
Signal conditioning for pyroelectric passive infrared (PIR) sensors

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Introduction

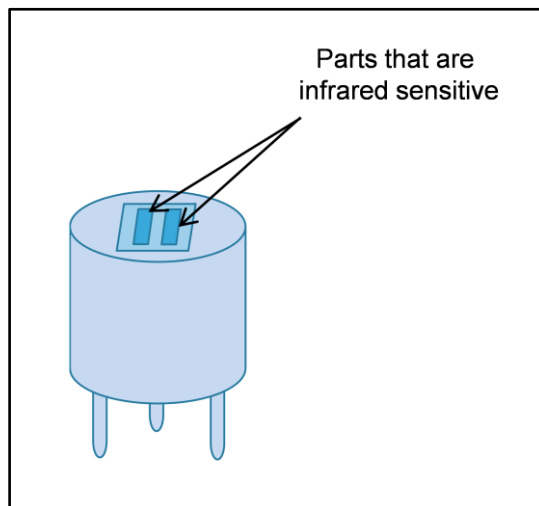
Pyroelectric passive infrared (PIR) sensors are widely used in daily life. They are a key component in motion detection and can be used for security systems, automatic doors, or automatic light control. They are commonly used to detect humans. For example, when someone is detected in a specified area an alarm may be triggered or a specific room may be lit. Another common use is with regard to pets, for example, cat flaps.

Everything on earth has infrared (IR) energy. The IR energy of an object depends on different parameters such as its temperature, color, and texture. This energy is not visible with the human eye, but PIR sensors can detect it.

Passive IR sensors are the opposite of active IR sensors that emit energy, such as ultrasound, light, or microwaves. Active sensors are able to detect a change in the environment when the reflected emitted signal is disturbed. Active sensors consume more energy than passive sensors.

A basic drawing of a PIR is shown below.

Figure 1: PIR sensor



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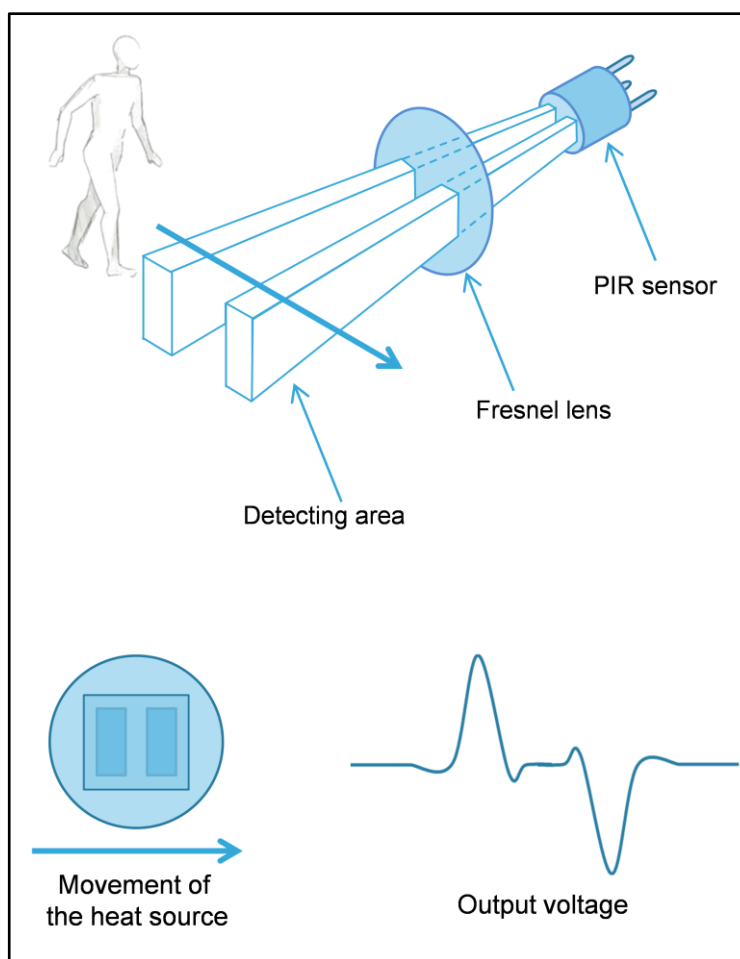
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1 How does the PIR sensor work

The aim of the PIR sensor is to detect motion in a specific area. As seen in [Figure 1: "PIR sensor"](#), these sensors contain two parts that are sensitive to IR. Since it is motion that is important, **the signal** delivered by the sensor **reflects different amounts of IR** detected by each part. If both parts "see" the same amount of IR, the sensor detects nothing. But, if one of the two parts "sees" more or less IR than the other part, the sensor detects something and the output voltage of the sensor varies.

