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# Improvement of Ir Proximity Sensor Based on Digital Simulation Mixed Subtraction Circuit

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**Abstract:** This paper analyses the working principle of infrared proximity sensor, puts forward an efficient environmental noise suppression method for the problem that the test results are susceptible to environmental noise impact. The method is based on digital simulation mixed subtraction circuit, through the optical coating filter to filter out noise environment step by step, filtering background current and dark current in the total current of the PD from the IR LED so as to realize the accurate detection of the sensor. On the basis of detailed analysis of the method, this paper designs the related sensor circuit. The circuit can filter the ambient noise with maximum background light of 4000 lx and temperature of 85. Implements the accurate determination of proximity degree of the objects within the scope of 25 cm. Spectre simulation results show that after filtering out the noise, it is close to the detect output value and the ideal value (that is, the background light of 0 lx), and the error is less than 1 %. The designed circuit has been verified under 0. 35 μm 3 V CMOS, the results meet the design targets. *Copyright © 2013 IFSA.*

**Keywords:** Mixed digital simulation subtraction circuit, Ir proximity sensor, Ambient noise rejection.

## 1. Introduction

Proximity sensor has been successful in industrial, medical, and aerospace and other fields [1], now it witnessed another success on the consumer electronics market. Proximity sensor according to its basic principle is divided into inductance type, capacitive type, magnetic inductive type, photoelectric type and ultrasonic type, etc. [4]. Ir proximity sensor is widely applied in portable handheld devices such as mobile phones, personal digital assistant (PDA). Ir proximity sensor adopts PD (photodiode) which is compatible with CMOS process [5], To integrate the photoelectric detection unit and the signal processing unit in the same chip, in order to reduce the circuit cost and power consumption. By PD detection of light power of the reflected infrared LED (light emitting diode) by the object, determine the degree of closeness of the objects.

Since the IR proximity sensor works under the condition of sunlight and background lights, reflected signals of tested content are faint and easy to be submerged in the complex background noises. And with the increase of temperature, the PD dark current index increases, even bigger than the photoelectric conversion current, so it is unable to accurately detect the degree of closeness of the objects. Traditional practice is to use large current to drive LED and increase the luminous intensity of LED, or keep the chip work under low temperature, thus inevitably increase the power or limit the scope of the chip. Based on the environmental noise problems of background light and dark current of the IR

proximity sensor, this paper puts forward a method of highly restrain of the influence of environmental noise, filter out ambient noise step by step through optical filtering and subtraction circuit [3], and the related circuit is designed.

## 2. Basic Principle of Infrared Proximity Detection

Infrared proximity sensor is mainly composed of infrared LED, PD and signal processing units. Its basic working principle [6] is shown in Fig. 1: Infrared LED sends a bunch of infrared signal to the detected objects, part of the signal will bounce back and sensed by PD sensor to produce the photocurrent which is in direct proportion to the degree of closeness of the object and the magnitude of detected infrared light. Through signal processing and analog digital conversion on the chip, digital infrared signals can be sent to the MCU (micro control unit) for post-processing and then used for various proximity detections.

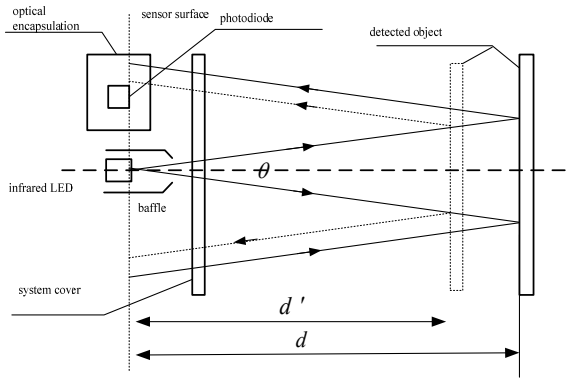


**Fig. 1.** Basic principle of infrared proximity detection.

Specific relationship between light current and degree of closeness of objects is as follows: Suppose the light wavelength sent by infrared LED is $\lambda_{LED}$, radiation flux is M, real output is $P_\circ$, scattering angle is $\theta$, infrared reflectivity of the detected object to the wavelength is $\alpha$, penetration rate of optical encapsulation and system cover is T, distance between the detected object and sensor surface is d. By the definition of radiation flux density, radiation flux of infrared LED sensed by photodiode is:

$$E = MP_\circ T^2 \alpha / [\pi (2d \tan(\theta / 2))^2] \quad (1)$$

The received power of photodiode is:

$$P = EA_{PD}, \quad (2)$$

where $A_{PD}$ is the area of the photodiode, light current of the photodiode is:

$$I = PR(\lambda_{LED}), \quad (3)$$

where $R(\lambda_{LED})$ is the responsibility of photodiode to wavelength $\lambda_{LED}$, by equation (1)-(3), the relationship between the photocurrent and distance can be obtained:

$$I = f / d^2, \quad (4)$$

where f is the invariant.

$$f = MP_\circ T^2 \alpha A_{PD} R(\lambda_{LED}) / [\pi (2 \tan(\theta / 2))^2] \quad (5)$$

By equation (5), it can be obtained that f is related to factors as photoelectric diode area, radiant power of infrared LED. By equation (4)-(5), the relationship between photocurrent, distance, radiant power of infrared LED and photoelectric diode area is obtained. Through the relationship, the required parameters can be set reasonably according to application requirements.

The light current [2] produced by PD theoretically under unit light is:

$$I = A_{PD} \int_0^\infty P_\lambda P_\lambda T_\lambda d\lambda, \quad (6)$$

where $P_\lambda$ is the light source spectral irradiance, $T_\lambda$ is the coating penetration rate, $R_\lambda$ is the spectral response of PD, by equation (6), it can be obtained that:

$$I \approx A_{PD} \sum_{i=1}^{n} P_{\lambda_i} P_{\lambda_i} T_{\lambda_i} \Delta\lambda, \quad (7)$$

where $\lambda_i = \lambda_1 + (i-1)\Delta\lambda$, $\lambda_1$ is the first wavelength of the known spectral data points, $\Delta\lambda$ is the difference between the i$^{th}$ wavelength and the i-1 wavelength, i is the serial number of spectral data points, $P_{\lambda_i}$, $T_{\lambda_i}$, and $R_{\lambda_i}$ are respectively the light source spectral irradiance, coating penetration rate and the value of spectral response of PD when $\lambda = \lambda_i$. By equation (7), the responsibility of photodiode on the light source can be approximately obtained. And then the light current produced by ambient light is obtained, and it is used for the design of the related parameters on filtering noise circuit.

Proximity sensor works under sunlight or background light, PD responses to LED infrared light reflected back by the object and also responses to the background light at the same time. Infrared light

reflected back by the object is submerged in complex background noise of light, thus may not be able to detect the proximity of the objects. For photodiode, optical filming is used for filtering out the light beyond infrared band of the background light to reduce background noise. But the effect of infrared light of background light on the proximity detection can not be eliminated. The spectral response of sunlight is very wide [7], about 50 % of spectrum falls within the range of infrared light and incandescent lamp also has high infrared radiation. When the infrared radiation power of LED is low or distance between the object and sensor is far, the infrared light of the background light generates light current too large that leads to sensor detection error. And PD dark current and light generated photocurrent is hard to distinguish, so the infrared light and dark current problems seriously affect the accurate detection of the sensor. This study using subtraction circuit of sequential control to shutdown current of infrared LED, which is to filter out the background current and dark current of the total current of PD in order to realize the accurate detection of sensor. First minus background current and dark current of the total current produced by PD, through analogue-to-digital conversion feedback current, reduce the noise current ratio. Then through the sequential control, subtract testing result with LED light and without LED light, after two times of subtraction, the noise current is filtered out and accurate result of proximity detection is obtained.

## 3. Circuit Design

System structure of the sensor is shown in Fig. 2. Circuit is mainly composed of PD and current control module, ADC (analog digital converter) and DAC (digital to analog converter), timing control circuit and the LED driver circuit, etc.

