COMMON INFORMATION

PIR Motion Sensors

ISL28194 and ISL28915 in Low-Power,
PIR Motion Sensors Prolong Battery Life

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Abstract

Sensor circuits in gas, fire, and burglar alarm systems normally draw their power from the electrical installation of the mains supplies. During power outages however, a sensor circuit's supply switches to battery power to ensure continued system operation until the mains supply is restored. Often this can take days and even weeks. To preserve battery life over this time span, the use of low-power sensors and ultra-low power op-amps and comparators, such as ISL28194 and ISL28915, with nano-amp quiescent currents are required.

This tech brief provides a design example of a signal conditioning stage for a motion detector using a Passive Infrared (PIR) sensor in combination with ultra-low power operational amplifiers and comparators.

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1. Functional Principle and Construction of PIR Sensors

PIR sensors are used for motion detection in security systems, automatic doors, and automatic light control to detect movements. For example, if a moving person or animal is detected in a specified area, an alarm may be triggered or a specific room may be lit. The Infrared (IR) energy, or heat of a moving object, depends on its temperature, color, and texture. This energy is not visible to the human eye, but PIR sensors can detect it.

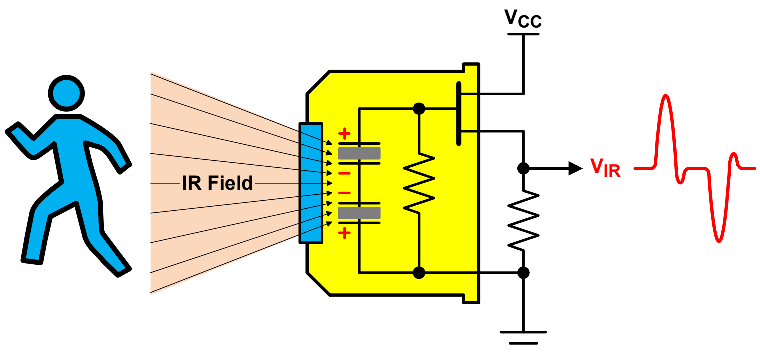

Figure 1. PIR Motion Sensing Principle

A PIR sensor consists of two or more pyroelectric elements that output a voltage proportional to the amount of incident infrared radiation. These elements are arranged in pairs and connected in series so that if each element detects the same amount of IR energy, as in the case of ambient room temperature or no motion, the resulting output is 0V. Figure 1 shows the structure of a PIR motion sensor and its output signal during movement detection.

The output voltage signal results from a moving object having a different temperature than its environment. The movement parallel to the sensor surface and through the field of view of both pyroelectric elements creates a signal amplitude that is proportional to the speed and distance of the object relative to the sensor.

Due to the small physical size of the sensor elements (approximately $2mm^2$ per element), a Fresnel lens is commonly placed in front of the PIR sensor to increase the distance and the field of view (angle) by focusing the IR energy onto the small sensor elements.

An important aspect of the PIR sensor is that upon its initial power up, it can take up to more than 30 seconds for the sensor output to stabilize. During this time, the sensor elements adjust themselves to the ambient background conditions. This long set-up time prohibits the application of power-cycling techniques, otherwise used to minimize battery drainage, and requires the sensor circuitry to be powered continuously.

2. Sensor Signal Conditioning

The sensor output during movement detection is a small AC signal component of typical $3mV_{P-P}$ to $4mV_{P-P}$, superimposed onto a high DC offset of 1V to 2V. To eliminate the DC offset and only amplify the AC component of the signal, two identical first order bandpass filters are connected in series (Figure 2). The filter output of the last stage is then fed into a window comparator. Its upper and lower reference voltage levels form switching thresholds, causing the comparator outputs to switch between VCC and GND, whenever the input signal exceeds either one of the thresholds. This switching action converts the analog input into digital output signals, thus representing a 1-bit analog-to-digital converter. The comparator outputs are connected to the I/O ports of a low-power microcontroller to indicate when motion has been detected.

2.1 Bandpass Filters

Each filter stage has a passband gain of 170V/V for an overall signal gain of 89dB. This gain is chosen to maximize the motion sensitivity range for the sensor bias point being used.

To limit the overall impact of 1/f noise of the analog front end while allowing for a minimum speed of motion that the sensor can detect, the cutoff or -3dB frequency of the high-pass section is set to 0.8Hz. To limit broadband noise, the amplifier's low Gain Bandwidth Product (GBW) of 3.5kHz is used to set the cutoff frequency of the low-pass section to 20Hz.