[Figure 2](#) shows how the output voltage varies when a heat source moves in or out of the area protected by a sensor.

Figure 2: Principle of the PIR sensor



The area of the two rectangles that is IR sensitive is small ($\approx 2 \text{ mm}^2$ for each rectangle). Clearly, it would be better to increase the IR sensitive area. This can be done in two ways:

- by increasing the number of sensors
- by using a **Fresnel** lens

The latter method is highly recommended as it is inexpensive and improves IR reception by the sensor. It multiplies the area visible to the sensor and it focuses reception of IR by the sensor.

2 The sensor signal

When a body, with a temperature different to ambient, moves into the detection field of a PIR sensor, the sensor provides a small AC signal. This signal is in the range of 1 mVpp. This small voltage is around a DC signal that may significantly vary from one sensor to another. For this reason, it is mandatory to cancel the DC part of the signal and to amplify the AC part. As the signal is disturbed by the environment, a noise filter is useful.

STMicroelectronics' operational amplifiers (op-amps) can perform all these functions.

The sensor used in this application note is the IRA-E700ST0 from muRata.

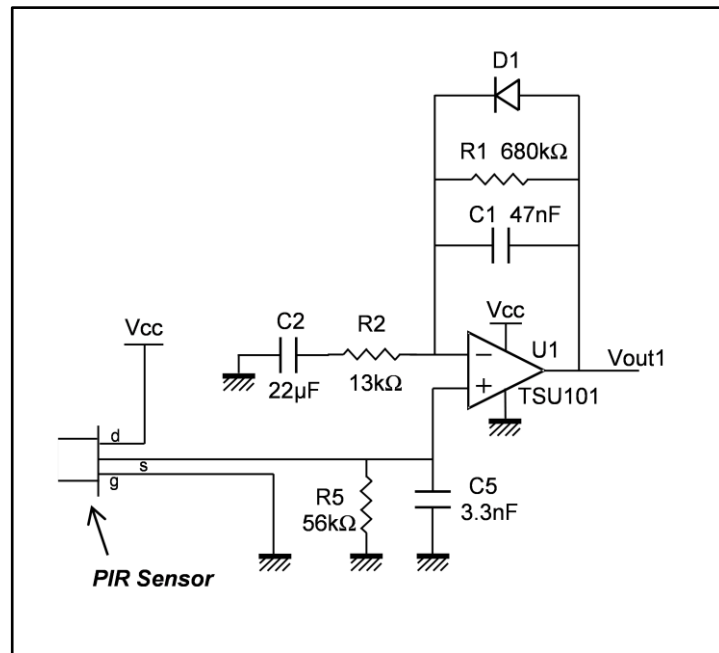
3 Three-stage architecture for detecting motion

To detect motion, a three-stage architecture based on op-amps is used to condition the signal of a PIR sensor. This architecture is explained below.

3.1 Stage 1

The first architectural stage amplifies the signal. It cancels the DC part of the signal and filters the high frequency noise that could lead to false detections. The schematic of this first architectural stage is shown in [Figure 3](#).

Figure 3: Schematic of the first architectural stage



1. C = capacitor, D = diode, R = resistor, U = op-amp

[Figure 3](#) shows that **noise is filtered** thanks to the components **R₁ and C₁**. The cut-off frequency is **5 Hz** ($f_{high1} = 1/(2 \times \pi \times R_1 \times C_1)$). This application does not need to work at higher frequencies because usually we are detecting **human motion**.

The second filter is used **to reject the DC part of the signal**. **R₂ and C₂** perform a **high pass filter** that has **a cut-off frequency of 0.6 Hz** ($f_{low1} = 1/(2 \times \pi \times R_2 \times C_2)$).

Since we do not amplify the DC part of the signal, the V_{io} , which is the **input offset voltage of the op-amp**, has **no importance in this application**.

The stage gain is **53.3** ($Gain_1 = 1 + R_1/R_2$). This amplification allows a usable signal that is higher than the noise level. The **DC bias of the first architectural stage** is determined by the sensor. To avoid saturation, the gain must not be too big because amplification is made around **this common mode voltage** (which is not $V_{cc}/2$).

