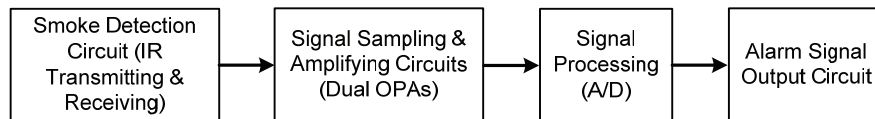


# HT45F23A/HT45F43 Smoke Detector and PIR Applications

D/N: AN0308E

## Smoke Detector Application Description

The HT45F23A is a highly functionally integrated microcontroller whose functions include dual Operational Amplifiers, dual Comparators, an A/D Converter, Serial Communication Interface functions as well as many others. It is very suitable for use in a wide range of applications one of which is smoke detectors which is the subject of this application note. The following block diagram illustrates the smoke detector basic circuit modules.



### Smoke Detector Basic Circuit Functions

Smoke detection methods, taking into account costs and the availability of material have led to the method of using a round labyrinth chamber coupled with optical refraction photoelectric detectors being the most widely used. The so-called optical refraction method is a means of detecting smoke particles using light-emitting components. An infrared light emitting diode (IR TX LED), and an optical component, an infrared receiver diode (IR RX LED) are used. The light-emitting component and the optical component are not face to face in a straight line, but rather as shown in Figure 1. The optical component emit a fixed energy light beam at a predefined period. Ideally, when the chamber is smoke-free, the infrared beam will be parallel to the top of the optical component. In this situation the optical receiver component receives the least infrared energy. When the chamber contains smoke, because of the smoke particle refraction, more infrared energy is received by the optical receiver. By detecting this increase of optical energy we have a means of smoke detection.

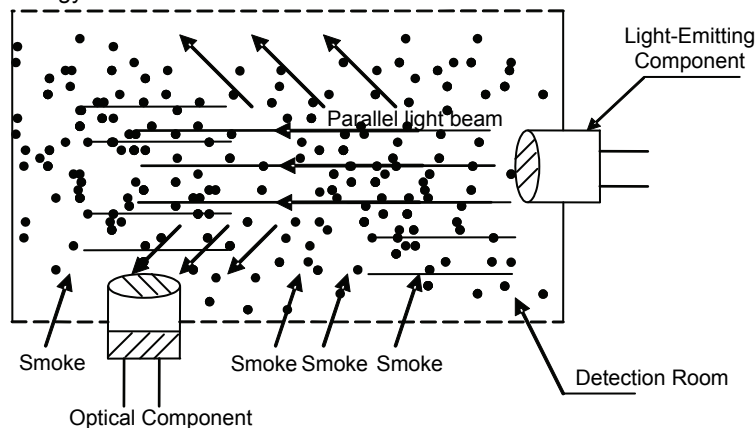
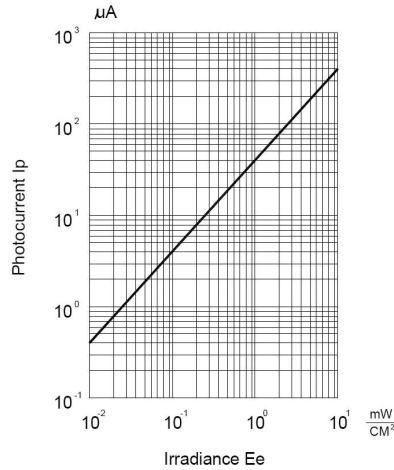


Figure 1. Optical Refraction Smoke Detector Diagram

For the signal sampling and amplifying circuit, the optical component (IR RX LED) signal change is based on the current performance (shown in Figure 2). Therefore a current detection circuit is required which can be implemented using an OPA current-voltage converter circuit. Because the IR RX LED current signal is very small, the output signal from the current-voltage conversion is still too small, however after an OPA amplifier circuit is added, the signal is large enough to be detected by the A/D convertor.

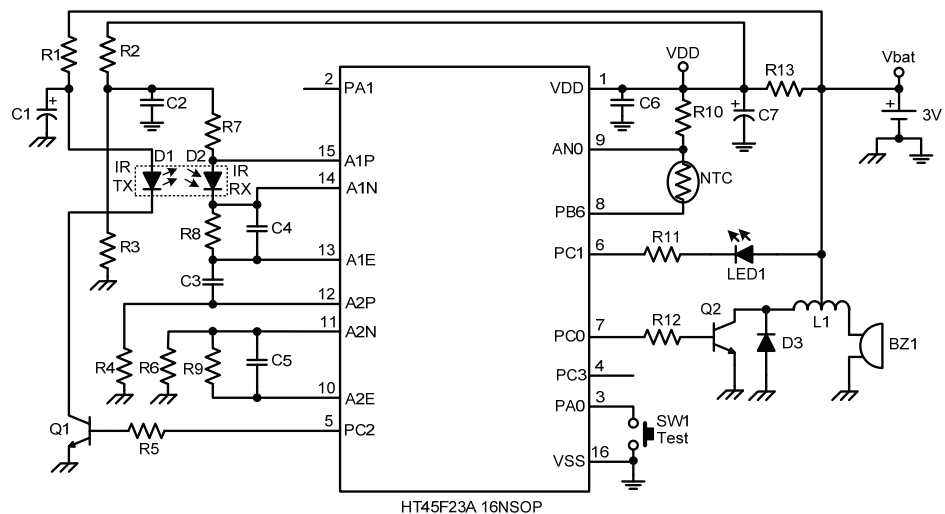


**Figure 2. IR RX LED Characteristic Curve**

With some signal processing, after the signal sampling and amplifying circuits, the user can obtain a voltage signal which is proportional to the smoke concentration. This is then converted into digital data using the HT45F23A analog to digital converter. The digital data generated by the A/D can be process by the microcontroller to determine if the detected smoke concentration should activate alarm circuits such as LEDs, alarm sounds or a message transmitted to a host via a network.