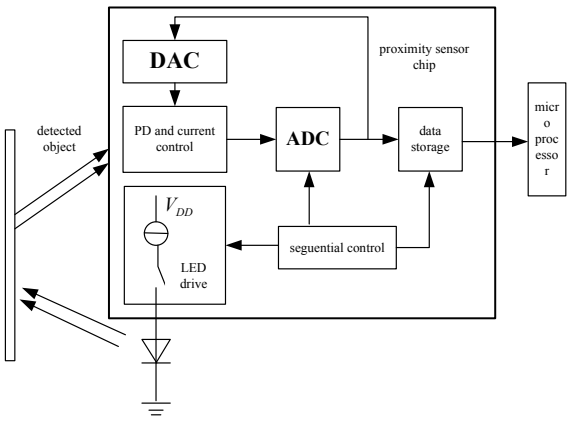


**Fig. 2.** System structure of proximity sensor.

### 3.1. Photodiode and Current Control Module

Photoelectric diode and current control module are shown in Fig. 3.

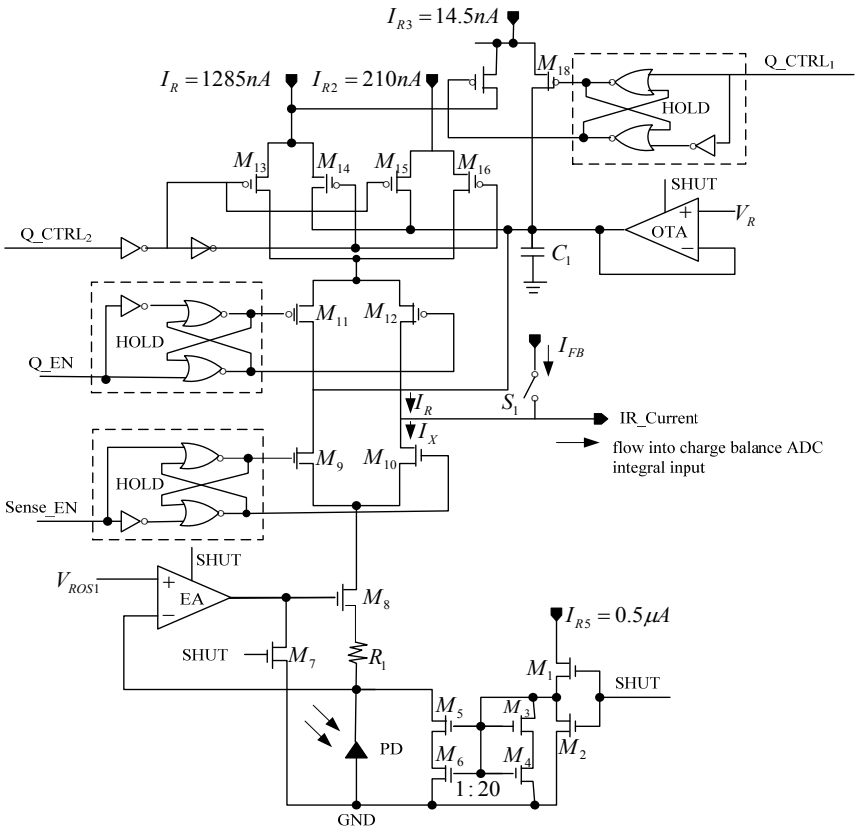


**Fig. 3.** Photodiode and current control module.

The module realizes the photoelectric conversion through the PD reversal of biasing. To make the PD output stable photocurrent, PD bias voltage must be stabilized. Through $M_1$ - $M_6$ , $M_8$ , $R_1$ and EA, constitutes a negative voltage collapse to stabilize grid voltage $M_8$ and makes the PD work under the stable bias voltage. Introduced current by voltage bias circuit (the current can be filtered out through the filter noise circuit with shutdown current of infrared LED.) and current produced by PD denoted by $I_X$ . Photocurrent produced by charge balance ADC is converted to the corresponding digital output. The control signal frequency of $M_9$ , $M_{10}$ , $M_{11}$ , $M_{12}$ , $M_{17}$ and $M_{18}$ is high, in order to prevent its conduction and introducing the noise at the same time, the signals produced by inverter directly are replaced by HOLD circuit. By adding the buffer circuit constituted by OTA (current amplifier) on leakage ends of $M_{11}$ , $M_{14}$ , $M_{15}$ and $M_{18}$ to reduce the current switching noise. Reference current $I_{R1}$ $I_{R3}$ in the figure through integrated control of switch control signal Q_EN, Q_CTRL1 and Q_CTRL2, finally outputs $I_R$ as the reference current in the process of analog-to-digital conversion. $I_{FB}$ is feedback current of background current and dark current through analog-to-digital conversion, $I_{FB} = n_1 I_{R1} / 127$ .

