Signal Conditioning
for pyroelectric Passive InfraRed Sensors

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Introduction to pyroelectric passive infrared sensors

Pyroelectric passive infrared (PIR) sensors are frequently used in everyday life. They are a key component in the motion detection and can be used for security systems, automatic doors or automatic lighting. A common application is human detection. When someone is detected in a specified area, these sensors can be used to trigger an alarm or switch on lighting for example.

Active sensors emit energy, such as ultrasound, light or microwaves, and determine a change has occurred when the reflected emitted signal is disturbed. Passive sensors do not emit signals, but rather detect changes in the level of IR radiation. These sensors consume less energy than active ones.

How does the sensor work?

Passive infrared sensors contain two halves that are sensitive to infrared radiation. Since it is motion that is important, the signal delivered by the sensor reflects the difference in the infrared levels detected by each half. This means that as long as both halves see the same amount of infrared radiation, the sensor has not detected any movement. But, if one of these two halves sees a different IR level than the other, the sensor's output will go either high or low.
Figure 1 shows how the output voltage varies when a heat source goes in or out of the area protected by the sensor.

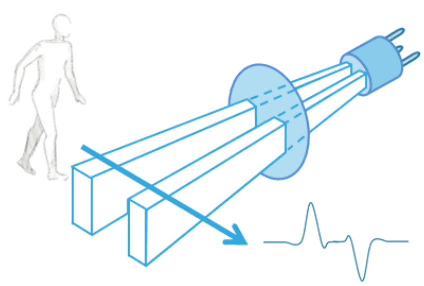

Figure 1: Principle of PIR sensor

The area of the two rectangles that are IR sensitive is small (≈2 mm² for each rectangle). Thus the vision of this sensor has to be improved. That's why it is highly recommended to use a Fresnel lens. It will increase the detection range.

Sensor signal conditioning

When a body with a temperature different than the ambient is moving in its field of detection, the PIR When a body with a temperature different than the ambient level moves across its field of detection, the PIR sensor emits a small AC signal in the range of 1 mVpp. Moreover this small voltage is around a DC signal that may vary significantly from one sensor to another.
Thus it is mandatory to cancel the DC part of the signal and to amplify only the AC part.
As this signal will be disturbed by the environment, noise filtering will also be helpful. ST's operational amplifiers (op amps) will help us perform all these functions.

If we want to detect human motion, we have to consider frequencies from 0.5 to 5 Hz. A TSU102, a dual-channel op amp, is used to amplify and filter this frequency range. Figure 2 shows a schematic.

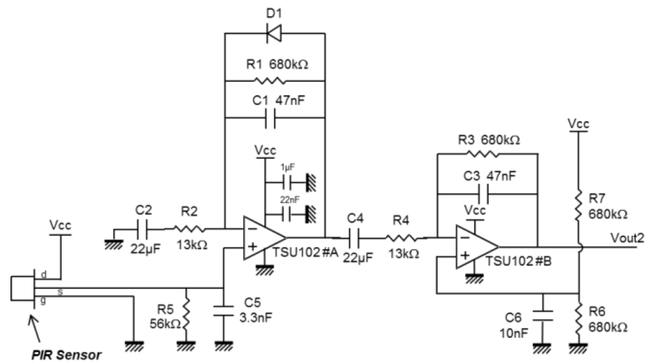

Figure 2: PIR Schematics

The AC signal generated by the PIR sensor is amplified by 69 dB: 35 dB on the first stage and 34 dB on the second one.

ST's TSU102 perfectly meets application needs. Actually, the gain bandwidth product (GBP) must be greater than 2.7 kHz (fmax x gain x 10 = 5x53x10 = 2.7 kHz). The factor 10 has been taken into consideration in order to have some margin and to be sure not to be limited by the GBP. Almost all GBP amplifiers will fit this GBP requirement. In addition, since the DC is cancelled for motion detection, the VIO has no importance.

Finally, if we are dealing with portable applications, consumption is a key factor. The schematic is designed in order to optimize consumption, which is why we are using a TSU102 which consumes only 1.2 µA.
Here, the main consumption is due to the sensor. It consumes 19 µA. The rest of the application consumes 3.6 µA:
1.2 µA by the TSU102 op amp
2.4 µA by the divider bridge composed of R6 and R7.
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.

What about a digital output?

Depending on your configuration, it can be interesting not to have an analog output but a digital output in order to ease the implementation on the microcontroller side.

Thus a last stage can be added to perform a window comparator. When a heat source is detected, the output of U3 or U4 will be at its low state.
Figure 3 shows the schematics of this last stage.

