The design of preamplifier and ADC circuit base on weak e-optical signal

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The design of preamplifier and ADC circuit base on weak e-optical signal

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Abstract: Combined with the demand of the process of weak e-optical signal in QPD detection system, the article introduced the circuit principle of deigning preamplifier and ADC circuit with I/V conversion, instrumentation amplifier, low-pass filter and 16-bit A/D transformation. At the same time the article discussed the circuit's noise suppression and isolation according to the characteristics of the weak signal, and gave the method of software rectification. Finally, tested the weak signal with keithley2000, and got a good effect.

1. Introduction

Four-quadrant position detector (QPD) is a type of non-imaging detection that applied in position system widely. Because of its high detection sensitivity, simple signal processing & strong anti-interference, it is used widely in military, surveying, astronomy, communications, engineering surveys[1]. QPD detection system adopted 650nm dot lasers (Pmax≤5mW) as the emission source, QP20-6 as the receiver. As the signals which obtained from the four detector are very weak, the signal strength is generally between 10uA ~ 400 uA in natural light conditions. In order to use the signals more accurately and effectively, the signals must be processed before the further use.

The quality of an e-optical system performance is largely depended on its Suppression to the noise and interference. To solve the weak signal problem, the key is to solve the noise problem in order to improve the NRS. At present, the methods to amplified the weak signal included JFET amplification[2], instrument amplification[3], phase-locked amplification[4] and so on. But these are resolved with hardware, these may led to high cost of hardware, complexity circuit and large uncertainties. According to the characteristics of the QPD signal and noise, the paper designed preamplifier and ADC circuit base on CA3140, INA129 and MAX7705. It not only reduced the hardware interference, but also optimize the measurement signal by using software rectification method. The design has low cost, high accuracy, stable, easy operation, portability, and also has some practical value.

2. The design and implementation of the circuit

The signal obtained from the four-quadrant detector is generally weak、low frequency current signal. For the current signal, first, we should convert it into voltage signal, then after amplification, filtering and A/D conversion just can we send it into processor to do the further processing. In order to get the signal which can be identified by the processor, the whole system is mainly divided into four parts[5], they are I/V conversion, voltage amplification, low pass filtering and A/D transformation, just as Fig.1.
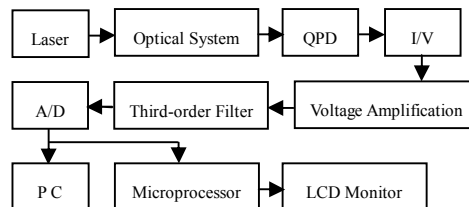

Fig.1 Structure of weak signal processing system

2.1. I/V conversion

The signal we got form the detector is weak current, so we always use high input impedance amplifier and take method of I/V conversion to achieve the weak current measurement. The main factor influencing the current measurement sensitivity is the bias current I_b of a amplifier, the smaller I_b is, the higher sensitivity are. Moreover, noise level and drift have some influence to a certain degree[6].

In the designing, we compared LF353、OPA2244 and CA3140 these there kinds operational amplifiers, Table1 is the measuring result ($R_f = 1k\Omega$).

Table1 Data of I/V conversion

	I(mA)	V(V)	ε (%)
LF 353	0.412	0.406	1.5
	0.393	0.379	3.56
	0.1984	0.2027	2.22
	I(mA)	V(V)	ε (%)
OPA 2244	0.3927	0.3871	1.43
	0.3382	0.3394	0.355
	0.1209	0.1192	1.41
	I(mA)	V(V)	ε (%)
CA 3140	0.4131	0.4148	0.4
	0.1483	0.1482	0.067
	0.0848	0.0857	1.06

According to the data in Table1, we know that using CA3140 as the front I/V conversion can achieve good result. CA3140 is an integrated circuit operational amplifier that integrate the advantages of high-voltage PMOS and Bipolar process in one chip, developed by RCA, it has the 1.5TΩ high input impedance and input current low to -10pA(in the ±15V voltage circumstances), and its operating supply voltage is from 4V to 36V(either single or dual power supply), so CA3140 can meet the front I/V conversion need[7].

