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Study on a Method to Improve the Stability of the Sensor Signal Based on Pd Controller

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Abstract: In order to solve the high frequency oscillation generated from the video signal of the camera, the paper proposes a method to improve the stability of high frequency oscillation of common sensor signal which means the high frequency oscillation signal generated from the sensor module can increase the phase margin of the unstable signal through PD controller, thus produces a stable video signal and then through the circuit of AGC (Automatic Gain Control), the automatic compensation of the frequency can be achieved and finally the fourth-order low-pass circuit is used to meet the requirement of cutoff frequency of the sensor signal processing and the stability of the signal and the high frequency performance can be ultimately improved.

Key words: Video signal, high-frequency oscillation, PD controller, phase margin,AGC circuit

INTRODUCTION

The definition of the video image is determined by the resolution of camera and the high frequency characteristic of the signal processing circuit of the camera. With further research and development of materials technology, the current resolution of the camera has been greatly improved but the definition of the image has not been greatly improved and the reason of that is because of the limit of the high frequency characteristic of the signal processing circuit (Bi *et al.*, 2009). The greater high-frequency component in signal processing is, the more details of the image there are and the resolution is higher too. The difficulty in current video processing lies in the high frequency oscillation in the process of camera's circuit module design, resulting in a significant decline of the high-frequency performance in video signal processing. The situation is also occurred in other sensor signal processing, such as the signal processing of 3D laser radar that is used for robots information acquisition (Zhang, 2000). As the oscillation of high-frequency signal makes the decline in the performance of the high-frequency signal, the signal collected is not rich enough, resulting in the inaccuracy of robot path planning, so the processing of path planning can be only solved by using algorithm in the MCU (Zhang *et al.*, 2007).

The approach of using the software algorithm to process the signal oscillation problem has been proposed to solve the problem in the domestic and foreign literature with longer space which is still a good method but it adds additional the problems of digital signal processing. Professor Zhang dian-fu has put forward a method to use FPGA to improve the circuit characteristics by achieving large-scale integrated circuit (Zhang and Zhao, 2009) but this increases the cost which makes the circuit structure more complex and brings other parasitic problem as well. We want to improve high frequency characteristics of camera by adopting the design of advance controller to prevent high frequency oscillation of camera signal processing circuit and improve the stability of the whole circuit and apply the method to other similar sensor signal processing.

OVERALL SYSTEM DESIGN

To improve the stability and solve the problem of the oscillation of the sensor's output signal waveform, the current primary task is to improve the phase margin (generally an increase of 60° is preferred). There are several ways to improve the phase margin (Nehorai and Acoustic, 1994). The design uses a phase lead theory in control theory which designs a priori-correction device (PD controller). The controller can make the system have an additional open-loop zero, increase the phase margin and improve system's stability and smoothness and eliminate oscillation generated from analog sensor circuit (Zhang, 2000). From the Bode diagram of the controller as shown in Fig. 1 it is concluded that it has a feature that the phase margin of output signal is increased.

As it can be seen from the overall block diagram of the design in Fig. 2, although an unstable signal is output from the analog circuit of the sensor, when the signal output goes through the PD controller, the phase margin can make the signal more stable as there is a phase lead

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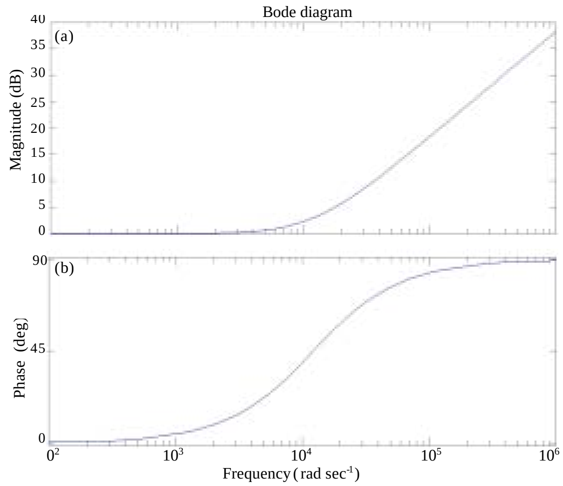