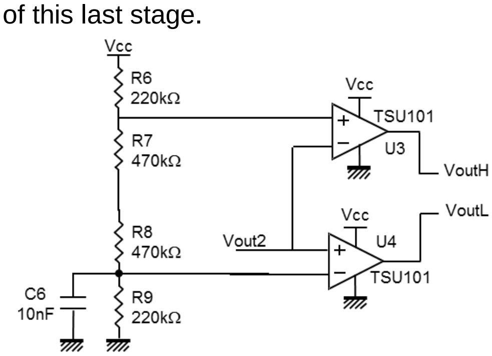

Figure 3: Window comparator stage

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The divider bridge composed of resistors R6, R7, R8 and R9 is used to set the voltage reference of devices U3 and U4. These resistors replace R6 and R7 in Figure 2.
Since the TSU101 is an input/output rail-to-rail op amp, there is no constraint on the input common mode voltage. Thus, while the voltage references of U3 and U4 are within the VCC range, the window comparator will work.

In our case, U3 will have a reference set to 0.84*VCC ((R_7+R_8+R_9)/(R_6+R_7+R_8+R_9)*Vcc=0.84*Vcc). When the signal (Vout2) is greater than this reference, which is equal to 2.77 V if VCC = 3.3 V, the output of U3 will be at its low state, close to the ground.
Similarly to U3, U4 is used to detect when the signal is less than its reference. In this example, its voltage reference has been set to 530 mV thanks to the divider bridge consisting of R6, R7, R8 and R9.
Voltage reference calculation:
R_9/(R_6+R_7+R_8+R_9)*Vcc=0.16*3.3=0.53V
Thus, when the signal (Vout2) is less than 0.53 V, the output voltage of U4 will be in low state.

Thanks to these schematics, we can see that a single quad-channel op amp can be used for this application: one channel for the first stage, another one for the second stage and two others for the last one. This means that by using a TSU104 you only need one active component for the signal conditioning.
Note that the TSU104 is not a comparator, but using an op amp for this function is not an issue at such a low speed.

If you only need a single digital output, you may use a NAND gate connected on the outputs of U3 and U4.

Hardware measurements

This section covers the main points of the schematics that allow the signal conditioning.

First of all we need to know the signal behavior at the output of the PIR sensor. Figure 4 shows this signal. Here, we can see the startup time, but we can't see if someone has been detected.

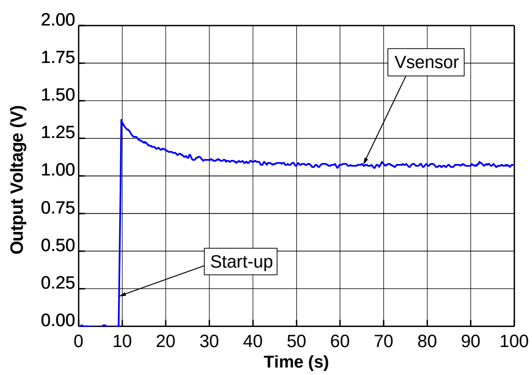

Figure 4: Output voltage of PIR sensor

However, in Figure 5, we can observe the signals after the amplification and the filtering stages. We can clearly see detections here, whereas it was impossible without signal conditioning.

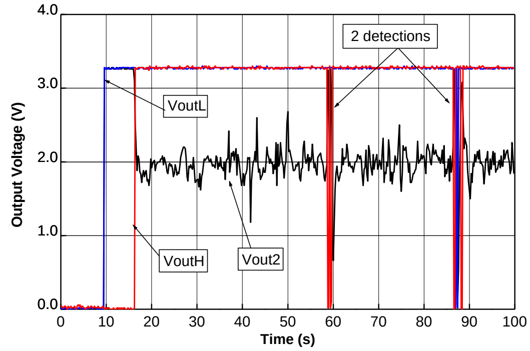

Figure 5: PIR signal conditioning

When motion is detected, output U3 or U4 go low, close to ground. Thus, the output of the global chain can directly be plugged into a microcontroller input. This can be used to trigger an alarm, switch on a light or whatever you would like to do.
Note that an initialization time has to be taken into consideration in order to detect a heat-source motion. It is due to the warm-up time of the sensor and the charge of the capacitors. That's why a proper blank time has to be taken into account at the microcontroller level.

Conclusion

Passive infrared sensors are widely used and require op amps to amplify and filter the signal they generate which is noisy and has a very small amplitude. Op amps can also be used to compare the amplified signal with threshold voltages before sending them to an I/O of the microcontroller (no need for an ADC).
Thanks to the TSU104 (quad-channel op-amp), you can design an application compliant with 3.3 V microcontrollers. The whole analog chain only consumes 24 µA using a TSU104.
STMicroelectronics can provide you with nanopower op amps and comparators for your portable applications as shown in this application note. In addition, if you need a larger bandwidth, a higher output current, a wider VCC range, or even op amps that are automotive-grade compliant, ST's wide portfolio will meet your needs.