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Symmetrical Structure Strong Drive Capability Optocoupler Sensor

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Abstract: A novel de-noising and strong driving current optocoupler sensor was designed and implemented in a standard 0.35 um BCD technology. A symmetrical structure of the photo detector array (PD) and the transimpedance amplifier (TIA) could eliminate the noise feedback from the substrate. The logic control module and the push-pull driver circuit could provide more than 3 A under the voltage lockout circuit (UVLO) protection. Experimental results confirmed that when the power supply is 30 V and the working temperature is 25 °C, the sensor forward peak current is 2.8 A and the negative peak drive current is 2.5A.

Keywords: Optocoupler sensor, Symmetrical structure, UVLO, Logic control, Driven current.

1. Introductions

Optocoupler sensor is the optoelectronic devices with the light as the medium to transmit the electrical signal [1, 2]. It is widely used to drive the metal-oxide-semiconductor field effect transistor (MOSFET) or insulated gate bipolar transistor (IGBT) devices in the power control of the industrial system. Fabricate the driven circuit with the optocoupler sensor between the control circuit and the main circuit. In recent years, in order to drive high power switching devices, the demand of the drive ability of the sensor is higher and higher. Even the whole system integrated in the power integrated circuit (PLC) on one chip. This will become a key point in the research in the future.

The output current could up to 2.5 A of the gate drive optocoupler which was presented by Avago cooperation in 2012 [3]. The driven circuit was fabricated by the HCPL316J can give 2.0 A driven current. At present, the research about the strong drive optocoupler sensor has already started. At the same time, the development of the power driven optocoupler sensor and the protection of its subsequent processing circuit have lots of problems to solve [4].

Based on the 1P3M 0.35 μm standard technology, designed a strong drive capability optocoupler sensor to drive the superpower IGBT. The symmetrical structure of PD [5, 6] and TIA can keep the stable working status to avoid the noise interference [7, 8]. The UVLO circuit protect the sensor during the course of the voltage establish and the logic model can produce the high drive current. The UVLO can control the subsequent PMOS and NMOS to avoid turn on and turn at the same time. It would guarantee the sensor stable operation [9].

2. Optocoupler Sensor Structure

Fig. 1 is the inner structure of the optocoupler sensor. The LED in the input port can generate the optical signal. The photons transmitted in the inner of the sensor and achieved by the receiver [10]. The PD was designed to be the symmetrical structure to cut down the glitch noise from the substrate. When PD received the photons the photo current (I_{ph}) will be generate.

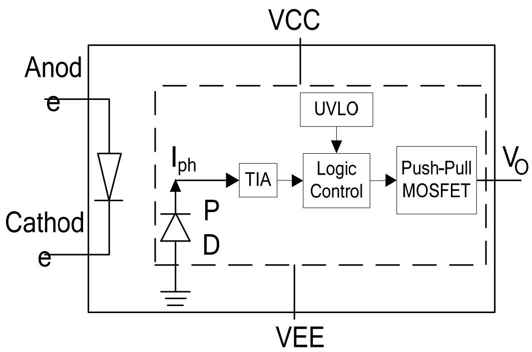

Fig. 1. Optocoupler sensor systematic structure.

The TIA used the differential circuit to reduce the noise from the output and convert I_{ph} into voltage signal. After the voltage get into the logic block, it would generate high drive current and drive the subsequent circuits. Now, the UVLO will become work and protect the sensor while the supply voltage (VCC) varied. At present, produced the dead-time control to prevent the NMOSFET and PMOSFET turn on and turn off at the same time.

3. Symmetrical Structure

3.1 PD Model

In order to cut down the glitch noise from the sensor itself, PD was designed to the symmetrical structure [11, 12]. When the glitch was feedback from the substrate, the symmetrical PD can eliminate it by itself rather than the outside circuit. So the PD model was showed in Fig. 2.

The upper one is the PD model, it consists of the N^+, N_body, P_well, N buried layer (NBL) and P_sub layer. Fabricated the symmetrical structure by this model and the photograph is the lower one.