Fig. 1: Bode diagram of PD controller

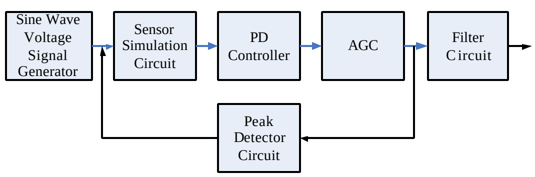

Fig. 2: Overall block diagram of the design scheme

feature in PD controller. However, the PD controller will result in signal attenuation in some certain frequency (Isik, 2010), so according to the requirements of the video signal processing, the phase must not be less than -180 degree when the high frequency band is at 100k. In order to meet the requirement of frequency, compensation AGC circuit is used (automatic gain of the controllable voltage) and compensation is made for the attenuation part. That is to say, take the output signal of PD controller as the input of AGC(automatic controllable voltage gain), the comparison voltage of which is provided by the output of the peak value detection circuit. The cutoff frequency will be greatly improved since the signal is processed by AGC. In the design scheme in Fig. 2, in order to meet the requirements of the video signal processing, a low-pass filter circuit is added finally so that the cutoff frequency can meet the requirements and the waveform is stabilized and enlarged, so the high frequency characteristic of the sensor circuit is improved.

KEY CIRCUIT DESIGN

Same kind sensor simulation circuit: In order to find similar sensor vibration rule, we first build a sensor analog

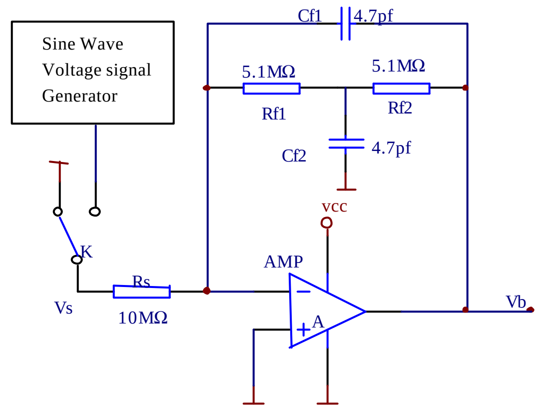

Fig. 3: Sensor analog circuit

circuit to simulate such sensor circuit that generates high-frequency oscillation. The circuit has features such as narrow pass band, waveform that is easy to have oscillation, on basis of which general method of signal processing is expected to be found. The circuit is also a controlled object of the method of the research. (The circuit taken as an example in the paper is mainly used for processing video signal).

The transfer function of the circuit system can be calculated from the parameters of each device as well as sensor analog circuit diagram in Fig. 3 as follows:

$$\phi(s) = \frac{\frac{4}{R^2C^2}}{(RCs+1)(s^2+\frac{4}{RC}s+\frac{4}{R^2C^2})}$$

The specific transfer function can be draw when the values are substituted as follows:

$$\phi(s) = \frac{42553^2}{0.000045s^3+5s^2+85106s+42553}$$

By analysis of the transfer function, closed-loop zero and poles, the closed loop zero poles are:

Closed loop poles: p1 = 6800, p2 = 3400, no closed loop zero.

The Bode diagram as shown in Fig. 4 can be drawn from MATLAB simulation: Through the analysis of amplitude-frequency characteristic curve and phase frequency characteristic curve it's found that the circuit begins to decay in the range about 4.5 k and the cutoff frequency is around 4.5 KHZ or so. The phase margin is not great under the frequency, and the phase is less than -180° in the high-frequency end.

Through the above analysis it is found that the system is an unstable high-frequency system and the