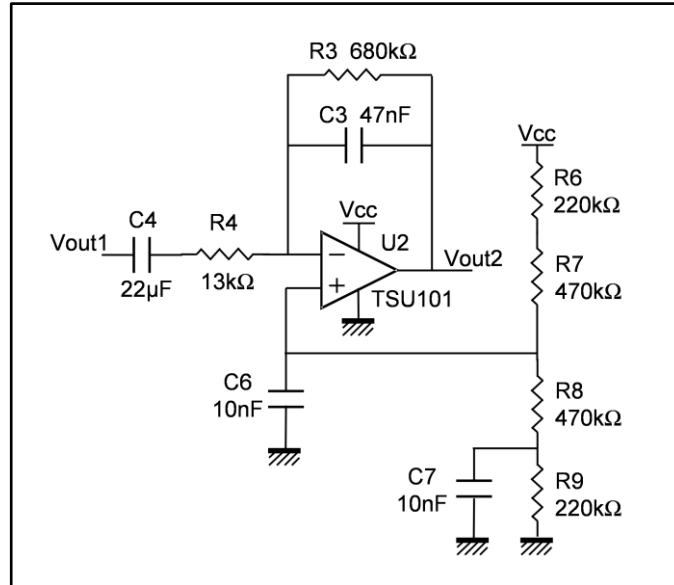
STMicroelectronics' TSU101 op-amp is a perfect fit for this architectural stage. As well as having very low consumption, the TSU101 operates with a typical current consumption of only 600 nA at $V_{cc} = 3.3$ V.

The diode, D₁, is explained in [Section 5: "Power-up"](#).

3.2 Stage 2

Stage 2 is very similar to stage 1 (see [Figure 4](#)). It is used to filter and amplify the AC signal.

Figure 4: Schematic of the second architectural stage



1. C = capacitor, R = resistor, U = op-amp

Regarding the filtering function, the low and high cut-off frequencies respectively are 0.6 Hz ($f_{low2} = 1/(2 \times \pi \times R_4 \times C_4)$) and 5 Hz ($f_{high2} = 1/(2 \times \pi \times R_3 \times C_3)$). The gain of this stage is -52.3 ($Gain_2 = -R_3/R_4$). This gain means that after stage 2 the signal between 0.6 Hz and 5 Hz will have been amplified 2790 times (69 dB).

In stage 2, the op-amp common mode voltage is set by the divider bridge composed of R_6 , R_7 , R_8 , and R_9 to $V_{cc}/2$. This allows greater amplification of the AC signal.

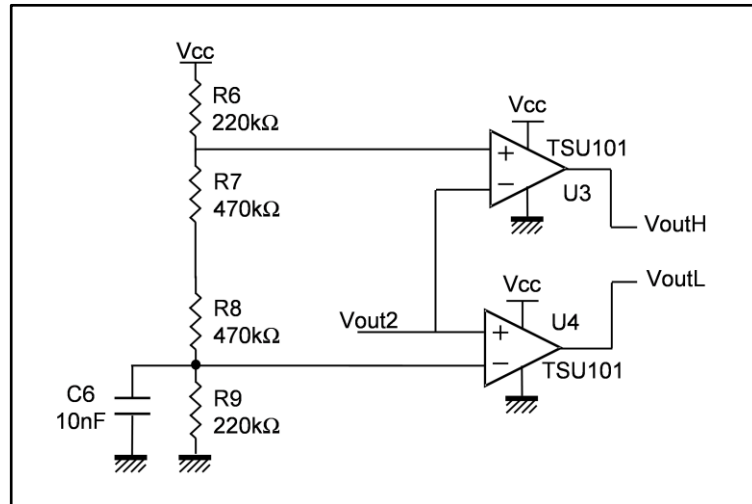
As with stage 1, the V_{io} of the op-amp has no importance since the DC part of the signal is not amplified. Moreover, there is no constraint on the gain bandwidth product (GBP), because the op-amp has to have a GBP greater than 2.6 kHz ($f_{high2} \times \text{gain} \times 10$). A factor of 10 has been used to avoid any limitations by the GBP. Almost all GBP amplifiers fit this 2.6 kHz requirement.

The TSU101 op-amp is very suitable for this architectural stage. Its low consumption is particularly advantageous. Although it is a nanopower op-amp, its GBP is higher than 2.6 kHz. Note that TSU101 is also available in dual (TSU102) and quad (TSU104) channel versions to optimize the footprint on board.

