Research on Phase Compensation and Bandwidth Matching Technology in the Light Illuminometer

Caixia Wang

School of Electronic and Information Engineering, Changchun University of Science and Technology, Changchun 130022, China

wcxhao@sina.com

Abstract

In order to ensure that the useful optical signal are transmitted with no missing, enhance the stability of light illuminance measuring system, this paper designs a kind of photoelectric sensor acquisition circuit based on the studies about the key factor influencing the stability of the measurement system, which achieves a high stability for the measurement system by reasonable phase compensation and bandwidth matching, and also provides a reliable method for the realization of illumination measurement system.

Keywords

illumination, phase margin, phase compensation, 3DB Bandwidth.

1. Introduction

Light meter is one of important detecting instruments in optical measurement. The light illuminance can reflect the light flux per unit area, and therefore, the light illuminance meter is as an important testing equipment in the medical care corporation, food companies and other corporation's light illuminance measurement, its value's accuracy and measurement results' stability are directly related to the production quality of the enterprises who use it. The front-end acquisition circuit of the optical signal is an important part of the light meter, and its performance directly affects the accuracy and stability of the entire measuring instrument, so this article focuses on the design of signal conditioning circuit in the photoelectric detection front-end circuit, discusses the realization of operational amplifier's phase compensation and bandwidth matching technique in the light meter.

2. Theoretical Basis

2.1 Illumination characteristic of Photocell.

Photocell is a photoelectric sensor based on photovoltaic effect, its open circuit voltage has a non-linear relationship with the illuminance. When the light irradiation is above 2000 lux, the Photocell will become saturated, but the short-circuit current has a good linear relationship with the illuminance [1], as shown in Fig.1. So if we choose photocell as a measuring element, we should apply short-circuit current characteristic and use photocell as a current source.

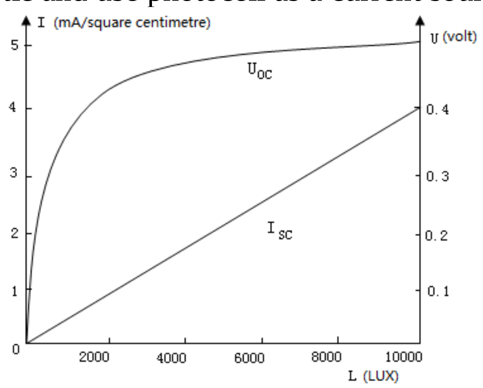

Fig.1 Illumination characteristic curve of photocell

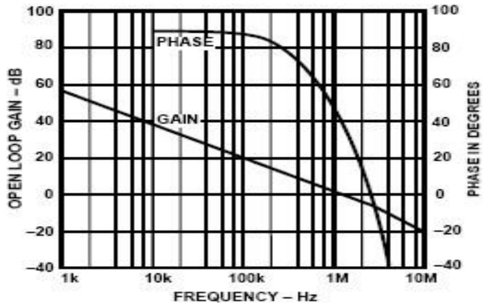

Fig.2 Open-loop frequency characteristic curve of AD548

2.2 Phase margin.

Phase margin is one of important indicators in the circuit design, which is mainly used to express the stability of the negative feedback system, to predict the overshoot during the process of step response for the closed-loop system. Phase margin can be considered as a possible increasing phase variety before the system enters the unstable state, the more phase margin, the more system stability, but at the same time the slower response speed, so the system must have a suitable phase margin. Studies showed that the phase margin is at least 45 °, the preferable one is 60 °.

Phase margin refers to the difference between the phase when the op-amp's open-loop gain is 0dB and the phase of 180 °, for a fixed operational amplifier, phase margin is only one. The paper chose AD548 as the operational amplifier chip to measure the illuminance, whose open-loop frequency characteristic curve is shown in Fig.2. From which, we can see the frequency AD548 is about 1MHz when the open-loop gain is 0dB, the phase value is about 40 °at this time, so the phase margin is 140 °.

