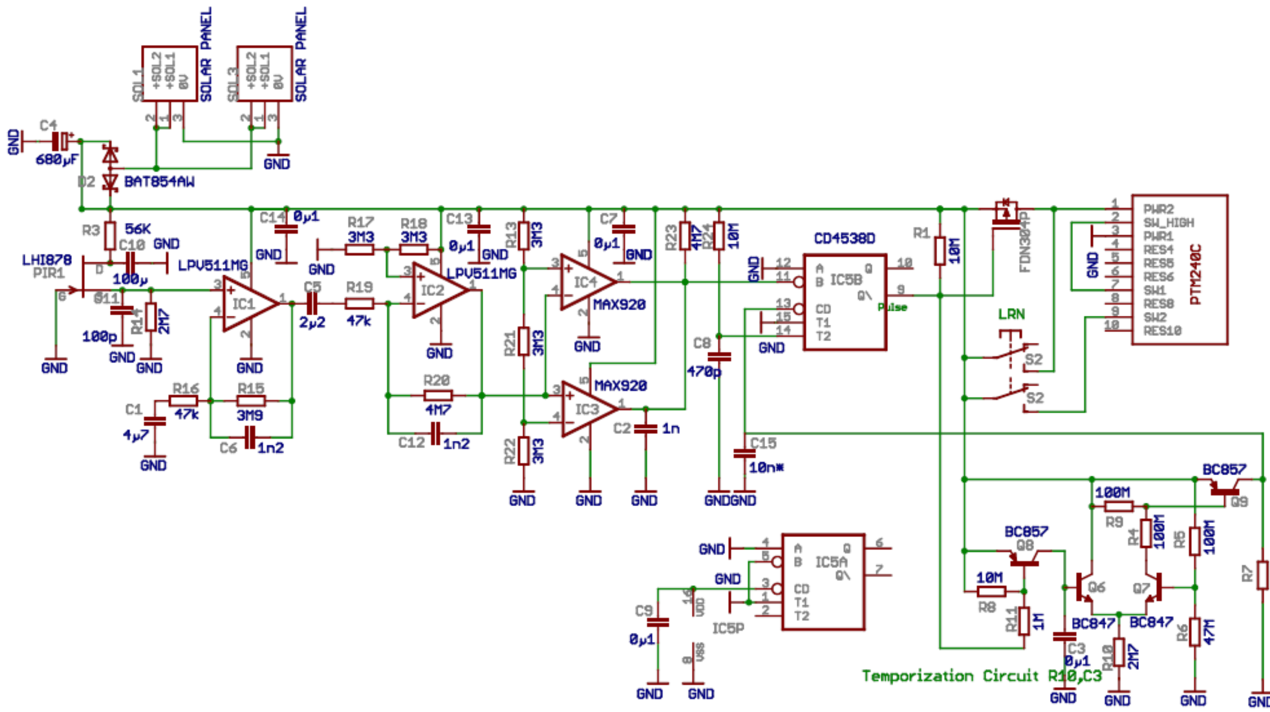

Fig. 4: Realization example based on PTM240C (315 MHz only

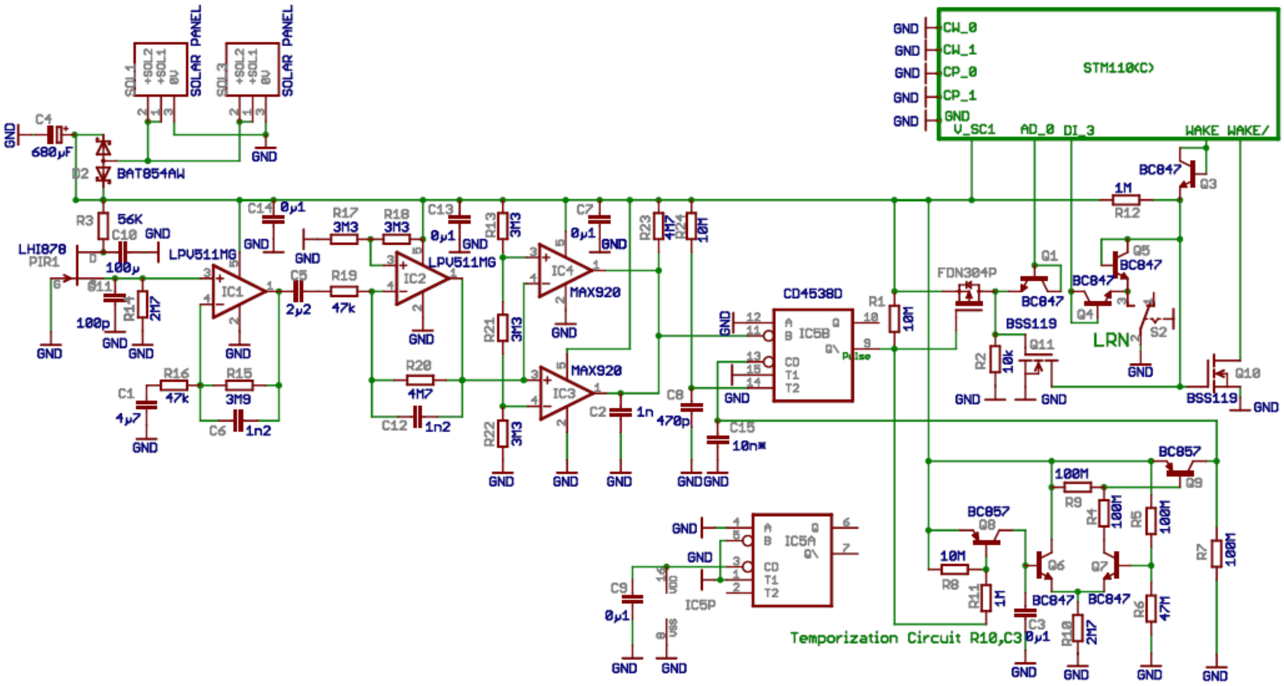

Fig. 5: Realization example based on STM110 (868 MHz) or STM110C (315 MHz)

Disclaimer

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