

Research on Prime Circuit With High Sensitivity for Photoelectric Detection Based on Pgtia

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Abstract. Photoelectric sensor is widely used in the fields of the measurements of fiber sensor and the chemical parameters. Photoelectric detection circuit based on the photodiode is constructed with transimpedance amplifier. The precision and sensitivity of circuit are adjusted by programmable gain. The index requirements of the amplifier are clear, and the feasible circuit is given at last.

Introduction

Basis for the requirement of precision and weak and the actual situation, precise signal detection system based on amperometric sensor or photodiode always need high sensitivity transimpedance amplifier (TIA) and programmable gain to further improve the detection dynamic range.

The essence of TIA is the current/voltage converter (I/V) which converts current signal to voltage signal. Resistance is the simplest I/V circuit. On the basis of Ohm's law, the current flowing on the resistance will yield pressure drop. When the weak sensitivity is measured or bigger sensitivity is need, the value of resistance must be bigger to get bigger voltage output. Generally, the resistance with big resistance value has low precision and high noise, and the resistance with high load combines with the input capacitance of rear stage circuit can product a bigger time constant RC, so the high frequency response of the system will be affected and the dynamic range will be decreased. In addition, I/V circuit which is the prime circuit of the detection system is crucial to realize high sensitivity and high resolution of the whole detection system. In the research of weak signal, rear stage need amplification and filter, and the amplification factor are hundreds to thousands times, if the precise design is not good, the signal and the noise are amplified. So the amplifier must be used, and the characteristic of virtual open is used to construct the TIA to realize the I/V convert of current signal with weak or high sensitivity. Programmable gain transimpedance amplifier (PGTIA) with wide bandwidth and high sensitivity is designed based on photoelectric detection by using photodiode.

Photoelectric Detection Circuit Based on the Photodiode

Photodiode is a device which converts optical signal to weak current signal, and it is widely used in the fields of fiber communication and sensor. When photodiode works under the reverse bias (or zero bias), current I will be yielded.

$$I = \Phi \cdot S \quad (1)$$

Where, S is receiving area of photodiode. Φ is luminous flux. The current is proportional to the luminous flux.

The equivalent circuit of photodiode is shown in Fig.1. The circuit contains a current source related to the light which parallels to a shunt resistance and a shunt capacitance.

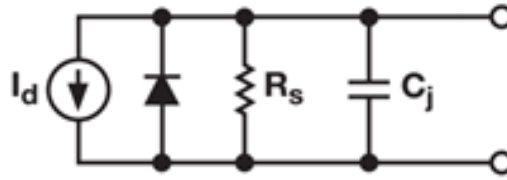


Fig.1 The equivalent circuit model of photodiode

Characteristic curves of typical photodiode is shown in Fig.2.

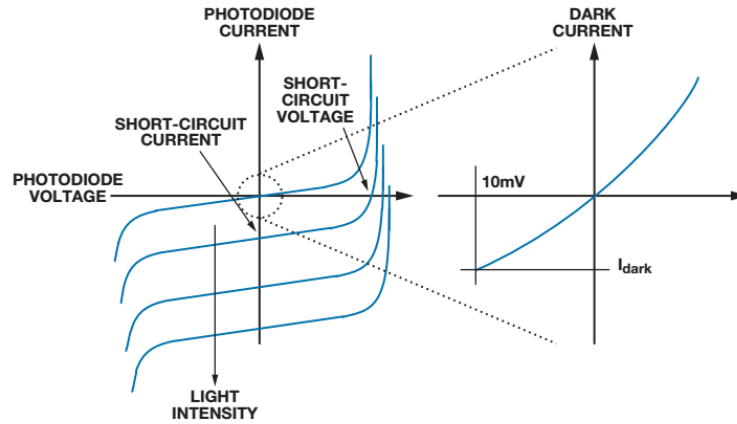


Fig.2 Characteristic curves of photodiode

The curve represents that there has no light. The current of photodiode is very weak, so the task of the photoelectric detection system is to extract the weak signal, especially to extract the weak signal covered by noise. Photoelectric detection circuit based on transimpedance amplifier realized by using transimpedance amplifier is shown in Fig.3. The pressure drop of feedback resistance R_F is given as following

$$V_{OUT} = I_d \cdot R_F = \Phi \cdot S \cdot R_F \quad (2)$$

The reversed-phase input of ideal amplifier is virtual ground, all current flow through feedback resistance R_F . So the input bias current and the input offset voltage must be very small.