If the loop gain of the system is equal or bigger than 0dB and phase shift exceeds 180 °, the closed loop amplifier circuit becomes unstable and produces oscillation. The phase margin indicates the margin size apart from the self-oscillation producing, this is also a reason why the phase margin becomes one of important parameter to flag op-amp's stability.

Factors affecting the phase margin include noise gain and closed-loop load. In general, the smaller the noise gain is, the smaller the phase margin is, so the unity gain system is the most difficult to be stable. At the same time, it should be noted whether the operational amplifier remains stable at unity gain when we choose the operational amplifier as a gain buffer. Pure resistive loads generally do not affect the phase margin, inductive loads improve phase margin, but in the practical application, capacitive loads are most commonly applied, which will reduce the phase margin of the operational amplifier circuit, causing the system easy to produce self-oscillation. So from the viewpoint of phase margin, the light meter front-end circuit's design must choose a reasonable capacitive load for the op-amp.

2.3 Bandwidth match.

The phase margin of the operational amplifier is firstly should be considered, and secondly should be considered the signal's passband when we design a light meter front-end circuit. Commonly, operational amplifier is capable of amplifying electrical signals for output. The core elements of the operational amplifier is the transistor, which has an important feature is that when the input signal frequency is within a certain range, the amplification effect is the best, beyond this range, the system appears phenomena such as signal distortion or magnification reduction. We call the frequency range that the signal can be passed normally as bandwidth. In the Illuminance measurement system, bandwidth matching refers to that the bandwidth of optical detection and the bandwidth of an enlarged electrical signal portion is consistent.

3. Phase compensation technology of photoelectric detection circuit for the light meter

According to 2.1, optoelectronic device is in the context of linear applications during the optical signal's illumination measurement, so the paper designed a kind of current - voltage conversion circuit using the photocell's short-circuit current characteristic, which is shown in Fig.3.

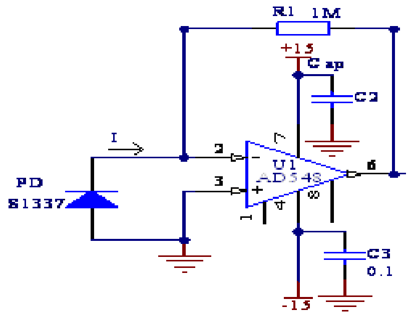

Fig.3 Current-voltage conversion circuit of photocell

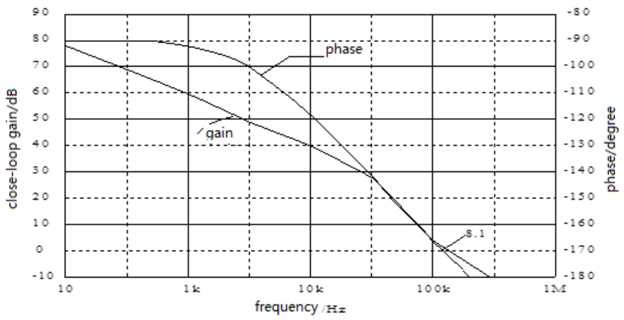

Fig.4 Frequency characteristic of I-V conversion circuit

In Fig.3, the silicon photocell output weak current signal at the level of microampere with the external light signal's irradiation, the current value is proportional to the value of the incident light illuminance. In order to facilitate subsequent electronics processing, we usually convert the photocell's output current signal into a voltage signal, the output voltage value of this current - voltage converting circuit can be expressed as:

$$V_{out} = -I \times R_1 \tag{1}$$

In (1), the value of V_{out} increases as we increase the value of feedback resistor R_1, which makes the amplifier design more simplistic. However, when the value of feedback resistor R_1 increased, the negative reaction is interference and oscillation appearing more easily. There is parasitic capacitance C in the integrated operational amplifier's input whose value is from several pF to several tens pF, which constitutes the RC circuit with feedback resistor R_1, thus a new frequency characteristic inflection point and a phase lag appear, which caused the system's oscillation, the system is instable too. The breakpoint frequency f_p is:

$$f_p = \frac{1}{2\pi \times C_{in} \times R_1} \tag{2}$$

If breakpoint frequency f_p approaches integrated amplifier's combination frequency or is lower than the combination frequency, the system's oscillation will be caused and the system becomes unstable. Chip AD548 is chosen as amplifier, from AD548's data sheet, we can see the input parasitic capacitance is from 5PF to 6PF, Substitute the value into (2):

$$f_p = \frac{1}{2\pi \times 6 \times 10^{-12} \times 10^5} \approx 26.5\text{kHz} \tag{3}$$