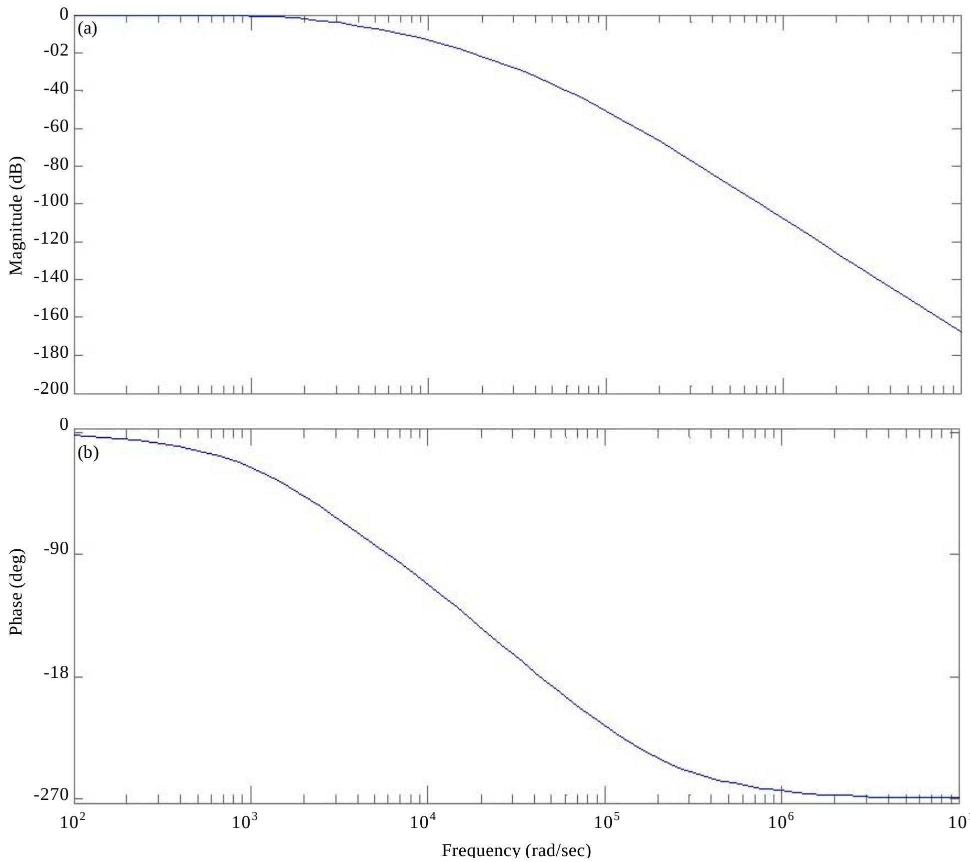

Fig. 4: System bode diagram

circuit is in an extremely unstable state. The signal processing oscillation existing in a lot of sensor circuit can be simulated through the circuit.

Design of circuit module of PD controller: According to the design of circuit module of PD controller as shown in Fig. 5, the corresponding resistance can be calculated and the capacitor value is: R1 = R2 = 27k|¸, C = 276 pF. When a circuit is built on breadboard for simulation debugging it is found that the output waveform of analog sensor is significantly improved. In order to improve its effectiveness, the capacitance value is increased to 303 pF and when it is tested again, the waveform displayed on an oscilloscope gets better improvement.

The waveform comparison chart after the improvement of the high-frequency part is as shown in Fig. 6:

Known from the Fig. 6 and 7: the mid and high frequency phase are increased, the phase margin are increased and the system tends to be stable. The circuit design of PD controller is successful.

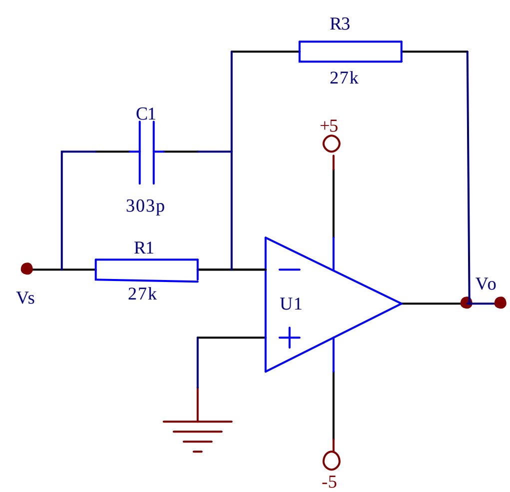

Fig. 5: Circuit module of PD controller

Module design of the peak detector: The role of the peak detector (PKD, Peak Detector) is to take sample of