3.3 Stage 3

The third and last architectural stage allows the user to perform a **window comparator**. As a consequence, **the signal is perfectly conditioned to go to a microcontroller**. Figure 5 shows the schematic of this stage.

Figure 5: Schematic of the third architectural stage



1. C = capacitor, R = resistor, U = op-amp

When a heat source is detected, the output of the op-amp U_3 and/or U_4 is in low state. The divider bridge, composed of the resistors R_6 , R_7 , R_8 , and R_9 , is used to set the voltage reference of these devices. The TSU101 op-amp is an **input/output rail to rail op-amp**, and there is **no constraint on the input common mode voltage**. Thus, while the voltage references of U_3 and U_4 are within the V_{cc} range the window comparator works.

For the following example, the reference of U_3 is set to $0.84 \times V_{cc}$:

$$\frac{R_7 + R_8 + R_9}{R_6 + R_7 + R_8 + R_9} \times V_{cc} = 0.84 \times V_{cc}$$

When the signal (V_{out2}) is above this reference (2.77 V if $V_{cc} = 3.3$ V), the output of U_3 is in low state, close to ground.

U_4 is used to detect when the signal is below a certain reference. In this example, the voltage reference is set to 530 mV thanks to the divider bridge composed of R_6 , R_7 , R_8 , and R_9 . The voltage reference calculation is:

$$\frac{R_9}{R_6 + R_7 + R_8 + R_9} \times V_{cc} = 0.16 \times 3.3 = 0.53 \text{ V}$$

Thus, when the signal (V_{out2}) is lower than 0.53 V, the output voltage of U_4 is in low state (see [Table 1](#)). If only one digital output is required, the user may use a NAND gate connected to the outputs of U_3 and U_4 .

Table 1: NAND truth table

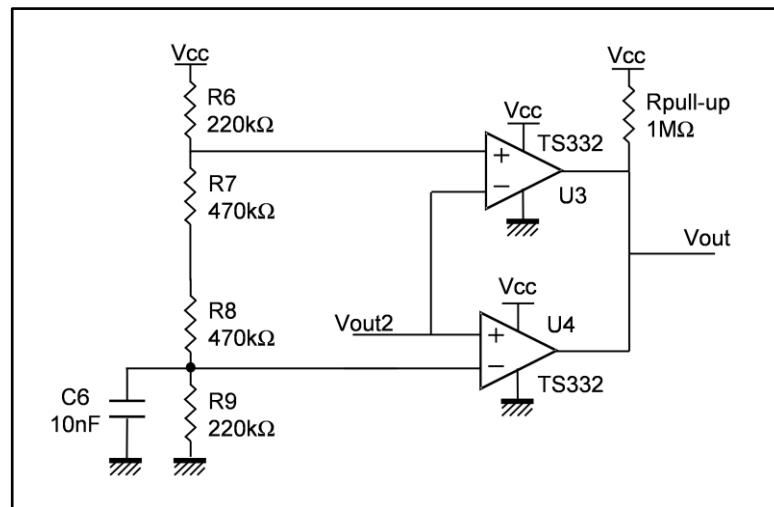
Vout2	Output U_3	Output U_4	Output NAND gate
$V_{out2} < 0.16 * V_{cc}$	High	Low	High
$0.16 * V_{cc} < V_{out2} < 0.84 * V_{cc}$	High	High	Low
$V_{out2} > 0.84 * V_{cc}$	Low	High	High

3.4 The best op-amp for each architectural stage

The schematics show that a quad op-amp is a good choice for the current application: one op-amp for stage 1, a second op-amp for stage 2 and two additional op-amps for stage 3. In this respect, the TSU104 is ideal as only one active component is needed for signal conditioning. The one drawback of the TSU104 is that it uses two op-amps for a comparator function but, this is not an issue at such low speeds.

However, it may be better to use **an open drain comparator (TS332)** whose outputs are connected together as described in [Figure 6](#).

Figure 6: Window comparator schematic



1. C = capacitor, R = resistor, U = op amp

As long as there is no detection, the output is in high state and it minimizes consumption through the pull-up resistor.

The global schematic that shows the three architectural stages together is available in [Section 8: "Appendix A"](#).

4 Consumption

Consumption is a key feature for portable applications. The schematics in [Section 3: "Three-stage architecture for detecting motion"](#) have been designed to optimize consumption and to be 3.3 V compatible, especially with regard to microcontrollers.