Fig.2 is the hardware circuit of I/V conversion with CA3140. In this circuit, R_4 play a role in adjusting bias, when the input current is 0mA, the output voltage is 0V, if R_4 is suitable. Meanwhile, there are two resistors R_5、R_6 in series at its tow ends to prevent one end of the current too large when adjusting.
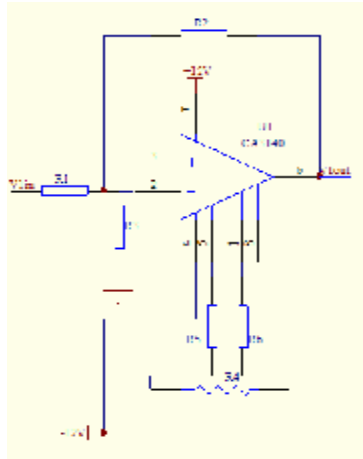

Fig.2 Circuit of I/V conversion with CA3140

2.2. Voltage amplification and filtering

As the signal obtained from the four-quadrant detector is very weak and easily influenced by noise, we select the precision、low power instrumentation amplifier INA129[8]. INA129 has a differential structure, has a strong inhibitory effect in common mode noise, and also has a high input impedance and low output impedance, so it is very suitable for the amplification of weak signals. Table2 show the measured data of voltage amplification, when the adjustment resistor $R = 5.18k\Omega$, $G = 9.5029$, we could get the desired results.

Table2 Data of voltage amplification with INA129

	V_i(V)	V_o(V)	ε (%)
INA	0.35	3.31	0.48
129	0.25	2.367	0.38
	0.15	1.420	0.35

In addition, in order to make the output voltage down faster at high frequencies and improve low-pass filter's ability to filter out noise, here we select the third-order low-pass filter[9].The low-pass filter is made up of dual operational amplifier LF353. LF353 has the feature of high precision、low offset and low power consumption, so could flexibility form various types of amplification and filter circuit, the hardware circuit is shown in Fig.3
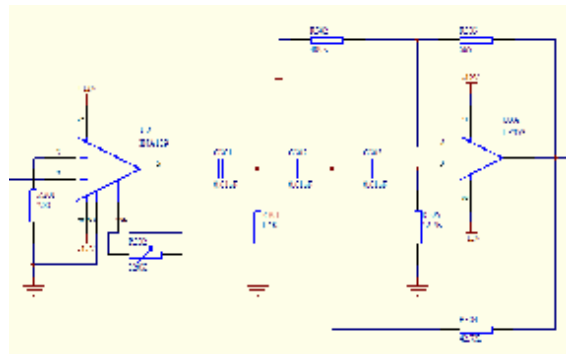
Fig.3 Circuit of vol amplification and wave filtering

In Fig.3, through adjusting sliding rheostat, we can adjust the voltage amplification on factor of 1 to 10000 of any value, to achieve a flexible adjustable magnification.

2.3. A/D transformation

The voltage values we got after amplified are analog signals, if you want to send them into microprocessor to do the further processing, here we should change them into digital signals. In order to ensure the conversion precision, we select 16 bit Σ-$\triangle$ type AD converter MAX7705[10-12] (Fig.4). MAX7705 is a 2/3 channel analog fore-end device widely used in low frequency measurements, its typical features are high resolution、wide dynamic range、self-calibration and so on. In the program, we set the sampling frequency 250MHz, and use different rectification formulas to do software rectification according to the measuring range.
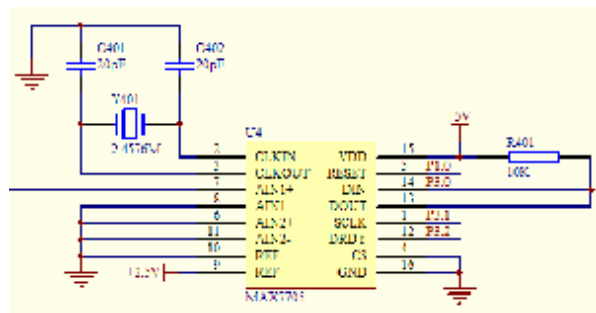
Fig.4 Circuit of A/D transformation

2.4. Circuit measurement

We make the PCB board according to Fig.2 to Fig.4, through debugging the system, we measured the weak signal that after I/V conversion、voltage amplification、low pass filtering and A/D transformation, the result is in Table3.

Table3 Some data of circuit testing

I_{in}（uA）	I/V（V）	A-F（V）	A/D（V）
10	0.01014	0.06069	0.0737
30	0.03036	0.18179	0.1892
50	0.05069	0.30326	0.3212
70	0.07102	0.42486	0.4378
90	0.09121	0.54586	0.5687
100	0.10137	0.60661	0.6345

150	0.15211	0.907211	0.9327
200	0.20276	1.210431	1.2462
250	0.25355	1.514021	1.5603
300	0.3043	1.817561	1.8745
350	0.35503	2.120551	2.1873
400	0.40576	2.424421	2.5022

In the production of circuit boards, we choose the basic components according to the output photocurrent's range of the four-quadrant position detector QP20-6 and reference voltage's range of the AD converter MAX7705. During I/V conversation, the feedback resistor of CA3140 $R_f \approx 1k\Omega$, so the actual magnification is 1.02379. During preamplifier, the adjustment resistor $R = 9.47k\Omega$, and magnification $G = 6.216473$.