In order to increase the light receiving area and cut down the cross-talk with the substrate constructed the PD in two arrays and the light receiving circuit with the differential structure. The inner-block were 45 μm wide and 45 μm long with two spacing of 10 μm, and the active areas was 166×166 μm^2.

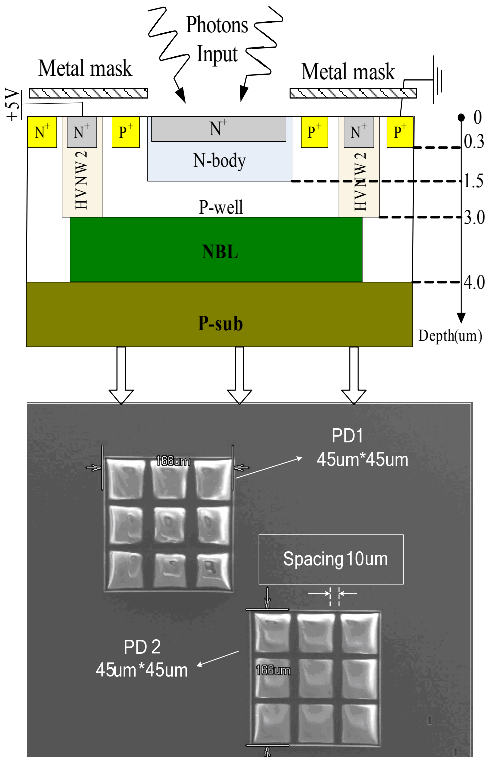

Fig. 2. Structure and photograph of PD.

3.2. Differential Circuit of TIA

The circuit has the differential operational amplifier. The symmetrical PD in Fig. 3 is PD1 and PD2, respectively. The R7 is more than R6 for the OUTP1 less than OUTN1 when there is no photo current. The purpose of the design is shut down the output of the compare when the I_{ph} less than the threshold. From this, the sensor will be no output and it will suppress the input noise to the output.

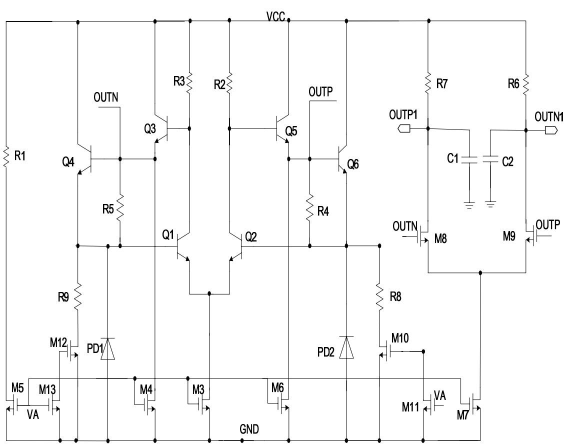

Fig. 3. Differential circuit of TIA.

4. Driving Structure

4.1. UVLO Module

When I_{ph} was converted into the voltage signal by the TIA, it would get into the logic block and generate the driven current. During the whole course of it, the sensor would be protecting by the UVLO. This model sample the power supply VCC by the resistance and compare with the reference voltage VREF. After the comparison, the UVLO output the under voltage signal thus realize the under voltage protection function. The specific circuit was showed in Fig. 4. The M2 can introduce the hysteresis to prevent the UVLO oscillation near the threshold.

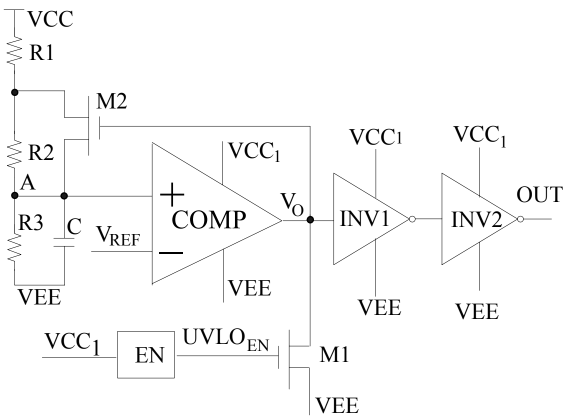

Fig. 4. Circuit of UVLO module.