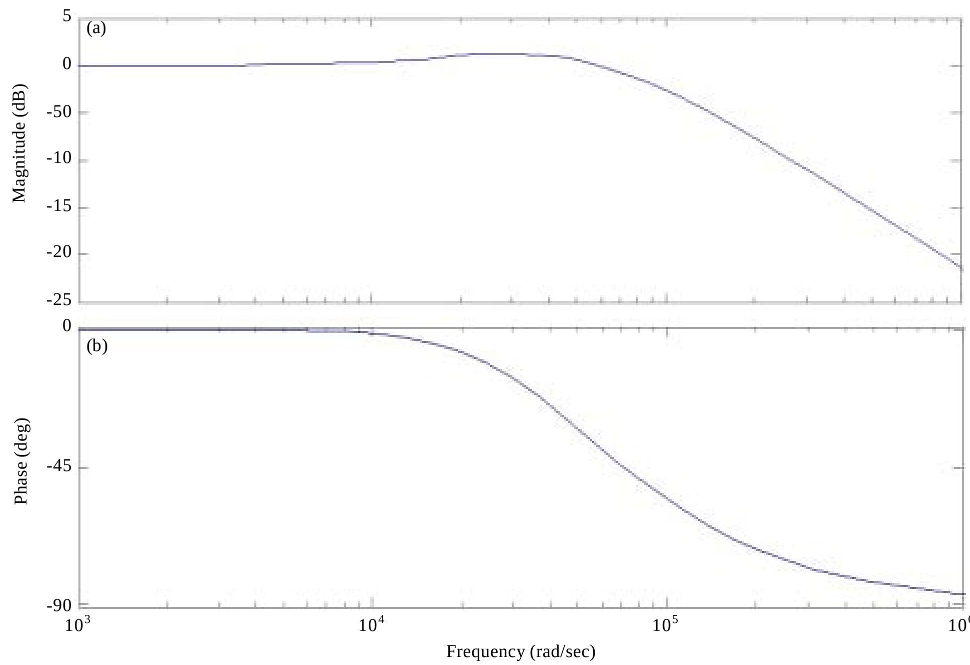

Fig. 6: Waveform comparison charts before adding to the frequency compensation circuit

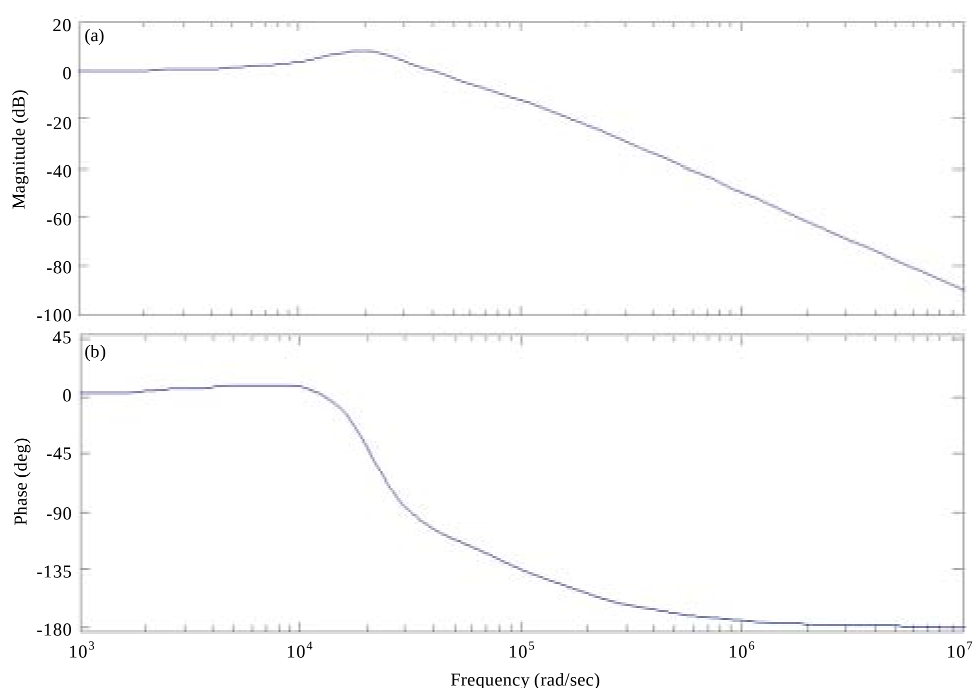

Fig. 7: Waveform comparison charts after adding to the frequency compensation circuit

the peak value of the input signal, so that the output Vo = Vpeak and the circuit output value will always keep the peak until there is a new larger peak or there is a reset in circuit. The peak detector has been widely applied in