3. Analysis and optimization of the system

In the actual test, we use constant current source keithley 2400 to output a constant current of 10uA ~ 400uA, and use accurate multimeter keithley 2000 with five and a half accuracy to measure data. But for the device noise and the interference between different devices, some error was existed in the measured data, so when designing the circuit, we can optimize the measured datas by means of software calibration while reducing the interference of hardware.

In the design of the system circuit, we use the tow-stage amplification in equal. Through the Friss formula[13] (1) based on multi-amplifier noise figure theory, we know that the size of multi-amplifier noise figure mainly depend on the first- stage amplifier noise figure. So as to reduce the noise figure of multi-stage amplifier, we should reduce the noise figure and improve the power magnification A_{p1} of the first-stage.

$$NF_{1,2\Lambda n} = NF_1 + \frac{NF_2 - 1}{A_{p1}} + \frac{NF_3 - 1}{A_{p1}A_{p2}} + \frac{NF_n - 1}{A_{p1} \cdot A_{p2} \Lambda A_{pn-1}} \quad (1)$$

In the design, we choose CA3140 as the first amplication, when processing their output signals, the most important factor determining the measurement is the bias current of CA3140 I_{os}, and then are insulating properties of the materials and wire connection method. The actual output voltage[14] is shown in formula (2).

$$V_o = -(I_p + I_{os})R_f + V_{os} \quad （2）$$

When load resistance R_f is too large, I_{os} will greatly affect the output result, so choosing a smaller bias current operational amplifier is quite needed. To CA3140, I_{os} is 1pA, and V_{os} is 5mV. Table4 show some result of primary amplification after been calibrated by linear function $y = 1.01007x + 2.12914 \times 10^{-6}$.

Table4 Some result of primary amplification after calibration

I_{in}（uA）	V_a（V）	V_t（V）	V_c（V）	ε(%)
10	0.01014	0.010238	0.010244	-0.06192
20	0.02028	0.020476	0.020486	-0.05152
30	0.03036	0.030714	0.030668	0.149268
40	0.04053	0.040952	0.04094	0.027676
50	0.05069	0.05119	0.051203	-0.02555
60	0.06085	0.061427	0.061465	-0.06103
70	0.07102	0.071665	0.071737	-0.10047
80	0.081	0.081903	0.081818	0.10427
90	0.09121	0.092141	0.092131	0.011381
100	0.10137	0.102379	0.102393	-0.0136

In order to improve the portability of the various modules, we use different functions to do software rectification according to different measurement range of each module, it does not list here. For the whole system, we divide the measurement range into 10uA~100uA and 100uA~400uA. Table5 show the result optimized by function $y = 1.04922x + 2.54155 \times 10^{-5}$ when the input current range of 10uA~100uA, and Table6 show the result optimized by function $y = 1.0494x + 0.00201$ when the input current range of 100uA~400uA.

Table5 Result 1 after optimization（10uA~100 uA）

I_{in}（uA）	V_a（V）	V_t（V）	V_c（V）	ε(%)
10	0.068062	0.063644	0.071437	-12.2455
20	0.116689	0.127287	0.122458	3.793731
30	0.179944	0.190931	0.188827	1.102157
40	0.243877	0.254575	0.255906	-0.5231
50	0.30781	0.318218	0.322986	-1.49825
60	0.356535	0.381862	0.374109	2.030343
70	0.420758	0.445505	0.441493	0.900588
80	0.483432	0.509149	0.507252	0.372663
90	0.547558	0.572793	0.574535	-0.30411
100	0.611297	0.636436	0.641411	-0.78164

Table6 Result 2 after optimization（100uA~400 uA）

I_{in}（uA）	V_a（V）	V_t（V）	V_c（V）	ε(%)
100	0.610551	0.636436	0.642722	-0.9877
125	0.755803	0.795545	0.79515	0.049699
150	0.900861	0.954654	0.947373	0.762701
175	1.061203	1.113764	1.115636	-0.16814
200	1.206066	1.272873	1.267655	0.409891
225	1.366408	1.431982	1.435918	-0.2749
250	1.511854	1.591091	1.58855	0.15968
275	1.672586	1.7502	1.757222	-0.4012
300	1.817741	1.909309	1.909547	-0.01248