For the alarm signal output circuit, the smoke detector will monitor the amount of the smoke and output an alarm signal, which is a circuit to ensure adequate alarm volume. If the smoke detector is a networking type product, the alarm signal is transmitted to the host and processed by the host.

### Independent Smoke Detector Application Circuit



**Figure 3. Independent Smoke Detector Application Circuit**

In the above HT45F23A circuit diagram, the left side circuit includes:

- Smoke detection circuit: Q1 and D1 (IR TX) comprise an infrared emitter circuit. D2 (IR RX) and an OPA which is contained within the HT45F23A comprise an infrared receiver circuit. D1 and D2 coupled with the chamber comprise a smoke detection circuit. R7 is a limit current resistor for the IR RX LED, R2 and R3 form a voltage divider circuit, which is used to output a DC Bias for OPA1.
- The current-voltage circuit comprised OPA1. The output voltage from OPA1 is determined using R8. Because the D2 output current is very low (nA level), it is better for the R8 resistance to be several M $\Omega$ , otherwise after OPA2 amplification, the signal will be too weak to be converted correctly by the A/D convertor. Additionally, the noise must not be too large, therefore it is better coupled with a low noise OPA such as that in the HT45F23A.
- The small signal amplifying circuit is constructed around the non-inverting amplifier OPA2 whose gain is determined by R6 and R9. R4 is the bias current compensation resistor, whose role is to offset the voltage drop on the parallel resistors formed by R6 and R9. C3 is the coupling capacitor of OPA1 and OPA2, which is used to isolate the DC signal. OPA2, in addition to being a non-inverting amplifier and which is coupled with C5, comprise an integrator circuit, which can smooth transient high frequency signals.

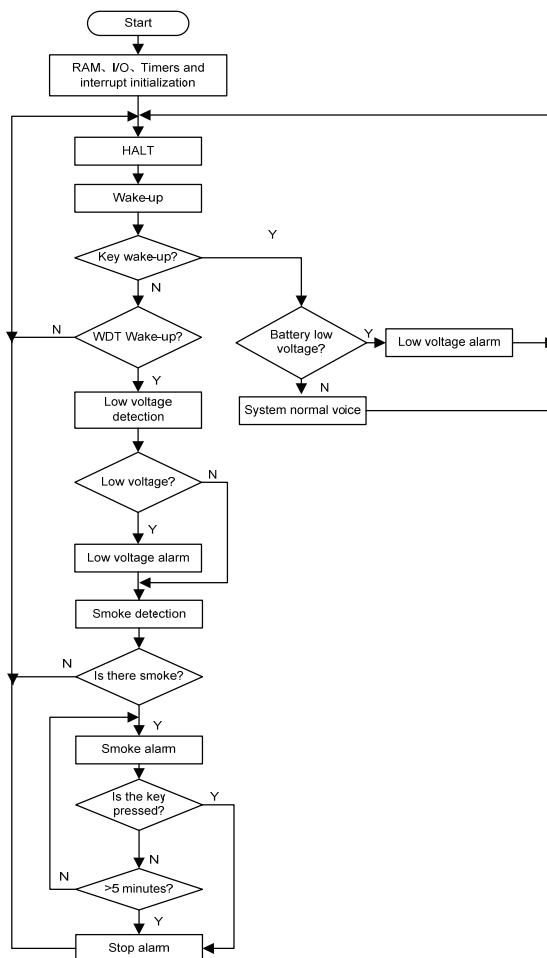
The right side application circuit shows:

- The temperature sensing circuit is comprised of R10 and an NTC sensor. When there is a fire, not only smoke is generated, but also a rise of temperature. Therefore, here an NTC is used to sense the temperature. When the temperature is greater than 35°C or 40°C, it will be assumed that a fire has started and the alarm circuit can be activated.
- The alarm circuit is comprised Q2 and BZ1. When the amount of the smoke is greater than some predefined value or the room temperature is greater than 35°C, the alarm will be on warning people to take proper action.
- The status display circuit is comprised of R11 and LED1. It is used to display the smoke detector operation status, the alarm status and any low voltage condition.
- The Test Key is SW1. A smoke detector, after installation, should not require battery changing for about 1~2 years. But if there is not regular checks and maintenance, it will become useless when a fire starts. For this reason a test key is used to check the unit.
- The power anti-crossover circuit, is composed of R13, C6 and C7. When D1 (IR TX) is on, the high current generated by Q1 and D1 could affect power stability. To prevent this, the electrolytic capacitor, C7, has a large capacitance value and is used to stabilise the power, otherwise the HT45F23A may not operate correctly due to a reduction of VDD. Therefore, R13 and C7 are mainly used to reduce power supply drops generated by D1 during infrared emission. R13 and C6 are used to reduce any high frequency noise generated from the circuit or external environment.