The main consumption is due to the sensor which consumes 19 μA . The rest of the application consumes 4.8 μA as follows:

- a TSU104 op-amp consumes 2.4 μA
- the divider bridge, composed of R_6 , R_7 , R_8 , and R_9 , consumes 2.4 μA

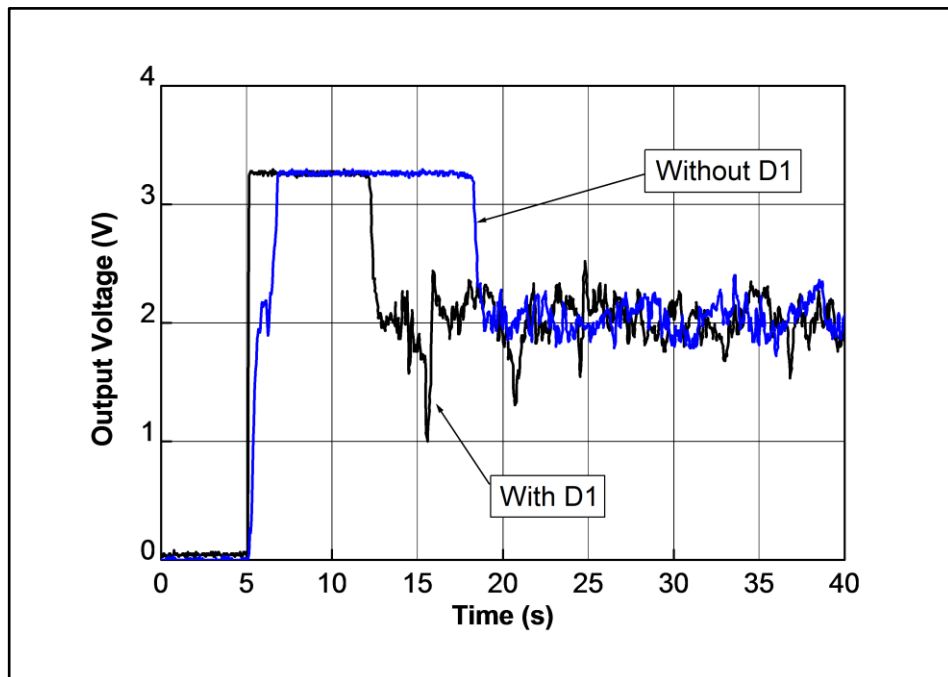
The consumption of the divider bridge could be reduced by multiplying the resistor values but at the cost of reliability. When impedances are high, the impact of dust or moisture is higher. These perturbations can create parasitic impedances.

5 Power-up

The diode in [Figure 3: "Schematic of the first architectural stage"](#) permits C_2 to be charged faster than normal at power up through R_1 . However, this method cannot be applied at architectural stage 2 because it would clamp the output level of the U_2 op-amp. A faster startup is possible with a lower R_3 value, but the gain need would lead to a lower R_4 . Consequently, a bigger C_4 would be needed to keep the low cutoff frequency.

[Figure 7](#) below shows the power up time with and without the diode D_1 . The initialization time has been observed by monitoring the output voltage of the second op-amp (V_{out2}). D_1 helps to reduce the power-up time. Thanks to this diode, the global application initialization time has been decreased from 14 s to 8 s.

Figure 7: Power-up time with and without diode 1



1. D = diode

6 Conditioning the signal

Figure 8 shows the output voltage of the first important signal generated by the PIR sensor. Once the application is supplied, the signal is almost constant. The common mode voltage is 1.1 V but, this voltage may vary from one sensor to another. Based on this figure, it is clear that the sensor has not detected any motion. However, thanks to signal conditioning, the signal can be amplified and peaks, representing motion, can be detected.