When the supply voltage start establish, the internal power VCC_1 which was generated by the VCC is low. The enable block output $UVLO_{EN}$ is high. So MOS M1 turns on and the V_O is low level. Then the output of the UVLO (OUT) is low.

During the course of the VCC rise, when the voltage in point A V_A less than V_{REF}, the comparator output low level. At this time, M2 turns off, and the V_A is:

$$V_A = \frac{R3}{R_1 + R_2 + R_3} VCC, \tag{1}$$

Now, the OUT is low, until the V_A=V_{REF}, the COMP flipped and the V_O became the high level. And then, M2 turned on and the OUT became high. At the beginning of the VCC fall, the V_A>V_{REF}, V_O kept the high level and the M2 remained turn on. Then:

$$V_A = \frac{R3}{R_1 + R_3} VCC, \tag{2}$$

Until V_A=V_{REF}, COMP flipped and V_O became the low level. Then M2 turn off and OUT is the low level. The output of the UVLO has a hysteresis, and the hysteresis voltage is:

$$\begin{aligned} \Delta V &= \left(\frac{R1+R2+R3}{R_3} - \frac{R3+R1}{R3}\right) V_{REF}, \\ &= \frac{R2}{R3} V_{REF} \end{aligned} \tag{3}$$

4.2. Logic Control Module

In the process of UVLO works, the logic control block provides powerful driven current to the MOSFET and produces the dead-time. It can avoid the NMOSFET and PMOSFET turn on and turn off at the same time. The circuit is showed in Fig. 5.

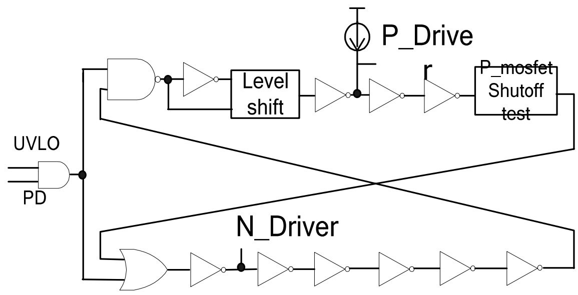

Fig. 5. Circuit of logic control module.

When the sensor is in the state of under voltage, UVLO is low level. Now, the P_Driver is the high level and the N_Driver is the low level. The subsequent push-pull MOSFET will be turn off. In order to prevent the V_O in an uncertainty status, a small current will pull down the V_O.

When the sensor leaves the state of under voltage, UVLO is high level. When a light illuminated, the PD received the photons and the Photo_Detet is the high level. Here, P_Driver will become to the high level and the N_Driver is the low level. And then, the PMOS in the push-pull MOSFET turn on, the V_O become high level. Otherwise the NMOS turn on and the V_O is the low level. In order to prevent the NMOS and the PMOS turn on at the same time, this circuit has the dead-time control circuit. Before the PMOS turn on, the NMOS turn off absolutely, vice versa.

5. Simulation and Test

5.1. Simulation Results

In order to test the driven capability of the optocoupler sensor, cascade all the modules and simulate the driven current. The simulation condition is VCC is 30 V, working temperature is 25 °C. The I_{ph} choose the square wave with the amplitude is 34 μA and the duty is 50 %. The simulation of the driven current is showed in Fig. 6.

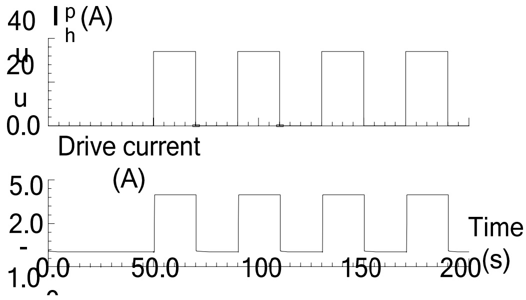

Fig. 6. Drive current of the sensor.

According to the Fig. 6, when the I_{ph} certain, the sensor could output more than 3.0 A drive current. This driven ability can match the design data and exceed all the drive current of the existing published photoelectric sensor.

5.2. Test Results

Fig. 7 showed the glitch noise which feedback through the substrate without the symmetrical structure.