Since the AD548's combination frequency f_T is 1MHz, f_p is 26.5 KHz, which is far lower than f_T, so it is easy to lead the oscillation and makes the system unstable. From 2, it shows that the system is more stable when the phase margin is about 45 °or more. Fig.4 shows the results of the closed-loop gain and phase angle determined by the circuit of Figure 3, phase marge is 8.1°, which is far lower than 45°, so it is easy to cause oscillation. Due to the generation of the turning point is at the situation f_p, so phase lag is 45°, the phase margin becomes small.

Based on the above analysis, in Fig.3, the input parasitic capacitance of amplifier makes the phase lag, the system is easy to cause oscillation, therefore, in order to improve the stability of the system, a method called leading phase compensation is used to compensate the lag phase. The action in detail is using a phase compensation capacitor C_1 in parallel with the feedback resistor, the circuit is shown as Fig.5.

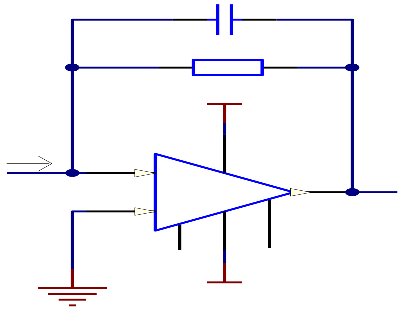

Fig.5 Phase compensation of I-V conversion circuit

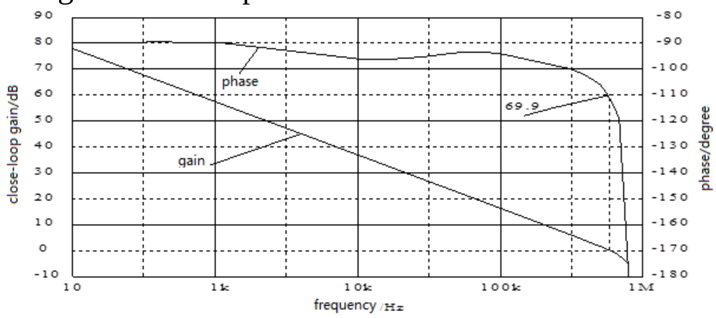

Fig.6 Frequency characteristic of I-V conversion circuit after phase compensation