**Independent Smoke Detector Control Flow**

The independent smoke detector control flow is shown in figure 4.

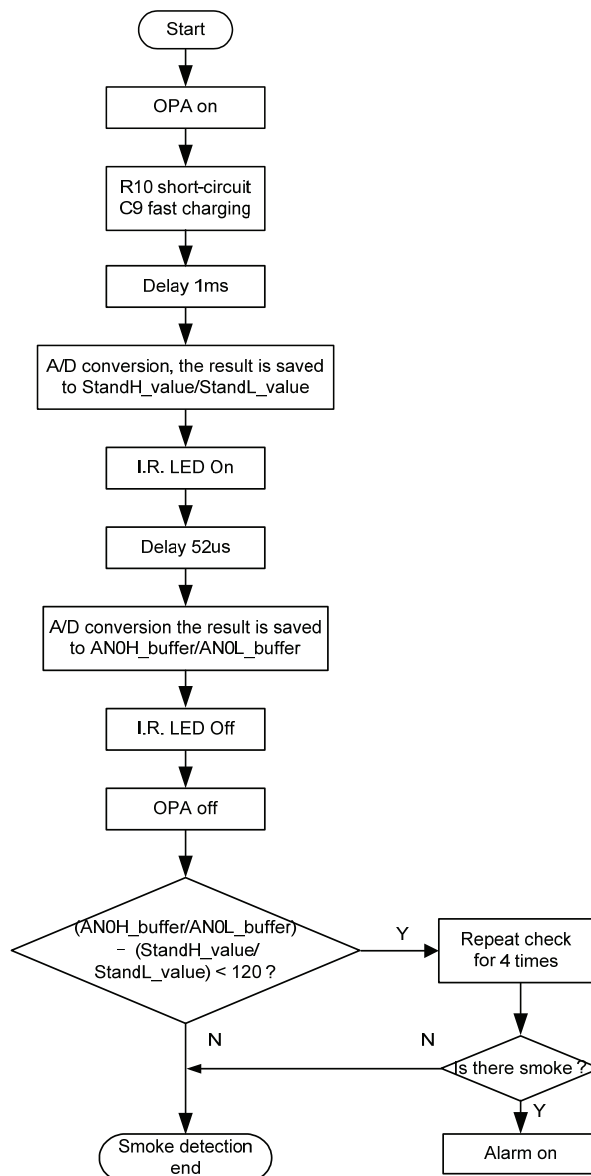
- After power on, the I/O ports, RAM, timer and interrupt etc. will be initialised and after this the system enters the standby mode.
- After a wake-up, first check if SW1 is pressed and if it is a key wake-up ? If it is a key wake-up, the system enters the test mode, and then the following will occur:
  - A low voltage detect. The internal LVD within the MCU will detect the battery voltage status and then the system will proceed accordingly.
  - If a battery low voltage is not detected, the system will issue a normal sound, and then enter the standby mode.
  - If a battery low voltage is detected, the system will issue an alarm, and then enter the standby mode.
  - If it is not a key wake-up, then check if it is a WDT wake-up.
  - If it is a WDT wake-up, the system will enter the normal operating mode.
- In the normal operating mode, the following will occur:
  - If there is a battery low voltage detection, the system will issue an alarm, and then enter the smoke detection status.
  - When the battery voltage is normal, the system will enter the smoke detection status directly. If smoke is detected, the system will issue an alarm, which will not stop until the key is pressed or the alarm time is greater than 5 minutes, and then enter the standby mode.
  - c. If it is neither a key wake-up nor a WDT wake-up, the system will enter the standby mode again.