325	1.962896	2.068418	2.061873	0.316443
350	2.122264	2.227527	2.229114	-0.07124
375	2.268392	2.386636	2.382461	0.174937
400	2.428832	2.545745	2.550826	-0.19958

In order to accurately and visually display the modified results, we use orgin8 to simulate the tested data, and Fig.5 is the result of data amended by linear curve fitting.
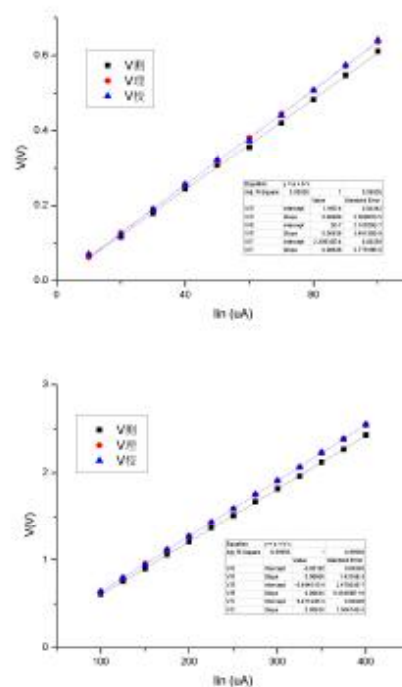

Fig.5 Result of data processing of the system

In the view of the data and curves above, although the circuit can be very good to restrain noise and interference, but the actual measured data slightly smaller than the theoretical value, this is mainly due to the loss of transmission. Through the corresponding liner fitting optimization, the output data is almost the same as the theoretical value. So the whole design can be good at pre-amplification and conversion of the weak e-optical signals, meet the requirement of quadrant detection system.

4. Conclusion

The design of preamplifier and ADC circuit which is discussed in the paper is applicable to QPD system, and each module has strong portability. The software rectification method which is adopted can reduced the hardware interference, and optimize the measurement signal too. Based on weak e-optical signal, through testing the preamplifier and ADC circuit which is mainly composed of low noise single dc amplifier CA3140, instrumentation amplifiers INA129 and 16 bit Σ-△ type AD converter MAX7705, the result was more satisfactory after software rectificating, and it indicated that the circuit could be applied in weak e-optical signal procession.

References:

[1] WANG Qing-you. Photoelectric technology[M]. Beijing: Electronic Industry Press, 2005. 4.

[2] JI Da-xiong, CHEN Xiao-zhen, et al. Optimal Design and Research of Small Signal Amplifier with Low Power Consumption[J]. Chinese Journal of Electron Devices, 2008, 31 (4): 1303-1306.

[3] LIU Hong-li, LI Chang-xi. Design of Lock-in Amplifier Circuit to Measure Weak Signal[J]. Journal of Wuhan University of Technology, 2002, 26(5): 619-621.

[4] ZHANG Shi-rui, ZHENG Wen-gang, et al. The design of preamplifier circuit base on weak signal detection[J]. CONTROL & AUTOMATION, 2009, 25 (8): 223-224.

[5] HOU Yue-xin, ZHOU Dong-liang, et al. The Amplifier Circuit for Weak Sianals[J]. Techniques of Automation & Application, 2008, 27 (11): 65-66.

[6] LI Yan, SONG Chang-qing, et al. Methods of improving performance of weak current integrated amplifier[J]. Nuclear Electronics & Detection Technology, 2007, 27 (5): 978-981.

[7] CA3140EZ Datasheet[S]. www.alldatasheet.com.

[8] INA128/INA129 Datasheet[S]. www.alldatasheet.com.

[9] MENG Li-xia, YU Lin-li, et al. Design of amplifying circuit for tiny signal[J]. Chinese Journal of Scientific Instrument, 2006, 27 (6): 1012-1013.

[10] MAX7705 Datasheet[S]. www.alldatasheet.com.

[11] MA Jing-yuan. Design of High-accuracy Temperature Measure Circuit Based On MX7705[J]. Automation Panorama, 2007. 6: 85-87.

[12] CHEN Yong-gang, WU Bo-nong. Implementation of high precision data acquisition based on AD7705[J]. Foreign Electronic Measurement Technology, 2006, 25(1): 38-40.

[13] HE Zhao-xiang. Photoelectric Signal Processing[M]. Wuhan: Huazhong University of Science and Technology Press, 2008. 1.

[14] KANG Hua-guang, CHEN Da-qing. Basic analog electronics(Fourth Edition)[M]. Beijing: Higher Education Press, 1999.