## 3.2. Analog - Digital Conversion Module and Environmental Noise Elimination

### 3.2.1. Analog - Digital Conversion

Based on the advantages of charge balance ADC such as strong anti-jamming capability, apply ADC to achieve analog-digital conversion of photo-signal, as shown in Fig. 4, the specific working mode is as follows:

Reset. Through the RESET signal to reset the ADC before work. Integral input/output short circuit, remove influence on analog - digital conversion accuracy of residual charge from the integrating capacitor.

b. Analog - digital conversion. Refer to the sequence diagram shown in Fig. 5. When the light current $I_X$ is conducted, integral voltage rises. When integral voltage is greater than $V_R$, the output of COMP is high through sequential control which breaks over $I_R$ . When $I_R$ and $I_X$ break over at the same time, integral voltage drops. When integral voltage is lower than $V_R$ , $I_R$ is shutoff and $I_X$ break over. Integral voltage rises again. It repeats until the testing process is complete. Through the counter, PROX — CLK pulses are counted when COMP is in high level. Thus complete the simulation - digital conversion.

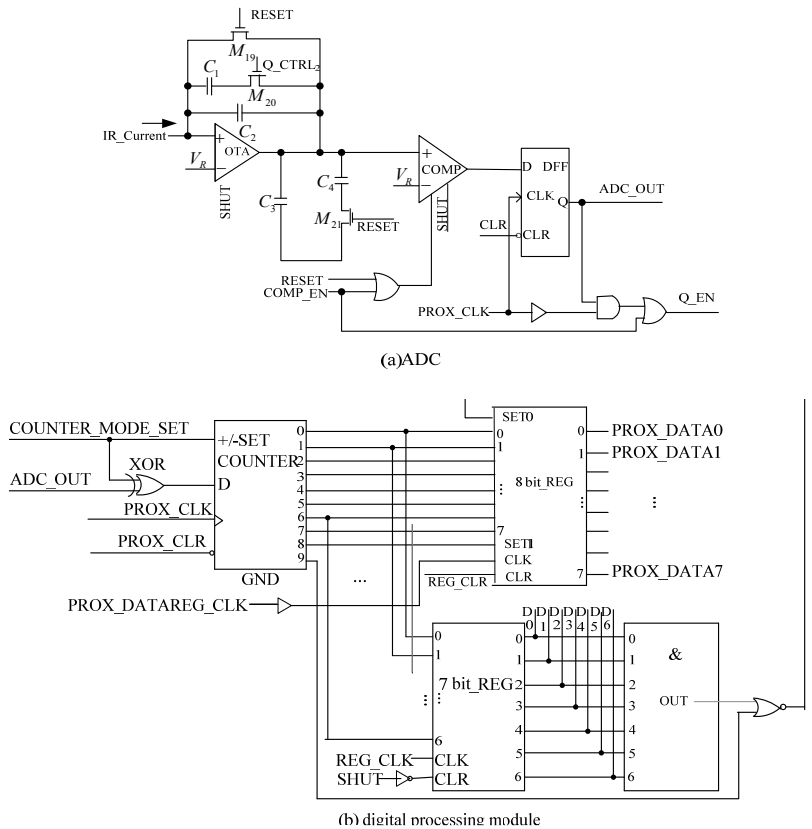


**Fig. 4** ADC and digital processing module.

### 3.2.2. Working Sequence and Environmental Noise Elimination

Environmental noise elimination is realized in the process of proximity detection. It has three stages, the specific sequence is shown in Fig. 5.

Stage 1 infrared LED turns off, shutdown current $I_X$ of infrared LED is in periodic conduction, the counter begins to count, by charge balance relationship, it can be obtained as follows:

$$n_1(I_R - I_X)T_{CLK}/2 = (2^{N_1} - 1 - n_1)I_X T_{CLK}/2, \quad (8)$$

where $n_1$ is the number of conduction of reference current $I_R$ in the environmental noise elimination phase 1. $I_R = I_{R1} + I_{R3}$. TCLK is one cycle of ambient light detection work. $N_1$ is the ADC digits (7 digits) of that stage. Simplify equation (8) to the following:

$$I_X = n_1 I_R / (2^{N_1} - 1) \quad (9)$$

When $I_X = I_R$, $n_1 = 2^{N_1} - 1$, maximum value that can be realized of analog to digital conversion $I_X$ is $I_{R1} + I_{R3}$. $n_1$ is the maximum count of shutdown current of infrared LED, input to 7 bit_REG.