**Figure 4. Independent Smoke Detection Control Flow**

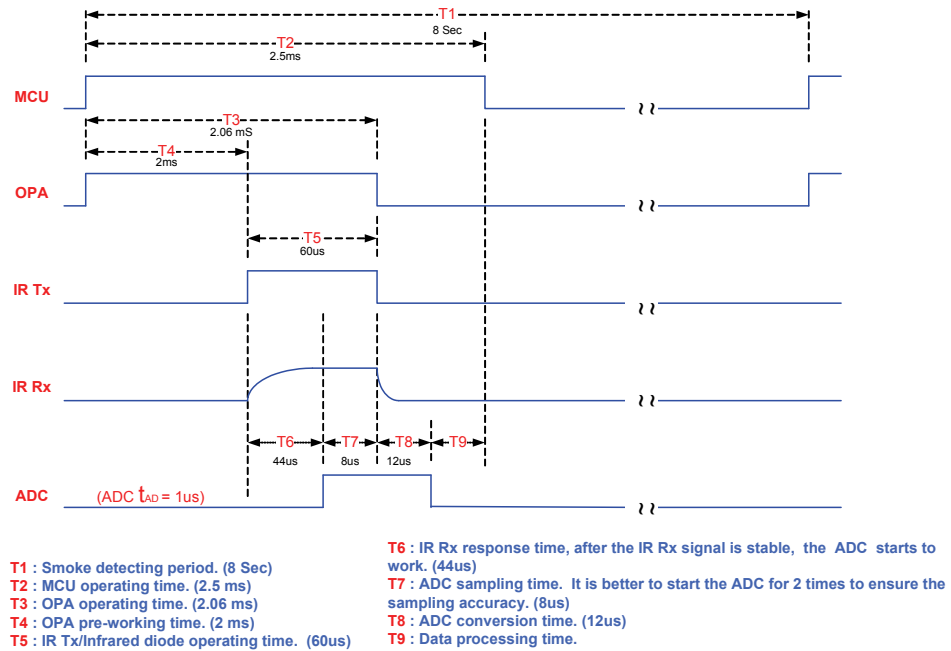
**Smoke Detection Flow**

The smoke detection module uses the OPA, ADC and other functions within the HT45F23A. The smoke detection circuit includes an infrared emitter circuit, infrared receiver circuit and a chamber. The amount of ambient smoke is judged by the infrared signal received during detection. The infrared signal is amplified separately by the dual level OPAs in the HT45F23A and then converted into digital data. During detection, the detection interval is 8s and the received data is checked a number of times to reduce the possibility of erroneous detection. When detecting smoke, the system will issue an alarm, and at that time, the buzzer alarm and LED flashing will be activated alternately. After the warning stops for 0.5s, its starts again and the action is repeated. The buzzer has four alarm sounds. After the first sound finishes, the second sound will start and so on. After all the four alarm sounds have finished, the first sound will start again and so on. When the alarm is issuing a warning, if the key is pressed or the alarm time is greater than 5 minutes, the alarm stops.



**Figure 5. Smoke Detection Flow**

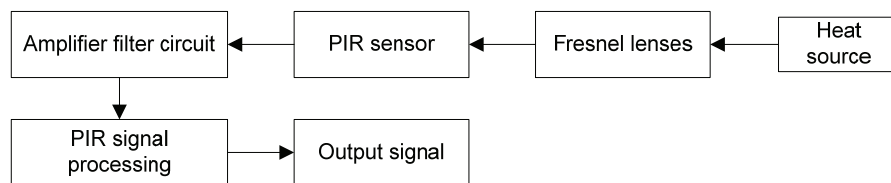
**Smoke Detection Timing**



**Figure 6. Smoke Detection Timing**

**PIR Application Description**

The HT45F23A is a highly functionally integrated microcontroller whose functions include dual Operational Amplifiers, dual Comparators, an A/D Converter, Serial Communication Interface functions as well as many others. It is very suitable for use in a wide range of applications one of which is PIR applications which is the subject of this application note. The following block diagram illustrates the PIR basic circuit modules.



**Figure 7. PIR Block Diagram**

## **PIR Product Block Functions**

### **PIR Sensor Theory and Characteristic**

- **Passive Infra-Red detector operation theory and characteristics**

In nature, any object with an absolute temperature above (-273K) will generate an IR spectra. Objects with different temperatures release different infrared energy wavelengths. This means that, both the infrared wavelength and the radiation energy are related to the temperature on the object's surface.

The human body has a constant temperature, generally around 37°C, and will emit an infrared wavelength of about 10mm. A passive infrared sensor operates by detecting the emitted human body infrared signal. By using an enhanced Fresnel optical filter the infrared is concentrated to the pyroelectric component, which will lose its charge balance and release its charges when it receives a changing body infrared radiation. These charges will be detected and processed and the alarm activated. A passive infrared sensor contains two series or parallel pyroelectric components with two opposite directional electrodes (shown in the side view of C @Figure 8). As the pyroelectric effect from the two pyroelectric components will cancel out because of the ambient influence, no detect signal is generated.
- **Passive Infra-Red Sensor strengths and weaknesses**

Unlike active infrared sensors, passive infrared sensors do not release any radiation and are can therefore be hidden. They also consume very little power and are inexpensive. However they have the following disadvantages:

  - Small signal amplitude therefore easily vulnerable to heat and light interferences
  - Poor passive infrared penetration where human body infrared radiation is likely to be blocked and not received by the sensor
  - Vulnerability to RF radiation interference
  - When the ambient temperature is close to body temperature, the detection sensitivity will decrease significantly, sometimes resulting in short-term failure.
  - The passive infrared detector detects mainly moving objects moving in a horizontal direction, but is not good at detecting moving objects in a radial direction.

### **Fresnel lens**

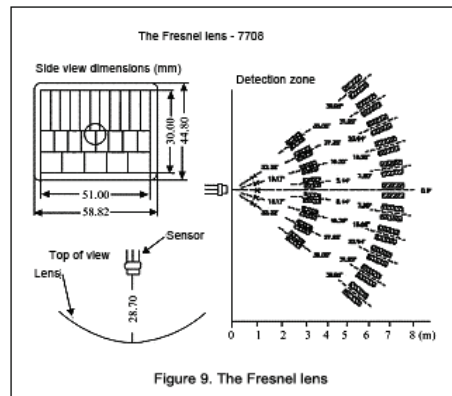
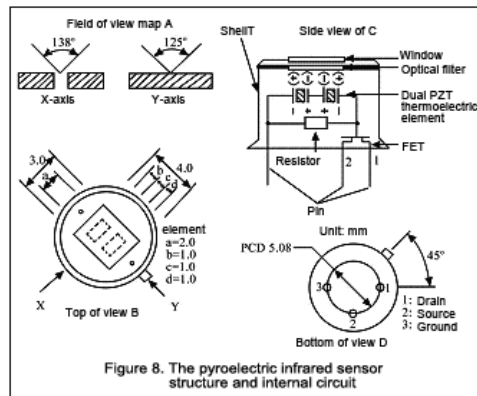
The Fresnel lens (Figure 9) is made according to Fresnel theory. This divides the infrared into a visible area and a blind area, while with focusing effect, so the passive infrared sensor (PIR) sensitivity is greatly increased. The Fresnel lens has two forms, refracting and reflecting. Firstly, for a focusing effect, the pyroelectric infrared signal is refracted (reflected) in the PIR; Secondly, the lens divides the detection area into several bright zones and dark zones, so that when moving objects in the detection area can generate changing pyroelectric infrared signals in the PIR in the form of temperature changes, the PIR can generate corresponding changing electrical signals.