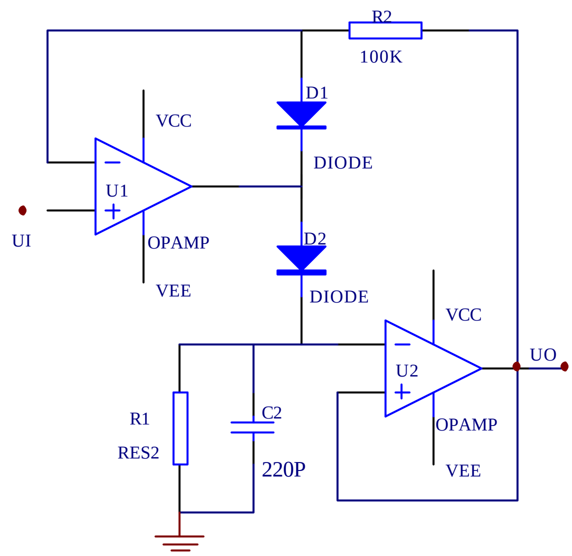

Fig. 8: PKD module

AGC (Automatic Gain Control) circuit and the sensor's maximum value drawing circuit which is generally taken as a judgment basis of selecting programmable gain amplifier multiples (Tu *et al*., 2004). As frequency compensation in AGC is used in the overall block diagram of the design, PKD must be used to make comparison between the signals (Deng *et al*., 1995). The module design of the peak detector is as shown in Fig. 8.

Module design of AGC: AGC (automatic controllable voltage gain) module gives a DC signal (peak sampling voltage) in the OPA820 input terminal and make comparison between it and the output signal of VCA810, then takes the comparing voltage as the voltage control terminal signal of the VCA810, thereby achieving the system's automatic gain adjustment. AGC circuit module is show as shown in Fig. 9.

Module design of fourth-order lowpass circuit: ThefourthorderChebyshewactivefilter is composed of four capacitors, six resistors and two amplifiers, whose structure are two infinite gain loop feedback circuit, as shown in Fig. 10 and its cutoff frequency can be adjusted within a very wide range. The signal attenuation speed is fast erthanthe second order with agood phase frequency characteristic ands tabilityetc. To effectively reduce the high frequency noise of out put signa it is better to choosefourth-order. The parameter design off our thorder low pass activefilter is alittlebit of complicated which prolongs the design period, sowecanuse Filter Pro Desktop developedby T It oshorten the design period and improve the developmentefficiency.

Filter stage:

- Passband Gain (Ao): 1
- Cutoff Frequecy(fn): 105.0005KHZ
- Quality Factor(Q): 0.957
- Filter Response: Chebyshev1db
- Circuit Topiogy: Multiplefeedback
- Min GBW redp: 10.0485MHZ

Transfer function:

$$\phi(s) = \frac{\frac{R2}{R1}}{R1R2C1C2s^2 + (R2R3 + R1R3 + R1R2)\frac{C1}{R1}S + 1}$$

The voltage magnification multiple in pass band:

$$Avo = -\frac{R2}{R1}$$

Natural angle frequency:

$$Wn = -\frac{1}{\sqrt{R1R2C1C2}}$$

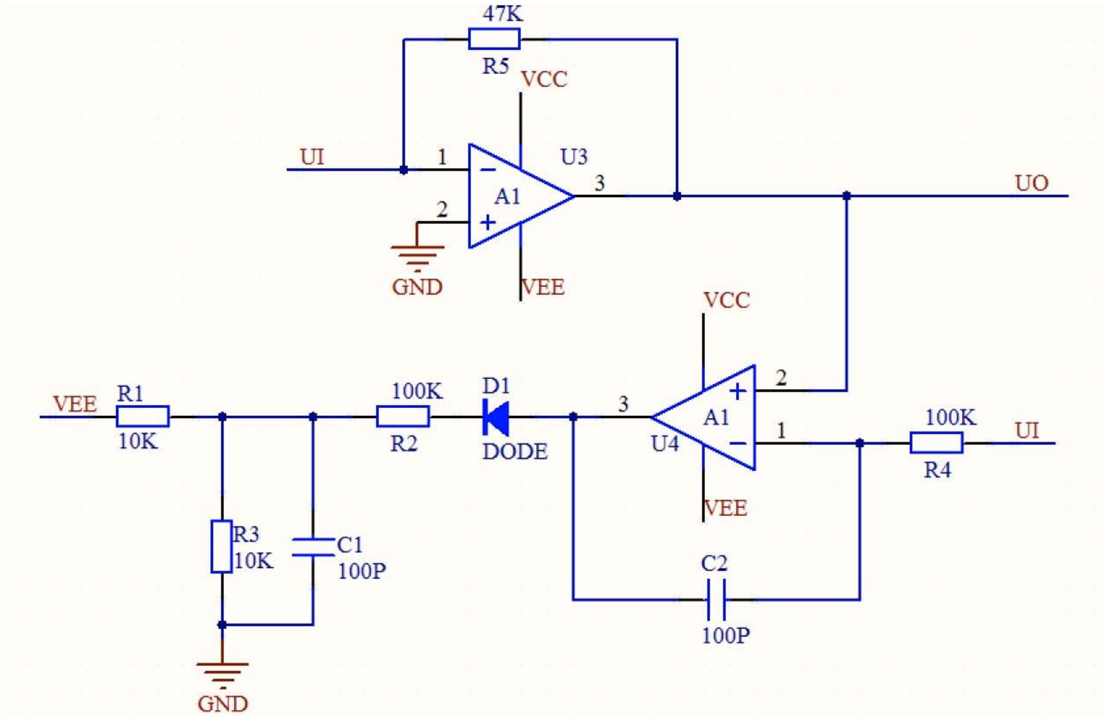

Fig. 9: AGC circuit module

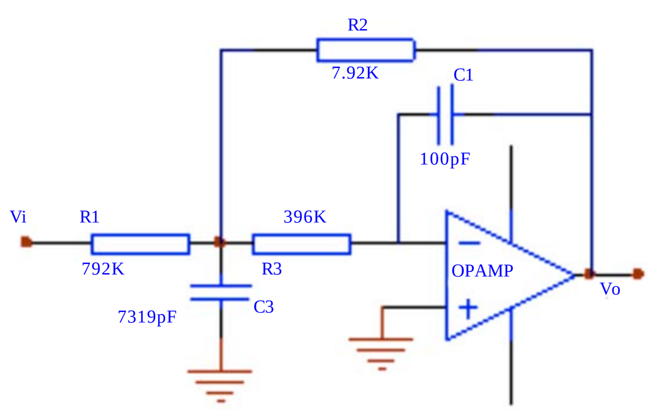

Fig. 10: Low-pass filter circuit modules

The general formula of the second-order low-pass filter circuit in transfer function:

$$Av(s)=\frac{Avow_n^{\,3}}{S3+w_{ns}}\left(\sqrt{\frac{R2R3}{R1}}+\sqrt{\frac{R2}{R3}}+\sqrt{\frac{R3}{R2}}\right)\sqrt{\frac{C1}{C2}+w^{n}_{3}}$$

$$\xi=\left(\sqrt{\frac{R2R3}{R1}}+\sqrt{\frac{R2}{R3}}+\sqrt{\frac{R3}{R2}}\right)\sqrt{\frac{C1}{C2}}=\frac{1}{Q}$$

Analysis of system transfer function and zero-pole: Please check PD controller for specific analysis process. The transfer function drawn is listed here:

The transfer function before correction is:

$$\phi(s)=\frac{\frac{4}{R2C2}}{(RCs+1)(s2+\frac{4}{RC}s+\frac{4}{R2C2})}$$

$$\phi(s)=\frac{42553^2}{0.000045s^3+5s^2+8516s+42553}$$

Transfer function after correction:

$$\phi(s) = \frac{\frac{4}{R^2C^2}}{(RCs+1)(s^2+\frac{4}{RC}s+\frac{4}{R^2C^2})}$$

$$\phi(s) = \frac{148138s+42553^2}{0.000045s^3+5s^2+8516s+42553}$$

Closed-loop pole and closed-loop zero before correction are:

p1 = 6800; p2 = 3400

without open-loop zero.