Figure 8: Output voltage of the PIR sensor

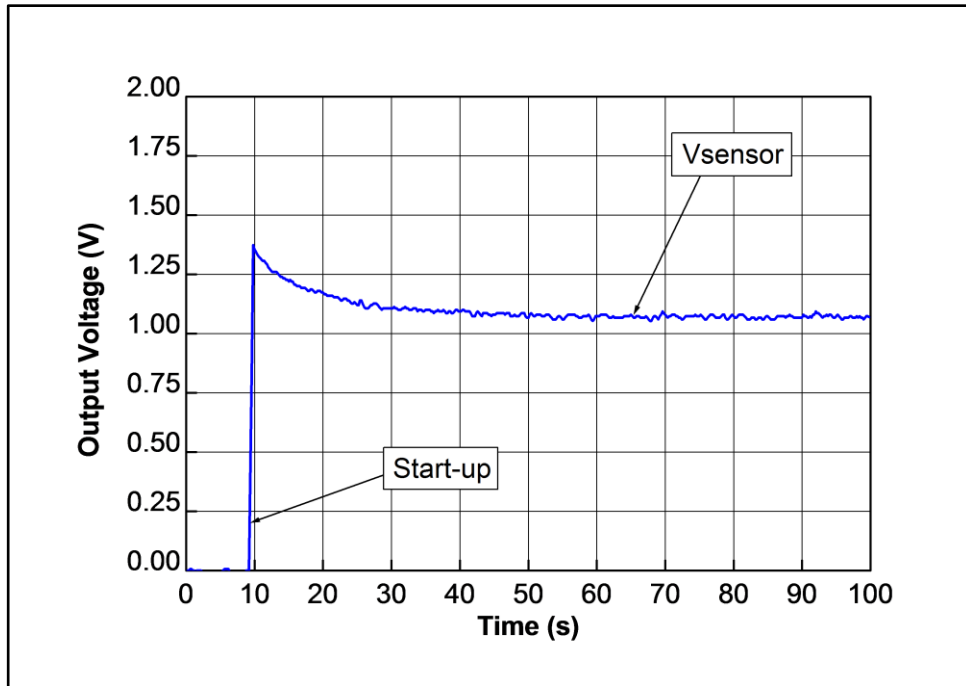
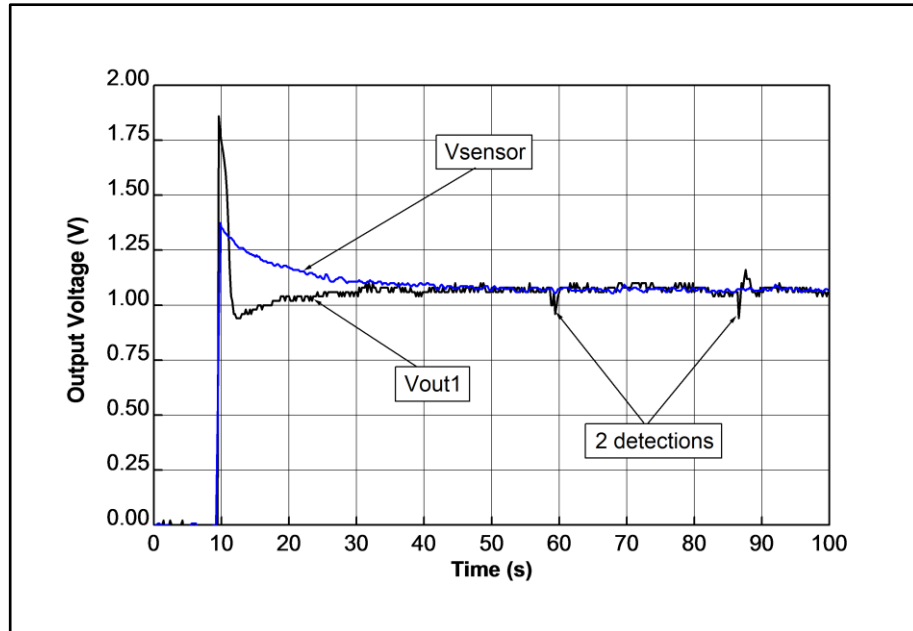