If an appropriate resistor is connected to the pyroelectric infrared component, when the component is heated, a current flows through the resistor and a voltage is generated across the resistor.

The Fresnel lens is a lens with equidistant ridges in its side, in which a specified optical band-pass range is reflected or refracted. Traditional polished equipment and band-pass optical filter mirrors are very expensive while using a Fresnel lens can greatly reduce costs, such as in passive infrared sensor-PIRs which are used widely in detectors. Upon examination, it can be seen that every PIR has a little plastic hat, which is the Fresnel

lens. There are ridges in the little hats. The Fresnel lens can limit the frequency peak of the incident light to about 10 microns and the cost is quite low.

The Fresnel lens main function is to focus the infrared into a detection space on the detection sensor. The infrared is focused by concentric narrow band circles on the lens or window, which is the role of the convex lens. These selections are also determined by the lens narrow band design and materials. Considering the lens parameters: luminous flux, lens concentric level, uneven thickness, the concentric level of the lens optical axis and the shape, through rate, focal length error and so on, the Fresnel lens narrow band or window are generally not uniform, which is divided into a few rows from top to bottom, more above, less below, denser in the middle and sparser on both sides. The infrared radiation on the human face, knees and arms is strong, and these body parts just face the top lens. However there is less with the bottom lens because the lower body infrared radiation is weaker and secondly, it is necessary to prevent interference from small animals on the ground. The material used tends to be plexiglass.

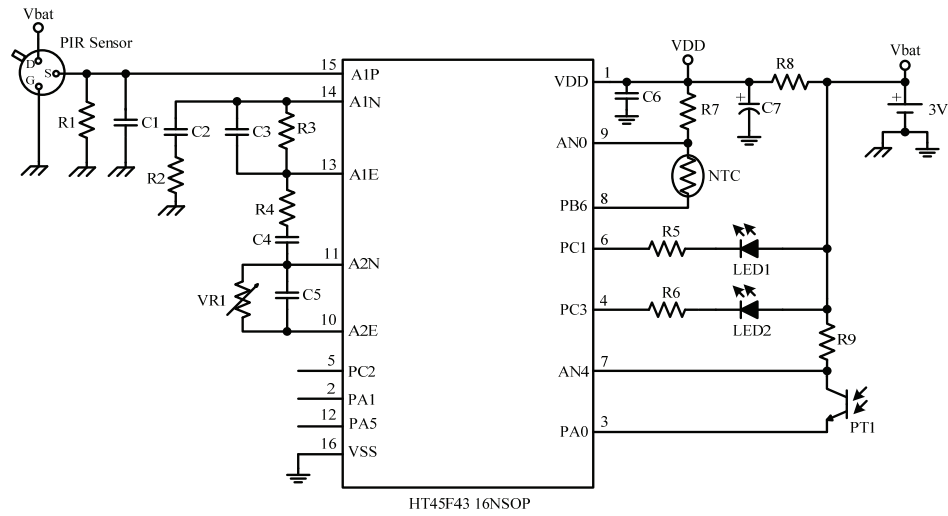


**The main system structure in pyroelectric infrared sensors include three parts: the pyroelectric infrared sensor, the Fresnel focusing lens and the signal amplifying and processing circuit.**

- Pyroelectric infrared sensor: a special type of PN semiconductor manufacturing process. It can sense infrared heat energy, the temperature of which is above absolute temperature (-273C° in the environment. The higher the sensing temperature is, the higher voltage on the sensor output.
- Fresnel focusing lens: because the pyroelectric infrared sensor window is not large, if the user wishes to enlarge the sensing range, the infrared heat energy in the area is focused by the lens, which can increase sensing range and sensitivity.
- Signal amplifying and processing circuit: when the pyroelectric infrared sensor detects human bodies moving in the sense area, the sensor voltage will change from 0.05mV to 0.5mV. Because the voltage is too low to be detected, it requires amplification. After this an internal comparator will compare if the voltage is greater than an internal predefined value of VH: 2.2V, VL: 1.1V, and set a trigger time. The system will drive a Relay and Triac output to activate an external lamp or activate an alarm.