Stage 2 infrared LED turns on, with X breaks over. Count begins after the counter reset. By the charge balance relationship:

$$n_2(I_R - I_X)T_{CLK}/2 = (2^{N_2} - 1 - n_2)I_X T_{CLK} + n_2 I_X T_{CLK}/2, \quad (10)$$

where $I_R = I_{R2}$, $I_X$ is the substraction of sum of shutdown current and light current generated by LED infrared light reflected by the object to $I_{FB}$. $I_{FB} = n_1 I_{R1}/127$, $n_2$ is the number of conduction of $I_R$ in the proximity detection stage 2 of environmental noise elimination. $N_2$ is the ADC digits (8 digits) of that stage. Simplify equation (10) to the following:

$$I_X = n_2 I_R / [2(2^{N_2} - 1)] \quad (11)$$

When $I_X = I_R/2$, $n_2 = 2^{N_2} - 1$, $n_2$ represents the maximum count of substraction of sum of shutdown current and light current generated by LED infrared light reflected by the object to $I_{FB}$.

Stage 3 infrared LED turns off, with $I_X$ breaks over, without the counter reset. Count based on $n_2$, By the charge balance relationship:

$$\begin{aligned}(n_2 - n_3)(I_R - I_X)T_{CLK}/2 = \\ = [2^{N_2} - 1 - (n_2 - n_3)]I_X T_{CLK} + \\ + (n_2 - n_3)I_X T_{CLK}/2\end{aligned} \quad (12)$$

$I_R = I_{R2}$, $n_3$ is the count value after the completion of stage 3. $n_2$ - $n_3$ is the number of conduction of reference current $I_R$ of stage 3. $N_2$ is the ADC digits (8 digits) of that stage. Simplify equation (12) to the following:

$$I_X = (n_2 - n_3)I_R / [2(2^{N_2} - 1)] \quad (13)$$

When $I_X = I_R/2$, $n_2 - n_3 = 2^{N_2} - 1$, $n_2 - n_3$ represents maximum count of substraction of shutdown current to $I_{FB}$, $n_3$ is the final count for the proximity degree detection of the object after the filtering out of the background light and dark current, input to 8 bit_REG.

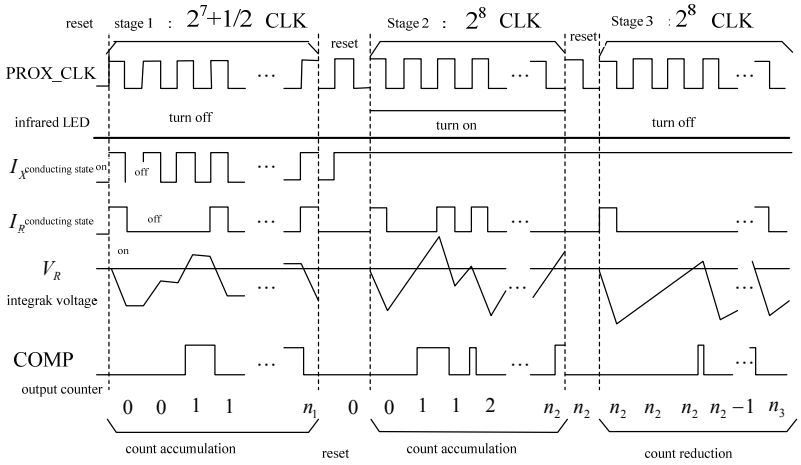


**Fig. 5.** Sequence chart of proximity detection.

All in all, PROX de noising process consists of two steps: Due to the discontinuity of ADC and DAC, in order to prevent that $I_{FB}$ is greater than the real sum of background current and dark current generated by PD, the sum of background current and dark current in the circuit designed $I_{FB} = I_{R1n1}/127$ is $I_{X1} = n_1(I_{R1} + I_{R3})/127$, of which, the value of $I_{R1}$ and $I_{R3}$ are respectively 1285nA and 14.5nA. And $I_{FB} = 0.99I_{X1}$. In stage 2 and 3, $I_X$ minus $I_{FB}$, which means that electric current undergoes analog to digital conversion in stage 2 has almost filtered out all shutoff current. Secondly, through the substraction of the testing result with LED light on in stage 2 and with LED light off in stage 3, the rest shutoff current will be further filtered out.