The closed-loop pole-zero after correction:

p1 '= 6800; p2' = 3400; Z1 = 12223

Resistance-capacitance values of PD controller circuit are:

R1 = R3 = R '= 27Ω

C1 = C2 = 303

SYSTEM DEBUGGING

The debugging process is divided into two parts: module debugging independently and the entire circuit debugging.

Module debugging independently

Analog sensor module debugging: First, the analog sensor module circuit is designed and produced, then debugging is carried out which are strictly in accordance with the requirements of the video signal processing (Le Bihan and Mars, 2004). The given input is 10V with a frequency at 200 Hz. When the output waveform is in the non-distorted state, increases the input frequency. When at around 4.5 K, the waveform attenuates to 3 dB which meets the requirements of the video signal processing. However, there is significant oscillation of the waveform in the medium and high frequency.

Module test for PD controller: First, theoretical parameters are determined through the analysis and calculation (Andrews *et al.*, 2001); then a circuit is built on a breadboard and continuously debugging is given to improve the parameters. Suitable phase margin can be obtained to ensure the stability of frequency band before 100 kHz. The circuit output of sensor is taken as the input of the controller and the input frequency is increased continuously. It is found that the waveform has been improved and then there will be more reasonable parameters through the fine adjustment.

Circuit debugging of peak detection: The AC signal is input from pin 3 of OPA2227. The pin 2 has the same waveform with the pin 3 according to the operational amplifier's virtual short rule; U1B is a voltage follower and the voltage amplitude of pin 7 is the same with the voltage of the capacitor C1

AGC (Automatic gain control) debugging: When the input signal is larger than the given voltage of the system, OPA820 generates a pressure drop to drive the control terminal of VCA810, so that when the input signal is large, the magnification becomes small, whereas when the input signal is small, the magnification becomes large, thereby realizing Automatic Gain Control of the system.

Fourth-order low pass filter debugging: Connect the circuit in accordance with the selected parameters, input the voltage and increase the input frequency constantly, then we can observe:

When the input is 100 K (cutoff frequency), the voltage attenuates for -3 dB; When the input is changed to 300K, the voltage attenuates for -30 dB.

Overall circuit debugging: Connect all the modules with SMA head and it can reduce noise and external disturbance by using corresponding connection and then connect the PD controller with the rear end of an analog sensor module. Take the output of PD as the input of the AGC and take the output of peak detection circuit as the voltage of reference point to give to the AGC. The rear end of AGC output is connected to a class 1 fourth-order lowpass circuit with a cut-off frequency of about 100K. After the circuit connection is complete, electrifying test is carried out and each test point is inspected and compared with the standard requirements. All the requirements are met. The circuit is accomplished in good design and the design is successful.

RESULTS AND DISCUSSION

Test equipment: YB4360 (60MHz) oscilloscope.

Test environment: Room temperature (normal temperature).

Index test (please see Annex VII for more details about data): (1)Test results for output voltage range are shown in Table 1.

Table 1: Test results for output voltage range

Input frequency (KHz)	3.00	3.50	4.0	4.20	4.4	4.60	4.8	5.00
Output frequency (KHz)	8.56	8.08	7.6	7.36	7.2	7.05	6.8	6.02

Table 2: Rule of variation of the voltage with the frequency after accessing to frequency compensation circuit

Input frequency (Khz)	200.00	500.00	1.00	3.000	4.00	5.00	8.000	10.00
Output voltage (V)	2.18	2.20	2.22	2.210	2.22	2.24	2.230	2.20
Voltage gain (V)	0.99	1.00	1.01	1.004	1.01	1.02	1.013	1.00
Input frequency (KHz)	20.00	30.00	50.00	80.000	100.00	102.00	105.000	110.00
Output voltage (V)	2.20	2.16	2.16	2.140	2.16	2.20	2.200	2.16
Voltage gain (V)	1.00	0.98	0.98	0.970	0.98	1.00	1.000	0.98

The rule of variation of the voltage with the frequency after accessing to frequency compensation circuit is as shown in Table 2:

CONCLUSION

Through the added PD controller and AGC circuit in the test circuit module, the phase of high frequency in circuit has been raised and phase margin has been increased, thereby the system has been stable and high frequency signal performance of system has been improved, making the signals collected by the camera real and rich. The method that PD controller is creatively added in the signal processing circuit presents a solution to the treatment of high frequency oscillation of general sensor signal.

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