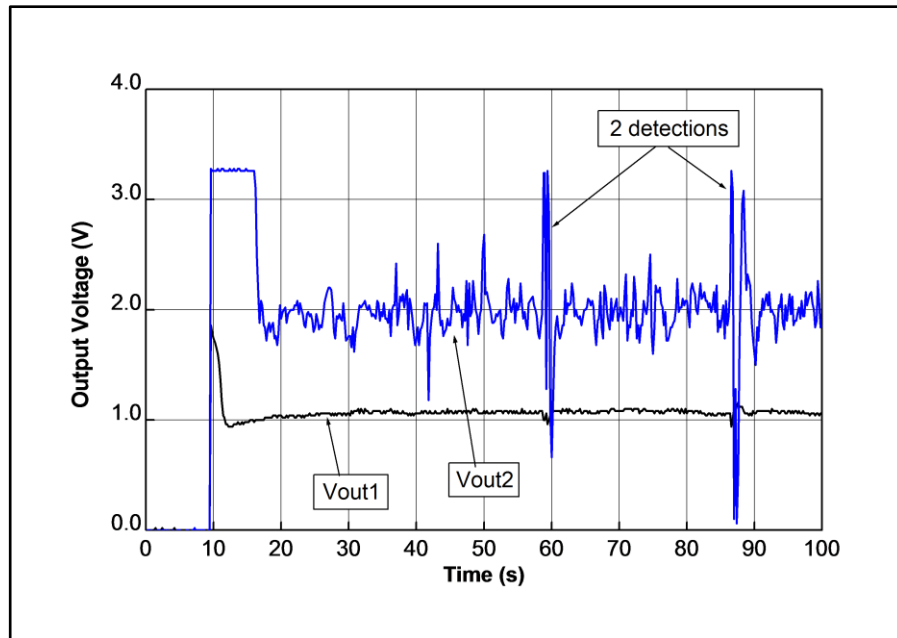
Figure 9 shows the output voltage of stage 1 where the AC signal has been amplified and filtered for the first time. In this example, the Vout1 signal is an amplification by 53 of the Vsensor signal around its average value. Two peaks can be discerned. However, at this stage, it is not possible to say if these peaks represent real motion or not. The magnitude of the signal is still not big enough for a microcontroller.

Figure 9: Output voltage of stage 1



[Figure 10](#) shows the output voltage of stage 2 where the signal has been further amplified. In this case, the Vout1 signal has been amplified by -52. Clear peaks can be detected. This figure allows us to see how common mode voltage has changed with amplification. In [Figure 8: "Output voltage of the PIR sensor"](#), common mode voltage (V_{cm}) was 1.1 V, whereas below, common mode voltage is half V_{cc} .

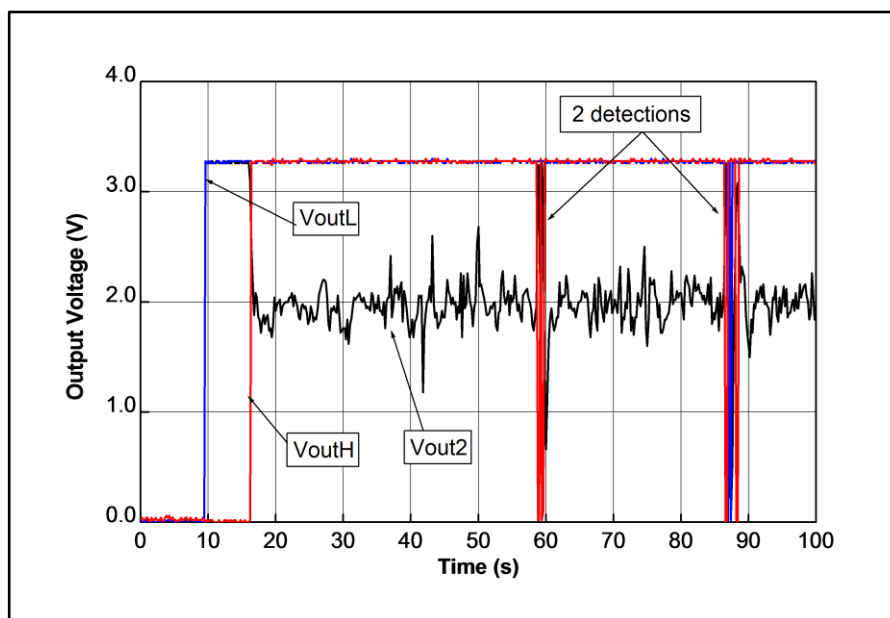
Figure 10: Output voltage of stage 2



The signal generated by the sensor is now sufficiently amplified to set a threshold detection. The divider bridges and the op-amps used as comparators create a window comparator. In our case (see [Section 3.3: "Stage 3"](#)), we have a low threshold voltage of 0.53 V and a high threshold voltage of 2.77 V ($V_{cc} - 0.53$ V). At the output of this comparator window, a NAND gate could be added to use only one microcontroller input.

Figure 11 shows the output of the U_3 and U_4 op-amps which are used as comparators. When motion is detected, the U_3 and/or U_4 output goes low, close to ground. The output of the global signal conditioning chain can be plugged directly to a microcontroller input and consequently, we can trigger an alarm, switch on a light, etc

Figure 11: Output voltage of the comparator stage



Note that an initialization time has to be taken into consideration to detect movement. This is due to the warm up time of the sensor and the charge of the capacitors. This means that a "blank" time has to be taken into account at microcontroller level.