It is important to note that, in equation (4), when $d = 0$, the light current generated by photodiode is not infinite, rather the light sent by infrared LED cannot be detected by a photodiode through object reflections. So the photoelectric diode current is 0(not consider dark current). The sensor designed works under sunlight or background light of 4000 lx (given indoor illumination light by GB 50034-2004 building lighting design standard is generally not more than 2000 lx), which meets the general demand. And since close distance between sensor and the detected object will keep out the light, illuminance sensed by the sensor is not more than 4000 lx. So it can be considered that the distance between the object and sensor is far when the sensed illuminance is greater than 4000 lx, so detected output data is set to be 0.

For equation (2), the parameters designed are $\lambda_{LED}$ = 865 nm, M = 14.25 W, $P_\circ$ = 50 %, $\theta = 30^\circ$, $\alpha$ = 30 %, T = 80 %, $A_{PD}$ = 0.076032 mm$^2$, R($\lambda_{LED}$) = 585.25 mA/W, Through the calculation, it can be obtained that when $f$ = 67.432869 × 10-12A•m$^2$, $d$ =25 mm$^2$, the light current of infrared LED reflected by the object is $I_{LED}$ =107 nA, the value of parameter R2 is 210 nA. Suppose when the distance between the object and the sensor is around 25 mm, detected output value is maximum. For equation (7), take incandescent light bulb as an example, when $\lambda_l$ = 350 nm, $\lambda_n$ =1100 nm, $\Delta\lambda$ = 5 nm, the light current generated by PD under unit light is $I_b$ = 0.3 nA/lx, when background light is 4000 lx, light current generated by PD is 1200 nA, in order to filter out the 4000 lx background light, $I_{R1} + I_{R3}$ must be greater than the sum of background current and dark current. Here, the value of $I_{R1} + I_{R3}$ is 1299.5 nA, which meets the design requirements.

## 4. Simulation Results and the Layout

The infrared proximity sensor designed is based on 0.35 μm CMOS technology. It applies Spectre simulation tool, when $V_{DD}$ = 3 V, the temperature is 25 V, on the condition of background light of 0 lx and different temperature, simulation verification was carried out before and after noise filtering respectively. The simulation results are shown in Fig. 6 and Fig. 7.

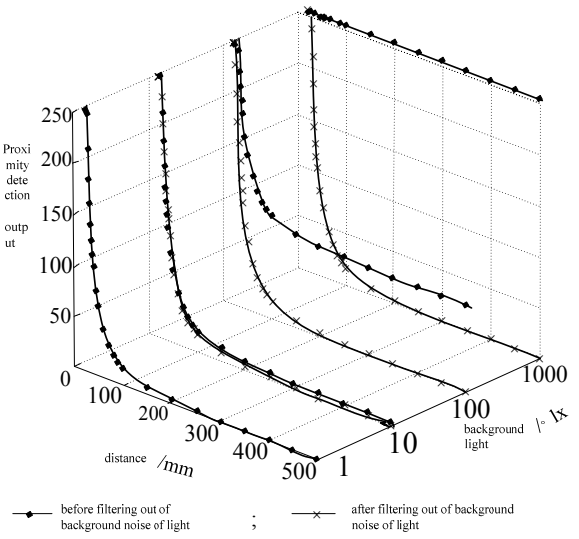


**Fig. 6.** Before and after comparison of noise filtering with different level of background light under the normal temperature.

As shown in Fig. 6, before filtering out background noise of light, with the increase of light, the scope which can be detected become smaller, to a certain value, the proximity detection always output maximum value and the proximity degree of the object cannot be detected. After filtering out the noise, the output value of proximity detection is similar to the ideal value (that is, the background light is 0 lx), with error less than 1 %. Background light in Fig. 7 is 0 lx, and detection range reduces with the increase of temperature. When the temperature is 85 °C, the proximity degree cannot be detected. After filtering out the dark current, the result is close to the ideal value. The circuit designed in this paper can filter out maximum environmental noise of background light of 4000 lx and temperature of 85 °C. The value can increase or decrease according to application requirements. The designed circuit module is shown in Fig. 8 (PD array for photoelectric diode, the digital processing module includes sequential control and data storage), the area is 440 μm×420 μm, tip out under 0.35 μm 3 V CMOS technology. The results show that the sensor designed meets the design requirements.