The first bandpass filter is a non-inverting gain stage that provides a high impedance input to the sensor, which ensures the sensor's bias point remains fixed. At the same time the sensor output bias voltage provides the DC bias for the first filter stage. Because of C_G, this stage has unity gain at DC, preventing the amplification of input offset errors.

The second bandpass filter is an inverting gain stage that is AC-coupled to the first stage. This requires the DC bias to be taken from the center ($V_{CC}/2$) of the bias resistor string, R_{B1} to R_{B4}.

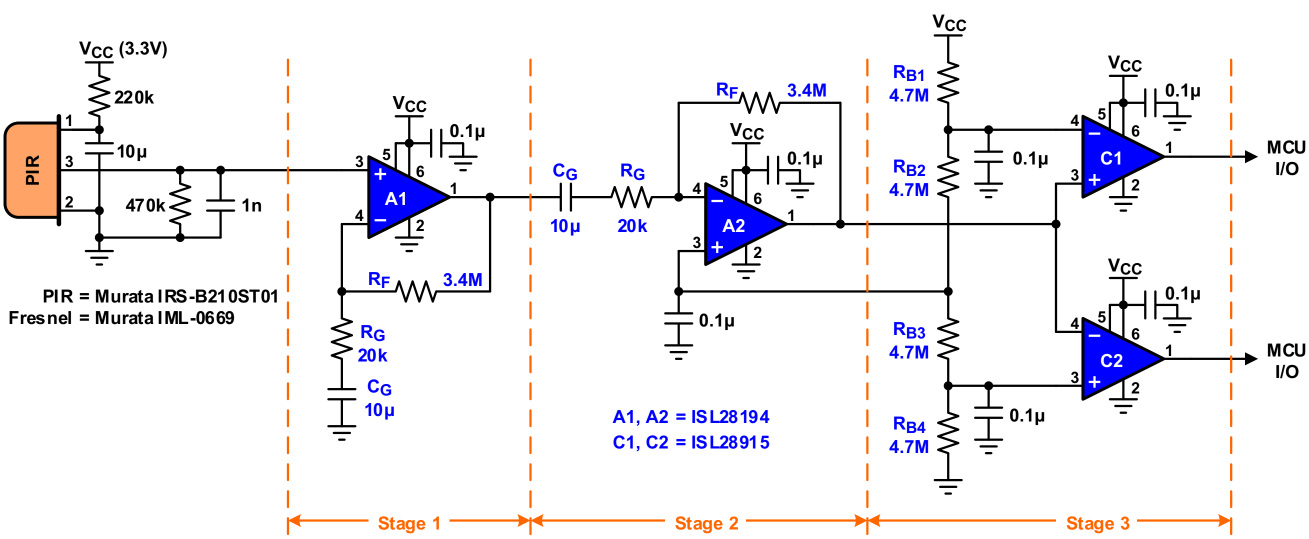

Figure 2. The Signal Conditioning Circuit Comprises a Second Order Bandpass and a Window Comparator

Equations 1 through 5 show the calculations of the gain factors and the cutoff frequencies for the individual filter stages.

(EQ. 1) $$|G_1| = 1 + \frac{R_F}{R_G} = 1 + \frac{3.4M\Omega}{20k\Omega} = 171V/V = 44.7dB$$

(EQ. 2) $$|G_2| = \frac{R_F}{R_G} = \frac{3.4M\Omega}{20k\Omega} = 170V/V = 44.6dB$$

(EQ. 3) $$f_{Low-1,2} = \frac{1}{2\pi \bullet R_G \bullet C_G} = \frac{1}{2\pi \bullet 20k\Omega \bullet 10\mu F} = 0.8Hz$$

(EQ. 4) $$f_{High-1} = \frac{GBW}{|G_1|} = \frac{3.5kHz}{171} = 20.5Hz$$

(EQ. 5) $$f_{High-2} = \frac{GBW}{|G_2|} = \frac{3.5kHz}{170} = 20.6Hz$$

Therefore, total passband gain, G_T, is $G_1 \bullet G_2$ = 29070V/V or 89.3dB.

Figure 3 depicts the ideal frequency responses of the noninverting gain stage (1/β) and the inverting gains stage (1-1/β). Their 20dB/decade rate-of-closure with the open-loop gain (A_{OL}) of the ISL28194 indicate about 90º of phase margin and sound stability. Figure 4 shows the real gain responses of the gain stages, G_1 and G_2, and the total gain, G_T.