Table 2 below shows the key parameters of the products (TSU10x and TS33x) used in this application.

Table 2: Key parameters of the products TSU10x and TS33x

Features	TSU10x (op amp)	TS33x (open-drain comparator)
Vcc range	1.5 V – 5.5 V	1.6 V – 5 V
Number of channels	Available in single, dual, and quad versions	
Icc (typ)	0.6 μ A	23 μ A
AC performance	Bandwidth 8 kHz	Propagation delay: - 270 ns (high to low) - 450 ns (low to high)
Vio (max)	3 mV	5 mV

7 Conclusion

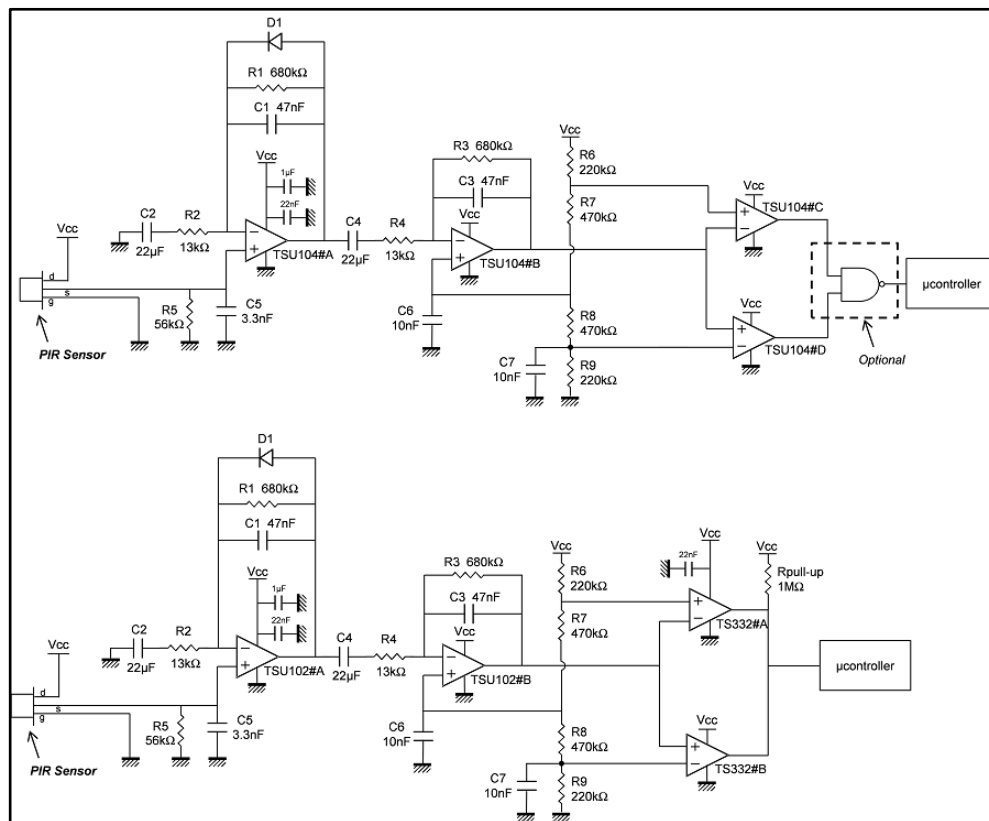
PIR sensors are widely used and require op-amps to amplify and filter the signal they generate which is noisy and small in amplitude. Op-amps or comparators can be used to compare the amplified signal with threshold voltages before it goes into the I/O of a microcontroller (i.e. there is no need for an analog-to-digital converter).

With the TSU104 (quad op-amp) or TSU102 (dual op-amp) and TS332 (dual comparator), an application can be designed which is compliant with a 3.3 V microcontroller. The whole analog chain consumes only 24 μ A with a micropower TSU104.

STMicroelectronics provides nanopower op-amps and comparators for portable applications. STMicroelectronics can also provide op-amps and comparators with a bigger bandwidth, a higher output current, a wider Vcc range, or even op-amps that are automotive grade compliant. The wide STMicroelectronics portfolio meets all needs.

8 Appendix A

Figure 12: Global schematic showing all architectural stages used in signal conditioning



9 Revision history

Table 3: Document revision history

Date	Revision	Changes
25-Nov-2013	1	Initial release

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