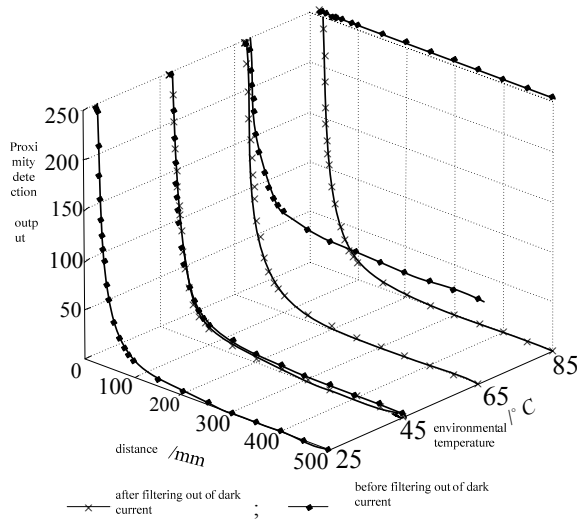


**Fig. 7.** Before and after comparison of noise filtering under different temperature with background light of 0 lx.

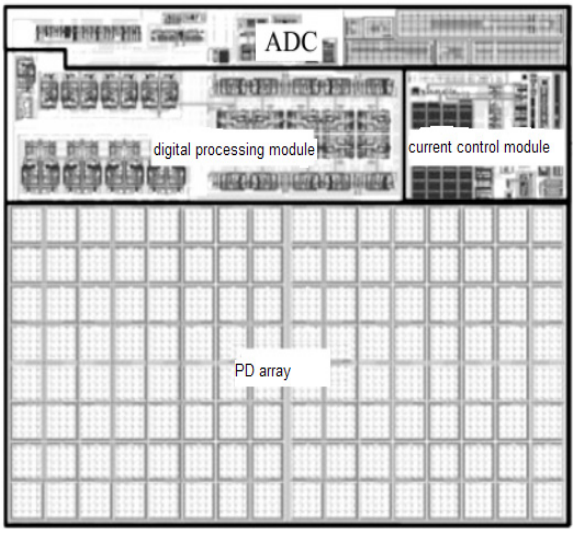


**Fig. 8.** Layout Design of Circuit Module.

## References


[1]. M. A. Swartwout, S. Jayaram, The argus mission: detecting thruster plumes for space situational awareness, in *Proceedings of the IEEE Aerospace Conference*, Big Sky, 2011, pp. 1-10.

[2]. S. Yingfeng, J. E. Speich, K. K. Leang, Low-cost IR reflective sensors for submicrolevel position measurement and control, *IEEE/ASME Transactions on Mechatronics,* Vol. 6, Issue 3, 2008, pp.700-709.

[3]. A. Tar, M. Koller, G. Cserey, 3D geometry reconstruction using large infrared proximity array for robotic applications, in *Proceedings of the IEEE International Conference on Mechatronics,* Malaga, 2009, pp. 1-6.

[4]. C. Enchen, S. Chengyang, D. Mingzhi, Polymer infrared proximity sensor array, *IEEE Transactions on Electron Devices,* Vol. 58, Issue 4, 2011, pp. 1215-1220.

[5], V. Rana, N. Paliwal, A. Chahar. Touch sensor assembly using infrared radiations and its applications. in *Proceedings of the IEEE International Conference on Computational Intelligence, Communication Systems and Networks,* Indore, 2009, pp. 96-98.

[6]. R. Ruijian, L. Xinquan, L. Yushan, CMOS image sensor chip imaging technology, *Microsystem Electronics*, Vol. 31, 2001, pp. 272-275.

[7]. Y. Huang, Q. Cao,. Laser and whole d visual fusion of mobile robot positioning, *Journal of Huazhong University of Science and Technology,* Vol. 32, Issue S1, 2004, pp. 93-96.


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