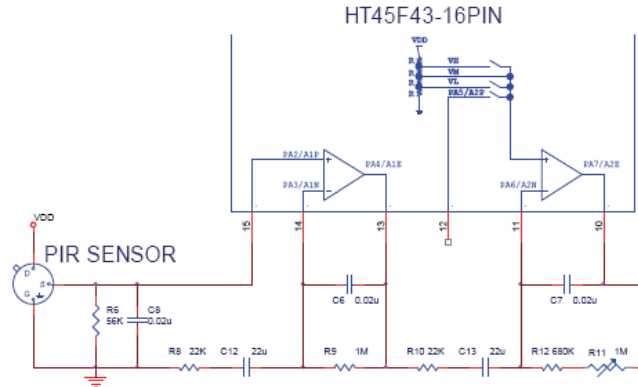
**PIR Application Circuit**



**Figure 10. PIR Application Circuit**

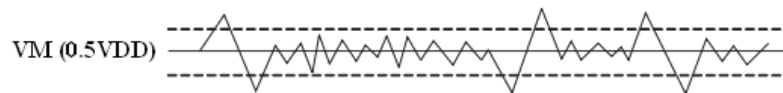
**PIR Signal Amplifying Circuit**

After the PIR output signal is amplified by the non-inverting op-amp OPA1 and then further amplified by the inverting op-amp OPA2. A 0.5VDD voltage is register selected and provided to the anode of op-amp OPA2 anode and then amplified by OPA2. This amplified analog signal is then converted into a digital signal by the A/D converter and the corresponding digital signal processed by the MCU.



**Figure 11. PIR Signal Amplifying Circuit**

When detecting moving human bodies, the op-amp OPA2 output signal fluctuates around 0.5VDD as shown in the following diagram:



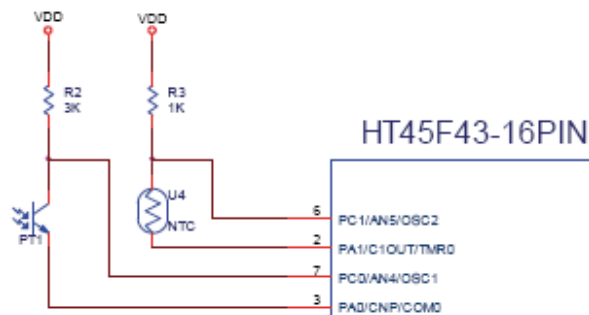
**OPA2 Amplifier**

**Figure 12. PIR Amplifying Signal Waveforms**

By adjusting the op-amp OPA2 magnification and the R11 resistance value, the OPA2 output signal is amplified and the PIR sensitivity is enhanced and the PIR detection distance is increased.

## Ambient Temperature and Light Detection Circuit

- Ambient temperature detection circuit: R3, U4 (NTC) and the MCU comprise the temperature detection circuit. When operating, the PA1 output is low and AN5 detects the divided voltage on the NTC, which is the temperature detect signal; When not operating, the PA1 output is high to reduce power consumption.
- Ambient light detection circuit: R2, PT1 and the MCU comprise a light detection circuit. When operating, the PA0 output is low and AN4 detects the divided voltage on the phototransistor PT1. By examination of the phototransistor characteristic it can be seen that, when the light intensity is strong, the divided voltage on PT1 is low. When the light intensity is weak, the divided voltage on PT1 is high which is the light detection. When not operating, the PA0 output is high to reduce power consumption.



**Figure 13. Ambient Temperature and Light Detection Circuit**

## LED Indicator Circuit

The LED indicator light functions include a PIR alarm, a low battery voltage indication and a power-on configuration indication.

The LED specific indicator functions are as follows:

- Power indication red LED1
  - After power-on, all configurations are setup within 10s and LED1 is on for 10s.
  - When the battery voltage is low LED1 is flashing.
- Signal indication - white LED2
  - When the system detects a PIR motion, the signal indication white LED2 will be on for 2s.
  - When the ambient light is greater than the predefined value or the battery voltage is low, LED2 remains unchanged.

Two MCU I/O lines are used to control LED1 and LED2 separately. When the HT45F43 operating voltage is 3V, the I/O pin source current typical value is about 4mA while the sink current typical value is about 12mA. Therefore the sink current is higher. Thus, when the I/O ports are used to drive an LED, the sink current is generally used as shown in Figure 5-8. When the I/O output is low, the LED is on and when the I/O output is high, the LED is off. The LED current is determined by the LED operating voltage and the current limiting resistor. Note that different colour LEDs have different LEDs voltages. The LEDs can operate at an appropriate light intensity by adjusting R4 and R5. When the system is powered down the LEDs will be switched off to reduce power consumption.

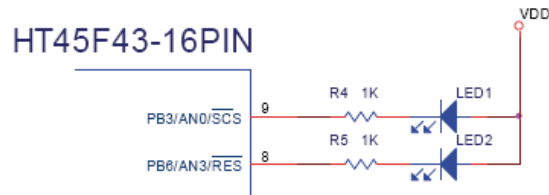


Figure 14. LED Indication Circuit

### PIR Main Program Control Flow

After power-on, the system will initialise the configurations. During this configuration time, the power indicator red LED will be on for 10s. The system will then be ready to detect low voltages, ambient temperature, ambient light intensity and PIR motion. Generally, when the PIR sensor does not detect human body motions, the system enters the power down mode. There are three wake-up methods, a low battery voltage, a PIR motion and a WDT overflow. After wake-up, the system will continue to detect low voltages, ambient temperature, ambient light intensity and PIR motion. When there is a low battery voltage, the power indication red LED will flash. Not until the low battery voltage condition disappears will the system begin another detection or an ambient temperature detection and set a reference valid value for PIR measurement. When detecting the ambient light intensity, when it is discovered that the ambient light intensity is greater than a predefined value or a low battery voltage, LED1 will remain unchanged. When a PIR motion is detected, the white LED1 will be on for 2s and the intrusion alarm will be activated. Conversely, if there are no PIR motions, the system will enter the power down mode to reduce power.