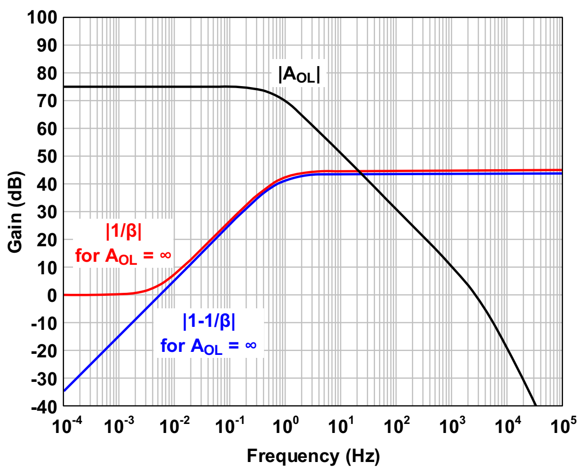

Figure 3. Frequency Responses of A_{OL}, 1/β, 1-1/β

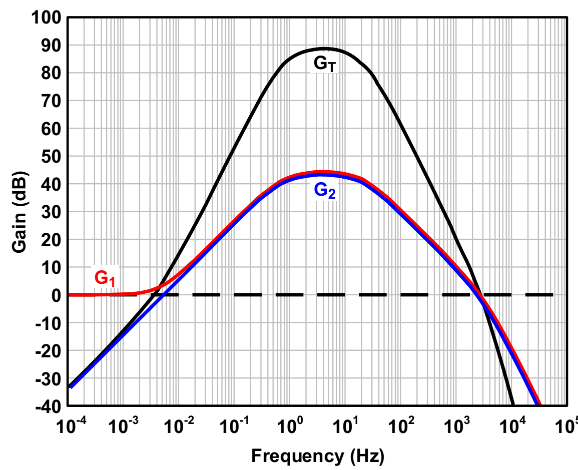

Figure 4. Frequency Responses of G_1, G_2, and G_T

2.2 Window Comparator

The third stage is a window comparator whose outputs signal to a microcontroller when movement is detected by turning the comparator outputs high. Voltage divider action of the bias resistor string, R_{B1} to R_{B4} sets the upper and lower switching thresholds of the comparators V_{TH-H} and V_{TH-L}, and the bias point for the second gain stage.

In the absence of movement, the second filter outputs a voltage between V_{TH-H} and V_{TH-L}, turning both push-pull comparator outputs low. When a heat source approaches, depending on the direction of movement, one of the comparator outputs will turn high first.

The switching thresholds for this sensor are set to $V_{TH-H} = 0.75\ V_{CC}$ and $V_{TH-L} = 0.25\ V_{CC}$. Making R_{B1} through $R_{B4} = R_B$, simplifies the equations for their calculations.

(EQ. 6) $$V_{TH-H} = V_{CC} \bullet \frac{3R_B}{4R_B} = 0.75V_{CC}$$

(EQ. 7) $$V_{TH-L} = V_{CC} \bullet \frac{R_B}{4R_B} = 0.25V_{CC}$$

2.3 Current Consumption

As power consumption is a key feature for battery powered applications, this three-stage architecture for motion detection has been designed for minimum current consumption at 3.3V to be compatible with Renesas low-power microcontrollers. Itemizing the current consumption by components (Table 1), reveals that the sensor current amounts to more than 50% of the total supply current.

Table 1. Supply Currents for V_{CC} = 3.3V

Circuit Path	Supply Current (Idle)
PIR Sensor	1.67µA
2 x ISL28194 Amplifiers	0.43µA
2 x ISL28915 Comparators	0.87µA
Resistor Bias String	0.18µA
Total Circuit	**3.15µA**

3. Conclusion

Battery backed-up motion sensors require ultra-low power amplifiers and comparators to preserve battery life during power outages. The Renesas nano-power amplifier, ISL28194, and nano-power comparator, ISL28915, represent one of industry's lowest-power signal conditioning components.

4. References

For more information on analog signal conditioning for Renesas microcontrollers visit our website.

- ISL28194 datasheet, "Ultra-Small, Nano Power, Rail-to-Rail Input/Output Op Amp"
- ISL28915 datasheet, "Nano Power, Push/Pull Output Comparator"
- IRS-B210ST0 datasheet, "Murata PIR Sensor"

5. Revision History

Rev.	Date	Description
0.00	Mar 16, 2018	Initial release

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