Fig.4a is the actual parameter circuit model of Fig.3. The system has two poles, one is the pole of the low frequency open loop transfer function, and the other is the closed loop pole which is caused by feedback resistance and the parasitic resistance and capacitance of photodiode. One pole causes phase shift 90 ° of open loop transfer function, so the total phase shift is 180 °, which is considerably lower than the open loop amplitude phase shift which the frequency strides 0dB. If phase margin is lack, pole has half plane in s plane (shown in Fig.4a), which must cause circuit oscillation.

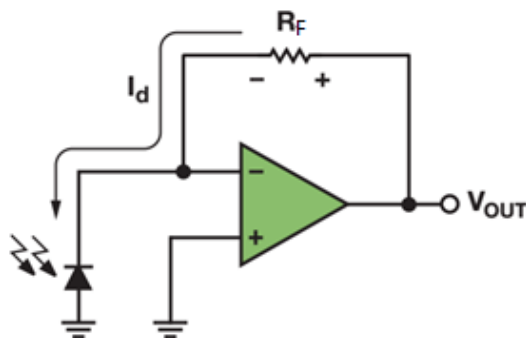


Fig.3 Photoelectric detection circuit based on transimpedance amplifier

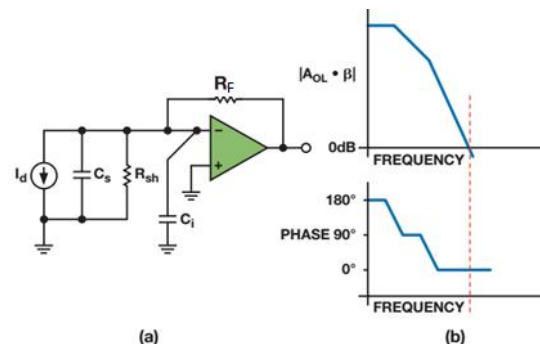


Fig.4 Frequency response model and response curves of photoelectric detection circuit based on the photodiode

In order to ensure working stable, to let a capacitance parallel to R_F , it can add a zero to the transfer function, and yields positive phase margin to ensure the stability. In order to get 45° phase margin, it must satisfy the following equation

$$C_f = \sqrt{\frac{C_{sh} + C_i}{2\pi R_f f_u}} \quad (3)$$

Where, f_u is the unit gain frequency of the operational amplifier, and the highest actual frequency of the system is determined by the value of C_f .

The programmable gain amplifier can cascade to ensure the transimpedance gain of amplifier is in the linear region, or the programmable gain is realized in TIA directly to structure PGTIA, which is shown in Fig.5. A type of PGTIA is shown in Fig.6. But the on-resistance and leakage current of analog switch may result in errors, so the improved circuit is shown in Fig.7.

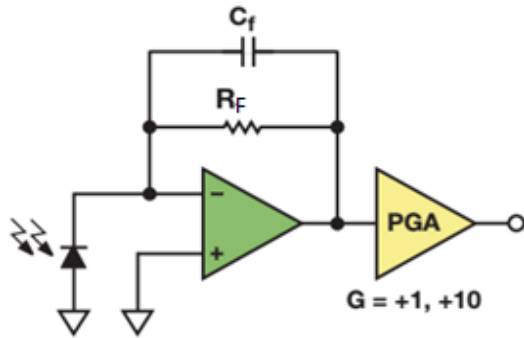


Fig.5 The first stage of TIA cascade to PGA forms PGTIA

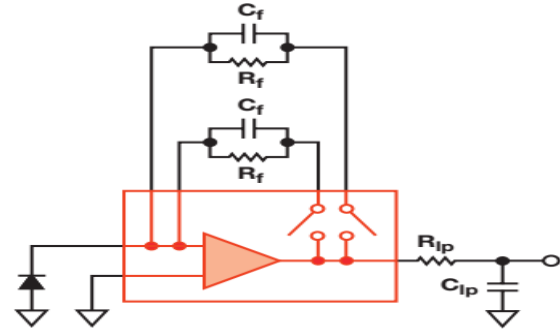


Fig.6 Programmable gain transimpedance amplifier

There are two switches in each transimpedance branch of the circuit shown in Fig.7, which avoids the above questions. Although the number of switches is double, the on-resistance of the left switches is in the feedback loop, so the output voltage depends on the current which flows through the selected resistance. The switches on the right are seemingly output impedance, the errors caused by who can be neglectable, if the amplifier drive high impedance load such as ADC driver.