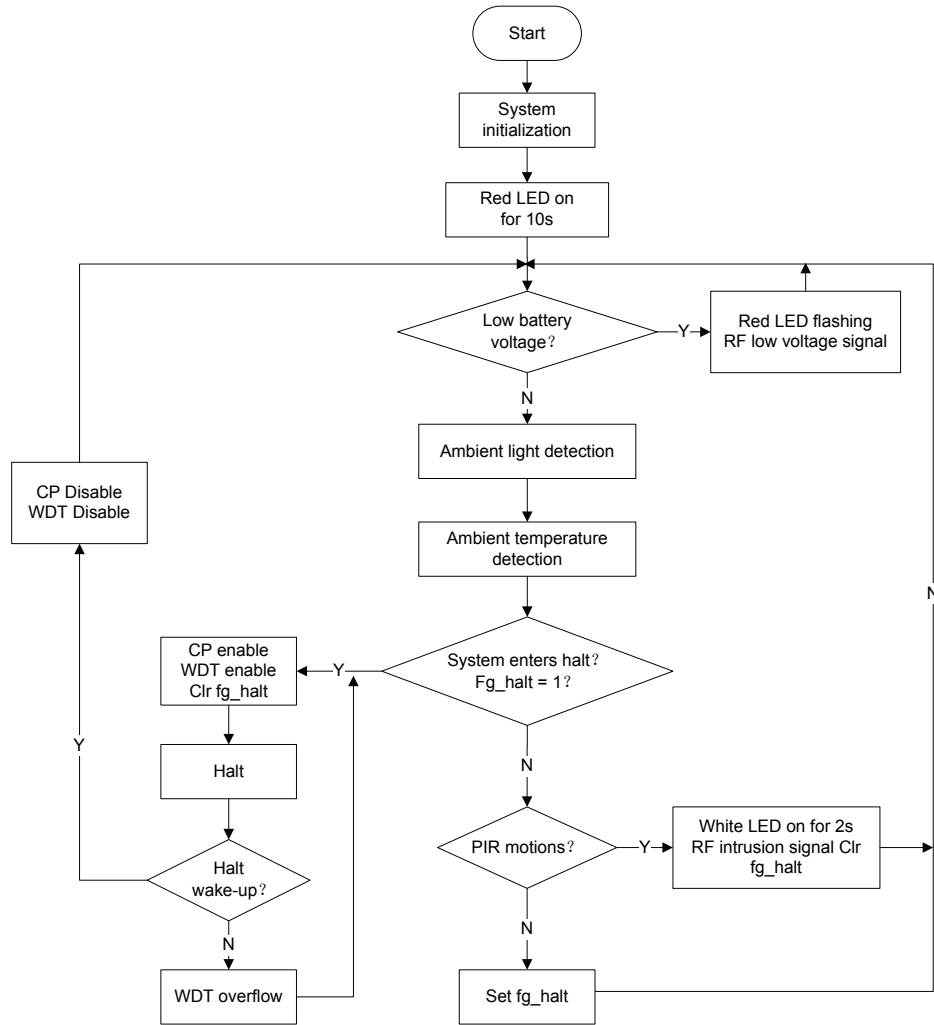


Figure 15 PIR Control Flow

**PIR Detection Flow**

By sampling the amplified PIR signal, the system will detect if the PIR signal is greater than  $c\_VAD\_H$  or less than  $c\_VAD\_L$  within a 1.5s time period. The  $c\_VAD\_H$  and  $c\_VAD\_L$  values are defined as system constant reference data values, where  $c\_VAD\_H$  is greater than  $0.5V_{DD}$  and  $c\_VAD\_L$  is less than  $0.5V_{DD}$ . These can be adjusted to change the PIR detection sensitivity to a certain extent. If the data is too close to the reference voltage value,  $0.5V_{DD}$ , then system malfunctions may occur. If it does not detect a signal which is greater than  $c\_VAD\_H$  or less than  $c\_VAD\_L$  within a 1.5s timer period, then the system will judge it to be a “no PIR motion” and enter the power down mode to reduce power. When it detects a signal which is greater than  $c\_VAD\_H$  or less than  $c\_VAD\_L$  within 1.5s, and the system continues to detect this signal for a fixed time (hereafter known as the pulse width), then according to the pulse width size, the system will determine if an intrusion has occurred and the white LED will be on for 2s and the intrusion alarm will be activated. The two cases are following:

- The single signal pulse width is greater than 0.5s
- Within a 2s period if two generated signal widths greater than 24ms are detected and the interval between the two signals is greater than 0.5s. If a pulse width less than 24ms is detected within 1.5s, the system will enter the power down mode. When it detects a pulse width greater than 0.5s within 1.5s, the alarm will be activated. The system will restart to continue detecting again PIR signals within a 1.5s period until no PIR valid signals are received at which point it will again enter the power down mode. When detecting pulse widths greater than 24ms but less than 0.5s and judging whether it is the first signal within a 2s period, if  $fg\_1st\_pulse$  is cleared to 0, then this means that it is the first signal within 2s. The system will then set  $fg\_1st\_pulse$  to 1, and after 0.5s, the system will continue to monitor for the next 1.5s to see if there are any pulse widths greater than 24ms. If  $fg\_1st\_pulse$  is set to 1, then this will be taken as an intrusion motion and after the alarm has been activated, the system restarts to continue to look for PIR signals. If no signals are detected the system will enter the power down mode once again.