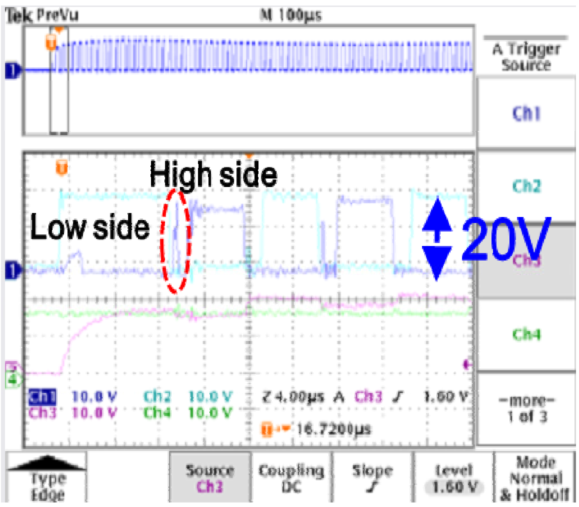

Fig. 7. Feedback noise in the sensor.

In the above figure, the purple line is the output signal of the sensor, but it occurred in the working time. The glitch noise in the red circle is just 20 V and last 1.2 us. So it will lead wrong operation in the subsequent circuit. By using the symmetrical structure of the PD and the TIA, this glitch was suppressed.

The following two figures illustrate the measurement results of the driven current of the whole sensor. Set the R_L is 5 Ω series connection 10nF capacitor to the ground. The working temperature is 25 °C and the VCC is 30 V.

The drive current of the sensor was tested by a LeCroy 954 oscilloscope. The purple line is the transient output current. The red line corresponds to the VCC and the yellow line represents to the output signal. The forward peak current can be 2.8 A, and the negative peak current is above 2.5 A.

Experimental results showed the sensor has a very power driven current and it could eliminate the noise by the symmetrical structure. The test date matched the simulation data very well, and the sensor has a good drive characteristics.

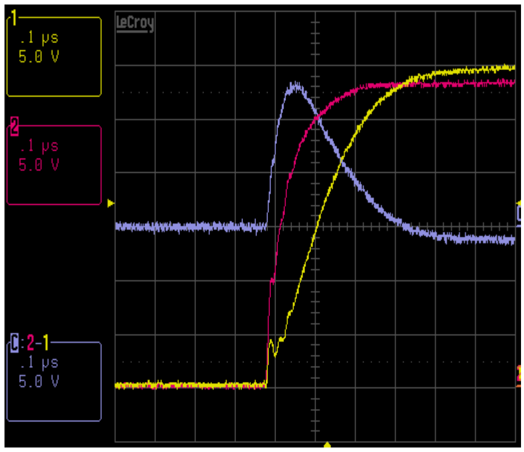

Fig. 8. Forward peak current of the sensor.

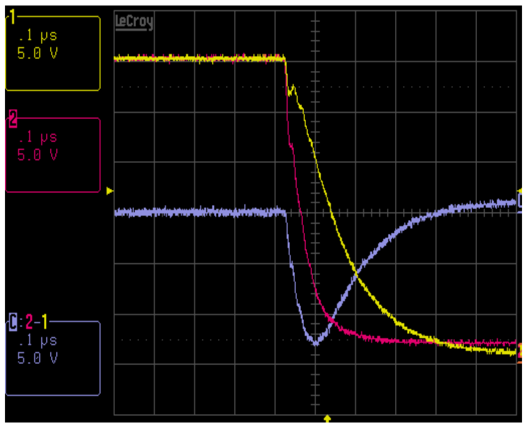

Fig. 9. Negative peak current of the sensor.

6. Conclusions

This paper, based on 0.35 μm BCD standard technology, fabricated a powerful driven current optocoupling sensor. Through the symmetrical PD and TIA structure, the glitch noise which could be feedback from the substrate was eliminated. It is verified that the UVLO, logic control and push-pull driven circuit can provide power drive ability to the sensor. When the sensor worked in the typical condition, the maximum forward current is 2.8 A. The negative peak current is 2.5 A. From this, this optocoupling sensor can be used in the higher demand power electronics industry.

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