The circuit shown in Fig.7 is suitable for DC and low frequency, when it is turn-off, parasitic capacitance on the switch will lead to new problems. The influence can be decreased by replacing the switches by two cascaded switches, the parasitic capacitance will be halving, but more elements are used.

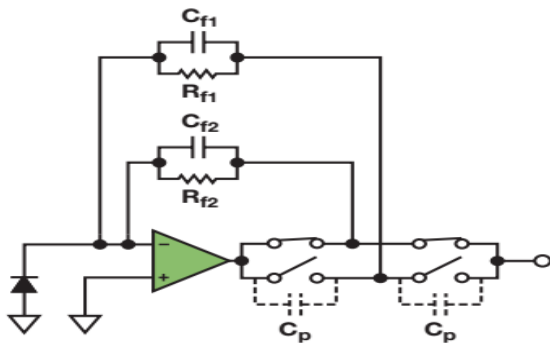


Fig.7 Programmable gain transimpedance amplifier with Kelvin switch

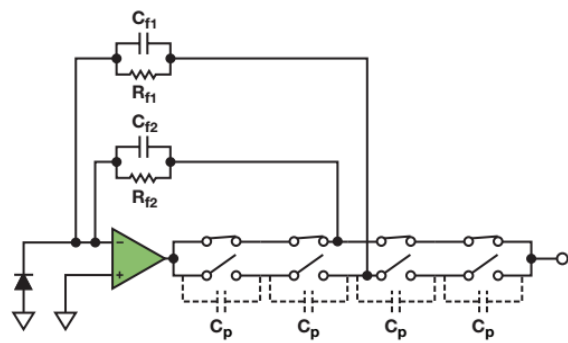


Fig.8 Increase cascaded switches to decrease total parasitic capacitance

$$\text{Total feedback capacitance} = C_{f2} + \frac{C_p C_{f1}}{C_p + C_{f1}} \quad (4)$$

Transimpedance amplifier has three main noise sources: input voltage noise of operational amplifier, input current noise and feedback resistance noise. In addition, PGA stage is thoroughly eliminated by using programmable gain transimpedance amplifier, so the transimpedance resistance just uses its own capacitance to compensate the input capacitance of photodiode.

Improved Circuit

In addition, in order to get big output voltage and not use big feedback resistance, it is improved by using T-type feedback network. The improved circuit is shown in Fig.9. In the improved circuit, the value of the feedback resistance is not need to select too big, and the proper adjustment result of T-type feedback network can be got by selecting the radio of R_1/R_2 . The conversion formula can be got based on kirchhoff ' s law

$$v_o = i_s \left[R_F + R_1 + \frac{R_F R_1}{R_2} \right] \quad (5)$$

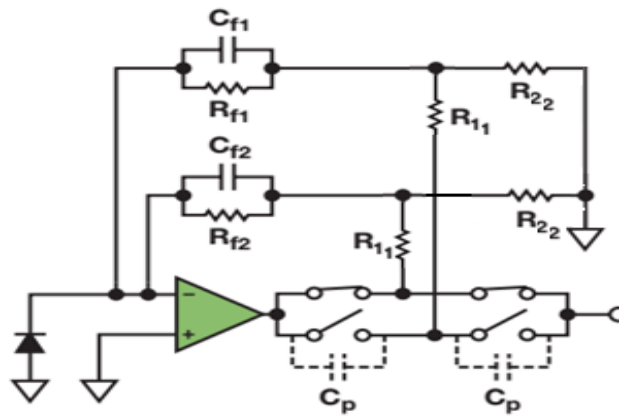


Fig.9 Improved circuit

Conclusions

Transimpedance signal detection circuit based on the photodiode is the basic component of the most photoelectric detection system. PGTIA is used in the paper, engineers can design a device to measure very big dynamic range, bandwidth and stability accurately, and select proper configuration, weigh the pros and cons, and at last, determine the detection circuit with actual index requirement.

Acknowledgement

To be explained that photodiode can be reverse connected, so the output voltage is reversed.

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