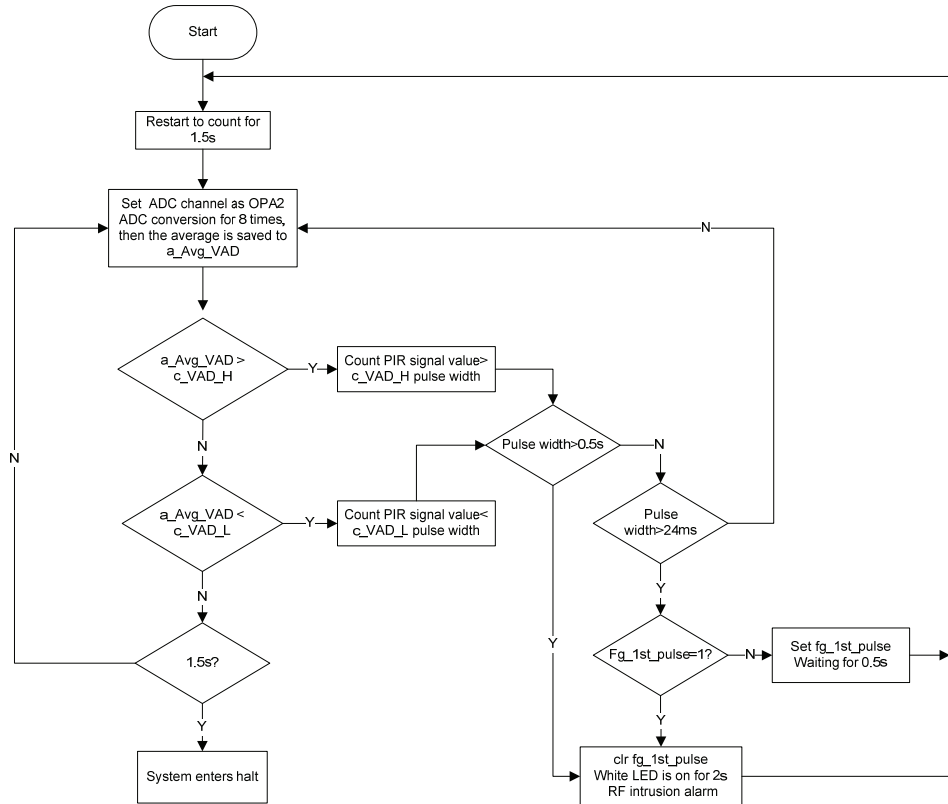
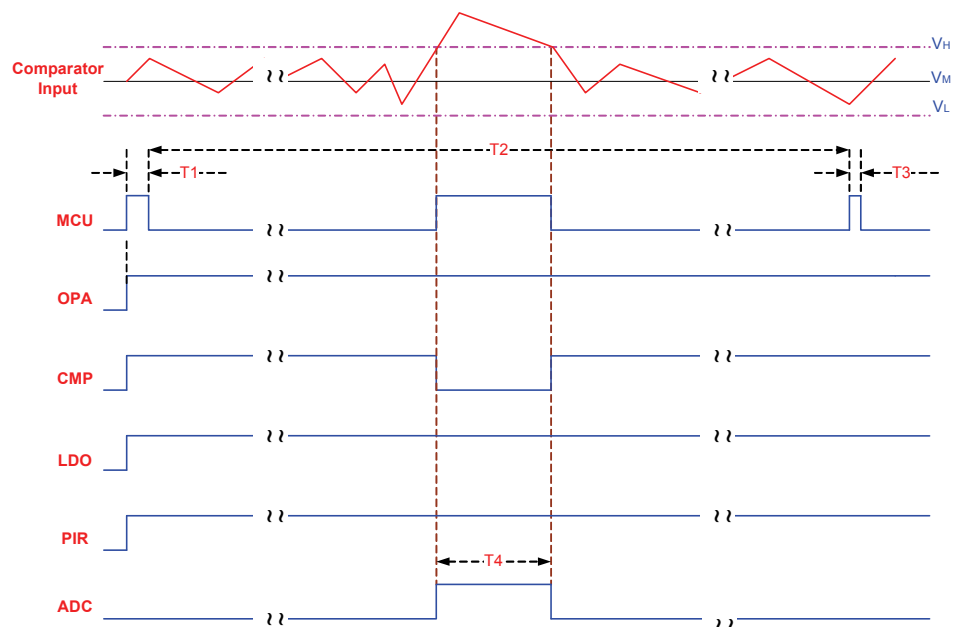


Figure 16. PIR Detection Flow

### PIR Detection Timing



- T1 : After MCU Power on initial , then entering the standby mode.
- T2 : MCU detection LVD interval. (60S)
- T3 : MCU detection LVD time. (100uS)
- T4 : When the comparator Input > VH or The comparator Input < VL, the CMP interrupt occurs and MCU wake-Up, then the ADC is restarted to analyze the PIR signal, during, when the comparator is off. ( < 1S )

Figure 17. PIR Detection Timing