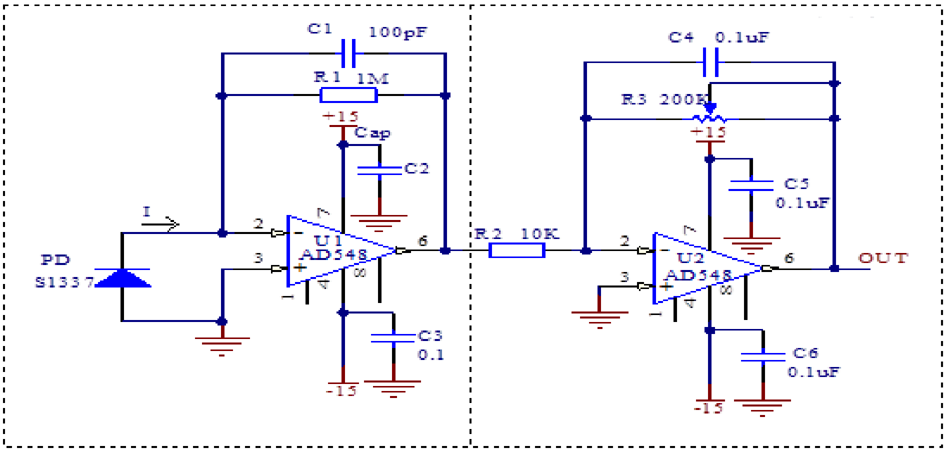

Fig.7 Diagram of front-end signal conditioning circuit

Fig.6 shows the results of closed-loop gain and phase angle after phase compensation, we can see the phase margin is 69.9 °,which is larger than 45 °, then the system is stable. Capacitor C1 plays a role of leading phase compensation, a turning point is also a zero frequency f_z, which is:

$$f_z = \frac{1}{2\pi \times C_1 \times R_1} \tag{4}$$

In (4), when the value of C_1 is 100pF, f_z is equal to 16 KHz. In addition, the actual sensor also includes a capacitance component C_{in}. The bigger the value of C_{in} is, the larger the value of C_1 is. According to that the value of C_{in} should be smaller than the value of C_1, we can determine the value of C_1, and also we should choose the CBB capacitor which has good temperature-compensation characteristic. Similarly, the light meter front-end signal conditioning circuitry also need phase compensation.

The final light meter front-end signal conditioning circuit is shown in Fig.7, wherein the capacitor C4 is to prevent system's oscillation in phase compensation circuit.

4. Bandwidth matching of photoelectric detection circuit for light meter

Since the compensation capacitor is added in current-voltage conversion circuit, resulting in a new turning point, the frequency characteristic curve changes, the -3dB cutoff frequency changes too. In this case, the cutoff frequency has a relationship with the rising time of the output waveform. The output waveform's rising time is shown in Fig.8 for a current-voltage conversion circuit, the -3dB cut-off frequency f_{ch} can be expressed as:

$$f_{ch} = \frac{0.35}{risingtime} \tag{5}$$

From (5), it can be concluded, $f_{ch} = 184kHz$, the amplifier circuit in Fig.7 is similar.

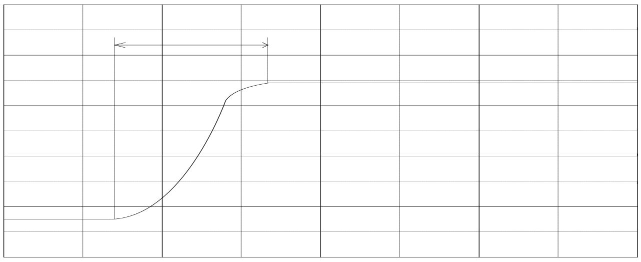

Fig.8 Output waveform of I-V conversion circuit

In order to take full advantage of the integrated operational amplifier bandwidth, the problem of bandwidth matching between the current-voltage conversion circuit and the amplifier circuit must be considered. If the bandwidth of current-voltage conversion circuit is too large, and the amplifier circuit's bandwidth is too narrow, the available signal frequency is cut off. If the bandwidth of current-voltage conversion circuit is too narrow, and the amplifier circuit's bandwidth is too large, the amplifier circuit's bandwidth will be squandered. In order to achieve a better bandwidth matching, from equation (5), the following must be met.

$$R_1C_1 \approx R_3C_4 \tag{6}$$

5. Conclusion

This article focuses on the light luminance measurement from the point of application design, discusses the phase compensation and bandwidth matching technology in the current-voltage conversion circuit and the amplifier circuit. It presents the test results of the actual compensation based on the frequency characteristics of the integrated operational amplifier. Test results show that, the actual value of the compensation capacitor can be determined by the phase compensation method mentioned with the premise of constant gain, the actual compensated bandwidth is consistent with the expected design specifications, which can greatly shorten the time to debug the circuit, improve the efficiency of the circuit design. It should be noted that the circuit frequency bandwidth compensation is also affected by circuit wiring, welding process, distribution parameters, electromagnetic compatibility and many other factors, so the final value of the compensation capacitor required should be accorded to the final results of the actual debugging and the limit of actual value of the capacitor.

Acknowledgements

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